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ORIGINAL ARTICLE

What's energy management got to do with it? Exploring the role of energy management in the smart home adoption process

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Abstract There are high hopes for smart home technology to deliver Home Energy Management (HEM) solutions, including through smart thermostats, plugs, lights, switches, and appliances. However, adoption of these technologies is lagging behind expectations. Moreover, it is unclear how energy management features in the smart home consumer adoption process. We know there is technical potential for the smart home to support energy management, but we know little about the degree to which energy benefits interest consumers and motivate them to adopt smart home technologies relative to non-energy benefits such as security, comfort, and convenience, which could have implications for increasing rather than decreasing energy consumption. To that point, we know little about whether and how the energy management functionalities of smart home products are actually used by adopters. The present research investigated consumers' knowledge of, attitudes toward, and experiences with smart home technologies that have energy management functionalities (smart HEMS), in order to assess barriers to adoption and to achieving purported energy benefits. Specifically, we studied shoppers at smart home retailers to gauge their existing awareness of and attitudes toward smart HEMS, and we analyzed Amazon customer reviews of smart HEMS to better understand early adopters' motivations and experiences. Results revealed challenges to achieving energy benefits with existing products and marketing strategies, and implications for shaping the future of these technologies to achieve energy demand reductions and load shifting capabilities at scale for the smart home and smart grid of the future.

Keywords Home energy management · Energy management technology · Consumer adoption · Smart home · Connected home

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Introduction

The presence and adoption of smart home technologies have been increasing significantly in recent years (McKinsey and Company 2018). Major technology companies have made large investments, such as Google's purchase of Nest and Amazon's development of the Echo. Retailers have been rolling out smart home dedicated displays and venues, such as Sears "Connected Solutions" display (2015) and Walmart's "Your Life. Connected: Home Automation" website (Walmart 2016).

Energy utility companies and regulatory bodies are also investing in smart home technology. As more and more connected products and systems emerge—combined with substantial infrastructure upgrades (smart grid)—wide-reaching opportunities are created for leveraging two-way communication between energy utility and customer, facilitating real-time data transmission, analytics, and control. The UK government recently put out a call for evidence to explore how smart

appliances enable consumers to support "the development of a more efficient, smart, and flexible energy system" (BEIS and Ofgem 2016, p. 59). In the USA, legislation like California's Assembly Bill 793 (2015) mandates that utilities promote and rebate energy management technologies.

Home energy management (HEM) technologies or systems (HEMS), are part of the broader smart home space and burgeoning Internet of Things landscape (Fig. 1). They enable households to better manage energy consumption by providing information about energy use and/or allowing them (or third parties) to more precisely control energy-consuming devices in the home. Thus, HEMS have potential to help utilities deliver on energy efficiency mandates and demand-side management (DSM) goals, both of which can contribute to a reduction in power grid operating costs.

Despite investments and expectations, years of smart home market growth predictions have not yet been fulfilled (Navigant 2012; The Harris Poll 2015; "Americans don't totally 'get' smart home," 2015). Consumer adoption of smart home technology, including HEMS, remains low. Moreover, the actual energy benefits of smart home technology depend on how adoption occurs, i.e., whether consumers know about, and care about, the energy benefits, and ultimately how they use their smart home products. While savings for traditional energy efficiency products (e.g., Energy Star appliances, tankless water heaters, LED bulbs) can be calculated and "deemed" through technical testing, the savings of a smart home product depends on how it is used within the home, and such savings can vary widely from person to person.

Smart home products that offer potential for home energy management include smart thermostats, lights, plugs/switches, and appliances. However, these products also have non-energy benefits such as comfort, security, convenience, that may lead to uses that run counter to energy benefits. Thus, we currently know more about the technical potential for energy benefits with HEM products than we do about the energy impacts that will actually be achieved in consumers' hands and homes. Despite the substantial non-energy benefits of these products, which are often cited as having a key role in driving uptake and subsequent use, little attention has been given to how the HEM capabilities of these products feature in consumer adoption. The present research explores the role of energy management at various stages in the smart home adoption process and identifies barriers to smart home HEM product uptake and associated energy benefits. We first provide a brief background on the energy benefits of smart home technologies and the consumer adoption process.

