# Table of Contents

Executive Summary .................................................................................................................. 1
The Human Element .................................................................................................................. 2
Designing a Thermostat for Usability ...................................................................................... 4
The Systems Approach of Human-Building Interaction (HBI) ................................................. 6
Leveraging Occupant Habits .................................................................................................. 7
Miscellaneous Energy Loads (MELs) .................................................................................... 8
Design Thinking ....................................................................................................................... 10
Human-Centered Design (HCD) ............................................................................................. 11
Observe and Listen .................................................................................................................. 12
Barriers to Taking Action ........................................................................................................ 13
Making Decisions .................................................................................................................... 14
The Fogg Behavior Model (FBM) ............................................................................................ 15
Triggers .................................................................................................................................... 16
Choice Architecture and Nudges ............................................................................................ 17
  iNcentives ............................................................................................................................... 17
  Understanding mappings .......................................................................................................... 18
  Defaults .................................................................................................................................. 18
  Give feedback .......................................................................................................................... 19
  Expect error ............................................................................................................................ 22
  Structure complex choices ...................................................................................................... 22
Know Your Customer ............................................................................................................. 23
New Energy Consumers .......................................................................................................... 25
Opportunities for HBI ............................................................................................................. 26
  Connectivity ............................................................................................................................. 26
  Smart Phones .......................................................................................................................... 27
  Location and Space .................................................................................................................. 27
  The Democratization of the Internet of Things .................................................................... 28
  Distributed Energy and the Marvel of DC ............................................................................ 29
Next Steps ............................................................................................................................... 31
Closing Remarks ...................................................................................................................... 33
Human-Building Interaction (HBI): Design Thinking and Energy Efficiency

Executive Summary

This whitepaper introduces the concept of Human-Building Interaction (HBI), a user-centered approach that focuses on how occupants interact with buildings to consume energy. The reasons and ways occupants use the buildings and the devices inside can reveal the assumptions, habits, and constraints that govern how we live and work in our buildings. Understanding the barriers and learning opportunities can lead to effective new strategies and designs. HBI takes a systems-thinking approach to promote occupant actions and building performance that achieve greater energy conservation and efficiency.

HBI employs the design thinking process to guide the innovation process and produce effective solutions. The five steps of design thinking are:

1. empathize with the users,
2. define the problem,
3. ideate solutions,
4. prototype possibilities, and
5. test with the users to create informed and effective solutions.

Based on an understanding of the user and the context in which they interact the building, HBI takes into account the important factors that drive their actions - motivation, ability, and triggers - to inform the design of effective and impactful energy saving solutions.

A great example of the HBI approach can be found in the creation of the Nest learning thermostat. While building a super-energy efficient house, Tony Fadell, a former Senior Vice President at Apple, was frustrated with how difficult thermostats were to operate and how ugly they looked. Working with Matt Rogers, a former colleague at Apple, they took a user-centered approach to innovate a new way for people to interact with their thermostat. Following glowing reviews in the popular press and after turning smart thermostats into a consumer electronics category, Google purchased Nest for $3.2 billion in January 2014.

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.
Human-Building Interaction (HBI): Design Thinking and Energy Efficiency

A system isn’t just any old collection of things. A system is an interconnected set of elements that is coherently organized in a way that achieves something. If you look at the definition closely for a minute, you can see that a system must consist of three kinds of things: elements, interconnections, and a function or purpose.

—Donella Meadows

The Human Element

About 40% of the United States’ energy use is consumed in residential and commercial buildings. If we are to lessen the threat of climate change, we need to strive for greater reductions in our energy use in our homes and offices. When we use energy at home or at work, it takes many forms and serves many functions. Unlike water, whose consumption we visually identify as a necessary ingredient in our washing, eating, or drinking, energy is embedded in uses that veil the actual consumption of the fuel or energy that we pay for. A therm of gas provides the comfort of a heated home on a cold winter night or a home cooked meal with the family. A kWh of electricity provides the music from the stereo, the entertainment from the television, the information from a computer, or the illumination while reading a book at night. Our lifestyle needs and intentions drive our energy consumption. As Lockton et al. point out:

‘Demand’ is not ‘people demanding energy’: it is a side effect of people, in all their diversity, meeting family and household needs, solving everyday problems, and enacting social practices, often with emotional contexts attached.

It can be said that our energy use is a response to our existential needs and desires. The human element drives the types of devices that we use and how they are operated.

One of the first studies to demonstrate the importance of the human element in home energy use was performed in the mid-1970s at the Twin Rivers townhouses near Princeton, New Jersey. Princeton University researchers found that in identical three-bedroom units, one house used more than twice the gas energy of another house. In another case, a house went from one of the highest users to one of the lowest after a new owner occupied the unit.

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Behavioral programs are designed to take into account the human element to increase energy efficiency. Applying the principles of social psychology, utility behavior programs are achieving savings on the order of 1 to 3%.5 And yet, on a per house basis, engineering calculations suggest total saving opportunities for specific measures along the lines of 10% to 20% occur through occupant actions such as thermostat setback and reducing miscellaneous energy loads (MELs) from consumer electronics.6,7 The savings from utility behavior programs represent a degree of increased customer engagement and show that social norms lead a larger proportion of customers to adopt energy efficient actions. However, while these programs can increase the motivation to save energy, we still appear to be leaving significant energy savings on the table.

Energy savings require more than motivation to take action. Operational issues also create barriers for homeowners that these behavioral programs cannot overcome. If the customer does not have the ability or control to take energy saving action, then those actions will not take place.

Consider the case of residential thermostats. They control 9% of the total energy in the United States.8 The U.S. Department of Energy (DOE) suggests that energy savings on heating and cooling of as much as 10% can be attained per year by turning the thermostat setting back 7°-10°F from its normal setting for eight hours a day.9 Programmable thermostats would seem to be an easy and simple way to achieve those savings. In 2010 Alan Meier of Lawrence Berkeley National Laboratory and his collaborators published their results on a study of the use and usability of programmable thermostats.10 The study found that nearly 90% of the respondents in a survey of homeowners reported that they rarely or never used their programmable thermostat to set a weekend or weekday program. Half of the homes had the thermostat set on continuous hold, meaning that no savings from setback were obtained. One of the study’s most important conclusions was the need to improve the user interface of programmable thermostats. The human element is not just a behavioral issue, it is also a design issue.

