Human-Building Interaction (HBI): A User-Centered Approach to Energy Efficiency Innovations

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ABSTRACT

In many ways, the Internet of Things and the connected smart technologies in buildings are like the early days of the Internet and the World Wide Web, centered more on the piecemeal, geeky creations of first adopters than thought-out, integrated solutions. The Web was transformed into a practical mainstream tool as the usability concepts and methods of Human-Computer Interaction (HCI) were applied. Similarly, an analogous approach like Human-Building Interaction (HBI) is needed to provide a foundation that helps inform and direct the development of useful innovations in energy efficiency in buildings. Like HCI, Human-Building Interaction (HBI) is outcome oriented, systems-based and user-centered. It focuses on how occupants interact with buildings and the devices and functions inside. The principles of HBI employ the design thinking process that encompasses the needs and goals of all the stakeholders to create well-leveraged solutions. Based on an understanding of the users and stakeholders, and the context in which they interact with the building and each other, HBI takes into account the important factors that drive their actions - motivation, ability, and triggers - to produce outcomes that are effective and impactful energy saving solutions. This approach can be the key to new upstream approaches that utility programs can adopt to achieve energy savings goals. This paper describes how the HBI approach was applied as part of a currently underway, commercial plug loads project.

Introduction

In 2010 Alan Meier of Lawrence Berkeley National Laboratory published the results of his study (Meier et al. 2010) on the use and usability of programmable thermostats. In a survey of homeowners (Meier et al. 2011), he found that half of the homes had the thermostats set on continuous hold, meaning that no savings from setback were being obtained. Once the homeowner placed the thermostat setting on hold, it remained locked on the hold setting. Meier made two conclusions about usability and thermostats:

- "Without careful attention to usability, the users will be frustrated and confused, frequently selecting settings that result in unnecessarily high energy consumption." (Meier et al. 2010)
- Research looking to quantify the usability of programmable thermostats "appears to have applicability to other energy-consuming devices and their controls such as lighting controls, televisions, and home energy management systems." (Meier et al. 2011)

The fields of product design (Norman 2002) and web design (Nielsen 1999) have developed well-established methods and practices in human factors and usability. The development of the Web is a good example of how the application of usability principles through

Human-Computer Interaction (HCI) has created a successful international tool of commerce. Researchers and designers took a user-centered approach to understand the expectations, tendencies, and practices of web users. This effort involved user interviews, lab and field observation, and iterative usability testing. By designing websites through this user centric approach, a level of functionality and usability has been attained where web users now expect, and even demand, the ability to quickly and effortlessly accomplish their intended tasks and seamless presentation of new experiences and information. Only recently has usability been evaluated with respect to programmable thermostats (Herter and Okuneva 2014).

As we strive to deliver energy-savings in buildings, we typically focus on individual elements of building system: the building envelope, the mechanical systems, or occupant behavior. Ignoring the interconnections within the building system and their various functions misses synergies that might exist or barriers that negate or worsen intended outcomes. In the same way HCI research led to insights that resulted in the high levels of utility that we enjoy with the Web, a user-centered approach can inform the design and delivery of energy efficient measures in buildings and create innovative and effective ways to produce the desired energy savings outcomes.

Human-Building Interaction (HBI)

We define Human-Building Interaction (HBI) as *the study of the interface between the occupants and the building's physical space and the objects within it*. HBI focuses on system interactions and interconnections with the aim of lowering the building-occupant system's energy use. Our goal is to increase the system energy efficiency.

Focusing on "why" and "how" the occupant interacts with the building and the products inside it can reveal the assumptions, habits, and constraints that govern how we use energy in our buildings. Insights gained from understanding these interactions can go beyond traditional opportunities to produce greater energy savings. Instead of forcing people to adopt new behaviors, HBI can help leverage existing behaviors into energy-efficient ones. The main tenets of the HBI approach as related to energy efficiency are: (Shen 2015)

- Solutions make energy saving actions easier and more convenient, not harder and more complicated.
- Solutions leverage occupant interactions with the building to reduce our energy use.
- Solutions often have secondary benefits that reinforce continued practice.
- Upstream solutions aim to prevent energy waste before it occurs, and that focus on systems and whole populations.
- Solutions are developed through user-centered design thinking.
- Solutions go beyond traditional behavior change.