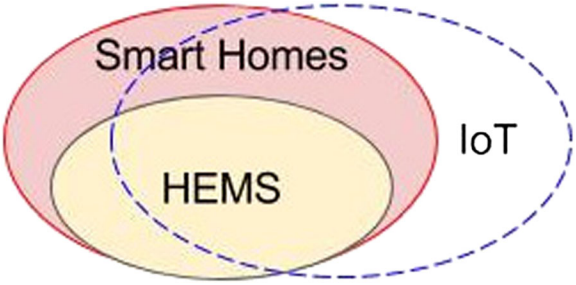

Fig. 1 HEMS in relation to smart home and Internet of Things (IoT)

Energy benefits of smart home technologies

There is a good deal of evidence for energy-saving outcomes with HEM feedback, or information-only (i.e., no control capabilities) products, such as load monitors, energy portals, and in-home displays (e.g., Allen and Janda 2006; Martinez and Geltz 2005; Matsukawa 2004; Mountain 2007; Opower 2014; Parker et al. 2008; Sipe and Castor 2009; Wood and Newborough 2003; Ueno et al. 2006). However, these feedback-only products are becoming a smaller part of the market, which now feature products that enable remote and autonomous control of devices in the home, such as smart thermostats, lights, plugs/switches, and appliances. With this control comes other benefits and uses besides tracking and learning about energy consumption, which may run counter to energy benefits (Ford et al. 2017).

Studies of energy savings associated with these newer smart home/HEM products include estimations based on simulations and modeling. For example, based on evidence from energy feedback studies, Sastry, Pratt, Srivastava, and Li (2010) estimated that appliance-level energy feedback with smart appliances could result in 3–6% likely savings across smart refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers. Southern California Edison (SCE, 2012a, b) conducted laboratory tests that estimated the demand response potential of different smart appliances (refrigerators and

dishwashers). Chua and Chou (2010) estimated that CFLs coupled with smart lighting may allow up to 7% reduction of total home electricity consumption, based on simulation studies with assumptions about user behavior. Williams and Matthews (2007) estimated that "an integrated system that includes monitoring and control of appliances, plus zone heating/cooling" (p. 239) could reduce energy consumption by 26%, based on data from the DOE Residential Energy Consumption Survey (RECS).

Studies with actual users have been less common. Some studies have quantified energy savings with smart lighting and smart plug strips in the commercial sector (Acker, Duarte, & Van Den Wymelenberg, 2012; Garg & Bansal, 2000; Guo, Tiller, Henze, & Waters, 2010), but less attention has been given to field-testing these technologies in the residential sector. Utilites have conducted a number of field tests for smart thermostats recently, most of which demonstrated some energy savings, but effects varied between − 5 and + 13% for heating and from 10 and 25% of cooling (NVEnergy, 2013; APEX, 2016; Lieb et al., 2016; Aarish, 2016; Cadmus, 2012). Coupling these technologies with additional software to enable participation in demand response events can deliver greater savings (Nest, 2014).

These studies demonstrate the technical potential for smart home technologies to contribute to energy management, but they largely rely on assumption about user behavior or the performance of recruited research participants as opposed to naturalistic adopters who independently acquired the products. While it is clear that there are opportunities for smart home products to help users manage home energy use, their full potential may be limited by a lack of information related to energy, conflicting value propositions resulting in the increase in energy use in order to make homes more secure and comfortable, and minimal interactions with demand shifting programs. The true potential for demand side flexibility will be driven by how users adopt these products.

The role of energy management in smart home adoption

Studies that have examined consumer adoption of smart home technologies do highlight energy management—particularly as it enables energy cost savings as a benefit that attracts and motivates consumers. For example, in a survey by Coldwell Banker and CNET (2015) 42% of homeowners said they would consider the purchase of a smart home product if it could yield $500 or more in yearly savings. Mennicken and Huang (2012) interviewed members of seven households that had adopted smart home technology and identified a desire to save energy as one of four themes in adopters' motivations (the others were perception of smart as modern, experience with smart home technology leading to further adoption, and "hacking the home" as a hobby). Hargreaves et al. (2015) and Hargreaves, Wilson, and Hauxwell-Baldwin (2017) recruited households to use smart home technology then assessed motivations for agreeing to participate, which included energy and associated cost savings, interest in technology and automation, environmental values, and control (Hargreaves et al., 2017). Security benefits are also often cited as drawing consumers to smart home technology (Chamberlain Group, Inc. 2016; Icontrol Networks 2015; Shelton Group 2015), for products such as garage door openers, smart door locks, and security cameras.