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Designing a Thermostat for Usability

Tony Fadell, a former Senior Vice President at Apple, was building a super energy-efficient house when he came across a problem:

When it came to the heating and cooling system, I discovered there was your thermostat that controls 50-60% of your energy costs every year -- and no one knows how to use them and they're ugly and frustrating.

To save any energy using a thermostat, you had to program them. And it turned out that it was so complicated -- like programming a VCR from the 1980s -- that literally only 10-11% of people in the U.S. would ever program their thermostat even once to save energy.\(^1\)

He soon enlisted Matt Rogers, a software engineer who worked on the iPod and the first iPhone. He describes the next step in their design process:

It started as our frustration and the more we talked to other people, the more we heard their frustration. That was the tipping point.

We brought in experts, interviewed contractors, and conducted meticulous research. We traveled and took pictures of people's homes, their thermostat, and how it was installed. We built a library of ugly thermostats around the country.\(^2\)

As they designed the Nest thermostat, they gained empathy with the user:

One of the things that I did very early with another Nest colleague is install a new thermostat at home every week. We installed every thermostat we could at our own homes to learn the frustrations that people have, the installation experience, everything.

Thermostats today have these switches on them that read “heat/cool/auto/off” and “fan/auto/on.” What does “fan/auto” versus “fan/on” even mean? How does a normal consumer understand these things?\(^3\)

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\(^3\) Ibid.
A new type of thermostat was created. Tony Fadell describes how they used what they learned to improve the thermostat:

So instead of saying: "let's just make its easier to program," we believe there should be a better way. So, literally, we watch your usage, or the device itself, the algorithm, watches your usage: you turn it up in the morning, you turn it down when you go away, you turn it up in the evening when you come home, you turn it down when you go to sleep. We watch those patterns over the weekdays and the weekends, and through this learning algorithm that we call "Autoschedule," it creates a schedule for you. And our huge set of customers out there have proven to us that 99% of those devices have schedules that save energy, as opposed to 11% before.

Another difference is: sometimes you don't always know when you're going to be home or you're going to be out and you don't turn down your thermostat. We actually have built sensors into the product itself that recognize when you're not at home and turn it down to an energy saving setting that you pre-specify.

Then there's a third type of thing that we've done differently: we control the heating and cooling differently to make it more efficient. So in the case of air conditioning, we have a feature called "Airwave" which can save 30% of run time very easily with no change in comfort whatsoever.¹⁴

In 2011 the Nest Learning Thermostat was introduced. It immediately received glowing reviews in both the popular press and tech media for its beautiful design, ease of use, and energy

¹⁴ Busari, op. cit.
savings functionality.\textsuperscript{15,16,17} The success of the Nest thermostat helped to create a new smart home device category in consumer electronics.\textsuperscript{18} Good design increased the public consciousness of the hitherto ignored thermostat and turned it into a sought after energy saving device that people want to show off in their homes.

The Systems Approach of Human-Building Interaction (HBI)

Smart, insightful design of energy-efficient products and services requires a systems approach. If we consider Donella Meadows’ definition of a system, typically we have focused solely on individual elements of building energy use: the building envelope, the mechanical systems, or occupant behavior. In a true systems thinking approach, we need to consider the interconnections within the system and their various functions and purposes. We need to take a more holistic approach. With this in mind, 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.

This paper comes from continuous observations of these techniques and their benefits. These solutions are all around us and are getting much attention in cutting edge design. We are in the age of HBI. We write this whitepaper to put a name to it and to start to dissect the process in order to replicate and potentially discover a whole new way to use energy more efficiently while facilitating ways to conserve.

As we’ll talk about in this paper, the main tenets of the HBI approach are:

- Solutions that make actions that save energy easier and more convenient, not harder and more complicated.
- Leveraging our interactions with the building to reduce our energy use.
- Solutions that often have secondary benefits that reinforce continued practice.

• Upstream solutions that aim to prevent energy waste before it occurs, and that focus on systems and whole populations.
• Solutions that are developed through user-centered design thinking.
• Going beyond traditional behavior change.

Leveraging Occupant Habits

Behavior change often connotes sacrifice and hardship. The goal of HBI is to build on people’s needs and expectations to make it more convenient to save energy. Smart design of products and processes can leverage the building occupants’ actions to be effortlessly energy efficient. Here are two examples of how design can turn occupant habits when leaving a room into energy-saving habits:

1. Many hotels in Europe and Asia require guests to place the room card key into the light switch by the door. Without this, power in the room will not go on, so no lights, air-conditioning, or TV. This is actually convenient for guests because there is now a place that the room key must be kept and won't be misplaced. And it is beneficial for hotels because when guests leave their room and take their room keys, the power is turned off and the hotel saves on energy costs. It is a simple and elegant solution to saving energy that understands how guests interact with the hotel. (Source: http://www.hotelnewsnow.com/Article/738/A-secret-to-green-is-in-the-keycard)

2. Belkin created a power strip that was similar to others that are promoted to manage phantom plug loads, but had a wall mounted remote control switch. Stand-alone power strips are generally hidden behind an entertainment center or under a desk, making it hard to access the off switch. Smart power strips are also available, but may not work for
certain devices, can be tricky to adjust, and may not always work properly. The Belkin device allows people to eliminate the phantom loads of the TV, receiver, disc players, or game consoles by simply flipping a switch on the wall. The wall switch turns off power at the power strip, cutting electricity to the entertainment center. The action is second nature and can be taken when turning off the lights in the room.

The central feature behind the good design of these two examples is the usability of both designs. ISO 9241 defines usability as the “[e]xtent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.” Both designs easily allow the user to perform the intended function in a clear, intuitive way. Through their functionality and usability, these products result in energy savings, and also facilitate adoption of energy-efficient behaviors.

