The Iterative Design of a University Energy Dashboard

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ABSTRACT

Energy dashboards are monitoring and display systems that provide information about building energy use. Dashboards may provide information, alarms, and complex trends to support engineers in identifying energy inefficiencies in a building. Public interfaces may contain simpler trends, with a greater focus on aesthetics and framing of content to promote interest and engagement. We have developed the Campus Energy Education Dashboard (CEED), a map-based dashboard that shows energy data for buildings on a large university campus. Analytic features, including energy use intensity metrics, real-time demand data, and historic data are available for our engineer and data analyst stakeholders. For students and staff, we focus on engagement features, such as providing context for the data, prioritizing aesthetics, and layering information in successive levels of detail. CEED enables Facilities Management to improve energy efficiency and empowers building occupants with knowledge of and input into campus energy operations. We will describe our design process, which included A/B and usability testing of design elements that informed successive iterations of the dashboard.

Introduction

Energy dashboards are monitoring and display systems that provide information about building energy use. Energy dashboards support engineers, analysts, and facilities management personnel in efforts to improve building energy efficiency and meet benchmarking mandates. Additionally, research suggests that public-facing energy dashboards can have a variety of benefits among building occupants, such as increased awareness and understanding of energy sources and processes, as well as engagement in energy-saving behaviors (Petersen, Frantz and Shammin 2007).

Energy dashboards have become popular at university campuses. Universities adopt an energy dashboard in one of three ways: (1) purchasing an out-of-the-box dashboard from a third party company, (2) integrating portions of an out-of-the-box product with their own website, or (3) creating a custom dashboard from scratch. Stanford University utilizes a Lucid dashboard within their own sustainability website[1]. This option is still relatively expedient to implement, while allowing the school greater ability to tailor the website. Another ambitious option is to develop a custom dashboard. Universities that have taken this route include Iowa State University[2], the University of Iowa[3], UC Merced[4] and UC Davis[5].

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[1] Stanford: http://sustainable.stanford.edu/buildings

[2] University of Iowa: https://www.fpm.iastate.edu/utilities/energy_dashboard/default.asp

[3] Iowa State University: http://itsnt1426.iowa.uiowa.edu/ECCDashboards/Home/Dashboards/Old%20Capitol

[4] UC Merced: http://cem.ucmerced.edu/building-dashboards

[5] Presented in this paper

A review of existing dashboards suggests a general distinction between analytics and engagement features. Analytics features support energy management (e.g., multivariable analysis, fault detection) and are particularly useful for building managers and engineers (Granderson, Lin and Piette 2013, Lehrer and Vasudev 2011; Filonik et al 2013; Figure 1). Engagement features include aesthetics and gamification to interest and educate non-expert users (Brewer et al. 2013, Schott et al. 2012; Figure 2).

Figure 1:Analytics features

Figure 2: Engagement features

At the Energy Conservation Office (ECO) at UC Davis, we work with a variety of siloed data sources and analysis tools. We wanted to unify some of these data sources to allow easy comparisons (e.g. building meter data, utility costs, and contextual building data such as age, size and geographic location) and provide analysis tools for our energy engineers. Our end goal was a dashboard to meet the requirements of engineers tasked with increasing energy efficiency on campus, as well as educating students and staff much less knowledgeable about energy issues. We decided allocate the University's resources towards one energy dashboard that can satisfy both energy analytic and public engagement requirements. The custom dashboard we have built is called the Campus Energy Education Dashboard (CEED).

Campus Energy Education Dashboard (CEED)

CEED was created by ECO by a team consisting of a project manager, user experience designer, data analyst, and two web developers. The site has undergone two main development phases to-date, and is completing a third phase throughout the spring and summer of 2016. User research was conducted to evaluate each version of CEED and inform subsequent iterations. User research included: (1) stakeholder input from UC Davis staff with a professional interest in energy issues on campus, (2) user testing with students and staff representing the general UC Davis community, and experimentation with data visualizations on Amazon Mechanical Turk[6]. To convey this process, we organize our paper according to the two versions of CEED. We describe the design of each version, user research conducted, and how the findings of our user research informed the goals and design of the successive versions of the dashboard.