Past research has also identified a number of barriers and drawbacks to smart home adoption, which extend to HEM-related products. The most comprehensive assessment of barriers was provided by Balta-Ozkan et al. (2013), who conducted a literature review, interviews with experts, and public deliberative workshops in the United Kingdom, resulting in an inventory of barriers, including interoperability, reliability, privacy and security, and costs. Concerns about data security and privacy are perhaps the most cited (Daws 2016; Tsukayama 2016), followed by cost (e.g., Honeywell 2015; The Harris Poll 2015; Paetz et al. 2012). There has also been a high degree of product turnover in the smart home and HEMS markets (Karlin et al. 2015), which may be adversely affecting adopter experience.

Most of the research on smart home consumer adoption has been conducted in contrived contexts, e.g., surveys, interviews, recruiting households to use technologies. Little work has investigated consumers in more naturalistic settings throughout the adoption process, such as learning about products while shopping at retailers and providing reviews on retail sites. Such observations would further understanding of the role of energy management in smart home adoption, and are the focus of this paper.

Understanding adoption as a process

Understanding the role of energy management in smart home adoption requires a conceptual model of the adoption process that represents the full customer journey, from learning about the technology to forming attitudes about it, making a purchase, and actually using it. Such a framework is needed to understand how energy management factors in to smart home adoption and identify barriers to adoption and the realization of associated potential energy benefits.

Rogers' (2003) Diffusion of Innovation Theory provides a framework for understanding the intrapersonal process of technology adoption, called the Innovation-Decision Process, which details how people adopt new technologies in five iterative stages:

1. Knowledge Stage: awareness and understanding of the technology
2. Persuasion Stage: attitudes regarding the degree to which the technology aligns with one's needs and values
3. Decision Stage: the choice to purchase/acquire the technology or not
4. Implementation Stage: user experience after acquisition
5. Confirmation Stage: mirrors the Persuasion Stage in that the customer can reassess the degree to which the technology aligns with their values and goals

We used the innovation-decision framework to guide our methodology and analysis, in order to observe consumers in all stages of the adoption process and draw implications about the role of energy management in smart home adoption, as well as barriers to adoption and to achieving energy benefits associated with the smart home.

Methodology

Two methodologies were employed, each targeting particular stages of the Innovation-Decision Process (Fig. 2). The first method (shopper studies) involved partnering with two retailers to study customers and employees at smart home retail displays. This research focused on the early stages of the Innovation-Decision Process (knowledge and persuasion); we sought to glean insights into consumers' existing levels of knowledge about, and interest in, smart home technologies and their energy management functionalities (relative to other aspects such as comfort, convenience, and security). The second method was a content analysis of customer reviews of smart home/HEM products on Amazon.com, designed to assess the later stages of adoption; we sought to glean insights about which smart HEM products are being adopted and adopters' experiences, usage patterns, and satisfaction/evaluation of products.

Shopper studies

We partnered with two major retailers to conduct research at their smart home retail spaces. The retailers were selected because each had an innovative and unique smart home demonstration and display space in one of their stores in the California Bay Area. Our research with these retailers consisted of three methodologies: customer observation, customer interviews, and employee interviews.

Retailer A Research at Retailer A was conducted by the lead author and three research assistants across two Saturdays, November 4 and December 5, 2015, from 10 a.m. to 4 p.m. The smart home display area where the research was conducted was set up as a faux home, consisting of areas decorated as typical rooms in a home: a nursery, gym, laundry room, kitchen with dining area, family room, garage, and patio. Product displays included interactive demonstrations and traditional shelf displays. Products on display included the following HEM products: smart plugs and switches, smart lights, smart thermostats, and smart hubs. Other smart home products on display focused on fitness and health (e.g., activity trackers), entertainment (e.g., smart speakers), security (e.g., smart cameras), cooking (e.g., smart coffee pot), and caregiving (e.g., smart infant scales). Posters displayed in the rooms indicated which products might appeal to different types of customers, i.e., wellness enthusiasts, new parents, busy parents, and family caretakers. In addition, products were labeled with tags to denote compatibility with various systems, e.g., "works with Wink".

Customer research with Retailer A centered around employee-guided tours of the smart home display. The tours were led by either the department manager (of the smart home area) or the lead sales employee, both of whom were highly experienced touring customers and vendors through the space. The researchers collaborated

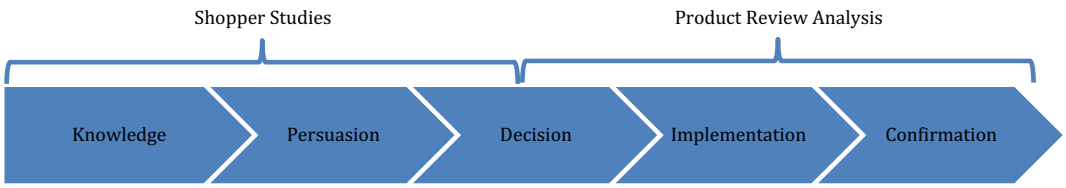

Fig. 2 Consumer research methodologies correspond to Innovation-decisions Stages

with the both employees prior to the research in order to develop the procedure for the tours, which was as follows.