**Miscellaneous Energy Loads (MELs)**

HBI provides a more holistic approach that takes advantage of how the user interacts with the technology, and how one technology works in tandem with another technology in the context of the user. The need for the HBI approach is particularly important with miscellaneous energy loads (MELs). These include the energy used by a long list of appliances and equipment such as computers, televisions, and other office equipment. MELs are the second largest category of building energy use after space conditioning, accounting for about 20% of the total energy used by buildings in 2010. A report by ACEEE states that a 40-50% energy savings from MELs could be achieved with currently available or proven technologies. This would be approximately equal to the U.S. oil imports from the Middle East. This once again raises the issue of adoption and use of these energy efficient technologies, as well as the operational and process barriers that inhibit adoption and proper use.

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**How Smart Power Strips Work**

Smart power strips are basically power strips with multiple outlets that have specialized functions. One outlet is designated as the Master outlet, a couple of outlets typically serve as unswitched outlets, and the remaining outlets are controlled by the Master outlet. The Master outlet can sense the power draw from the device that is connected to it. When that device (the Master device) draws full power during its “on” state, the Master outlet supplies power to the switched outlets. When the power draw to the Master device is at its minimal amount during the standby state, the power to the switched outlets is turned off. The unswitched outlets are unaffected by the Master outlet and devices like the cable box and DVR are connected to these outlets since they must be continuously powered to work properly (e.g. keeping the time for recording programs or maintaining their programming from the cable provider). Typically the TV or the AV receiver serves as the Master device. All other peripheral devices are plugged into the switched outlets and their phantom loads are eliminated when the Master device is turned off. Only the Master device continues to draw a phantom load as it waits in standby.

Smart power strips add additional cost as an accessory to the home entertainment center. Additionally, they may require manual adjusting in order to ensure that the Master outlet is properly set to read the threshold power draw of the Master device standby mode.

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The need for the HBI approach is clear in order to achieve these potential savings and take advantage of any synergies that might exist.

Today’s home entertainment system is an example of how HBI could be applied to increase system efficiency. Standby loads of entertainment systems could be reduced using the Belkin power strip example above or a smart powerstrip. However, there is an easier solution that was available during the time of cassettes, vinyl albums, and turntables. Back then, audio receivers and amplifiers came equipped with switched outlets, as shown below:

Cassette decks, radio tuners, and turntables could be plugged into these outlets and only powered on when the receiver or amp was turned on. Basically, they accommodated the functionality of the smart powerstrip without the need for one. Manufacturers understood how their products would be used and what their users needed. Today, AV receivers rarely have any switched or unswitched outlets so for customers to get the functionality they provide they need to buy a special power strip. If manufacturers used an HBI approach they might conclude that switched outlets should be a standard feature on TVs and AV receivers, which would provide a straightforward, cost-effective way to eliminate phantom loads.

New houses provide opportunity to take advantage of HBI by designing rooms intended as home offices and rooms for home theaters. These rooms can be wired with a wall outlet that is controlled by a wall switch. This outlet would serve all the switched devices so they could be easily turned off to eliminate standby loads. A second normally wired outlet could serve the unswitched devices. These two solutions could be considered “upstream” measures which “aim to prevent harm before it occurs and usually focus on whole populations and systems.” This is different from midstream and downstream solutions that are solutions that either mitigate or cope with the consequences of the problem, respectively.

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. As we become more technologically dependent on how we live and work, we can expect our use of MELs to increase with time. This makes the need for HBI even more necessary. The U.S.

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Energy Information Administration (EIA) in their 2014 Energy Outlook report MELs in residential and commercial buildings to increase significantly by 2040.²²

HBI can provide an upstream approach to deal with the expected increase in MELs. To optimize system efficiencies and anticipate the introduction of new technologies, we must understand how all the individual components interplay. This is the goal of the HBI approach, and will help to achieve goals and needs of users.

**Design Thinking**

The HBI approach is based on user-centered research via a method called design thinking. Tim Brown, the CEO and president of the product design firm IDEO, defines design thinking as:

> "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."²³

Design thinking has become an innovation model for businesses. As Brown continues to explain:²⁴

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²⁴ Ibid.
Design thinking can be described as a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.

The HBI design-thinking approach requires an interdisciplinary team of engineers, designers, and ethnographers that is open and in tune with the vernacular. The solutions that are developed need to be deep, integrated, and lasting. Functionality and usability embrace energy efficiency.

**Human-Centered Design (HCD)**

The basis of design thinking is human-centered design. According to Tim Brown of IDEO:

Design thinking is a human-centered approach to innovation that draws from the designer’s toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.

Human-centered design is “an approach that puts human needs, capabilities, and behavior first, then designs to accommodate those needs, capabilities, and ways of behaving.”

The design of the Nest thermostat is an example of this human-centered design. Donald Norman, the well-known cognitive engineer and author of *The Design of Everyday Things*, defines four objectives for human-centered design:

1. the user's needs are met,
2. the product is understandable and usable,
3. the product performs the desired tasks, and
4. the experience of using the product is both positive and enjoyable.

Clearly the Nest thermostat accomplished all four of these objectives.

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**The Five Steps of Design Thinking**

The design thinking process is performed through a sequence of five steps. These are:

**EMPATHIZE**: Work to fully understand the experience of the user for whom you are designing. Do this through observation, interaction, and immersing yourself in their experiences.

**DEFINE**: Process and synthesize the findings from your empathy work in order to form a user point of view that you will address with your design.

**IDEATE**: Explore a wide variety of possible solutions through generating a large quantity of diverse possible solutions, allowing you to step beyond the obvious and explore a range of ideas.

**PROTOTYPE**: Transform your ideas into a physical form so that you can experience and interact with them and, in the process, learn and develop more empathy.

**TEST**: Try out high-resolution products and use observations and feedback to refine prototypes, learn more about the user, and refine your original point of view.

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27 Ibid.
Observe and Listen

Observation and understanding are important aspects of this approach. To apply the principles of human-centered design to energy conservation and efficiency, you need to know how people actually live and work in buildings. Some questions to ask are:

- What are their experiences and expectations when they perform specific activities?
- What are the cues they use to perform tasks and control devices?
- What constraints or prompts guide them in performing a task?
- What information do they need to receive during the task and when and how do they expect it?
- Are there efficiencies to be gained by synthesizing tasks or systems?

