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Megan M Switzer
Purdue, United States of America, mswitzer0221@gmail.com

William Hutzel
Purdue, United States of America, hutzelw@purdue.edu

Hazar Dib
Purdue, United States of America, hdib@purdue.edu

Jason Ostanek
Purdue, United States of America, jostanek@purdue.edu

Applying User Experience (UX) Principles to Net Zero Energy Buildings

Megan SWITZER[1]*, William HUTZEL[2], Nicholas DIB[3], Jason OSTANEK[4]

[1]Purdue University,
West Lafayette, IN, United States
mswitzer0221@gmail.com

[2]Purdue University
West Lafayette, IN, United States
hutzelw@purdue.edu

[3]Purdue University
West Lafayette, IN, United States
jostanek@purdue.edu

[4]Purdue University
West Lafayette, IN, United States
hdib@purdue.edu

* Corresponding Author

ABSTRACT

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. Increasingly, energy dashboards are developed to actively manage and optimize the performance of sophisticated net zero energy buildings (NZEBs). This research applied User Experience (UX) principles to improve an energy dashboard for a prototype net zero energy building and evaluated user's ability to understand and interpret the information. The research found statistical significance that UX increases a user's ability to identify building performance metrics. Understanding the user's skill level is one of biggest challenges in energy dashboard design. This study designed a new categorical testing method to help design the layout of the graphic interface for an energy dashboard that matches the expectations and needs of diverse users.

1. INTRODUCTION

Building Automation Systems (BAS) have grown in scope and sophistication as a solution to the overarching goal of optimizing the energy consumption of buildings. Energy dashboards aim to simplify the thousands of data points in a large building to create a graphical interface illustrating building performance to encourage energy efficiency behavior. Complications arise because visualizing the massive amounts of building energy data is still in the research stage. Current research is reviewing best practices to find indicators that alert occupants and owners of underperforming buildings. Data visualization and interpretation using a BAS is a major component in achieving a smart building that operates efficiently. An energy dashboard is the link between collecting massive amounts of building data and providing facility managers and occupants with actionable information to improve building performance.

Malfunctioning equipment or broken sensors detecting inaccurate data is one of the issues with using a BAS to track thousands of data points. Larger buildings have BAS capabilities to control room setpoints accurately and create a better environment for occupants. However, one bad sensor has the potential to cause excess energy consumption across a whole building. If one sensor that tracks pressure to control a fan is not accurate, the results are excess energy use and potentially poor indoor air quality. Using data to identify malfunctioning controls is a powerful tool that requires research on data processing and notification methods to diverse groups of people moving through a building.

The increase energy efficiency in equipment draws more attention to the impact occupants have in buildings, recent studies show 30-50% of energy consumption in a building is determined by occupant behavior (Timm & Deal, 2016). Therefore, understanding human interaction is a crucial factor for increasing a building's performance. The psychology of designing an energy dashboard to promote sustainable behaviors is an influential factor that is based on User Experience (UX) principles (Irizar-Arrieta & Casado Mansilla, 2017). Research combining both UX and energy conservation is limited, but has significant potential to improve a building's operation. For example, one study found occupants decreased energy consumption the most when told how much energy their neighbors were consuming (Nolan, Cialdini, Goldstein & Griskevicius, 2008). Translating human behavior characteristics into energy dashboards messages creates a clearer communication to encourage the user to increase energy efficiency.

Occupant behavior is just one aspect of building performance. Experienced facility managers need a different type of energy dashboard to quickly assess building performance. UX research allows energy dashboard designers to understand how different users interface with BAS to create a unique experience that increases the potential for saving energy. Energy dashboard design needs to build off psychological research on human behavior and user experience to maximize the overarching goal of decreasing costs and demand on the electrical grid.

Today's Net Zero Energy Building (NZEB) requires direct human involvement in the operations process to meet energy goals. NZEB rely on occupants understanding of energy consumption patterns and knowing how to reduce energy use to meet the overarching goal. A study found that NZEB owners want more control over their building and often do not understand if they are reaching performance goals (Torcellini et al, 2017). California has implemented support for NZEB construct with goals for all commercial construction to be net zero by 2020 (Deng et al 2014). NZEB of the future are predicted to be managed by people with little knowledge of building systems. As NZEB become available to the general market, the average user's knowledge of the how they operate will be even more limited. An energy dashboard is the critical interface between a building's operation and the facility manager/occupants understanding of day to day operations. These changes can be as simple as finding lights that should be turned off at night or calibrating a sensor that has malfunctioned. Properly operating smart buildings require seamless interactions between buildings and humans to optimize building performance.