CEED 1.0

Design. The design of CEED v1 (Figure 3) began with a list of required features developed by the energy manager and project manager (Table 1). These features were derived from the aforementioned review of energy dashboard projects and the desire to unify several data sources in a display for the University's energy engineers and general campus community. The project manager and user experience designer drafted a dashboard to meet these requirements. Emphasis was on making the dashboard simple and approachable, without oversimplifying the energy data. A central goal was to show users how energy consumption varies across campus buildings.

A campus map was chosen as the back-drop of the dashboard for the spatial and contextual information it provides. The dashboard's customized campus map was developed using campus-specific GIS shapefiles, a campus dataset that is specific to the buildings' geographic information.

Energy Use Intensity (EUI) was selected as the metric to be displayed. EUI is a measure of a building's energy use that is normalized by its square footage, allowing for comparison of different buildings. The data to calculate a building's EUI is taken from a campus database for building utility meters. In CEED v1, buildings were color-coded by EUI on a four-point scale (1-99 dark green; 100-249 light green; 250-400 light orange; 401+ dark orange). Colored buildings could be selected to navigate to an energy data page with real-time demand and historic usage graphs. The graphs were customized from the JavaScript library HighCharts[7], showing data in a common energy metric, kBtu.

The metrics EUI and kBtu were selected because they are meaningful to energy analysts and engineers, and in an effort to educate the general campus community--hence the name Campus Energy *Education* Dashboard. Therefore, we did not attempt to translate energy metrics into more familiar or emotional metrics (e.g., cost, carbon emissions; Ahmed and Sanguinetti 2015, Lehrer and Vasudev 2011). Instead, we aimed to leverage user-friendly design to make the actual energy data more approachable and interpretable.

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[6] https://www.mturk.com/mturk/welcome
[7] http://www.highcharts.com/demo

Figure 3: CEED v1 design

Stakeholder Input 1.0. After the development of CEED v1, we solicited input from our stakeholders, UC Davis staff with a professional interest in energy issues on campus; specifically, 11 staff with a position related to energy, engineering, sustainability, or web development, representing the following departments: Facilities Management, Utilities, Environmental Stewardship and Sustainability, and Design and Construction Management). We conducted informal interviews with these expert users (mostly one-on-one), which began by showing them CEED v1 and explaining our goals. We encouraged feedback on existing features (e.g., map, graphs, metrics) and suggestions for future iteration and development.

Expert users expressed concerns about the four-point color scale corresponding to EUI values; specifically, that it may convey green buildings are 'good' and orange buildings are 'bad' when the reality is a variety of factors contribute to EUI. New features they suggested included the ability to download data on the dashboard to a csv, context to the energy data (e.g. building age, square footage and primary use), and the addition of more buildings on the campus map.

Table 1: Comparison of features in the different versions of CEED

Version of CEED	Feature
CEED v1	Map-based dashboard
	Energy Use Intensity (EUI) Metric
	Color scale for buildings based on EUI
	Demand and Usage Energy Graphs

CEED v2	EUI values represented by circles overlaid on buildings on the campus map, with ability to toggle by building type
	Side-panel with building benchmarks and contextual data, including cost
	Download to csv for energy graphs
	Introduction video to easily share the project with stakeholders
CEED v3 (Spring-Summer 2016)	CEED user stories that give clear call to action on what other users can do to save energy on campus
	Visualization that orders EUI values largest to smallest (for benchmarking)
	Comparisons between different buildings (by EUI and monthly usage)
	Outside air temperature and ability to 'compare to last week' added to energy graphs
	Download contextual info in csv (to augment energy data and create energy report)

Testing with UC Davis Community 1.0. User testing was conducted with members of the campus community, specifically 14 undergraduate students, recruited by our office interns, with majors spanning mechanical engineering, environmental policy and planning, economics, and undeclared. The researcher provided each participant with a brief description CEED, a questionnaire, and a laptop with CEED v1 open. Questions covered familiarity with this type of website, most interesting features, usability, and interests related to energy use on campus.