This is not a new approach. In the early 1900s time and motion studies were used to increase industrial efficiency. The Toyota Production System has refined the process and refers to it as “genchi-genbutsu” which loosely translates to “going to the place to see the actual situation for understanding.” The purpose is to observe how work is actually done and gain insights on how to improve that process. It is one of the guiding principles of lean manufacturing and process improvement. The goal is to understand the value stream, to discover any issues in the process flows, and make practical improvements to reduce waste. It is a well-accepted and proven approach to increase efficiency that has revolutionized the automobile industry and has been successfully applied to other manufacturing processes and more recently to healthcare. The U.S. Environmental Protection Agency (EPA) has applied methods to energy efficiency and has published a toolkit that provides strategies and techniques to apply lean methods for increasing energy efficiency and reducing energy use.

Ethnographic work results in contextual insights that can inform the design of more energy-efficient human-building interactions.

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Barriers to Taking Action

In observing these interactions and determining opportunities for improvement, we need to determine if there are any gulfs between the intentions that people have and the results of the actions that they take. Donald Norman has defined these gulfs as the Gulf of Execution, where the user tries to figure out how the product works, and the Gulf of Evaluation, where their user tries to figure out if the goal is attained. The Gulf of Execution embodies the barriers that impede the user to properly perform the action. The Gulf of Evaluation encompasses any restrictions that the user encounters from learning if the action is succeeding. Opportunities for enhancements in the interaction design lies within these gulfs. The solutions to bridging those gulfs contain the leverage points that can create energy efficiency opportunities.

Let’s return to the Nest thermostat design. The goal was to design a programmable thermostat that would actually be programmed properly and would achieve actual energy savings. Below is a table that describes the gulfs of execution and evaluation.

<table>
<thead>
<tr>
<th></th>
<th>standard programmable thermostat</th>
<th>Nest Thermostat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gulfs of Execution</strong></td>
<td>1. the thermostat is frustrating to program the settings to save energy</td>
<td>1. the thermostat has a learning algorithm to “autoschedule” based on how you set it</td>
</tr>
<tr>
<td></td>
<td>2. the thermostat is ugly</td>
<td>2. the thermostat senses when you are not home and lowers temperature to your pre-specified value</td>
</tr>
<tr>
<td></td>
<td>3. the thermostat controls the heating and cooling differently to make it more efficient</td>
<td>3. the thermostat controls the heating and cooling differently to make it more efficient</td>
</tr>
<tr>
<td></td>
<td>4. the design is attractive and appealing</td>
<td>4. the design is attractive and appealing</td>
</tr>
<tr>
<td><strong>Gulf of Evaluation</strong></td>
<td>50% of occupants who said they programmed their thermostats actually had their thermostats set on permanent hold</td>
<td>99% of users had thermostat schedules to save energy and their thermostats showed a leaf icon when they were saving energy</td>
</tr>
</tbody>
</table>

By overcoming the barriers in the Gulfs of Execution and Evaluation for standard programmable thermostats, Nest was able to successfully create a programmable thermostat that provided actual energy savings to their customers.
Making Decisions

To help us solve how to bridge these gulfs, we need to understand how people decide to take action and how they choose which actions to take. Daniel Kahneman in his book *Thinking, Fast and Slow* describes a two-system approach in judgment and decision-making. System 1 operates fast, automatically, and effortlessly. It is our intuitive, emotional self. System 2 is our rational, conscious self that acts slowly and deliberately. This is the self that uses reason to weigh through the information, analyze options, and choose the steps to take. As Kahneman explains,

System 2 receives questions or generates them: in either case it directs attention and searches the memory to find the answers. System 1 operates differently. It continuously monitors what is going on outside and inside the mind, and continuously generates assessments of various aspects of the situation without specific intention and with little or no effort.

System 1 makes use of heuristics and biases to simplify choices and make decisions by reducing the situation to a simpler one. Patterns and rules of thumb guide the System 1 mind.

Consider the door pictured below.

![Door Handle](image)

As you approach the door to leave the building, you grab the handle as seems obvious and pull. Your quick System 1 mind saw the door handle and recognized a shape that said pull. But the door doesn’t budge. “What? Is the door locked?” After getting over your surprise, you slow down and let your System 2 mind go to work. You look at the handle and notice the word “PUSH” has been punched into each door handle. Your System 2 mind now tells you that despite the shape

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you should push on the door handle. The door opens and you leave the building, a little embarrassed.

The design implications of System 1 and System 2 are revealed in Donald Norman’s concept of knowledge in the head and knowledge in the world.\(^3\) Knowledge in the head is the knowledge collected in your memory. Knowledge in the world is the cues provided in the physical surroundings: the signifiers (e.g. labels), physical constraints, and natural mappings that are provided. In the case of the door handles above, the knowledge in the head is contradicted by knowledge in the world. Good design will combine knowledge in the world with knowledge in the head to create usable products that appropriately activate both your System 1 and System 2 minds.

**The Fogg Behavior Model (FBM)**

B.J. Fogg of the Persuasive Technology Lab at Stanford University defines persuasive technology as “interactive computing systems designed to change people’s attitudes and behaviors.”\(^3\) He has developed a behavior model for persuasive technology that is useful for HBI. The Fogg Behavior Model (FBM) states:\(^4\)

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.

and is represented by the equation:

\[
B = M \cdot A \cdot T
\]

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. Most energy efficiency behavior programs are motivation-based programs that use social norms or gamification to achieve energy savings.

A represents the level of ability that the person is provided to perform the action. The preceding discussions have shown the importance of usability in ensuring that the

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\(^3\) Norman, op. cit.


design of the device or process is enabling of the behavior and that barriers to performing the action are minimized.

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.

The M answers the question “why,” the A answers “how,” and the T answers “when.” It is important to look at triggers and their important role in creating action.

**Triggers**

You want a nice hot cup of tea so you add some water to the teapot, place it on the burner, and go back to the book you were reading. After a while, the whistle of the teapot calls you to action. Time to make your cup of tea. The teapot’s whistle is a trigger that the water is boiling and that you can now turn off the burner. It’s a cue not only to make tea, but also to stop wasting energy now that the job is done. Triggers are important because they serve as an instigator.

Nir Eyal, in his book *Hooked: How to Build Habit-Forming Products*, defines two types of triggers, external and internal, and defines them as:35

- External triggers tell the user what to do next by placing information within the user’s environment.
- Internal triggers tell the user what to do next through associations stored in the user’s memory.