2. EVALUATION

This research merged knowledge of BAS and UX principles to evaluate the performance of a net zero energy building. A pretest and posttest survey methodology was deployed to evaluate a user's ability to navigate an energy dashboard. Participants were asked to locate energy performance metrics from a basic energy dashboard during the pretest. After UX principles and net zero analysis of the laboratory were added to the system a posttest assessment was conducted. The difference between the pretest and posttest results were evaluated using a z-test proportions statistical test to identify differences in performance using statistics. The methodology for the energy dashboard research also used Key Performance Indicators (KPI) to determine the granularity of data appropriate for the energy dashboard, based on the needs of the user. The interlacing of KPI, NZEB and UX was evaluated in this study to assist users to understand the performance of complex building controls.

2.1 Testing Location: Applied Energy Laboratory

The Applied Energy Laboratory (AEL) in Knoy Hall at Purdue University in West Lafayette, IN is used for teaching and research into high performance buildings. The AEL has a variety of HVAC systems and BAS that mimic what could be found in a modern NZEB. The facility also features a variety of solar energy systems on the roof of the building. An 8 kW solar photovoltaic system provides enough electricity to power a typical U.S. home. Two different types of solar thermal systems are also featured. One solar thermal system heats air and a second system heats glycol. Different types of solar thermal panels are deployed so differences in performance can be measured.

Figure 1 shows an overview of the mechanical systems in the AEL. The air handling unit (AHU) is a small commercial system and features an energy recovery wheel. The environmental chamber (EC) in the background of Figure 1 is serviced by the AHU and provides a controlled environment for a variety of testing purposes. The heat pump (HP) in the middle of Figure 1 provides backup heat for the solar thermal collectors on the roof when the sun is not shining. The 3 ton chiller (CH) provides cooled glycol for use in the AHU or cooling the EC. Collectively, these systems represent typical equipment required to operate a modern commercial building.