Aesthetics and engagement were highlighted by the students (e.g., "[CEED is a] visually appealing website that illustrates energy use in an engaging way"), and student responses validated the goal of CEED to reach multiple stakeholder groups (e.g., "There is a lot of useful information for all types of people, both for experts and amateurs"). Most students were able to understand the concept of EUI. The green and orange scale was associated with good and poor performance, respectively, which was consistent with findings from Stakeholder Input 1.0. Students were particularly interested in *why* some buildings used more or less energy than others, as demonstrated by frequently clicking on outliers (dark orange or dark green buildings) and comments; e.g., "Why is this building worse than the others?" Students also expressed an interest in learning how they can participate in energy conservation on campus.

Data Visualization Experiment: Map v. Bar Chart 1.0. Map-based data visualization is a unique aspect of CEED, the intention of which was to make the data more enjoyable and interesting than a conventional visualization (e.g., graph or chart), without sacrificing interpretability. To test these hypotheses, we designed an online experiment using Surveymonkey and recruited 277 participants via Amazon Mechanical Turk. Participation was restricted to the US and persons at least 18 years old (age ranged from 18 to 67; M = 34 years). Participants were randomly assigned to view either a bar graph or map visualization of the same data, which were energy use intensity (EUI) levels for campus buildings (Figure 4). On the same screen, beneath the visualization, participants were asked about the usability of the information in terms of ease of use, engagement, interest, enjoyment, and trust (Table 2; adapted from the UPscale; Karlin and Ford 2013). Two additional items were included: one measuring understanding of the energy use intensity (EUI) metric (What is your opinion of the metric Energy Use Intensity?), and another directly measuring interpretation of the information (Which building uses the most energy?).

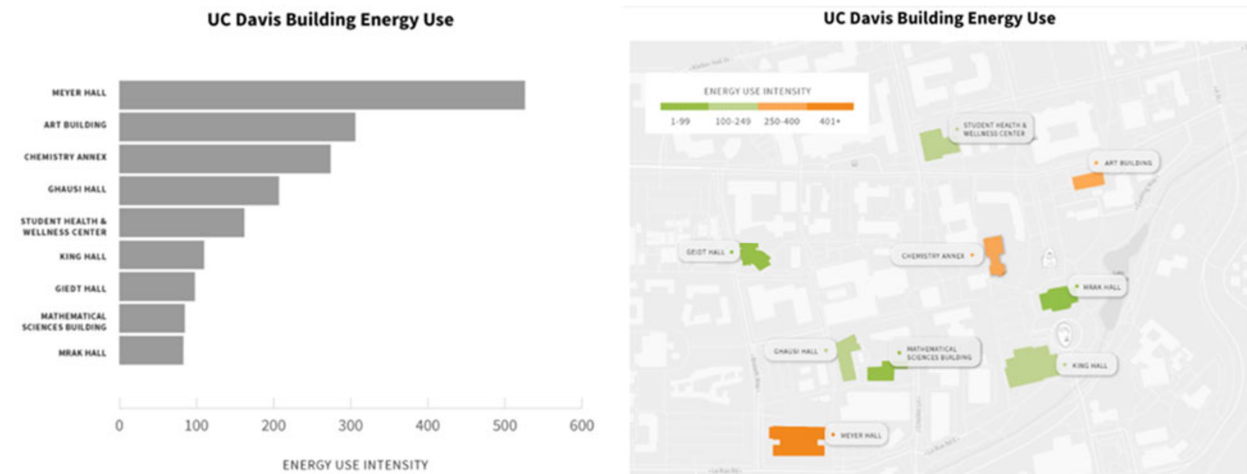

Figure 4: Map and bar chart used in Data Visualization Experiment 1.0.

Table 2. Usability scale adapted from UPscale (Karlin and Ford 2013)

Ease of use	I am able to get the information easily.
	The information is difficult to understand.
	I feel confident interpreting the information.
	A person needs to learn a lot to understand the information.
Trust	I trust the information.
	I do not have confidence in the accuracy of the information.
Interest	I find the information interesting.
Enjoyment	The information is provided in a fun manner.
Engagement	The information would be useful to the UC Davis campus community.