In many ways, the ideal energy-efficiency behavior would be a habit that is done automatically, with little thought. In other words, it would be something that is triggered by some situational cue. Can we create energy-efficient habits? Eyal has developed a Hook Model for creating habit-forming technology. The model includes a trigger that cues an action, a variable reward from the action that creates craving, and an investment of time and effort that makes the user value the product or service more. He provides five fundamental questions for creating habit-forming products or services:

1. What do users really want? What pain is your product relieving? *(Internal trigger)*
2. What brings users to your service? *(External triggers)*
3. What is the simplest action users take in anticipation of reward, and how can you simplify your product to make this action easier? *(Action)*
4. Are users fulfilled by the reward yet left wanting more? *(Variable reward)*
5. What “bit of work” do users invest in your product? Does it load the next trigger and store value to improve the product with use? *(Investment)*

Notice that this is very user-centered and one that begs for a design-thinking approach. In terms of HBI, are there existing habits that we can leverage to piggyback energy-saving actions? New

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technologies and new user interactions create opportunities for new behaviors and habits, as well as the opportunity for new energy-efficiency gains. While hook creation and habit forming border on a form of manipulation, as we examine how we make our energy-saving decisions, it is worth putting some thought into how we design the choices that we leave for the user.

**Choice Architecture and Nudges**

The design of products and processes can influence the choices that people take through a concept known as “choice architecture.” Richard Thaler and Cass Sunstein in their book *Nudge* define choice architecture as “organizing the context in which people make decisions” and they define a nudge as “any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives.” Thaler and Sunstein have created a NUDGE mnemonic to describe the principles of choice architecture and these can be adapted as specific strategies to take:

- iNcentives
- Understanding mappings
- Defaults
- Give feedback
- Expect error
- Structure complex choices

Let’s examine each of these principles to see how human factors and choice architecture can promote energy efficiency via HBI.

**iNcentives**

Financial incentives are a traditional and well-accepted nudge to promote consumers to purchase products and services. Saving money, energy, or the environment can be used as an incentive to increase adoption. ENERGY STAR-certified products provide a framework for making a product’s energy efficiency capabilities more salient to customers. By increasing the desirability of the product by being Energy STAR-certified, and as a result increasing sales of the product, the ENERGY STAR label also incentivizes suppliers to create products that conform to their standards. U.S. Green Building Council’s LEED certification is another example of this for buildings. Using these standards to inform their design, designers, and engineers can create products and systems that have increased adoption through accepted certification. Social norms and other social psychology strategies that create motivation to change behavior could also be defined as incentives.

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Understanding mappings
When users are confronted with options on a device, how these options are mapped out will help the user not only understand the options available, but also nudge them to choose the option that is most favorable. Below shows a screen from the Honeywell Lyric thermostat smart phone app:

The mapping clearly shows the current temperature in the house and the four programmable settings for the thermostat, and also allows the user to manually switch to an appropriate setting. It also shows when the upcoming Wake Up and Night Setback states will take effect. The orange background shows that the thermostat is in heating mode. A blue background would indicate that the system is in cooling mode.

Defaults
Generally people find it difficult to overcome the inertia of changing current conditions. Some of this is due to our loss aversion tendencies in which change might lead to loss (as the saying goes, a bird in hand is worth two in the bush). Mindless acceptance of the current situation is another cause of what is known as the status quo bias. Furthermore, the default option comes with an implicit suggestion that the default state is the recommended or normal course of action. The path of least resistance typically results in the default option being the one most chosen. The default option for the state of a device is a strong and powerful nudge.

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39 Thaler and Sunstein, op. cit.
A desktop computer in its power savings mode can save up to $50 per year in electricity.\textsuperscript{40} Unfortunately when you first set up your computer or update the operating system, the default option is not necessarily the most energy-saving option.\textsuperscript{41} When given a choice, most users choose the recommended install. Afterward, they will be hesitant to change the system options because they lack the know-how or confidence to change the computer settings and don’t want to “hurt” the computer. This is a classic example of the status quo bias and a great opportunity to increase energy efficiency through the default option.

Another example can be found with washing machines. Almost 90\% of the energy that is consumed during the operation of a washing machine is in heating the water, even though washing in cold water can get clothes as clean as washing in hot water.\textsuperscript{42} And yet, when you do a load of laundry, the default option for the clothes washer is typically warm wash/cold rinse. Why isn’t the default option cold wash/cold rinse? This is a lost opportunity.\textsuperscript{43}

Finally, the smart home is an example of user-created defaults. With home automation comes the concept known as “set it and forget it.” The user takes the first step by programming the thermostat or light controls and then everything is taken care of automatically without any further effort via schedules, motion sensors, presence sensors, etc. Apps like IF by IFTTT (IF This Then That) let you automate device functionality via the Internet.\textsuperscript{44} The learning capabilities of the Nest thermostat hints at a device-aware default state that tailors itself and evolves to routines of the occupants. The smart home can deliver the convenience of device-assisted habits.

**Give feedback**

Unless you get feedback, you will not know if you are doing well or doing poorly. Building in feedback can improve user performance and increase energy efficiency. The Nest thermostat includes user feedback in the form of a green leaf on its display.

\textsuperscript{40} ENERGY STAR, “Activate Power Management on Your Computer,”  
https://www.energystar.gov/index.cfm?c=power_mgt.pr_power_mgt_users


\textsuperscript{42} Alliance to Save Energy, “Efficient Laundry: Wash Clothes in Cold Water to Save Energy,” 10/5/11.  

\textsuperscript{43} Thanks to Susan Norris of Pacific Gas & Electric for pointing out this example.

The green leaf signifies that you are doing something to save energy. Nest has even created a game out of this feedback tool by keeping track of how many leaves you earn each month. This also brings a reward system that reinforces the energy-saving behavior or habit. Coupled with feedback, gamification can also be a powerful motivator for energy-saving behavior by introducing competition and social norms.

Salt River Project, one of Arizona’s largest utilities, employs feedback in their M-Power pre-paid electricity plan. Rather than paying monthly electric bills that charge for the previous month’s consumption, customers of the M-Power plan opt for a pay-as-you-go method. Using an SRP M-Power® smart card, they buy fixed amounts of energy from ATM-like machines at locations throughout their community. An in-home display allows them to monitor their energy use as their costs are deducted from their smart card.