Prior to each tour, announcements were made over the store intercom to alert customers to the opportunity to take a tour and receive a gift bag containing a $5 gift card and a few other small gifts. There were four tours on the November date and three in December. Tours ranged in size, from 1 to approximately 30 customers. Due to the semi-structured nature of the tours and multiple opportunities for customers to ask questions, tours ranged widely in terms of duration, lasting between about 15 to 40 min.

The tour guide led customers through the space room-by-room, introducing the products and offering customers a chance to ask questions. Tours on the November date progressed from the entry to the space, to the kitchen, and product area which focused mostly smart lights and smart plugs, onto the fitness area, and ending up at the patio and garage. On the December date, the tours focused more exclusively on products with energy implications: starting with smart lights and smart thermostats in the family room area, then onto smart plugs and hubs. The tour guide typically described product types rather than specific products except in cases where there was a product with unique features or only one product of a certain type displayed. Throughout the tours, the guide occasionally asked customers if there was anything they particularly liked or disliked.

In total, there were approximately 75 tour participants across both days (an exact headcount was not possible with one very large tour that some participants joined late). Customers ranged in age, sex, group composition, and ethnicity. Families included those with small children and teenagers, mother-only or two parents, and one family with a grandparent. There were couples and single adults; the majority were Asian and Hispanic. At least one non-English speaking customer (Hispanic) participated in a tour, as well as one young adult who communicated via American Sign Language.

Retailer B Research at Retailer B was conducted by the lead author, a research assistant, and an in-house researcher for Retailer B, on April 18 and 19, 2016, from 11:30 a.m. to 7:30 p.m. This smart home retail space included product display tables with interactive touch-screens offering product information, and an interactive demo faux home space with products set up throughout five rooms: living room, bedroom, nursery, kitchen, and entry/exit. Each room contained a tablet with several vignettes (e.g., arriving home, bedtime) that, when selected, animated the devices in the room to illustrate a user scenario.

Research at Retailer B consisted of passive observation of approximately 250 customers at the product display tables and cashiers, as well as 21 customer and 6 employee interviews. Customer interviews were conducted during self-guided tours of the faux home demo space. Interviewees were provided with $15 store gift cards.

Customer observation at product display tables and cashiers was conducted by a researcher stationed in the area for the duration of the research on both days (i.e., for approximately 16 h). She took detailed notes describing customer interactions with each other, products, and employees, including purchases made. Additionally, we used a time sampling method whereby the researcher noted the location and activity of each customer in the space at regular 10-min intervals, particularly noting which products were receiving attention.

Customer interviews were initiated by the lead researcher approaching customers, both individuals and groups, shortly after they entered the store and offering the $15 gift card to each customer for participation. Two researchers then guided the participant(s) through the demo space and prompted them to independently explore the scenarios in each room via the tablet, taking as little or as much time as they wished. The tour and interview duration ranged from 5 to 45 min, depending on customer interest and responsiveness to questions. Demographic data on customers were not recorded per request of the retailer.

During each interview, one researcher asked participants questions at the beginning and end of the tour, as well as after each room, while the other took detailed notes on customers' responses and nonverbal behavior. At the beginning of the tour, we asked customers if they had ever been to this retail space before, why they had come in that day, how familiar they were with smart home technology, and whether they owned any smart home products. Both before and after the tour we asked them how they thought smart home technology might benefit their household. After each room in the faux home display, we asked them what they thought about the different scenarios illustrated, which products or features they would want in their own home (and why), and which products seemed less relevant for them personally (and why). We asked follow-up questions to each of the above based on customers' responses.

To learn from their informal experiences interacting with customers, we conducted semi-structured interviews with six retail employees who worked exclusively in the smart home retail space. A 30-min interview was conducted in a small closed meeting room in the staff area. Participation was voluntary and no incentive was provided. Interviews were conducted during each employee's regular shift and were scheduled by their manager. Participants' employment tenure ranged from 3 to 12 months.

