Building User Audit: Capturing Behavior, Energy, and Culture

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ABSTRACT

This project developed an analysis tool called the Building User Audit Procedure (BUAP) for understanding how people impact energy use patterns in campus buildings. For this study the authors developed the protocols for the BUAP in order to 1) understand actual and perceived energy use practices for particular buildings, 2) establish a baseline for behaviors that affect energy use, 3) create a benchmark for the design of new buildings, and 4) guide future intervention programs aimed at fostering pro-environmental behavior. To create the BUAP, the research team modified the ASHRAE "Procedures for Commercial Building Energy Audits" to create a three-tiered analysis tool including direct observations, automated monitoring and a questionnaire to qualitatively and quantitative assess the interaction between individuals' behavior and building performance. Tools like the BUAP are important because they can better capture cultural and behavioral factors that influence pro-environmental behavior such as users' values, beliefs and attitudes; awareness of issues; personal and social norms; perceived control over environmental outcomes, and behavioral intentions leading to conservation behaviors. Building owners who use the BUAP instrument can improve their ability to increase building energy efficiency by accounting for the effects of building user behaviors.

Introduction & Rationale

Currently, efforts to measure (and increase) building energy performance do not include detailed information about building users' practices, beliefs, and norms. This is a problem because increasingly building occupants' decisions influence a growing proportion of energy use. In United States more than 40% of all energy is consumed by the building sector, and buildings are also a major source of greenhouse gas (GHG) emissions (EIA 2007). Education buildings such as those on college campuses consume 74 KBtu/SF year on average and a quarter of this energy consumption involves consumption that building occupants influence by controlling lights, computers, and other plug loads (EIA 2007). The proportional impact of plug loads on building energy consumption is becoming larger as more people have portable devices (e.g. laptops, smart phones, tablets). However, energy codes that are becoming increasingly stringent typically do not regulate plug loads. Buildings may be designed to reduce whole-building energy consumption, but there remain significant demand-side issues related to how people use buildings and these issues represent a greater proportion of energy impact. For example, in one net-zero office building in Seattle, the end-uses related to occupant behavior represent over 75% of the overall energy footprint of the building, and the number of people in the building had a direct correlation to overall energy use (Hanford et al. 2016). Without clear information on users' behavior within buildings, decisions about buildings' design and operation will miss major factors influencing energy use.

The Building User Audit Procedure (BUAP)

A typical building energy audit identifies the systems and technologies in a building and analyzes how the systems affect energy consumption. Such audits quantitatively measure the energy consumption of a building by assessing the general operation of building-level lighting, HVAC&R equipment, controls systems, and the performance of the building envelope. Existing energy audit tools do look at people's behaviors at a very high level, and some identify behaviors of building operators. Typically these tools do not entail an in-depth analysis of the behaviors of regular building occupants, thereby missing key information about factors that influence energy performance.

To fill this gap, researchers at the University of Washington (UW) developed the Building User Audit Procedure (BUAP) to assess users' impact on energy use in campus buildings. This building use audit focuses on occupants' beliefs and behaviors as mechanisms for understanding how to improve energy performance thereby filling a gap in energy consumption analyses that typical energy audit information does not address.

For this project, researchers piloted the method for the Building User Audit Procedure to provide the owner, in this case the University of Washington, a tool for understanding how people use energy in campus buildings and how building facilities and equipment are used in practice. The tool created a benchmark for the design of new buildings and a guide for future intervention programs aimed at fostering pro-environmental behavior.

The research team developed the BUAP based on "Procedures for Commercial Building Energy Audits" (ASHRAE 2009). The BUAP added two distinct components (Figure 1), *User Energy Behavior* and *User Culture Context*. *User Energy Behavior* recorded the physical characteristics of a building and its users' energy-related behavior. *User Cultural Context* recorded the social context of buildings and their users, including an analysis of the interplay between individuals' culture and their built environments. This included users' values, beliefs and attitudes; their awareness of issues and consequences of their actions; their perceived control over outcomes; and behavioral intention and motivations leading to actions in the context of a specific place or environment (Clayton, 2012; Steg De Groot, 2012; Steg et al. 2014a & 2014b).