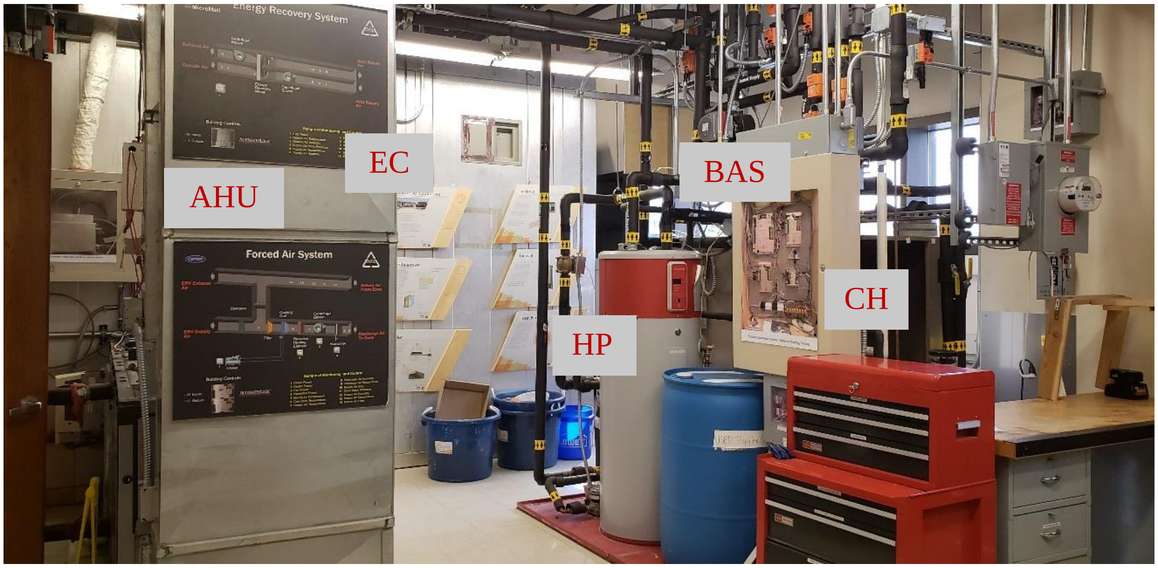

Figure 1: The Applied Energy Laboratory

A sophisticated web-based BAS has been developed for operating and controlling all the equipment in the AEL. The middle of Figure 1, labeled BAS, shows the control panel used to control the solar thermal heat pump system, one of many control panels required to operate the AEL. The BAS platform has evolved over time as new equipment is installed. Currently the BAS in AEL has over 200 I/O points to control and monitor the all the equipment. Even though the different systems operate within the same BAS network, each system operates discretely. Before the posttest edits were integrated into the system, there was no overarching energy dashboard to assess the operation of the AEL collectively only on an individual equipment basis.

This research developed a centralized dashboard to assess whether the entire laboratory operated within net zero parameters. In other words, the component level energy consumption of equipment like the AHU, chiller, and other systems were compiled. An estimate of the additional loads for lighting, computers, and other plug loads was included in this energy calculation. The total energy use was compared to the energy supplied by the 8 kW solar photovoltaic system on the roof. The net zero energy status of the lab is determined by tracking the ongoing energy use and energy supply over time. The ultimate goal is achieving net zero energy status on an ongoing basis and determining energy consumption changes needed to make AEL a net zero laboratory.

2.2 Survey Methodology

Two aspects of designing this UX inspired energy dashboard were particularly important. The first issue was categorizing users to determine the granularity level needed for the energy dashboard. In other words, the energy dashboard must provide information that matches the technical expectations of the user. A facility manager needs different information than a building occupant. The second related issue is whether a user's self-evaluation of technical background aligns with their ability to find and use building performance metrics. Are people able to accurately assess their own skills and abilities so that they can effectively use the energy dashboard?

A survey was developed to collect data on the users' ability to find energy performance metrics on the energy dashboard. The survey was administered to 23 students in a senior-level HVAC design class as a homework assignment. The survey was graded for technical correctness. Since the users completed the survey for a grade, the assumption was that the work was completed to the best of the user's ability. The survey was administered twice, before and after the NZEB dashboard was created. A statistical analysis was conducted comparing the proportion of correct answers on pretest and posttest surveys. The statistical analysis determined whether UX principles helped to improve a user's understanding of the energy dashboard.

2.3 Designing the Energy Dashboard

The graphics for the BAS in the AEL had known design flaws that were updated using UX principles, including the development of an entirely new NZEB interface. The limits of using a traditional BAS and designing energy dashboards was the main constraint. A multitude of companies offer energy dashboard solutions but come with an added expense in terms of development time that not all organizations can afford. This study applied UX principles by consciously including technical detail at a level appropriate for the intended user. This was accomplished by adding a new net zero energy dashboard and updating graphics for other equipment's through simple tools provided in a typical BAS graphic software package.

Figure 2 was the existing energy dashboard for the heat pump in AEL prior to integrating UX principles. The energy dashboard had missing data and was not designed to be aesthetically attractive. The interface had not been edited in over a year and had missing data points, outlined in red. The trend shown in Figure 2 was not the correct data point nor was it a useful value to be displayed over a daily period.