The opportunity of HBI is to do things differently: to design products, technologies, and processes that facilitate and empower building occupants to live and work using less energy. The goal of HBI is to build on people's perceived needs and expectations to make it more convenient to save energy. Along the way, this can streamline and systematize new ways for customers to interact with energy consumption information and will shape future customer expectations and literacy. Smart design of products and processes can leverage building occupants' actions to be effortlessly energy efficient.

Functionality and Usability

The focus of HBI is on the interaction between the user and the device to create a targeted energy savings outcome. This might be approached in a number of ways, by either defining the type of interaction as the leverage point or the type of behavior change as the outcome. In some cases the functionality of a product or process might be better served by taking the control out of the hands of the user. In this case, devices could operate in the energy savings mode by default or have the ability to be programmed initially by the user to work automatically in that way (also known as “set it and forget it”). This essentially removes the need for an explicit user action. A properly programmed setback thermostat or a smart thermostat would be examples of this. When using these devices, the user no longer needs to worry about manually setting back the thermostat at night or when the building is unoccupied. As described above, usability is essential if the desired functionality is to be achieved, even in this passive-user scenario.

In other cases, the outcome may require a specific action or behavior by the user and if that action is not currently performed, then a change in behavior is required. A number of possible behavior changes may be desired. These would include:

- Creating a new behavior (drying clothes on a clothes line),
- Ceasing an old behavior (stop washing partial loads), or
- Modifying a behavior (wash clothes using the cold water setting).

The fields of social psychology (Cialdini 2007) and behavioral economics (Ariely 2010) have studied how behaviors can be influenced by both intrinsic and extrinsic motivators. The field of community-based social marketing has developed strategies and tools to foster sustainable behavior (McKenzie-Mohr and Smith 2008). HBI supplements this work by considering how user interaction with the physical space can be designed and planned to effect energy saving behaviors and outcomes. B.J. Fogg of the Persuasive Technology Lab at Stanford University has developed a behavior model (Fogg 2009) that is useful for the framing the functionality and usability questions that arise out of HBI within the context of behavior change. He states:

> for a target behavior to happen, a person must have sufficient motivation, sufficient ability, and an effective trigger. All three factors must be present at the same instant for the behavior to occur.

This is represented by the equation:

$$B = M * A * T$$

Where:

- B is the behavior of interest. In our case, this would be the energy efficiency behavior or action that we are trying to generate.
- M is the motivation that the targeted actor(s) need to want to perform the action. The fields of social psychology and behavioral economics have been put to use to find the intrinsic and extrinsic motivators that can influence behavior change
- A represents the level of ability that the person is provided to perform the action. In this case, ability is the degree of simplicity to perform the behavior.
- T is the trigger that acts as the catalyst for the person to take the specific energy saving behavior or action. It is the call to action that stimulates the behavior to be performed.

Motivation answers the question “why,” Ability answers “how,” and the Trigger answers “when.” These three factors are important design considerations that help determine both functionality and usability as well as provide context in space and time. The Fogg Behavior Model can be adapted to provide a framework to analyze and classify products and systems through an HBI lens.

HBI can also be targeted through strategically changing the effect of the behavior (Plummer 2016) so that the user(s):

- Adapts to the behavior,
- Learns from the behavior,
- Augments the effect of the behavior, or
- Creates a new effect of the behavior.

Adapting to or learning from the behavior may involve the behavior of one person influencing the behavior of a group by creating social norms or making use of other motivational strategies. Creating a new effect of the behavior or augmenting the effect of that behavior would leverage certain actions to perform energy savings outcomes. Examples of piggy-backing energy-savings actions with existing behaviors are: geofencing with smart phones to set back the thermostat setting when user is a certain distance from the home or turning off a wall switch to shut off the power to the entertainment system.

To determine the most effective solution, an approach that is user-centered is required. Design-thinking is one approach where methods and processes can provide the insights to bring innovative and lasting improvements.

User Centered Design and Design Thinking

Design thinking is a user-centered approach that has successfully been extended beyond design-oriented fields into mainstream business applications. Tim Brown of the product design firm IDEO defines design thinking as: (Brown 2008)

> “a methodology that imbues the full spectrum of innovation activities with a human-centered ethos. … by this I mean that innovation is powered by a thorough understanding, through direct observation, of what people want and need in their lives and what they like or dislike about the way particular products are made, packaged, marketed, sold, and supported.”