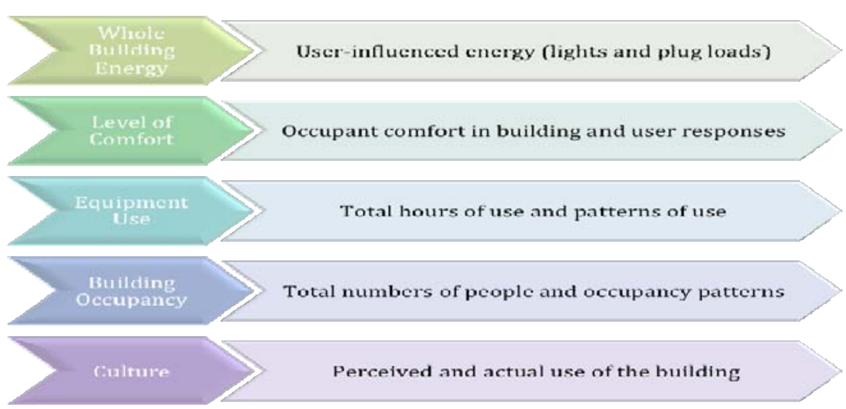

Figure 1: Data Collection Components

BUAP UW Pilot

The University of Washington (UW) pilot study for the BUAP was envisioned to provide useful information for campus facilities managers through the development and testing of the BUAP instrument. While UW had previously implemented several programs and initiatives to raise awareness of energy use on campus and reduce campus energy consumption, the UW needed an instrument to accurately account for the effects of building user behaviors that influence energy use in campus buildings. The UW pilot of the BAUP tool focused on three buildings with classrooms and administrative offices. The tool is applicable and transferable to other buildings and campuses based on the goals and objectives of the audit.

The BUAP - Level 1: Preliminary Analysis

During the level 1 preliminary analysis stage, researchers selected the buildings and gathered basic information on their energy consumption and use. Researchers used campus databases, including UW Energy Dashboard, GeoSIMS, and UW Room Schedule Finder. We gathered basic information on buildings such as year of construction, Gross Square Footage (GSF), and amount of classroom and office space from a facilities management database ("GeoSIMS" developed by UW Office of Planning & Budgeting). We calculated a whole building Energy Use Index (EUI) and compared monthly energy use patterns for the buildings selected for the BUAP using the information from the UW Energy Dashboard. We used a "room finder" database provided by UW Office of Registrar to map and how rooms were being scheduled.

We anticipate that many campus building managers have similar information systems on buildings, but much of the same information could come from other sources such as architectural and mechanical as-built drawings, utility bills, utility meter data, and interviews with building operators.

The BUAP - Level 2: Building-walk through Analysis

For the second level walk through stage of the BUAP we identified the use, condition, and operation of each building by interviewing the building manager and conducting a basic building walkthrough to gain familiarity with the building. We found effective collaboration and communication between the research team and the building manager to be key for the success of the BUAP. Building managers helped the team gain access to the building for observations and audits, inform building occupants of the presence of the research team, recruit faculty & staff volunteers for the study, facilitate access to selected rooms for installing the energy monitoring equipment, and invite building occupants to participate in a survey. In the interview, the building manager reported the types and number of building occupants and the pattern of building and equipment energy use. Next, an analyst conducted an initial walk-through of the building to (1) become familiar with the buildings' construction, operation equipment; (2) compare the floor plans and expected space functions to actual use; (3) identify potential locations for automated monitoring and sensing; (4) address potential challenges for performing manual and automated monitoring, such as accessing private spaces or closed floors; (5) create a building overview using the floor plans including numbers of types of rooms and building features, such as operable windows; and (6) identify areas that should be excluded from the audit.

The BUAP - Level 3: Energy Survey & Engineering Analysis

The third stage of the audit entailed observation of uses, deploying automated energy monitors and implementing the survey. The goal was to triangulate across these data on user behaviors and beliefs and assess their influences on energy use. Combining methods provides a more comprehensive understanding of the building performance and energy use.

