A Taxonomy for Building Energy Dashboards

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ABSTRACT

Dashboards are increasingly being used in commercial buildings to show building data in an intuitive way to occupants and facility operators. Such dashboards make relevant parties aware of the impact that they have on a building's behavior and enable them to understand the dynamics of building systems and current/historical energy use, and as a result, support reduction in energy use and improvement of operations of such systems. This paper gives an overview of an approach for designing and implementing an energy dashboard for a monitored building that includes highly sensed building automation systems and sensors for energy consumption. This project is part of the Energy Efficient Buildings Hub in the Philadelphia Navy Yard. The developed approach incorporates formalization of a taxonomy for building energy dashboards, identification of visualization aids and requirements through a questionnaire, and a prototype implementation. The findings show that effective building energy dashboards should contain query-based and quick-access based functionalities for showing building energy data through the use of various widgets and user interactions. Such dashboards should also enable decomposing data within spatial and temporal dimensions, interacting with static and dynamic data sources, and providing information about directly measurable energy usage vs. resulting energy use indicators.

INTRODUCTION

In order to facilitate the operation of complex mechanical and electrical systems in buildings and help monitor the performance of a BAS, many sensors are installed throughout a building. Some examples of measurements taken by sensors in buildings include electricity consumption, gas consumption and temperature. The large amount of data collected from these sensors challenges monitoring and assessing performance of a facility manually in order to identify energy saving opportunities (Lehrer 2010). Similarly, occupants should be able to assess the implications of their energy use decisions on the overall energy consumption in the building. A visual representation of the collected data can help in understanding the energy consumption of a facility and increasing awareness about the performance of a facility for all stakeholders. Dashboards provide a great medium to visually represent data.

Energy dashboards are increasingly being deployed to support the monitoring of energy usage of buildings as they provide an easy and visual way of digesting large amounts of sensor data quickly (Few 2006). They are used on campuses and companies like Oberlin College, University of California - San Diego, Wal-Mart Stores Inc., and Sysco Corporation to name a few to monitor the energy consumption of buildings (Oberlin College; Agarwal 2010; Granderson 2011). Despite the increasing popularity of dashboards, not a lot of research has been done to identify components that need to be present in an effective energy dashboard. Many commercially available energy dashboards are designed by vendors to look aesthetically pleasant to captivate the users but do not always look into the needs of a user or how the dashboard would benefit users the most (Few 2006). By helping a user visualize their energy consumption, it is possible to gain as much as 80% energy savings (Agarwal 2007). Having a taxonomy that clearly defines all the elements that need to be present in a dashboard will help structure the various use cases that a building energy dashboard should contain.

This paper discusses the development of a taxonomy to give a generic representation of components that need to be present on a dashboard. A questionnaire was developed based on the taxonomy to understand the individual preferences and requirements of different stakeholders. The results of the questionnaire summarize the information that needs to be displayed as well as how it should be displayed that would satisfy the majority of stakeholders. Building on these findings, the research team implemented a prototype design of a dashboard on a test bed building at the Navy Yard in Philadelphia.

TAXONOMY DEVELOPMENT

The research team analyzed 28 commercially available building energy dashboards along with 15 low and high fidelity prototyping environments for designing dashboards. It was found that many available energy dashboards were designed for different use cases, which can broadly be divided into query-based and quick-access based, and for different types of users. The team examined various components of these dashboards and development environments, and synthesized the findings based on the common characteristics of these dashboards/environments. These common characteristics that should be defined during the design of a building energy dashboard are shown in Figure 1, along with the relationships between them.

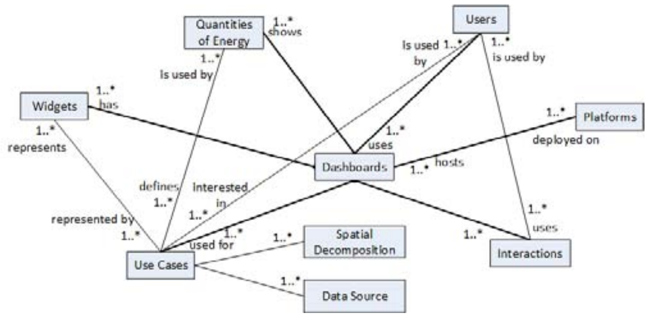

Figure 1. Taxonomy for Energy Dashboard

The main functionalities of a dashboard are represented by the *use cases* entity in the taxonomy. This is sub divided into query-based use cases and quick-access based use cases as shown in Figure 2. The query-based use case is dependent on a data source, such as real time input from sensors in the building. It enables the user to request and view results from a predetermined set of queries on the available data sources. The quick-access based use case encapsulates cases where a user can view fixed information from a data source, such as the current electricity consumption or temperature in the building. It can also be used to show information that is not dependent on a data source, such as green tips and company information.