The Stanford d.school defines the design thinking process as being performed through a sequence of five steps that takes an understanding of the user to create effective, innovative solutions. These steps are defined as: (d.school 2011)

- **EMPATHIZE:** This step develops a strong understanding of the users by observing their behaviors within the context of their lives. This involves both observing and interviewing the users, as well as engaging with all the stakeholders.
- **DEFINE:** Taking the findings from the empathy step, the design problem is focused and framed into a point of view that defines the course of action.
- **IDEATE:** The innovation process begins with the ideate step as a wide range of solutions are brainstormed to drive beyond obvious solutions and uncover new areas of exploration.
- **PROTOTYPE:** The goal of prototyping is to bring the ideas and explorations out of the head and into physical forms that allow interaction and experimentation. Prototypes do not have to be an object. They can also be a wall of post-it notes, a process map, role-playing activity, or any other form that allows presentation, exploration, and refinement.
- **TEST:** This is an iterative process to gain feedback from the users on the solutions in order to refine the solutions and obtain deeper insights into the user.

Design-thinking is an example of an empirical, systems approach that considers the relationships within a system to effect change. This is particularly important when searching for insights and solutions to building energy problems that are often complex in nature and governed by many moving parts. The “House as a System” approach has been effective in helping building scientists diagnose building envelope and mechanical system issues and find solutions with synergistic benefits. Adding occupant interactions requires additional system-based solutions.

Applying Design Thinking Methods to Commercial Plug Loads

To leverage this methodology, we applied design thinking to develop possible behavioral strategies to reduce commercial plug loads. This was performed as part of a project funded by the State of Minnesota (Hackel, Plum, and Carter 2016).[1] One intended behavior change to be studied by the project was to encourage office workers to turn off their work station plug loads at the end of the day and determine the energy savings from that effort. At the time of writing of this paper, the field study is still underway and the results will be reported by the end of 2016.

The first step of the design-thinking process is to get an understanding of the users as well as gain the perspective of all the stakeholders. For office workstation plug loads, we defined the following stakeholders:

- Office Workers
- Financial Officer/Accounting/Managerial
- IT Staff

[1] The commercial project is supported in part by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program.

- Building Owners/Operators/ Managers
- Facilities/Custodial

We performed surveys and interviews with representatives of each stakeholder group from a number of offices and buildings. The following table shows some representatives responses.

Table 1. Representative Responses from Stakeholder Groups

Stakeholder Group	Responses
Office Workers	“The power strip is hard to reach so it’s not convenient to actually turn off.” “I’m not aware of what things to unplug at the end of the day.”
Financial Officer/ Accounting/Managerial	“They’ll do it if doesn’t inconvenience them. They will only go so far.” “You just don’t change your behavior unless someone shows you that you should.”
IT Staff	“People can get annoyed with computers/monitors sleeping too soon. Sometimes software or peripherals will not function properly after computer sleep.” “We have other priorities we’re working on.”
Building Owners/Operators/ Manager	“Lights are left on. Computers are the biggest thing. No one turns them off at night.” “They just don’t care. “It’s not my money, Just here to do my job and then leave.”
Facilities/Custodial	“They forget. They are busy. They just want to leave because they have things to do. It is easy to forget small things. In the winter, space heaters are left on under the desk.” “I have a few cleaners that want to unplug heaters but can’t without pre-approval.”

Based on these responses, a number of desired results of the design could be identified (which we will define as our creative brief).

<u>Creative Brief: User Needs</u>

- The user should be able to easily and conveniently turn off the defined plug loads.
- The devices that should be turned off should be identified and isolated.

- The device that controls plug loads should result in saved energy (e.g. the standing loads of the device should be less than the saved energy from the device).
- A reminder that the devices have not been turned off is needed.
- A feeling of community can be leveraged to help users adopt this behavior.
- The solution should be able to allow other interested stakeholders (like co-workers or facilities/custodial personnel) to assist in following through on the energy saving action, if possible.