We asked employees about customers' level of knowledge and typical reactions to smart home technology. More particularly, we asked them what products and features customers find interesting (and why), what they dislike or are less interested in (and why), and what they have difficulty understanding. We asked these questions about the technology in general, as well as about each HEM-related product they sold (smart plugs, smart lights, smart thermostats, and hubs). Finally, we asked employees about customers' interest in energy implications of smart home products (including energy savings or potential for increased energy consumption/costs).

Product review analysis

We performed content analysis of Amazon.com customer reviews for the most-reviewed products within each of four HEM/smart home product categories: smart thermostats, smart lights, smart plugs and switches, and hubs. Data were collected at two time points, November 2015 and July 2016. In November 2015, we selected the top three most-reviewed products within each category. In July 2016, any products that had moved into the top three for any category since the first collection time were added. This resulted in a total of three to five products per category.

If two models of the same product were among the top three most-reviewed, only the most recent product model was included. We first sorted reviews by most recent, then selected ten proportionally representing each star rating based on the entire population of reviews. For example, if half the reviews were 5-star reviews, we selected five 5-star reviews. Additional reviews were collected to supplement reviews with low word counts (less than 25th percentile). For example, if the word counts of five reviews were below the 25th percentile for the sample of ten reviews, five additional reviews were added to the sample, again drawing from the most recent and to proportionally represent the overall star rating. This method resulted 14–17 reviews per product. Table 1 shows the products and total number of reviews in July 2016.

Results

Data from both studies were analyzed qualitatively and then synthesized to construct themes based on the five Innovation-decision Stages. Findings are organized according to those five stages to highlight benefits and barriers to adoption at each stage. To differentiate between findings from the two methods, we refer to customers in the shopper studies as shoppers and customers in product review analysis as "reviewers." Actual comments from shoppers, employees, and reviewers are presented in quotation marks throughout the results in support of findings. As anticipated, most of the findings from the shopper studies pertained to the Knowledge and Persuasion Stages, whereas most of the findings from the product review analysis pertained to implementation and Confirmation Stages; findings from both methods shed light on the Decision Stage.

Knowledge

The data revealed consumers' existing levels of knowledge regarding smart home technology, as well as what they do not know (knowledge gaps) and what they are having trouble understanding (knowledge barriers).

Table 1 Smart HEM product categories, products selected, and total number of Amazon reviews

Product category	Product	Total reviews	Reviews sampled
Smart plugs and switches	WeMo Switch	3725	17
	Etekcity Wireless Remote control Electrical outlet switch	3123	16
	Ankuoo NEO Smart Switch	648	14
Smart thermostats	Nest Learning Thermostat, 3rd Generation	4489	16
	Honeywell Wi-Fi Smart Touchscreen Thermostat	1924	14
	Sensi Wi-Fi Programmable Thermostat	1677	16
	EcoBee3, 2nd Generation	1280	15
Smart lights	GE Link, Wireless A19 Smart Connected LED Light Bulb	953	17
	MagicLight Bluetooth Smart LED Light Bulb	909	15
	Philips 456,210 Hue White and Color Ambiance A19 Bulb Starter Kit 2nd Generation	537	15
	Flux Bluetooth Smart LED Light Bulb	1187	31
Hubs	Samsung Smart things Hub 2nd Generation	735	18
	Wink Connected Home Hub	700	14
	Lutron L-BDG2-WH Caseta Wireless Smart Bridge	44	15

Existing knowledge Shoppers ranged greatly in their level of awareness of smart home technology. Among smart HEM products, shoppers were most familiar with smart thermostats and least familiar with smart plugs/switches. Nest, in particular, was the most familiar product (Nest thermostat) and brand to shoppers at one retailer.

Knowledge gaps Regardless of familiarity with products, shoppers were consistently surprised to learn about the possibilities for integrating multiple products. In several cases, shoppers who already owned a smart home product (e.g., Nest thermostat) were unaware that it could be integrated with other products.

Shoppers were generally interested in learning more about the technology. Analysis revealed six types of questions they had about smart home products and systems: *What does it do? How does it work? What products do I need? Does it work with what I have? How do I install it? How do I use it?*

To begin with, shoppers were not always clear on the basic functions and features of products, including interoperability. They also wanted to know how products work (e.g., how a water leak sensor detects leaks), with tech-savvy customers asking more targeted and deeper technical questions about performance, storage, and cloud protection, according to retail employees. When retail displays highlighted a use case that shoppers appreciated, they wanted to be sure they understood which products were involved.