In line with our hypotheses, the map was rated as significantly more interesting [$t(277) = -3.41$; $p = .001$] and enjoyable [$t(277) = -7.03$; $p < .001$] than the bar chart (Figure 5). Surprisingly, the map was also rated as significantly more trustworthy as measured by the item *I trust the information* [$t(277) = -2.02$; $p = .045$], but not the full two-item trust scale [$t(277) = -1.17$; $p = .243$]. Another unexpected finding was that participants who viewed the map responded more favorably to the metric Energy Use Intensity [($X2(2) = 12.48$; $p = .002$]. There was no significant difference in engagement [t(277) = 0.88; p = .381], ease of use [t(277) = -0.80; p = .426], or ability to interpret the data: each group was 98% accurate when asked to identify the building with the highest energy use.

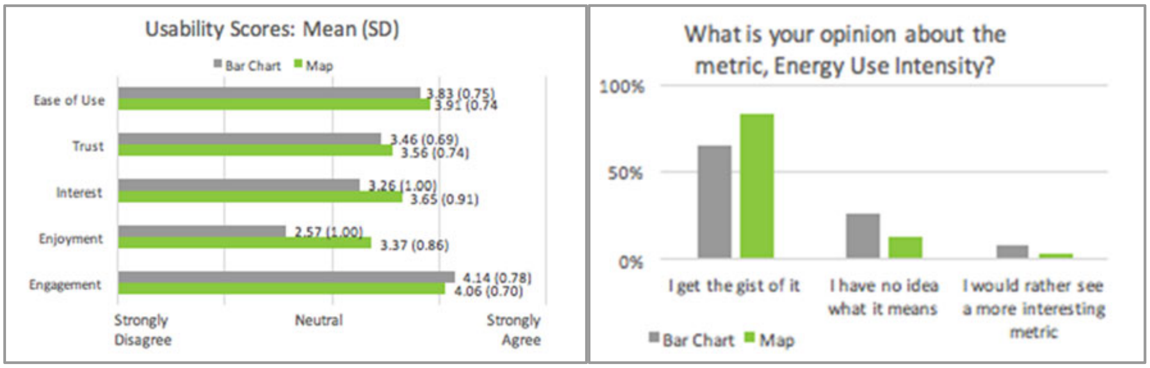

Figure 5: Results from Data Visualization Experiment 1.0.

Summary of CEED 1.0 User Research. User research with CEED v1 confirms that the map-based data visualization is an interesting and enjoyable way to present energy data. Furthermore, our map-based approach did not hinder interpretation of the data. The metric EUI was appreciated by both stakeholders and UC Davis community members; however, to both groups the four-point color scale implied 'good' or 'bad' energy performance. For the stakeholder group, this was not an accurate conclusion as there are many factors that affect a building's energy use. This group highlighted building type as a main influence on energy use in a building, a suggestion that greatly impacted the design of CEED v2. Students representing the campus community also showed interest in learning *why* some buildings had higher or lower energy use and what contributes to energy use in a building. These interests supplement the stakeholders input to add contextual data about building types to the dashboard.

CEED 2.0

Design. The design for CEED v2 (Figure 6) was heavily influenced by input from our stakeholders and user testing with CEED v1. The team addressed the main finding from CEED v1 user testing by changing the representation of EUI on the campus map. We then moved on to add additional building contextual data and benchmarking. Features to satisfy stakeholder requests included a download to csv feature and an expansion of the dashboard to include a total of 98 buildings on the campus map. A "Take a Tour" video was added to CEED to give users a more concrete idea of the dashboard and as a presentation tool to share our dashboard with new stakeholders (Table 1).