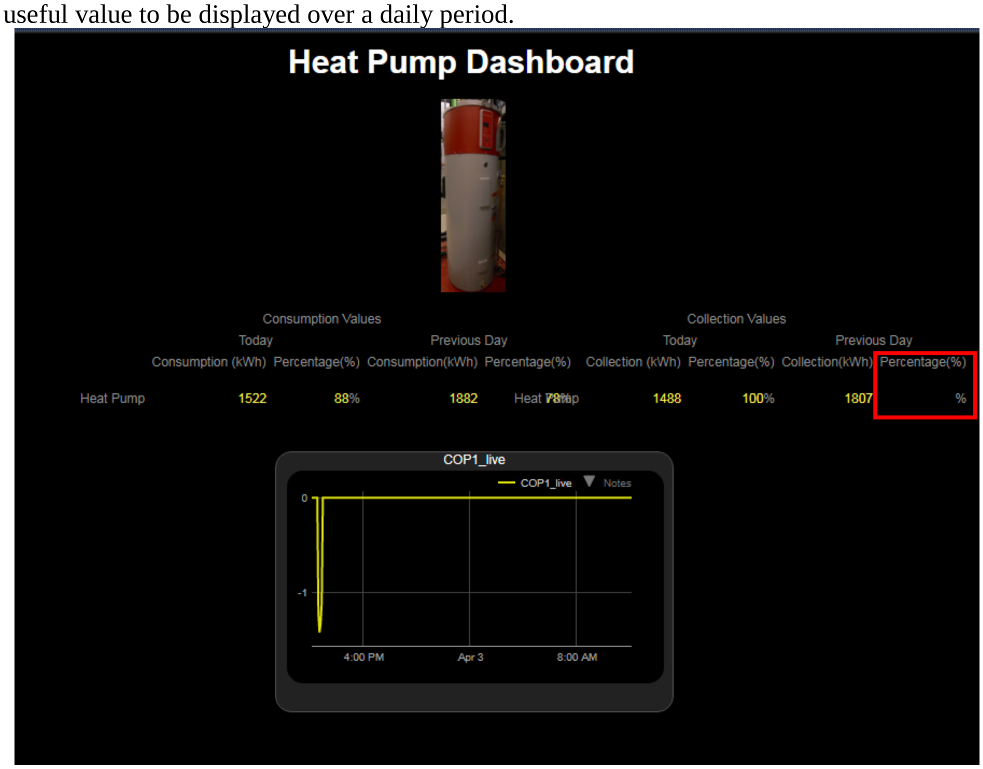

Figure 2: The Solar Heat Pump Energy Dashboard evaluated in the pretest before design edits.

The results of the pretest survey, using graphic found in Figure 2, found that appearance and usability navigating between systems was the biggest complaints. Based on ten usability heuristics of UX, matching the system to the real world, one of the major features integrated into the new system was adding animation into the energy dashboards (Nielsen, 1995). Although the energy dashboard in Figure 2 was difficult to navigate, users were still able to identify energy consumption of the heat pump.

Figure 3 is one example of where improved animation and trends were added to the energy dashboard. One limitation was using stock graphics provided in typical BAS based because their appearance did not match the real-world system. Stock images of fans and pumps were added to clearly show when systems were on and off. Updated trends were designed based on actionable and reproducible data, a characteristic of key performance indicators, or KPIs (O'Brien et al, 2017). 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). The KPIs focused in this study were six of the eight; fit-for-purpose, reproducible, easy to obtain, comparable, quantitative and actionable. Alleviating issues navigating the system that were found in the pretest survey between different equipment, links were added throughout the system to alleviate navigation issues.