For smart lights in particular, shoppers wanted to know whether they would be compatible with their lighting fixtures; e.g., "You can put this (smart bulb) in a regular lamp?". Questions about compatibility were also raised about smart plugs, switches, and thermostats, as well as whether products could integrate with a home security service. Retail store employees noted that shoppers had many questions about how to install and set up a variety of products, especially smart thermostats, speakers, and door locks.

Finally, shoppers had questions about how to interface with the products. One way shoppers who were new to smart home technology came to understand it was "everything by the phone". Comments like this were delivered in a tone suggesting comprehension (an "ah-ha" moment), with accompanying head nods and smiles.

Knowledge barriers Even with access to highly trained and experienced retail staff, many shoppers had difficulty grasping some of the complexities of these technologies. For example, at the end of a tour one shopper summarized, "Very interesting. It was way over my head." Three concepts were especially difficult for shoppers to understand: hubs, platforms, and protocols. Shoppers struggled to understand the function of hubs (e.g., "Do I use it for Internet?"), why they are required or work for certain products but not others ("For the doorknob, do you need the hub?"), and whether the hub might replace the function of another product ("Do I need the hub or the smart switch or both?").

Retail store employees mentioned that shoppers also struggle with the concept of platforms, reporting that it is helpful to explain them in terms of apps, with Yonomi being the easiest to introduce. Employees reported that Nest is among the platforms customers more readily grasp, whereas SmartThings is more "advanced". Few shoppers we interviewed mentioned protocols (e.g., "I am assuming everything is Bluetooth?"), but

employees reported this is also something shoppers have difficulty understanding. For example, employees often have to explain the difference between Wi-Fi, Bluetooth, and ZigBee, and the implications of each for product functionality (e.g., smart products using Bluetooth cannot be controlled remotely when away from home).

Persuasion

In terms of the Persuasion Stage, the data allowed an assessment of the relative appeal of products and the perceived benefits and values underlying adoption. Themes emerged regarding the relative appeal of products in isolation versus in the context of a multi-product system, the perceived value of products on-the-shelf versus in the context of a user scenario, and barriers at the Persuasion Stage.

Appeal of specific products In general, shoppers were most interested in smart doorbells, garage door openers, door locks, and cameras, all products that provide security benefits and do not obviously contribute to HEM. An interesting theme that emerged was that some products seemed to provide a strong value proposition on their own, as a single product, whereas others were more valuable in multiples of the same product, and yet others were appreciated in the context of a system of different types of products. Relatedly, some products could convey their value in a box on a shelf (conventional retail display), whereas customers were much more likely to perceive the value of other products when they were either displayed to illustrate a use case or an employee described a use case.

Products that shoppers typically appreciated in a conventional shelf display included smart thermostats, doorbells, door locks, garage door openers, and cameras. Products that were appealing in multiples or systems and attracted more attention in the context of a use case included other smart HEM categories—smart lights, plugs, and switches, as well as smart buttons and sensors. Use cases employees suggested that resonated with some shoppers revolved around forgetting something, highlighting the remote control feature of various products (smart plugs for curling iron or entertainment center; smart garage door control for forgetful mornings) and "coming home" use cases involving turning on smart lights and thermostats upon, or preceding, one's arrival.

A strong and consistent theme among shoppers was appreciation of the integration of multiple products; for example, "The connection between all of them is neat"; "Being able to leave home and the practicality of everything being off"; "For the light stuff, how many lights could plug in?"; "I like the combination of products"; "I like the communication between devices." Despite this interest in whole-home solutions or systems, retail employees noted that shoppers often come in with one specific product in mind. Also, when shoppers are just discovering smart home technology, it usually takes one particular product that resonates with them before they warm up to the whole general idea; for example, "It's usually a specific product that brings people around, and they say 'I get this now'"; "One or two items will stick out to them; it's very random which ones." They discussed how whole systems could be overwhelming at first; customers just want "one or two things to make life easier."

Perceived benefits and values underlying adoption When shoppers and employees were asked about the benefits of smart home technology, the most prevalent theme was convenience (e.g., "Simpler, faster, and easier"). However, convenience in itself was not necessarily a strong value proposition for shoppers (e.g., "Would be easier, but I do not see a big benefit right now"). Instead, it appeared that convenience was of greater importance as it related to achieving valued goals, such as making it convenient to monitor the safety of one's household. Some customers mentioned safety, energy savings, and comfort, but more commonly customers only implicitly suggested their underlying values by the way they responded to the products. Three sets of underlying values were identified: *Protect, Nurture,* and *Conserve.*

Values related to protecting the health and safety of one's household were implied by shoppers' interest in the smart doorbell, door lock, camera, and water leak sensor. One shopper remarked about the smart door lock, "If you hear a noise in the night, it is comforting for the nervous person." Another shopper expressed a desire for a 911 call feature. Both shoppers and employees noted the appeal of some smart home products as a do-it-yourself replacement for a security service, eliminating the need for a monthly fee.