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45 Yoky Matsuoka, “Understanding the Nest Leaf,” Nest blog, 12/14/12, https://nest.com/blog/2012/12/14/understanding-the-nest-leaf/
The customer can purchase additional energy as needed by adding amounts of energy to their smart card. From the direct feedback of seeing what’s left in your account, the average M-Power customer reduced their energy usage by 12% annually.⁴⁹

There are a number of ways to provide feedback, from the iconography of the Nest thermostat to the textual display of the SRP M-Power ecoMeter. Another example is the Ambient’s Energy Dash, which uses colors as part of their in-home display to show either individual home or neighborhood level comparative billing data.⁵⁰

Sound can be an effective tool for feedback. The whistling teapot is one example of the power of sound and feedback that call you to take action. Pavlov’s experiments with dogs is another example. Hearing the musical notes of the ESPN SportsCenter theme song or the theme from

⁴⁹ SRP, op. cit.
Law and Order are triggers that immediately grab and focus your attention for the show that is beginning. Lockton\textsuperscript{51} is currently investigating the use of sound to represent the electricity use of three office items.

**Expect error**

Despite all your efforts at designing a product that is usable, people will make mistakes. It is important to anticipate user error and design for it, making the device as forgiving as possible. Programmable thermostats again provide an example of this concept. In 2010 Alan Meier of Lawrence Berkeley National Laboratory published the results of his study\textsuperscript{52} on the use and usability of programmable thermostats. In a survey\textsuperscript{53} of homeowners, he found that half of the homes had the thermostats set on continuous hold, meaning that no savings from setback were being obtained, and once the homeowner placed the thermostat setting on hold, it remained locked on the hold setting. This new setting essentially became the new default setting of the thermostat because the homeowner forgot they placed the thermostat on hold, and any intended energy savings from programming were lost. Ideally, the thermostat should have been designed with a temporary hold setting to return to the programmed schedule when the next programmed period was reached. An important purpose of user testing is to reveal these possible user errors and allow the product design to account for them.

**Structure complex choices**

When consumers are confronted with many choices or options, this can present more of a problem than the freedom, self-determination, and variety that greater choice provides. Instead, too much choice becomes confusing and paralyzing because:

- making a decision requires more effort,
- decision-making mistakes happen more easily, and
- psychologically, the consequences of the mistakes (the feeling of loss) are more severe.\textsuperscript{54}

Structuring and filtering choices can increase usability and influence the choices that are made. Let’s consider the options of temperature settings provided by menu of the Lyric thermostat smart phone app:

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\textsuperscript{51} Dan Lockton, "Work in progress: Ambient audio energy data," http://architectures.danlockton.co.uk/2014/03/08/work-in-progress-ambient-audible-energy-data/


The choices have been simplified and characterized by an easily identifiable and understandable name for each setting. The names give both a temporal and functional meaning for each programmable period. Home management systems provide another opportunity for structuring complex choices and actions, bundling lighting, heating and cooling, and other functions together. For more ideas about how choices can be contextualized and framed to promote more energy efficient behaviors, it is worth exploring the field of behavioral economics where strategies have been developed and tested.\(^{55}\)

### Know Your Customer

In this systems approach it is essential that we understand the need and desires of those whom we are trying to instill energy saving actions. Furthermore, knowing the attitudes and concerns of your target audience is essential not only in the design of a product or system, but also in creating one that has market demand. This understanding can uncover valuable leverage points that can be used to ensure adoption, use, and action. For example, suppose you have created a thermostat that monitors occupancy and indoor temperature to create an auto-schedule to save energy. Ideally, additional sensors in the house could improve the learning capabilities and ensure comfort throughout the house. Since saving energy is not always the top concern for the homeowner, we need to determine what other entry points exist could induce homeowners to introduce additional sensors into their homes. Nest performed a survey of their customers and found that fire and carbon monoxide were two of the top three concerns that they worry about.

In the Fall of 2013, Nest introduced the Protect smoke alarm. The Protect has sensors that monitor smoke, carbon monoxide (CO), temperature, humidity, and motion. It provides interactivity and Wi-fi interconnectivity and communicates with the Nest Thermostat. With the Protect, Nest has added additional sensors into the house and has increased its presence as a player in the smart home arena.

Further examination of Nest’s customer survey shows that burglary and home invasion also rank high on people’s concerns about their home. It should not come as a surprise that security companies are now including connected smart home devices in their list of offerings to consumers. Cable companies are also getting into the act by offering home management and security systems. Finally, even the companies that create the devices that allow interconnectivity (Samsung, Apple, and Google Android) are seeing the commercial opportunities presented by the synergies of the smart home.

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New Energy Consumers

The rapid advancements in IT and telecommunications are bringing a huge shift in our lifestyles and expectations. Smart technologies, connected devices, and distributed generation are huge disruptive forces that will bring big changes in how energy is provided and consumed. With the Internet of Things, people are becoming more social and connected. Big data will soon mean that consumers and businesses will have access to more information than ever before. In anticipation of these changes, Accenture’s New Energy Consumer research program studies the impacts on energy providers of the “critical trends in product innovation, consumer interaction paradigms and new partnerships, as well as the changing role of data in consumers’ daily lives.”

Based on surveys with customers from around the world, their main findings are:

- “Vocal, energy-literate consumers represent a growing portion of consumers … [with] the themes of energy independence and environmental impact as key drivers for the next-generation consumer.”
- “Consumers have become ‘omnipresent,’ … always available and online and mov[ing] between the Web, telephony, social media, and messaging.”
- “Choice has emerged as a key driver of customer satisfaction and a powerful lever to create a personalized experience.”
- “Social levers - including recommendations from friends and family or online reviews - play a larger role in increasing younger consumers’ interest in energy-related products and services.”
- “more consumers are technology savvy - increasing the appeal of set-and-forget solutions that deliver financial savings, convenience and control.”
- “Consumers are becoming ‘prosumers’ who are creating their own energy and, in some cases, selling it back to the grid.”