Manual Observation of Uses

Auditors observed building use at six pre-scheduled times (8am, 10am, 12pm, 3pm, 6pm, 9pm) from Monday to Saturday. The observed use often differed from expected use. The types of data that were gathered during manual observation included:

- Occupancy
- Electric Lighting utilization
- Windows open/closed
- Blinds or drapes open/closed
- Number of desktop computers in use
- Number of laptop computers
- Number of laptops plugged in
- Number of desk/floor lamps in use
- Number of TVs and Projectors in use
- Number of personal fans/heaters in use
- Number of other plug loads (e.g., cell phones and tablets)

Auditors were undergraduate and masters' level students who used standard checklists, noting data outlined above. They were well informed about the goals, procedures, and processes of the audit project. They were also instructed to have minimum interruption for the building occupants. Conducting this audit during the building walkthrough allowed the research team to respond preemptively to any issues that the student auditors might have faced on the first day of the audit.

Automated Monitoring

Automated data loggers were used to capture detailed information about the building and occupants' behavior in faculty and staff offices. The team installed sensors to collect data on electricity use, occupancy, and indoor environmental quality (IEQ).

The Watts UP meter monitored the plug loads of miscellaneous electric load equipment or MELs, measuring power (kW) and energy (kWh) usage at 15-minute intervals. Since the goal of the audit was to identify the amount of electricity used by the room occupants, all electrical equipment present in the room was plugged into the meter. However, the amount of energy consumed for lighting was determined separately.

We installed people counters at all entrances of the buildings to record the number of people who entered and exited. Building auditors also manually recorded the number of occupants.

Indoor environmental quality measures, such as temperature, humidity, and lighting, may help explain triggers for building users' behaviors and fluctuations or changes in sensor or energy monitor data. Therefor, we installed HOBO data loggers, battery-operated devices to log indoor environmental quality. We used the UX90 to record room occupancy and light use and the UX100 to capture average room temperature and relative humidity. Both devices were programmed to record data in 15-minute intervals for 24 hours per day throughout the period of audit.

The automated monitoring and manual observations occurred at the same time. The sampling of rooms was selected from different parts of the building so that the results of analysis are generalizable. For example, selecting offices on different floors and with various orientations to the exterior environment allows for occupant behaviors and insights that impact overall building performance.

Survey

The BUAP User Survey gathered information on building occupants' perceptions of energy use. The User Survey established a baseline for the purpose of comparative analysis now (between buildings) and in the future (within buildings) to better understand how occupant behavior impacts energy use in the built environment.

The survey was sent to all students, faculty and staff by building managers through existing building occupant lists. One limitation of this method was that the University did not keep accurate records of the current numbers users in each building and our team was unable to gather accurate information about how many people received the request to take the survey. A total number 149 people responded to the user survey. In comparison to another University-wide survey about the Campus Climate Action Plan, the BAUP survey received a higher number of responses, validating a high response rate compared to other UW campus wide initiatives. For future deployment, an accurate accounting of how many people received the request to take the survey and subsequent response rate would make analysis of survey bias clearer.

There are three major reasons to conduct the User Survey. First, a comparative analysis of perceived and actual energy use is used to identify concordant or divergent energy use patterns by building occupants. Second, researchers seek to understand the wide range of building user motivations underscoring pro-environmental behaviors (PEB) that, when analyzed, allow the analyst to assess the likelihood of a building user to engage in pro-environmental energy saving behaviors. Finally, by gathering data on the often dynamic relationship between individuals and their built environment (cultural context) building managers have a baseline profile for future building designs and longitudinal studies.