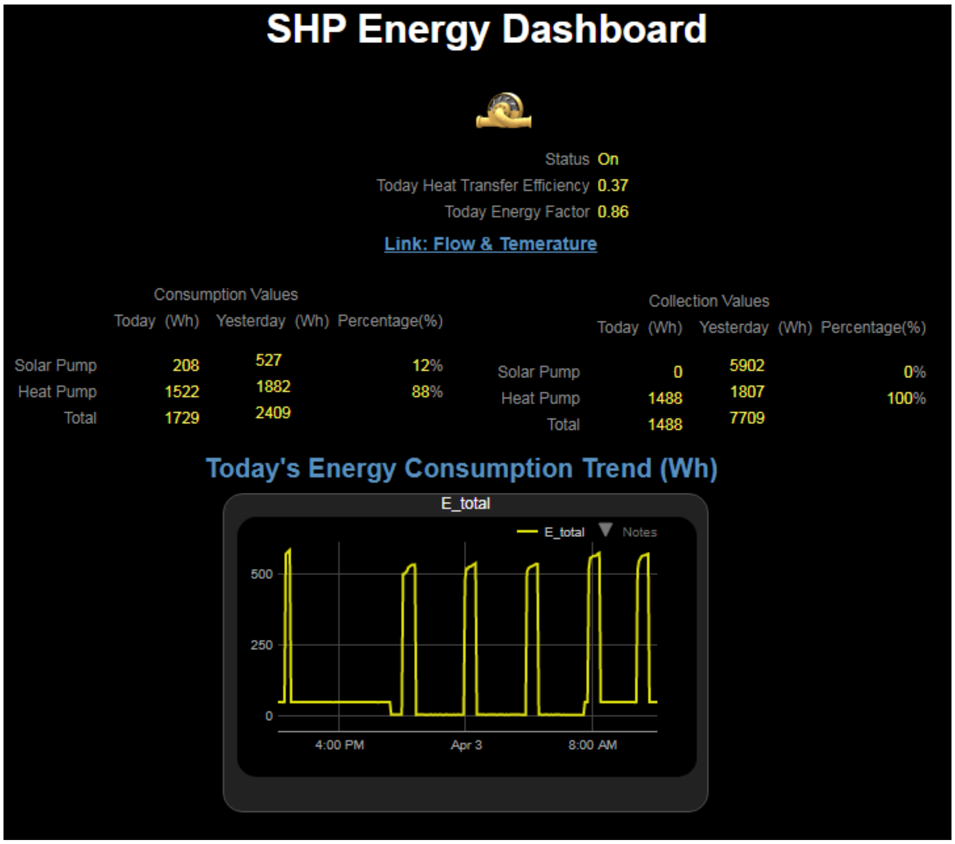

Figure 3: The Solar Heat Pump Energy Dashboard evaluated in the Posttest after design edits.

Literature defines four different levels of energy dashboards (Shadpour, 2015). The different levels signify the differing viewpoints of a building occupant and a facility manager. UX principles suggest that the level of technical detail in the graphic should align with the technical background of the intended user. A level two energy dashboard was designed for AEL, which aligned with technical background of an engineer. The results from the pretest and posttest surveys showed a statistically significant improvement in user performance after the graphic upgrades.

Figure 4 is the energy dashboard illustrating the net zero calculations for the AEL. The system tracks the lab's energy consumption and the electricity generation of an 8 kW solar photovoltaic system located on the roof of the building. The energy dashboard shows real-time energy consumption of the entire AEL and net zero status. A NZEB produces as much energy as it consumes on an annual basis. The two gages in Figure 4 shows the net zero energy status on both a daily and yearly basis. A dial gage indicator greater than zero is desirable. On the bottom border of the energy dashboard are links connecting to all the other equipment. The dashboard features were built using UX principles and feedback from the pretest and posttest.

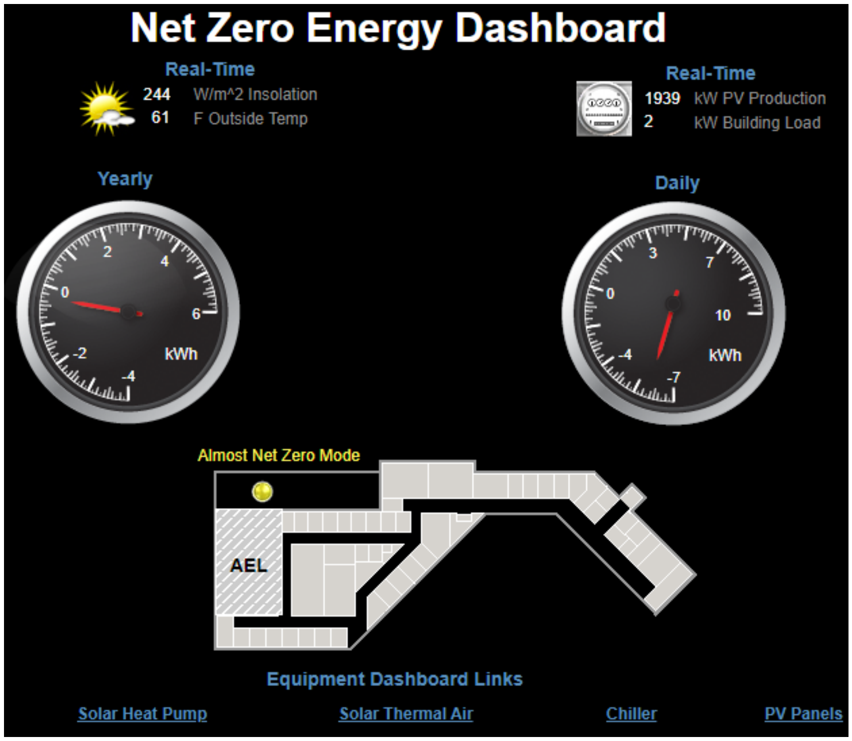

Figure 4: Energy Dashboard for tracking net zero status.