As part of the ideation phase, we identified a couple of opportunities. Using footswitch-controlled power strips could solve the first identified need since they can easily be turned off by the office worker by having the footswitch under the desk or within reach on top of the desk. An untethered remote switch would also work well. These advanced power strips have both switched and unswitched outlets and the footswitch manually controls the switched outlets. This addresses the second need of the design brief. Desktop computers, laptop computers, and routers could be plugged into the unswitched or always on outlets. Some workers require their computers to always remain on so that they can use a remote desktop connection to access their work stations from home during evenings and weekends. Monitors, task lights, radios, space heaters, and other devices that draw phantom loads or should be powered off at night are plugged into the switched outlets.

To deal with the remaining creative brief needs, we proposed creating an LED status light that would be plugged into one of the switched outlets of the power strip. The status light is controlled by the foot switch so that it would light when the monitor and other switched devices were on when the office worker is at the desk. The status light would turn off when the power strip is switched off when the worker leaves at night. The status light would be mounted on the cubicle wall so that it is visible to the rest of the office. Thus, the status light not only provides a trigger to remind office workers to turn off their plug loads when they leave the office but it will also trigger co-workers to take action.

The public display of the status creates motivation, providing social proof that an office worker is making the effort to save energy by turning their phantom plug loads are off at their workstation. Social proof and norms are important can have important roles in motivating people to take action (Schultz et al. 2007). Social norms of the office will create the expectation that all of the cubicle status lights are off when the office is vacant at the beginning and end of the workday.

Finally, with all the unnecessary plug loads isolated on the switched outlets of the power strip, an office campaign might grant permissions to co-workers to turn off cubicles that were mistakenly left on. Arrangements could also be made between the office and maintenance management to permit custodians to turn idle loads off. These efforts could also be built into a larger framework as described by Alschuler (2012).

A number of prototypes were created to test colors, intensity, shape, and placement. Red and yellow lights were found to be distracting while blue and green lights were preferred. The ideal brightness of the lights tended toward a diffuse night light effect rather than a more direct beam lighting. Office workers did not want to see their lights while they were working at their computers. Placement was more effective when the lights shone for others to see since: 1) it served as a reminder to the office worker of their equipment status as they left or entered their cubicle and 2) provided social proof to their colleagues of actions that they did or did not take.

Figure 1 shows three status lights placed in an office setting during initial testing. An anecdote from this testing shows the social proof effect of the lights. One office worker began turning off her power strip whenever she left her cubicle. This led to others taking the same action and resulted in some discussion as to whether it was an action that everyone should adopt based on how they used their laptops.

Figure 1. Prototype status lights mounted at three office cubicles.

Figure 2 shows the status light that was developed for use during the commercial plug load study.[2] These are currently being deployed in the select participating sites of the commercial plug load study.

[2] Thanks to Lindsay Kieffaber and Thea Holmberg-Johnson of LHB-Minneapolis for the design and fabrication of the final status light version and Scott Hackel of SeventhWave for his support, input, and feedback.