The User Survey was based on tested items from scales used in environmental psychological research questions focused on values (Steg, Perlaviciute, van der Werff, and Lurvink, 2014b) and climate change beliefs (Poortinga, Steg, & Velk, 2004) as well as questions from the longitudinal UW Climate Action Plan survey instrument (given campus wide every two years). The eight categories in the User Survey are:

1. Building Use
2. Miscellaneous Electric Loads (MELs) Equipment Inventory
3. Energy Related Intentions and Behaviors
4. Occupant Comfort
5. Climate Action Plan (UW CAP) related items
6. Value Orientations
7. Climate Change Beliefs
8. Socio-demographic measures

Selected Results and Triangulation of Data

For the purposes of this paper, a small sample of results are shown to demonstrate the types of analysis that can be conducted using the data gathered through the BUAP.

For example, analysis of the lighting and occupancy data recorded by the HOBO devices indicate the total number of hours per day that the electric lighting was used and the occupancy patterns of the monitored rooms as highlighted in Figure 2.

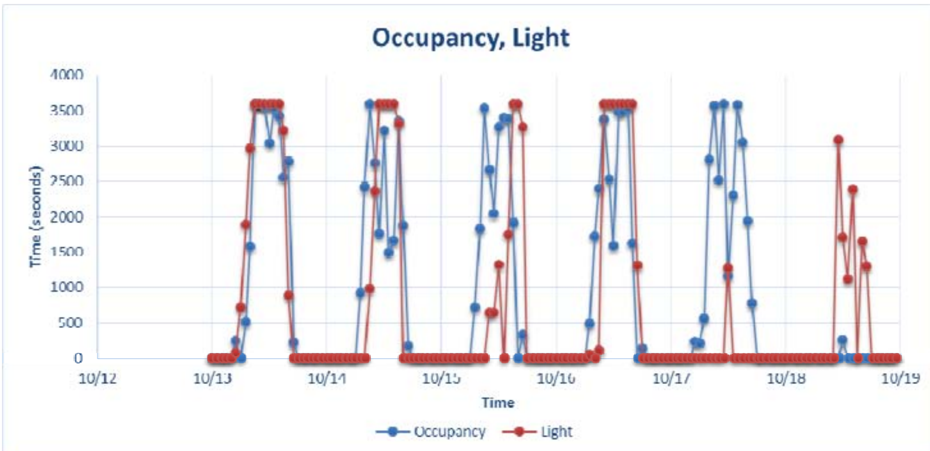

Figure 2: Profiles of room occupancy and lights on. Red indicates lighting and Blue indicates occupancy. The X axis shows a one-week interval and the Y axis shows the amount of time the lights were on and/or the room was occupied. Times where the room is occupied, and no lights are on, the user is conserving energy (e.g., 10/17). Times where the lights are on, and no one is in the room, energy is being wasted (e.g, 10/18).

Indoor temperature and humidity were analyzed in 15-minute intervals and as daily averages. Unusual changes in temperature may detect the influence of user behaviors and actions (such as opening a window, or using a space heater). An example room is shown in Figure 3.