Other positive reactions to smart home technology implied a set of values related to fostering a nurturing home environment. These values included comfort (e.g., "Do the lights come on when it gets dark?"; "I

like to read in bed, and I do not like to get up to shut off the lights"); caregiving (e.g., "I like keeping track of the baby"; "Love that you can take care of a cat for a few days"), cleanliness (interest in robotic vacuum), and convenient cooking (e.g., "I like that you can brew coffee from bed").

A small segment of shoppers named energy and/or associated cost savings as a primary value of smart home technology (e.g., "I drag my feet at the idea of letting electronics control my house, but to save energy, I am fine with that"; "It's all about saving money and saving energy."). More shoppers acknowledged savings as a benefit of smart thermostats in particular. While energy savings was not top-of-mind for most shoppers, when asked about the benefits of smart home technology, it was universally appreciated as an added value (e.g., "Would like it to be efficient, but not a deterrent"; "Prefer low energy"; "If it could achieve energy savings that'd be great"). Employees noted that questions about energy savings tend to come up later after shoppers become interested in a product for other reasons.

Persuasion barriers Analysis revealed two main reasons smart home products did not appeal to shoppers: (1) insufficient value proposition, or (2) not applicable to their household/lifestyle. Shoppers who did not perceive sufficient value in some of the technology used terms like "overkill," "excessive," "luxury," "novelty," and "gimmicky." A common sentiment was that it was unnecessary (e.g., "I understand it but seems like a lot, unneeded") or moreover an unnecessary encroachment of technology (e.g., "Too much technology… Way too much"). The promise of convenience (e.g., saving time and effort) alone was a turn-off for some shoppers, who perceived certain products or use cases as promoting laziness or waste. For example, one shopper noted that curtains should be opened for natural light in the morning rather than artificial lights coming on automatically. Another shopper sarcastically implied the wastefulness of adopting these new technologies to replace basic models that are still functional: "So your crock pot at home is useless."

Regardless of whether customers appreciated the value of certain products, systems, or uses, in some cases their life situation was such that they would not personally benefit; "Security is not a big case for me, I live in a condo complex. Would be hard to break in and if someone goes through that much effort, they are welcome to my stuff... and good luck getting it out"; "The temperature thing is nice, but I am a San Francisco native so [there are] not a lot of hot days." This issue was most prevalent for nursery, pet, and kitchen products.

Decision

Regarding the Decision Stage, our research provided insight into the relative rate of consumer adoption of different types of smart HEM products, as well as popular products within each category, and barriers to adoption at the Decision Stage.

Product ownership Table 1 shows the sample of most-reviewed products in each of the smart HEM categories analyzed in the study of customer reviews. It is important to note that other factors, such as date of product release, also affect number of reviews; therefore, this is not a rigorous proxy for popularity ranking.

Decision barriers Data from the shopper studies revealed nine barriers at the Decision Stage: cost, privacy/security, effort required, performance, lack of knowledge, lack of foundational technology, redundancy with other products/services, structural incompatibility, and renting.

Cost likely contributes to shoppers' tendency to buy one or two items with standalone functions rather than systems that include products with more abstract values (e.g., hubs), according to retail employees. For example, a slightly sarcastic remark from one shopper was, "Do you have to buy *everything* (to make it a smart area)?" This theme was also found specifically in discussions about smart lighting, for example, "Do I need to buy a switch for every lamp?" At the end of one tour, one shopper remarked, "Wish I had the money to buy it all!" High product costs also seemed to interact with a perception of insufficient value proposition. For example, one shopper was very interested in a water leak sensor that required a hub. The cost of the hub was much higher than the cost of the sensor. "Why do I need to buy this?" she remarked, perplexed about the need to buy the hub when, from her perspective, she just wanted the functionality of the sensor.

Shoppers had concerns about product installation and setup, with particular anxieties about installing smart thermostats and setting up integrations of products. Shoppers also shared concerns about performance and reliability (e.g., one customer's comment: "What if there

is a power outage? Would I need a backup battery for my connected products?"). A few shoppers mentioned concerns about smart products being "hacked", and employees noted that this is a concern among shoppers regardless of their technological savviness.