To address the issue with the EUI color scale found in CEED v1, the scale was replaced with a transparent circle of varying size (where size denotes the EUI value) overlaid on each building. With circle size representing EUI, we were able to add a variable to the map explaining why some buildings may use more energy than others. We chose to make the color of the overlaid circles represent the type of building, i.e., if the majority of space is dedicated to classroom, office, community or lab use. This dataset is from a database on campus that is specific to building contextual information. Building types can be toggled on and off the map. For additional contextual information we added a side panel that slides into view when a building is clicked. The side panel includes an average EUI for the building types, which can be used as a benchmarking capability to compare one building its average building type. Data to explain why a building may be using more or less energy than its average type is also displayed in the side panel, showing building construction date, square footage, and annual energy consumption and cost. In sum, whereas the goal for CEED v1 was to show *how* EUI varies among buildings, an additional goal for CEED v2 was to show *why* EUI varies among buildings.

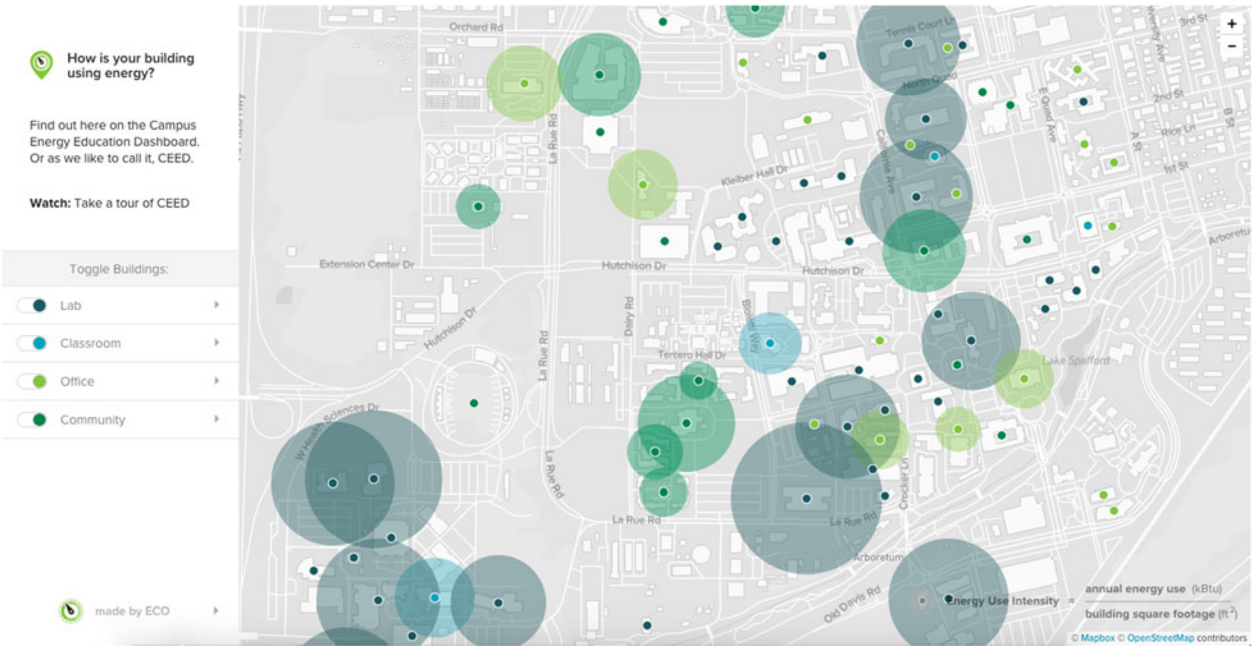

Figure 6: CEED v2 design

Stakeholder Input 2.0. The same stakeholders were approached to give feedback after CEED v2 was released. Interviews with expert users were conducted by the CEED project manager to discuss the new features of CEED v2 and solicit suggestions for further changes or additions.

The updates developed in version 2 were well-received by our stakeholders. They appreciated the added contextual information; e.g., "[users can] begin to see why a building uses more energy than it's neighbor." They easily identified that lab buildings use more energy than other building types. Furthermore, they were curious about how energy usage compared across lab buildings on campus and opportunities to reduce energy use in lab spaces. They appreciated the annual cost on the side bar and suggested cost could be an additional metric for the map; i.e., a user could toggle to have the circles represent either EUI or annual energy cost in dollars.