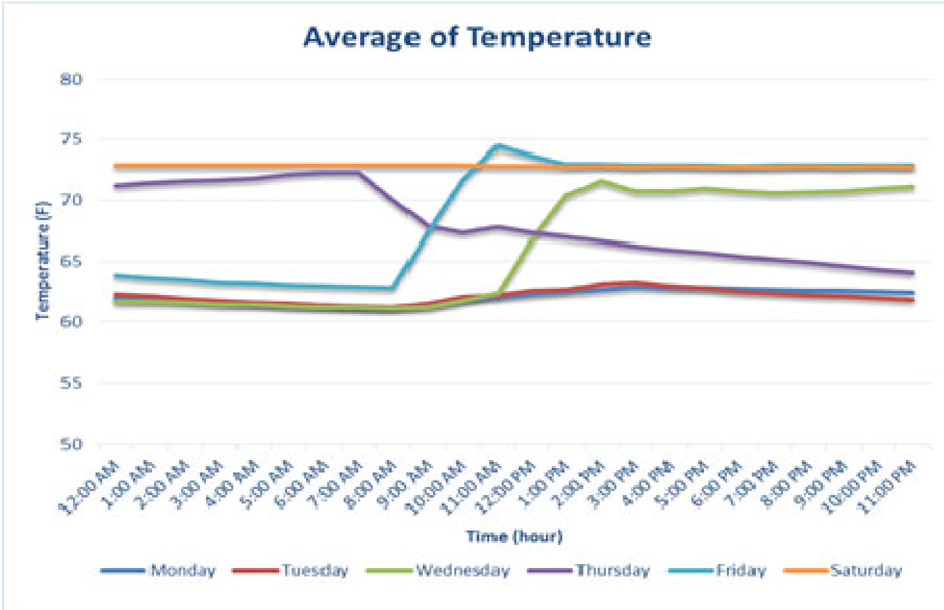

Figure 3: Average temperature of one room shown on an hourly scale (X axis) for each day of monitoring. Fluctuations on Monday and Wednesday may be related to the occupant's intervention, turning on a space heater to raise the temperature, for example. The fluctuation on Thursday may be related to the occupant opening a window to cool the space.

The team analyzed workstation energy use using the Watts Up meter data collected from offices and determined daily use patterns and calculated overall energy used. Examples of these data are shown in Figures 4 and 5.