The goal of this research was to improve energy dashboards by incorporating UX principles, particularly for net zero buildings. The net zero dashboard was added to the AEL BAS system helps to validate that the laboratory is truly achieving net zero status. Gages were recently added to the standard BAS graphic package and provide enough detail to allow the user to understand the net zero status without overloading the user with information. The energy dashboard in Figure 4 demonstrated that UX principles help a user to identify energy performance metrics for a net zero laboratory.

2.3 Categorizing the Population

The evolving field of Key Performance Indicators (KPIs) focuses on the parameters used to understand the energy performance of a building. Originally the term KPI was used in business applications but the ideology carries into building performance metrics. A total of eight characteristics are considered when designing a KPI; fit-for-purpose, reproducible, accessible, unbiased, easy to obtain, comparable, quantitative, and actionable. Incorporating all these characteristics is challenging, but using them decreases the communication gap between clients and design engineers (O'Brien et al, 2017). Related research encompasses understanding the correct demographic for defined KPIs.

A self-evaluation aspect was used in the survey to find how confident the users felt using the energy dashboard. According to literature, energy dashboards are broken down into four different level types. In each level of energy dashboard, the main differences are: 1) granularity of data displayed and 2) depth of building performance analysis. The highest level of energy dashboard design allows some controls to be done through interface compared to the lowest level, which simply displays real-time data to give a basic overview. The self-evaluation was done to find whether there was a correlation between users who felt confident using the interface and overall performance of identifying KPIs based on technical correctness.

Figure 5 illustrates the second evaluation to categorize the user to determine level of energy dashboard. The users were asked to rank KPIs for building performance metrics for importance on a scale of one to five. The KPI ranking was included in the posttest after the edits were integrated into the system. The answers were averaged and compared with person types found in the study of Li et al. (2017). Figure 5 shows the levels of analysis compared with the level of dashboard. The users in Li et al's study were participants involved in the design a net zero home and comprise of the majority of person types in a typical building.

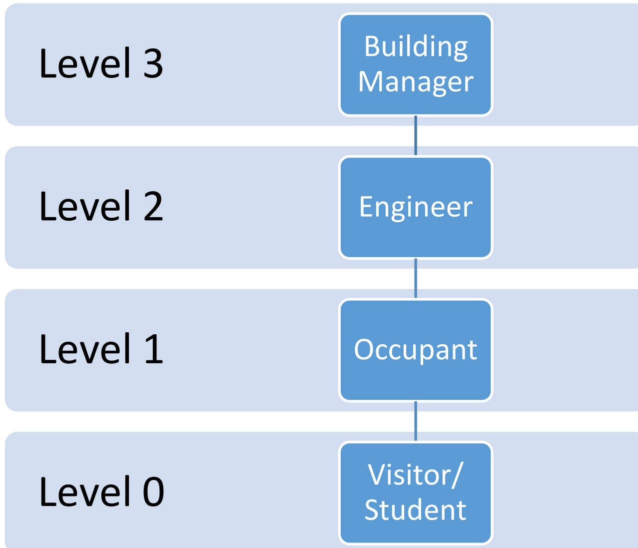

Figure 5: Energy dashboard level type compared to person type.

Designing an energy dashboard centered on UX and promoting energy efficiency behaviors must incorporate the idea of diverse dashboards for users of differing knowledge levels. At the highest level of energy dashboard (level 5 - building manger) a user can control a building and use it for failure detection down to the equipment level. At the lowest level (level 0 – visitor/student) users merely informed of the real-time data and informed of previous day's performance to help encourage energy efficiency. The purpose of understanding the level types of energy dashboards is asking the question, "What is the goal after viewing the energy dashboard?" A building manager's goal and an occupant's goal are different in terms of the desire to save energy. Energy dashboards designed at the lowest level 0 and 1 are for monitoring and alerting proper personal of underperformance. The higher levels 2 and 3 are used to control equipment through the BAS and display actionable trends.