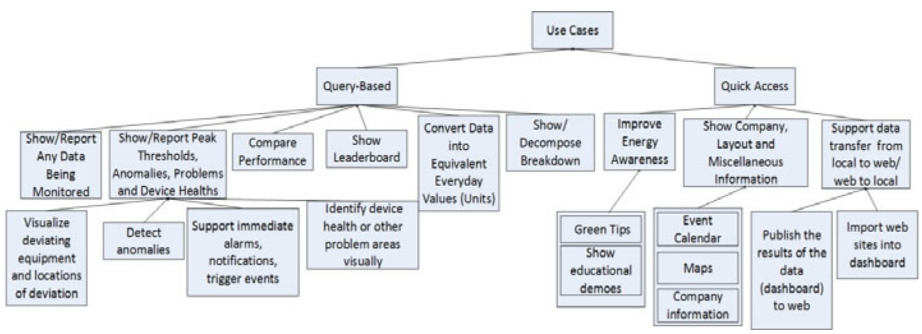

Figure 2. Sub-Taxonomy of Different User Cases

The *platform* entity refers to the devices and hardware requirements that the energy dashboard is deployed on. It has two main sub groups, which are mobile (phones,) and non-mobile (desktop computers, televisions) platforms.

Multiple ways of communicating with the dashboard is summarized in the *interactions* entity of the taxonomy. The two sub groups are interactions that require an external device for input such as a mouse, keyboard or motion sensing controller, and interactions that do not require any external devices, such as using our hands.

The *data source* entity refers to the source of data that can be utilized on the dashboards. It is divided into two sub groups which are dynamic data sources and static data sources. Dynamic data sources store real-time and historic sensor data from equipment and sensors in a building based on a predefined frequency and granularity. Static data sources refer to information such as the building information model which does not change frequently over time.

The *quantity of energy* entity defines the two types of data collected by sensors. The first subgroup is sensor data that directly measures energy consumption, such as electricity, gas and water consumption. The second subgroup refers to sensor data that measures resulting outcomes after the energy is consumed such as temperature, humidity, CO_2 and greenhouse gas emissions.

One of the important components in dashboards is visual aids, described in the *widgets* entity of the taxonomy. The first sub-group which is layout widgets captures multiple ways to layout the widgets, such as horizontal and vertical. The most effective way of visually representing data is by using charts, gauges and tables which belong to different subgroups. Different types of charts, gauges and tables provide an easy way to represent large sets of data, such as historical electricity consumption and current temperatures. Text indictors such as labels and text input boxes and form elements such as drop down menus, check boxes and date pickers, are components used for taking user input. Various types of media, such as pictures and videos, are also used to convey information to users, which are subgroups under the widgets entity. Dashboards that are specialized for specific tasks, such as for FM, use specialized visual aids to model equipment and floor layouts for displaying information about equipment or locations are another subgroup.

The *user* entity represents the individuals who will potentially interact with the dashboard and define use cases. When analyzing commercial dashboards, the team recognized that they were being designed for a specific group of users. The type of user significantly impacts the other entities because the functionality of the dashboard changes depending on who the dashboard is predominantly designed for. Therefore, this entity has two sub groups namely individuals, who have a direct impact on the energy consumption of the building such as owners, occupants, and public and individuals, who do not such as users from outside organizations.

For every query that a user can perform, the scope of the query needs to be defined. This is captured by the *spatial decomposition* entity. The user defines the spatial coverage for which they would like to view information from. Some identified levels include, a floor of a building, the whole building or even the entire campus.