They also appreciated the download to csv feature for the energy data, and requested that the contextual building information in the side panel also be included in the downloadable data. There were also requests for the addition of outside air temperature to provide context for, and help explain, monthly fluctuations in energy use. One engineer suggested adding another visualization to show buildings in order of EUI for easier comparison than the circles on the map. Another suggestion was the addition of testimonials to show how different users employ CEED to answer questions and solve problems.

Testing with UC Davis Community 2.0. User testing for CEED v2 was conducted with 17 students and 10 staff. Staff were recruited via a promotion in a staff newsletter and students were recruited via departmental email; all participants received a custom t-shirt for their participation. Questionnaires were similar to User Testing 1.0, with the addition of task-based questions and one question about the perceived main message of CEED. Task-based questions included finding the EUI of a given building, comparing EUI within and among buildings types, and navigating to the live data page.

Overall, the changes to the map were well-received by our testing participants, e.g., "I like that you can look at the buildings broken down by type." Along the same lines, another participant appreciated the layering of information and when commenting on the information in the side panel said, "When clicking on a building, (it) shows you 3 most interesting data points… and then if you want more info you can explore." CEED v2 testing revealed that users easily understood that energy use depends on multiple factors, with 80% of the tested students and 50% of the tested staff able to interpret and explain in their own words that energy use is affected by building type. With this confirmation, the initial question prompted by v1 testing has been answered ("Why do some buildings use more than others?").

A recurring theme in the testing of CEED v2 was users not knowing what to do with the information presented to them. Both students and staff members discussed a desire to make a direct comparison between similar buildings, by type, size and population. Other recurring questions included, "What can I do to help?" and "How [can] individual people can influence energy reduction?" Overall, participants showed interest in how much energy their building uses and what they could do to reduce its energy use.

Data Visualization Experiment 2.0. We were curious whether the addition of building type as another variable displayed in the CEED map would detrimentally affect usability, so we performed another online experiment similar to Map v. Bar Chart 1.0. Using the same methodology as described in Map v. Bar 1.0, we assessed the usability of the modified map in CEED 2.0 compared to a bar chart with the same information (Figure 7). This experiment was conducted with 200 participants (18 to 68 years old, M = 35) on Mechanical Turk.

Figure 7: Map and bar chart used in Data Visualization Experiment 2.0.

Consistent with the previous experiment, the map visualization was rated as significantly more enjoyable [t(198) = -4.27; p < .001] compared to the bar chart (Figure 8). There was no significant difference in trustworthiness [t(198) = 1.72; p = .087], interest [t(198) = -1.49; p = .138], or usefulness to the UC Davis community [t(198) = 0.61; p = .542]. There was also no difference in the ease of use scale [t(198) = 0.51; p = .608]. However, participants who viewed the bar chart more accurately interpreted the data in response to the question, *Which building type uses the most energy?* (p < .012, Fisher's exact); the bar chart was interpreted with 95% accuracy, whereas the map was interpreted with 81% accuracy. Despite less successful interpretation of the data, participants who viewed the map again responded more favorably to the metric Energy Use Intensity; this time the difference was not statistically significant [(X2(2) = 1.95; p = .377].

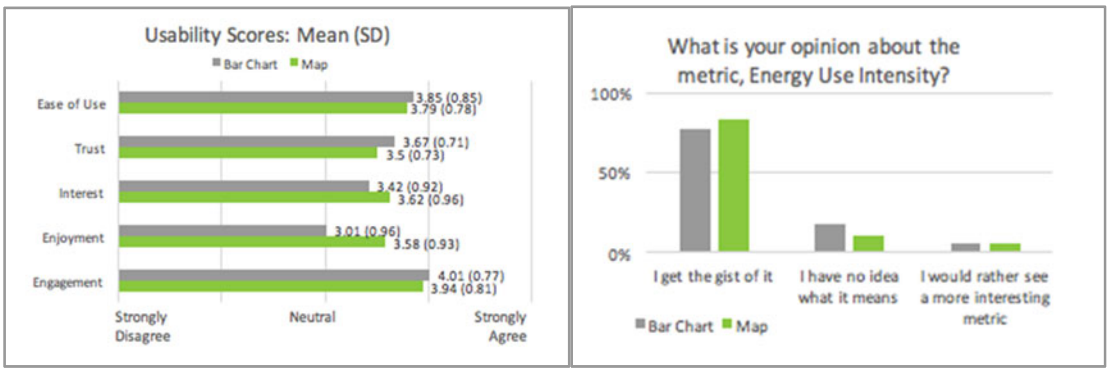

Figure 8: Results from Data Visualization Experiment 2.0.