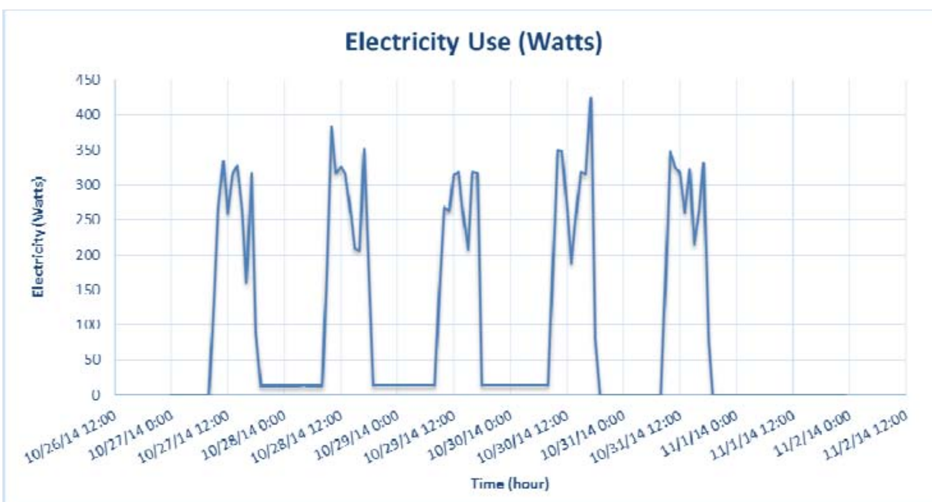

Figure 4: The amount and pattern of electricity use for a sample workstation

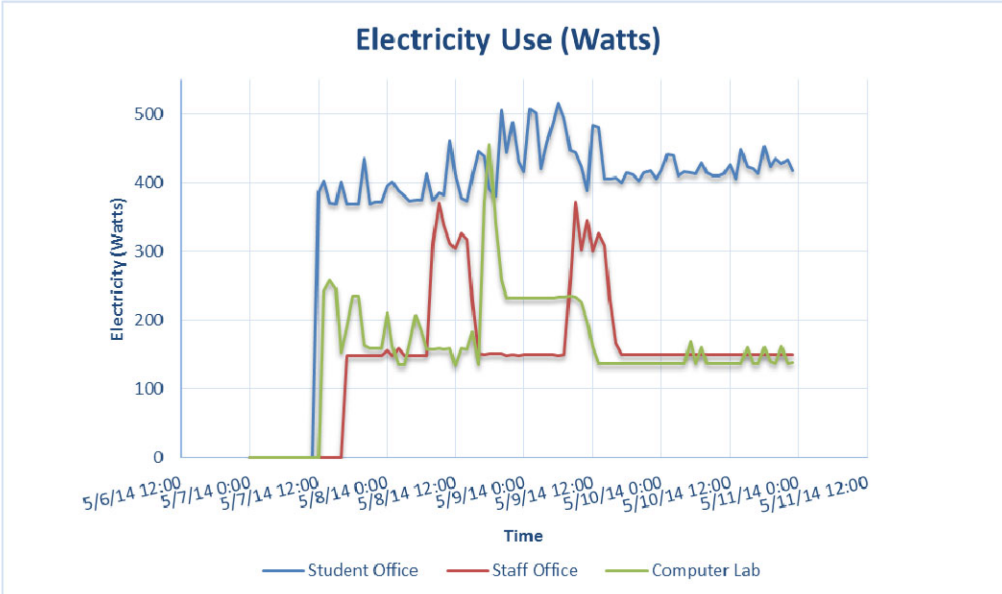

Figure 5: comparison of electricity use between workstation types

People counters identified daily and hourly occupancy/traffic in the buildings, which allowed the research team to calibrate occupancy information for energy modeling. Auditing building occupancy by two methods, observations and automated monitoring meant the researchers had the exact location of people present in the building from observations and a precise count of occupancy from the counters. A secondary benefit of this monitoring was that it helped building managers better understand their facility's use in both quantitative and qualitative terms.

The research team compared the data from the people counters to observation data. The automated monitoring counts were slightly higher than what auditors observed, but within the range of expectations. Example occupancy data collected with automated monitors is shown in Figure 6.

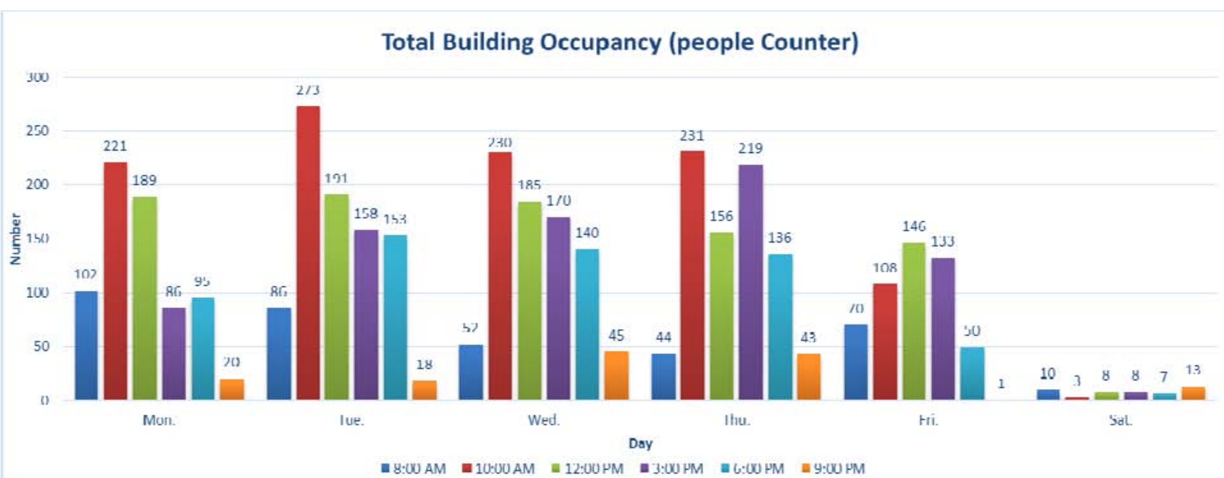

Figure 6: Building occupancy derived by automated people counters showing hourly, daily and weekly patterns.

The team compared data gathered across meters and sensors, observations, and the building energy performance information. The purpose of our triangulation was to holistically understand the multidimensional influences of the occupant's behavior on the building and energy use. Below we describe several examples of how integrating this data provides insights for the design and operation of buildings.

Estimating the total amount of energy influenced by users could help facility managers quickly and cost-effectively understand the impact of user behavior and accordingly pursue proper actions for energy reductions. The research team calculated percentages of user influenced energy use for each specific building, which was then compared with national benchmarks for typical educational buildings.

Buildings are not always used as designed or modeled. Observation data showed unexpected uses of classroom buildings after hours and different intensities of use during normal class times. This suggests that after hours use be consolidated and grouped into one or two buildings designated for this purpose and highlights creative ways that buildings could be more effectively utilized during normal class times.