This taxonomy details all the entities that are required to create an informative energy dashboard and the relationships between them. Although there are many ways to create energy dashboards, the entities in the taxonomy can be used to collect user requirements in a structured way so that the dashboard is designed to satisfy the users that it is intended for. In order to develop a dashboard, the team used the taxonomy as a template and created a questionnaire for the stakeholders for a specific building test-bed that is described in the next section. By analyzing the results, the team concluded on what information had to be represented in a common dashboard to be displayed at a public space in the building.

BUILDING 101 TEST-BED

The test-bed that was chosen to implement the taxonomy and design a building energy dashboard is a building at the Navy Yard. The test building is instrumented to collect and store large amounts of sensor data. These sensor points measure major electricity and natural gas consumption in the building, heating and cooling capacities delivered by the HVAC system, operating conditions of equipment, occupancy, indoor air quality and ventilation flow rates (EEB Hub). With 1,500 data points generated every minute, it provides a test-bed to implement a dashboard that is built on the concepts described in the developed taxonomy.

Requirements Collection from Stakeholders. There are many ways to design and show information on a dashboard. The taxonomy defines all the entities that should be considered, but does not specify the requirements of users. All the information that is displayed on the dashboard may not be relevant to all users. In order to study what information needs to be shown for stakeholders to effectively use the dashboard, the team prepared a questionnaire based on the taxonomy. It asked users about the energy data that they would like to see, features, such as current energy consumption trends, historical energy consumption, trends they wanted to compare, queries they wanted to perform, layout, visualization and navigational preferences and the way they wanted to interact with the dashboard. It also included questions about what information needed to be displayed about equipment in the building, what information about greenhouse emissions users would find useful, and whether the dashboard should show energy consumption per person. Each question was given with a set of predefined answers and an option to add other options. The questions covered all entities in the taxonomy to gain a better understanding of user preferences.

The platform entity is one that the designer of the dashboard has to decide based on user preferences. The spatial decomposition entity was represented in the questionnaire based on the way data was collected. All of these questions were followed up with a list of various widgets to represent the information.

The questionnaire was given to a total of 22 participants that belonged to different stakeholder groups: 10 occupants, 3 frequent visitors, 4 personnel from FM and 5 owners. Based on the results of the questionnaire, functional requirements of the energy dashboard for the building were identified. Features and preferences that at least 30% of the individuals surveyed desired were included in the dashboard prototype. FM stakeholders were interested in information about equipment conditions and statuses that were not identified as apparent requirements in other stakeholder groups. As compared to FM group, users/visitors wanted to see basic energy consumption trends rather than equipment specific energy uses or equipment conditions. The spatial and temporal options that stakeholders wanted for the query-based use cases also showed differences in the sense that FM operators wanted to look at the data in hourly, daily basis vs. other stakeholder groups were interested in looking at the data at a less granular level (e.g., yearly, monthly).

Analysis of Questionnaire Results and Implementation. All the features that were requested by users broadly fall into the two use cases that were defined earlier which are query based and quick access based.

Quick Access Based Use Cases. Most users prefer to access the dashboard through the internet and interact with it using their hands or a mouse. The results indicate that users prefer to see limited information on the main screen and have icons to navigate to their desired use case as shown in Figure 3. Another important feature that users wanted was to provide green tips for energy conservation. Users also want to be able to view information about the company, maps of the building and event calendars which are not related to energy usage, but provide information to all stakeholders.

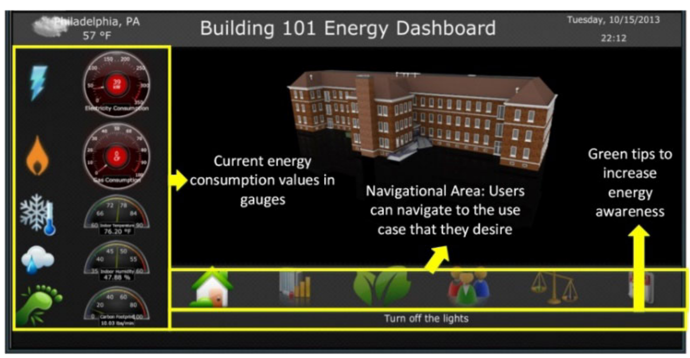

Figure 3. Main screen of energy dashboard

Query Based Use Cases. Users wanted to see current and historical energy usage of electricity consumption, gas consumption, greenhouse gas emissions, indoor air temperature and indoor humidity level. The spatial options they wanted to choose from are by floor and by building. The temporal options are hourly, weekly, monthly and yearly. The results show that current energy consumption should be shown in gauges as seen in Figure 3 and historical energy consumption as a bar graph with the spatial option chosen by the user as shown in Figure 4.