Summary of CEED 2.0 User Research. User research with CEED v2 confirmed that the re-representation of EUI on the map and adding the second variable of building type is still an enjoyable way to present the data. However, our results indicate that the map with two variables isn't interpreted as easily as a standard bar chart. This finding also supports input from a stakeholder, who thought EUI represented by the size of a circle made it difficult to compare across a building portfolio. Another suggestion about building comparisons, made by both students in our user tests and our stakeholders, was that the dashboard was lacking a feature to enable direct comparisons between buildings of the same type. Lastly, input from a stakeholder to add testimonials showing use cases for CEED, along with students and staff in user testing asking what they could do with the data to save energy made it evident that CEED v2 was missing a clear call to action for our users. All of these findings heavily influenced the design of CEED v3 and bring to light a pattern that the findings from our stakeholder interviews, user tests and visualization experiments compliment each other and help determine what is needed in the next version of the dashboard.

Challenges and Limitations. The biggest challenge in designing and developing CEED has been the availability of data. We use building-level metering data from 98 buildings on campus, but there are a lot of buildings with only electricity data (lacking chilled water and steam data). We also gather data from two other sources (for contextual building data and geographic information) to augment the energy data and provide the context our users need. We would like to connect to at least three other data sources to collect information on sustainability and facilities condition index metrics, but we are finding that this is a lengthy process. Based on our user research with CEED, these datasets would be valuable to engineers and energy analysts and could further enhance engagement for the general campus community.

We believe the current version 2 of CEED is highly generalizable to other campuses. However, as we continue to tailor the information and features on CEED to UC Davis stakeholder and user groups, it is possible that the product itself will become less generalizable. The development process, which we have described in this paper, will remain relevant and help other universities develop a building dashboard tailored to their unique campus and community.

Future Work. Emergent from our iterative design and user testing process, we noticed an evolution in the general goals of successive iterations of CEED--progressing from awareness, to understanding, to action. Our goal for v1 was to raise awareness and highlight the variability in energy use across campus buildings. Based on v1 user research findings, the goal of v2 was to help users understand the reasons for this variability. Based on v2 user research findings, our goal for v3 is to answer the recurring questions from all stakeholder and user groups, “How can energy use be reduced?” and “What can I do as an individual to save energy?” The main feature we are planning to implement to achieve this goal is embedding user stories in the map, with analyses performed by the campus community and our engineering stakeholders to give all dashboard users an idea of how the energy data on CEED can be used to save energy. We are also planning more explicit calls to action for users to participate in energy savings (Table 1).

User research with CEED v2 suggests there is a threshold to the number of variables that can be easily interpreted with a map-based data visualization. For v3, we plan to add a visualization that more clearly ranks buildings and building types by EUI. We will continue to experiment with data visualizations in order to maximize both engagement and analytics. We will also add a feature that allows comparisons between different buildings in the UC Davis building portfolio. Outside air temperature and a preset comparison of this week to last week’s data will be added to the live data graphs to enable analysis of temporal and seasonal patterns. Finally, we will expand the download to csv feature to include contextual information, which will allow users to create a more complete energy report.

Conclusion

Creating a custom product yielded the flexibility to tailor CEED for multiple stakeholders and the general UC Davis community. The custom dashboard has also enabled us to combine several datasets that were available but otherwise disconnected. CEED has been in continuous iteration since its conception and will continue to improve to meet the needs and wishes of users as determined through extensive user research. CEED v1 was largely influenced by other dashboards, but through design iterations based on user research it has taken on a unique character. With this paper, we have shared lessons learned, challenges faced, and what we believe has been an innovative and successful development process. We hope it will be useful to other universities with similar needs and goals.

Acknowledgments

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