3. APPLYING USER EXERIENCE PRINCIPLES

The research connecting energy dashboards and user experience to human behavior is limited. There is research in both subjects individually but not how the two affect each other. An influential study examined what people identify as the reason they save energy versus the messages that caused a reduction in energy usage. Interestingly, the study found that the reason people claimed to save energy was not the same as what actually caused them to decrease energy consumption. People were motivated to act based on perceived difference with their neighbors. The use of normative social influences is effective at increasing energy consumption behaviors. Understanding how people respond to messages and displaying them effectively advances the field the energy dashboards.

Figure 6 shows the statistical results from the energy dashboard study evaluating if applying UX principles increased a user's ability to identify KPIs. The left-hand column on Figure 6 shows a total of nine questions asked on the survey. The number correct for each survey is located on the middle two columns next to each question. A proportions statistical test was done with an alpha of .05. The hypothesis that UX increases identification of KPIs was correct with the test of null hypothesis: proportion $\text{correct}_{\text{pretest}}$ = proportion $\text{correct}_{\text{posttest}}$ and the alternative hypothesis: $\text{correct}_{\text{pretest}}$ < proportion $\text{correct}_{\text{posttest}}$. The p-value shows the significance that applying UX principles allowed the user to correctly identify the KPI. The p-value columns that are filled in with green passed the statistical significance test.

Question on Survey	Pretest Correct	Posttest Correct	p-value
Systems Monitored	9	15	0.0383
Alarm Notification	1	20	0.0000
Operated Outside Setpoints	9	17	0.0087
FA Currently Operating	20	23	0.0366
SHP Currently Operating	20	23	0.0366
Energy Consumption of AEL	60%	72%	0.4579
Real-time Conditions	22	22	0.5000
Solar Air Thermal Running	6	18	0.0002
AEL Net Zero	4	6	0.0003

Figure 6: The statistical analysis of applying UX principles to energy dashboards

The users showed statistical improvement finding KPIs when UX principles were applied to the energy dashboard in the AEL. All but two of the questions showed improvement between the two surveys. The ability to find real-time conditions did not show statistical significance mainly because all users except one correctly answered the question. The integration of UX principles into BAS and energy dashboards increases the user's ability to find building performance metrics to achieve the overarching goal of increasing a building's performance.

The energy dashboard study asked users to identify their energy dashboard knowledge and examined correlations between survey performance and self-identified knowledge. Users were asked to rank their energy dashboard knowledge on a scale of 1 to 10 with 10 being the highest. The correlation between how users preformed based on technical correctness and self-identification found was virtually nonexistent. The study found statistical significance that applying KPI and UX principles to the energy dashboard design increased a user's performance. However, the users showed no correlation between technical performance and self-identification of their energy dashboard knowledge.

Similar to Nolan et al's study, how users identified themselves was not a predictor for performance. A clear disconnect exists. Users who are unaware of why they are saving energy correlates with how well they understand energy data in the first place. Users are so disconnected from buildings and energy dashboards that they are unable to self-evaluate their reasons for saving energy.

A constraint designing energy dashboards is the diverse groups of users interfacing with the system. This research explored a methodology to classify a population according to the building parameters that resonate with the user. A previous study found that UX and usability has a positive relation to increasing sustainability behaviors (Irizar-Arrieta et al, 2017). Tailoring an energy dashboard to a user allows for them to understand thus increasing desired behaviors. Figure 7 shows the alignment of the users from this study with the different groups of people typically within a building. The four groups correspond to the four different levels of energy dashboards. The chart constructed using the data from how the users ranked KPI's compared with answers from Li et al's study. Figure 7 shows how users in this study related to different person types as methodology to determine the appropriate level of energy dashboard design.