Comparison of energy consumption of different equipment and parts of the building along with leader boards is also a requirement. The spatial options include multiple floors and the temporal options include hourly, weekly, monthly and yearly.

For the leader boards, the spatial options are across the floors in the building and across multiple buildings. The dashboard should show the leader boards as the best for a week and the best for a month as temporal options.

In order for energy consumption to be easily understood by the users, the dashboard should provide energy consumption of the building in equivalent everyday values. The options that users preferred are to show the energy consumption in corresponding dollars spent, number of light bulbs, number of laptops and greenhouse gas emissions, which are shown in Figure 5. The dashboard should also provide energy consumption per person, which can be seen in Figure 5. From the analysis, it was seen that users want the dashboard to signal alarms and notifications to users when a piece of equipment is operating outside the norm for similar equipment or deviating from historical performance.

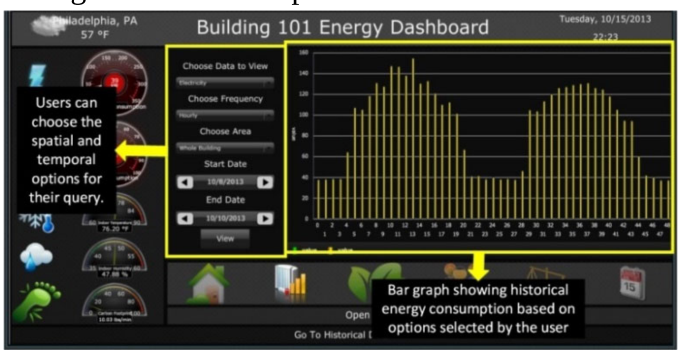

Figure 4. Historical energy consumption view on dashboard

The current design of the dashboard is primarily focused on requirements that are relevant mostly to occupants and visitors of the building. It gives an informative display of energy consumption and its decomposition in the building. It enables the user to view current energy consumption decomposed into electricity and gas. The user can quickly get a sense of temperature, humidity and greenhouse gas emissions. The dashboard enables the user to view historical energy consumption, compare equipment and parts of the buildings and view leader boards based on the spatial and temporal options from the questionnaire. Additionally, it also provides the users to see the energy consumption per person and in equivalent everyday values.

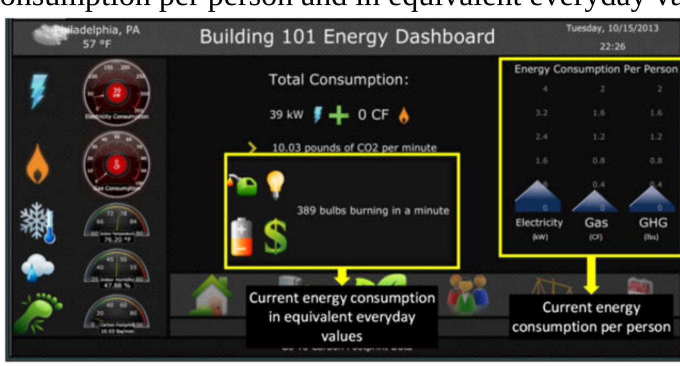

Figure 5. Greenhouse gas emissions and energy consumption per person view

CONCLUSION

The developed taxonomy represents all the entities required to produce a building energy dashboard. It provides a structured way for collecting requirements from users when implementing energy dashboards in buildings. Collecting these requirements from stakeholders based on the taxonomy for the building will increase the usability of the dashboard and ensure that it satisfies the majority of the stakeholders' needs in the building. Future dashboards on other buildings developed based on the taxonomy will ensure that relevant information is displayed based on the required use cases, interaction and visualization needs. With the initial development of the dashboard complete, the research team is going to add more functionality to enable real-time user response to the data being shown. The goal of this is to motivate individuals to actively make decisions about their energy consumption based on information from the dashboard. Another feature that is important is to have a reference point against which all the data being displayed is compared to. This reference point will help users to understand the potential energy savings that can be achieved by adopting certain practices. A dashboard will also be developed to incorporate the use cases that are important for FM purposes.

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