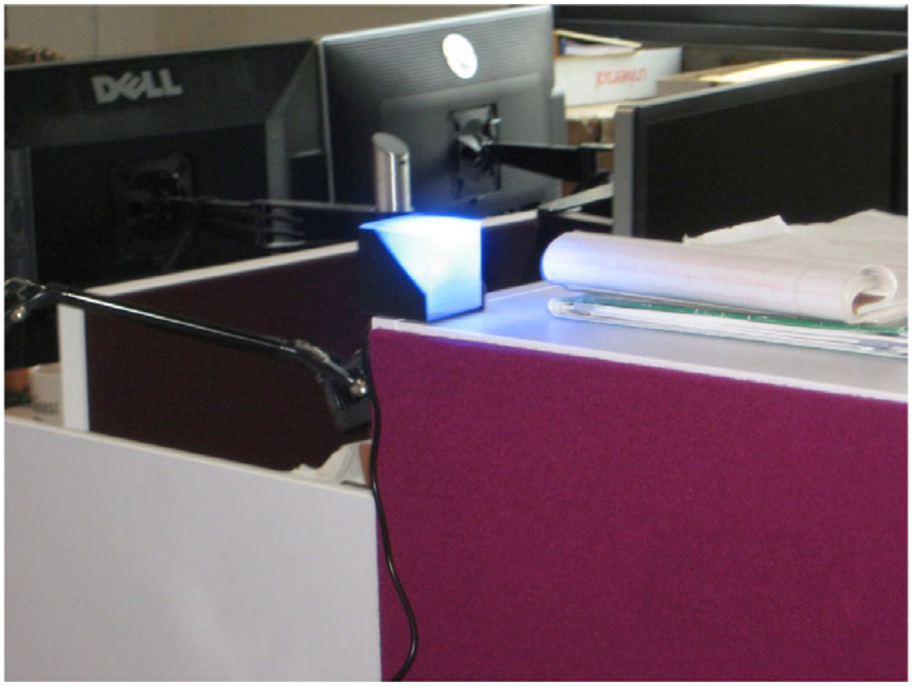

Figure 2. Final version of status light installed on site.

The full results of this project will be available when the commercial plugs loads project is completed by the end of 2016.

Influencing Product Development

The status light example shows how a creative brief can be used to inform and guide the design and development process. The creative brief is a well-known document used in the design world that defines the desired goals and outcomes of a project. It specifically details the main issues to be considered and the expectations to be met. In the case of the HBI approach, the creative brief is a document that synthesizes the input from the stakeholders to inspire new and effective solutions and strategies. In this way, the creative brief can serve as a mouthpiece for normally unheard stakeholders to influence the design process. This is particularly relevant to issues of building energy efficiency. The creative brief generated from this approach also takes into account system interactions (HBI) that otherwise would be ignored.

Market forces typically drive the design and production of goods and services. Manufacturers are primarily concerned sales and unless energy efficiency is a driving force for sales, it will be ignored without specifications or regulations being incurred. A process that also included stakeholder voices such as utilities and regulators would allow for an upstream approach to influence manufacturers to bring energy efficiency to the market. It could further be applied in the evaluation of needs in a building project, including stakeholders such as utilities and regulators to consider additional strategies and design solutions.

Since utilities can claim energy savings for each unit sold, most energy efficiency programs target the consumers of the products and services. These are downstream approaches and include strategies like rebates, incentives, ratings, and labels to influence consumer choices.

Utilities have also turned to midstream approaches that center on retailers to incent which products are put on the shelves and/or the prices that they are sold. The prices of CFL and LED lamps currently found on retail shelves are a result of midstream approaches. Utilities have paid down the price to retailers, resulting in the discounted prices offered to consumers. An upstream approach would target the manufacturers and would be a way to have energy efficiency features incorporated in the design and manufacture of products. The ENERGY STAR® is an example of an upstream approach where device-centric specifications can be adopted by product and equipment manufacturers in order to gain ENERGY STAR® certification. This certification can lead to greater market penetration via consumer awareness of the ENERGY STAR® label and utility midstream and downstream efforts. Applying an HBI approach along with design-thinking to inform product design and development is another potential opportunity for utilities to increase their influence upstream and could serve as a driving force behind a contextual, user-centered upstream approach. The potential impact on energy savings could be massive, but there is much work to be done to figure out exactly how this process might work, and how utilities could attribute savings to any intervention that was designed.

While additional research is required to determine the best path forward, utilities should consider applying HBI with design thinking to inform product development through interactions with manufacturers and increase their influence upstream. This approach could engage customers in a new way, helping the utility industry transform from a commodity-sales model to a service model, elevating devices as a new delivery platform for utility services.

Conclusions

We are experiencing a disruptive time in the energy sector and we need to be insightful and innovative to find and deliver effective solutions. A contextual understanding is required to uncover new leverage points for achieving energy efficiency gains in our homes and workplaces. The HBI approach takes a systems approach to studying how occupants interact both with the buildings they inhabit and with the devices they use within those buildings to consume energy. By using a design thinking approach centering on the occupants, opportunities for innovative solutions can be revealed by looking at the attitudes, motivations, constraints, and technologies that ultimately drive how energy is used. The need for the HBI process will grow as we look ahead to how we live and work in buildings in the future. Smart technologies, social media, and automation are creating a new type of consumer that is tech savvy, connected, and demanding of individualized and custom experiences. Understanding these trends and anticipating the changing landscape of how we interact with buildings is crucial to creating innovative energy efficient products and facilitating and maintaining energy saving practices and services.

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