Faculty and staff use cannot model student use of campus buildings. Comparing the use of classroom and office buildings use by faculty, staff and students suggest differences in energy saving behavior. These differences suggest very distinct interventions are needed for people who work regularly in buildings and students who may use computer labs or classrooms occasionally.

Differences found between perceived and actual use of equipment and energy helped UW target specific behavior change campaigns. Building users thought their energy practices were fundamentally different from what was found through sensors and observations. People were asked questions about their value orientations (e.g. biospheric), their problem awareness (e.g. climate change), and their pro-environmental behaviors (e.g. turning off lights and equipment when not in use), and the audit measured their actual energy use (e.g. turning off lights and equipment). For example as Figure 7 illustrates, we found that many occupants reported in the survey that they turn lights off when leaving a room on a regular basis when they reported pro-environmental values. The findings from manual and automated monitoring show, however, that often times lights are left on when no one is there. The gap between actual and perceived behavior, values, and beliefs offers an opportunity for the University to target specific behavior change campaigns and suggests which campaign messages may prove most effective for ingraining this conflicting perception vs. behavior.

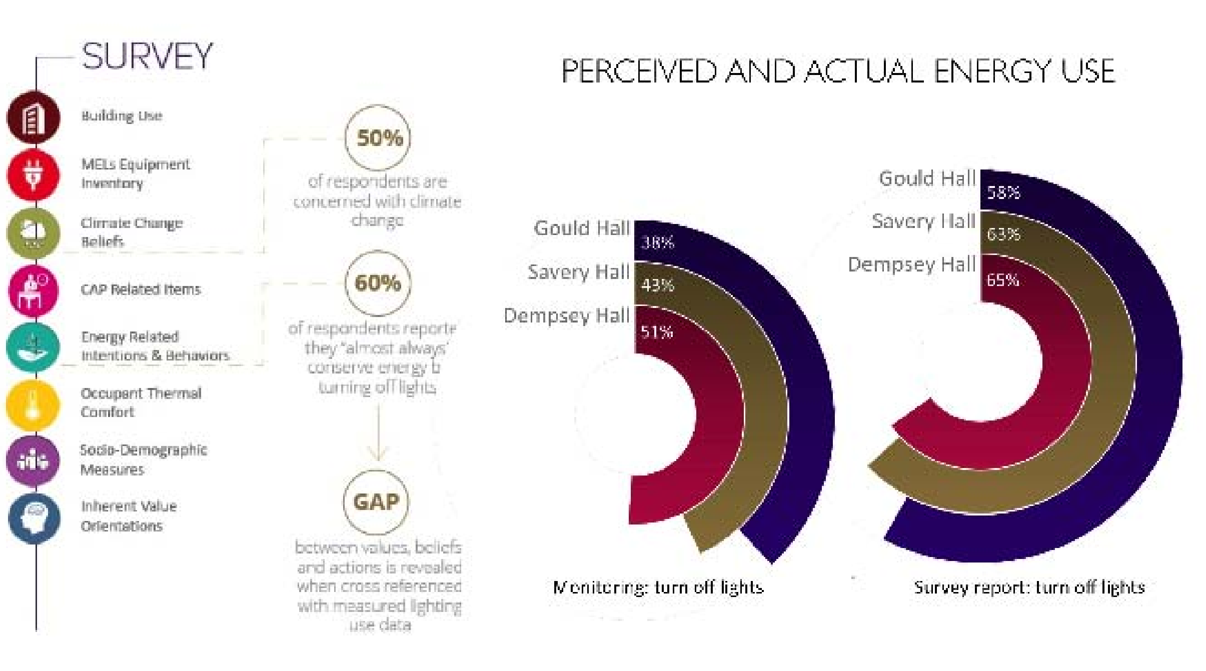

Figure 7: Perceptions and actions gap.