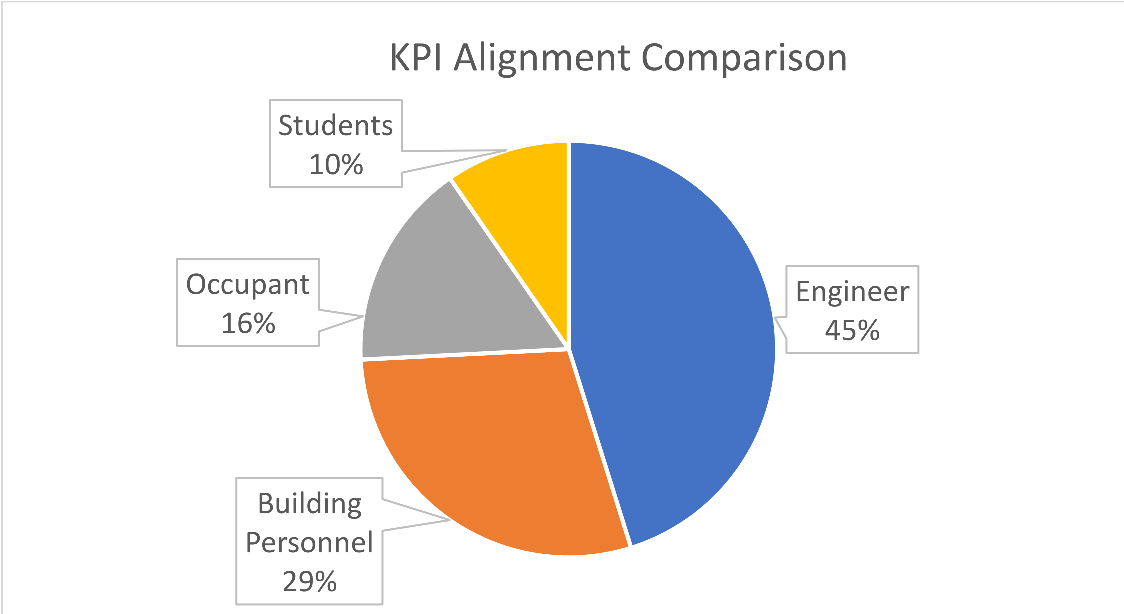

Figure 7: The percentage of alignment with diverse people type in a building.

Figure 7 shows that the users identified most closely to engineers from Li et al's study. The users for this study were engineering technology students confirming that the results aligned. Discovering parameters that are important to users helps to classify the level of knowledge they have through practice. As demonstrated through Nolan *et al*'s study asking people to self-identify importance is not the best measure for what is important, but it can be used as an aptitude test. The KPIs that were found to be of importance were not as critical as understanding that the users for this study closely identified with other engineers. A diverse group of people use energy dashboard in a building, understanding who is using it helps to better identification of energy dashboard design.

An analysis looked at correlation to self-identified knowledge level and KPI's ranked of importance. There was no correlation, just because a person felt more confident using an energy dashboard did not determine how they ranked building performance metrics. This draws more importance to using alternative methods for determining how to categorize a population to tailor UX and energy dashboard design.

4. CONCLUSIONS

Within a building there are diverse groups of people with varying skills sets but all trying to achieve the same goal in a net zero building; assess and optimize performance to alert appropriate personal when the building is underperforming. The sector of NZEB is receiving attention from all levels of the government as an appropriate means to decrease energy consumption. Energy dashboards are the interface between occupants and building owners for NZEB to operate their building to the best of its' designed ability. The integration of UX principles into displaying building controls has proven in this study to increase a user's ability to identify a building performance. A pretest and posttest survey method were used to identify a user's success of using an energy dashboard before and after edits to the energy dashboard were integrated. Statistical significance was found between the pretest and posttest that integrating UX principles increased a user's ability to use an energy dashboard.

Data was collected within the surveys to determine if there was correlation between how users identified important KPIs and the level of energy dashboard needed for that group of people. The pretest survey included a method allow the user to identify their comfort level using an energy dashboard and the posttest required users to prioritize KPIs. No correlation was found in how users identified their comfort using an energy dashboard and actual performance, shedding light on the construct that a KPI importance test hold more value evaluating the group than allowing the user to self-identify. This UX principles within energy dashboards for net zero buildings study found that categorizing a population through KPIs and using UX principles is an effective methodology to energy dashboard design.

NOMENCLATURE

AEL	Applied Energy Laboratory
BAS	Building Automation System
KPI	Key Performance Indicator
NZEB	Net Zero Energy Building
UX	User Experience

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