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68 Ibid.
● “consumers seek a convenient solution for home products and services [and] welcome the convenience of receiving multiple services from a single provider.”
● “Smart metering, connected homes, electric vehicles and other technologies are giving consumers more control over their energy use and increasing the prevalence of point-of-use billing.”
● “interest in in-home and other disruptive energy technologies and services is on the rise - perhaps attracting other product and service providers to the new energy marketplace.”

These findings clearly show a major shift in the attitudes, habits, and expectations that people have in their interactions with the buildings they inhabit. Consumers are savvier today and there are more opportunities to reach and interact with them and their communities. They are open to new technologies and services and this can provide a gateway for implementing more energy-efficient solutions.

Opportunities for HBI

Connectivity
The advent of smart buildings brings connectivity. This has a number of implications. Firstly, device-to-device communication allows for people to remotely control devices or program devices to control other devices. “Set it and forget it” opportunities are now possible on a wider scale. Secondly, data from devices can be collected and analyzed and information can be returned and presented to the user. The leaf icon on the Nest thermostat is a good example of this, as is the dashboard on the SRP M-Power ecoMeter. Finally, the combination of data and device-to-user communication introduces the possibility of social messaging with these devices. This permits the use of social psychology strategies to nudge consumers toward energy-efficient behaviors.

Using connectivity to tap into social media like Facebook or to create communities of users of specific devices and systems can facilitate the additional leverage provided through social psychology.

Tools from Social Psychology

McKenzie-Mohr and Schultz describe a number of behavior change tools for fostering sustainable behavior:

- Commitment - “commitments work when an individual comes to see him or herself as the type of person who believes it is important to behave in a particular way. … those commitments that are public and durable are more likely to be particularly effective.”
- Social Diffusion - “One of the most common reasons for the adoption of a new sustainable behavior is the fact the friends and colleagues have already adopted the action and have told others in their social networks about it.”
- Goal Setting - “The simple act of contemplating when a behavior will occur lays the cognitive foundation that precedes a new behavior.”
- Social Norms - “norms are what other people do and what they approve of doing. … in the energy domain norms messaging and normative feedback have been found to produce the largest behavioral changes among the individuals who are the highest users.”
- Prompts - “Prompts need to be noticeable and self-explanatory and presented in close proximity to the behavior.”
- Incentives - “they typically work best in instances where cost operates as a barrier to the action.”
- Feedback - “feedback alone is rarely sufficient to change behavior. … feedback strategies need to couple the information with a goal.”
- Convenience - “If the target behavior can be made more convenient than the alternative, behavior change will naturally follow.”

These eight tools can influence product design considerations such as the information display for dashboards; the use of colors or icons to display commitments, goals, prompts, or feedback; or the choice of default states.

Smart Phones
Smart phones play an integral role in the Internet of Things. With the ability to connect to devices and the cloud through the Internet, Wifi, and Bluetooth, consumers can make use of information displays, sensors, and controllers for connected devices and systems. Many connected devices have apps that allow smart phones to directly communicate with them, ranging from smart thermostats to lighting systems, from appliances to security systems.

Other smart phone capabilities can also be put to use to enhance human-building interactions. For instance, the smart phone’s GPS can be used as a proximity sensor, allowing devices like Honeywell’s Lyric thermostat or Philip’s Hue LED system to employ geofencing. With geofencing, when you and your smart phone are beyond a certain distance from the device, it will go into a preprogrammed “away” mode. When the smart phone is within that distance or geofence, the device will go into the “at home” mode. The app IF by IFTTT lets you create your own geofences using your smart phone. IFTTT recipes exist for Nest thermostats and Belkin WeMo devices.

Another possible feature that could be incorporated is the near-field communication (NFC) capabilities of smart phones that allow mobile payments. Rather than using a credit card, you can make purchases with the swipe of your smart phone. Imagine how much easier it would be with the SRP M-Power ecoMeter if you could use your smartphone to increase your pre-payment, rather than leaving your house to add more money to the smart card at the SRP ATM machine. ApplePay and GoogleWallet could also become a vehicle to allow devices to provide rebates, coupons, loyalty points, and other incentives based on device use.

Apple’s iBeacon might also be a possibility for HBI applications. iBeacon is a Bluetooth-powered location system that is currently being tested by retailers. With beacons placed around the store, they can sense your location in the store based on the signal transmitted by your phone. As a result, special offers, coupons, or information can be sent directly to your device. Besides the retail applications, imagine an electronic docent at a museum that provided the appropriate information as you walked through an exhibit. Location-based applications at home or at work might turn on and off devices, readjust room settings as you move around the building, or give you location-based reminders, notifications, or prompts.

Location and Space
With the ability to track location within a space comes the ability to map movement through and the activities within buildings. This can lead to improved space designs and control devices that take advantage of scheduling, occupancy, and use. Recently we have been seeing a change in

the interior design of buildings as our lifestyles and work habits have shifted. In homes, there has been a shift from floor plans with an enclosed dining room and separate kitchen to a grand open space that includes the kitchen, an eating area, and a living area. Home office areas are now common (often by the front door) and a home theater is also a necessity. Some of this new space specialization can bring opportunities for energy efficiency. For instance, recall the discussion above about smart power strips and plug loads. For home theaters and offices, some outlets in those rooms can be wired to a wall switch allowing the homeowner to turn off the power to the outlet when leaving the room and thereby shutting off any devices on standby. Similarly, as offices are moving from closed offices and cubicles to open office spaces, new lighting options and equipment use could bring opportunities for energy savings.

The advancement in control options and strategies along with new technologies are allowing new ways of individualizing comfort in buildings while increasing energy efficiency. For example, the company 75F has developed a dynamic airflow balancing system in buildings for zonal heating and cooling control based on occupancy and use. Building Robotics’ Comfy system takes another approach to provide individualized comfort in office spaces, allowing each office worker control of their space temperature using their smartphone. ecovent takes a similar approach to Comfy, but for houses where the ecobee3 thermostat system allows homeowners to add additional remote sensors to let the thermostat know what rooms in the house have heating or cooling needs based on occupancy and temperature.