Motivations underpin actions with respect to actual and perceived energy use. The survey found that many respondents who held biospheric values and worry about global warming did not believe that they could do something about climate change. The gap between values, beliefs and attitudes, awareness of issues and consequences, personal and social norms, perceived control over outcomes, and/or behavioral intentions leading to conservation behaviors is an opportunity for the University to develop targeted behavior change campaigns that truly impact energy utilization and match positive perceptions of pro-environmental behavior within the communities that are helping impact that change.

Conclusion

During the last decade, significant efforts have been made by stakeholders in the construction industry to better understand the main energy drivers in buildings and apply most effective energy efficiency strategies. The BUAP was piloted at the UW in order to develop a tool to uncover how people impact energy use in buildings, and to understand the background cultural context of building occupants. The findings can be used to understand current energy impacts of building occupants, influence current building use through behavior-change campaigns, and/or impact future development of building projects with data-driven decision-making. In addition, the procedure can highlight where there are gaps between the occupants expected behaviors/actions and their actual behaviors/actions.

Results on the UW campus reveal that there is a considerable influence of building occupants on energy use, about 10% of electrical energy consumed in two campus classroom buildings (equal to 7,341 KWh and 5,523 KWh respectively) and 18% (of total energy used) in another classroom building (equal to 18,583 KWh). Since these user-influenced energy uses are a significant source of energy use campus-wide, developing a method for assessing this current baseline use will enable the UW to outline a clear plan for reducing their relative impact. This is one small step in addressing the overall campus Climate Action Plan and aligned carbon reduction goals.

One of the most significant findings of the BUAP on the UW campus is that students, faculty, and staff are well-positioned to and interested in making pro-environmental choices, however, they do not feel empowered to make changes that can significantly impact major problems such as climate change. Having the knowledge that the community is willing and interested in environmental change lays a solid ground for UW to provide its building occupants knowledge and tools for positively impacting the overarching aims of the campus's Climate Action Plan through daily, actionable behaviors.

This protocol is highly applicable for other University buildings, or other organizations that are interested in gathering similar information about a building(s) energy use and cultural characteristics. While this team utilized existing databases for some underlying information, these data could just as easily be gathered through the collection of architectural and mechanical drawings paired with interviews of building operations that are familiar with the day-to-day functions of the building(s).

Future research to deepen the impact of the BUAP include adding more buildings to the data-set in order to compare occupancy, energy use and culture across building types; and adapt the protocol to include buildings beyond classroom buildings such as labs, libraries, and medical facilities. Additionally, looking beyond the UW campus would lend insight into the energy and cultural context of buildings across sites, providing greater applicability of the protocol and the data derived from the BUAP.

References

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). 2009. *2009 ASHRAE handbook fundamentals*. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

Clayton, S. D. (2012). *The Oxford Handbook of Environmental and Conservation Psychology*. New York: Oxford University Press.

Hanford, J., Brune, M., Meek, C., Gilbride, M. “Building Change: The Bullitt Center in Seattle, WA.” *High Performing Buildings, The ASHRAE Journal.* Winter 2016.

EIA (Energy Information Administration). 2007. *Commercial Buildings Energy Consumption Survey (CBECS).* Washington, D.C.: Energy Information Administration.

Poortinga, W., Steg, L.,Velk, C.. (2004)."Values, Environmental Concern and Environmental Behaviour. A Study into Household Energy Use." *Environment and Behavior,* 36 (1), 70-93.

Steg, L., Bolderdijk, J. W., Keizer, K., & Perlaviciute, G. (2014a). "An Integrated Framework for Encouraging Pro-Environmental Behaviour: The Role of Values, Situational Factors and Goals". *Journal of Environmental Psychology*, 38, 104–115.

Steg, L., & De Groot, J.I.M. (2012). Environmental values. In S. Clayton (ed.),*The Oxford handbook of environmental and conservation psychology* (pp. 81-92). New York: Oxford University Press

Steg, L., Perlaviciute, G., Van der Werff, E., & Lurvink, J. (2014b). "The significance of hedonic values for environmentally-relevant attitudes, preferences and actions." *Environment and Behavior*, 46 (2), 163-192.