The Democratization of the Internet of Things

Tim O’Reilly, founder of O’Reilly Media, defines the Internet of Things paradigm as “sensors + network + actuators + local and cloud intelligence + creative UI for gathering both explicit and implicit instructions from humans.” Sensors provide the means to monitor the surroundings while actuators are the change agents that perform the actions in response to the surrounding conditions. The network includes the controllers that take the inputs from the sensors and provide the instructions to the actuators to take specific actions. With the low cost of microcontrollers (Arduino and Spark Core) and single board computers (Raspberry Pi and Beaglebone Black), a burgeoning community of DIY innovators are pushing the edges of connected devices and HBI. To fuel these communities, Nest and others are making available APIs to increase functionality and connectivity of their products. SmartThings and Belkin.

81 BeagleBoard.org Foundation,”http://beagleboard.org/black.
have made available products specifically for inventors and tinkerers to incorporate their inventions within existing home automation systems. Internet websites like Kickstarter\(^{85}\) and Indiegogo\(^{86}\) encourage and support these efforts by facilitating crowdsourced funding opportunities to bring these efforts to market. Tapping into and guiding these communities of inventors can provide a well-spring for innovative emerging HBI technologies.

**Distributed Energy and the Marvel of DC**

Accenture’s New Energy Consumer research found that as micro-generation solutions become more and more cost-effective, residential and commercial consumers will more and more become prosumers, creating some of their own energy and selling some of it back to the grid.\(^{87}\) One HBI implication of this is that the electricity generated from these distributed sources (like solar photovoltaics and small wind generators) is in the form of direct current (DC), as opposed to the alternating current (AC) electricity that is received from the electric utility’s power lines. The standard practice with distributed generation is to employ inverters to convert the DC power into AC power. The converted AC power is then added to the meter and can be readily used by the appliances and devices in the home or office.

Interestingly, components in electronic devices run on DC power. The external power supplies (EPS) like “power bricks,” “wall warts,” and other power adapters that you use to plug computers, laptops, smartphones, and other devices into the wall outlet are actually inverters that convert the 120vAC line current to 5vDC, 12vDC, or 20vDC that is used by the electronic device.

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\(^{85}\) Kickstarter, [https://www.kickstarter.com/](https://www.kickstarter.com/).

\(^{86}\) Indiegogo, [https://www.indiegogo.com/](https://www.indiegogo.com/).

\(^{87}\) Accenture, op. cit.
These are typically 50-90% efficient when in active use.\(^{88}\) When you consider that devices like desktop computers and TVs that have internal power supplies to distribute DC power to its components and LED lighting which also runs on DC current, homes and offices have a significant DC electricity load. And this load is increasing. The U.S. Energy Information Administration found that energy consumption from appliances, electronics, and lighting increased in homes by over 40% from 1993 to 2009.\(^{89}\)

IEEE suggests that more than 70 terawatt hours of electricity are lost annually in the U.S. from AC-DC power conversion for small appliances and consumer electronics.\(^ {90}\)

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Using DC current in houses and offices is not farfetched. Telephone landlines in buildings are already wired with 48vDC. Ethernet lines for Internet connections can also carry low DC voltages. On the end use side, a wide range of DC-powered devices are currently available to consumers in the recreational vehicle (RV) market. RVs are wired for 12vDC and TVs, stereos, lights, and some appliances can be run directly off DC power. While it is difficult to predict the future of DC-powered homes and offices, the HBI implications of DC usage can lead to new energy-efficient designs in office layouts, consumer electronics systems, and LED lighting systems.

Next Steps

This white paper has introduced the concept of HBI and described how this approach can achieve significant energy savings that are often lost because of operational barriers and system inefficiencies. The advantage of HBI is that it is fundamentally an upstream approach that works with manufacturers to create energy-efficient products through strategic planning and good design. By working with manufacturers and distributors, utilities can create incentives for specific technologies and take credit for the energy savings resulting from the market adoption of those products. According to Quaid and Geller:

> Upstream incentive programs, which work through manufacturers and distributors, have the potential to dramatically increase the market penetration of efficient technologies, at a

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significantly reduced unit cost, compared to downstream incentive programs which directly engage the consumer.

Working with distributors provides economy of scale and the ability to have a large impact on the marketplace working with a relatively limited number of entities.

In this way, utilities can work with the companies that are the market drivers and influencers (like Google/ Nest, Apple, and Samsung) and help shape the devices’ functionality to optimize their energy savings benefits and spur energy efficient product innovation. This approach can be market transformative. For utilities that are required to reach annual energy efficiency targets, upstream approaches provide an opportunity to take credit for technological advances that may otherwise be lost as a result of free ridership. The EISA lighting standards are an example of how Federal manufacturing regulations reduced the energy savings credits that utilities could take for their lighting programs.

We propose the following steps to promote wider adoption of the HBI and assist utilities in an upstream approach that will help them attain their savings goals:

- Perform field research to identify residential and commercial opportunities based on existing and emerging technologies and process/system inefficiencies. This would include usability studies of office cubicle systems and home office and living areas, building and home automation controls, building energy information dashboards, and other important human-building interactions that impact energy use. Lean methods should also be defined to identify inefficiencies and recruit occupants to uncover solutions. This would follow the Empathize and Define steps of the design thinking process.
- Generate and promote ideas and solutions through an innovation hub, created by bringing together designers, engineers, entrepreneurs, and manufacturers to guide and define innovative business opportunities. This would be a multi-sector approach which would include private, public, non-profit, and utility representatives. Creative briefs for HBI design competitions dealing with MELs, building controls, and system processes would be developed to spur interest and generate development. This would employ the Ideate, Prototype, and Test steps of the design thinking process.
- Develop and test upstream and midstream programs with utilities, manufacturers, distributors, suppliers, and/or retailers to bring these innovations to market and assess prospective market adoption rates and energy savings.
- Institute these programs into the normal utility program portfolio. This would serve as an important and integral approach to helping utilities meet their mandated energy efficiency goals.

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These steps should be an ongoing process to take advantage of continuing trends in emerging technologies and user needs. HBI should be embraced as a fundamental approach to instilling energy efficiency in buildings.

Closing Remarks

We are experiencing a disruptive time in the energy arena and we need to be insightful and innovative to find and deliver effective solutions. A contextual understanding is required to uncover the leverage points for achieving energy efficiency gains in our homes and workplaces. HBI takes a systems approach to study 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. As Donella Meadows points out:\footnote{Donella H. Meadows, op. cit.}

> We can't impose our will on a system. We can listen to what the system tells us, and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone.
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