When unaddressed, the knowledge gaps described earlier, e.g., *How does it work? What products do I need? Is it compatible with what I have at home?* become barriers to the decision to purchase products. For example, one shopper concluded, "I need more info before I buy this," and another, "(I) have to digest… See how my home fit… It is old version."

Shoppers often did not have enough information to differentiate between products. Shoppers who were seeking a particular product may have done their research on a particular brand and not be aware of other similar products and differentiating features. For example, the myriad of options for implementing smart lighting—smart bulbs versus smart switches versus smart plugs—within all of which there are multiple kinds, was difficult for customers to navigate. One couple came into a retail store with a coupon, intent to buy a product, but were unsure which to choose; they left without purchasing, conceding, "We have time to do more research" (before the coupon expired).

Another decision barrier for some shoppers was the technology required (or perceived to be required) for smart home products, specifically not having internet at home or a smartphone. Some cases were concerned about access for another person in their household (e.g., older parent). As previously mentioned, many shoppers began to form an understanding of the smart home revolving around the smartphone. Thus, there was a distinct impression that not having a smartphone was an insurmountable barrier and many comments to this effect were made during discussions of smart HEM products in particular, for example, "I do not have a smartphone yet, so I do not understand how it works" (while discussing Belkin WeMo products); "What if my mom is home all day, and she wants to turn off the light? She does not have a smartphone" (regarding smart light). These shoppers were interested in motion sensors and automation that would preclude the need to use a digital device to interface with the products.

Shoppers were often unsure whether a product would work with their home (e.g., lights would not fit light fixtures; old home has limited electrical outlets so would not be able to plug in products). Sometimes product functions were valued but redundant with products/services already owned, for example, "I have already switched all my lights to LED. Do I need new lights?"; "We would not replace our current alarm system." Finally, renting was perceived as a barrier to adoption, for example, "I rent and Nest is more permanent, not worth installing and uninstalling…What if I broke it?"

Implementation

Rogers' (2003) noted the importance of understanding the adoption process beyond the point of purchase: "It is one thing for an individual to decide to adopt a new idea, quite a different thing to put the innovation to use, as problems in exactly how to use the innovation crop up at the implementation stage" (p. 179). Amazon.com customer reviews of smart HEM products revealed some of the problems that "crop up" on smart HEM adopters, especially pertaining to product installation and setup, as well as insights into how early adopters are using these products (e.g., use cases), and desired features and interoperability.

Installation and setup Reviewers appreciated when product installation/setup was fast and simple (few steps), they could do it themselves, and it only needed to be done once. Some seemed pleasantly surprised at the ease of installation, perhaps especially with smart thermostats. Difficulties with installation and setup featured problems with connectivity, such as connecting the product to household Wi-Fi or to one's phone via Bluetooth. There were reports of wireless setup taking multiple tries and connections being unreliable throughout product use. There were also reports of poor or insufficient instructions and poor customer support. Some reviewers experienced difficulties or disappointments with software updates and hardware upgrades, including cases where products were no longer supported by manufacturers. Less frequently, reviewers experienced structural incompatibilities, such as needing extensive rewiring to install a smart thermostat.

Use cases Use cases described in smart HEM product reviews on Amazon.com give insight into how early adopters are using these products, along with the implications for energy consumption. For example, smart thermostats were used: to help couple's compromise (or counter-control each other's behavior) with respect to managing their thermal comfort; to

adjust the temperature remotely from bed; to monitor and control their home or second home while away or leasing it out, respectively; and to adjust the temperature before arriving home.

Lighting was the predominant use case, not only for smart lights but also for smart plugs and switches. With plugs and switches, the lighting uses were more utilitarian: easing access to inconveniently located switches/plugs; remote control away from home; scheduling on/off times in coordination with sunrise/sunset; and centralized control of multiple lights (and other devices). With smart lights, use cases were also about novelty, entertainment, and esthetics: gift/fun for children; showing off to friends; and mood and decorative lighting. Use in the context of social relationships was featured for both plugs/switches and lights. Specifically, plugs and switches were used for taking care of pets, small children, teens, and older parents (monitoring their behavior and improving their comfort), whereas smart lights were used to entertain children and guests. Customers tended to use (or discover they wanted) multiple smart plugs/switches or lights, not just one.

Finally, hubs were touted for enabling whole home automation, and one reviewer highlighted the utility for persons with disabilities affecting their mobility.

Confirmation

Smart HEM product reviews yielded insights into early adopters' experiences in the Confirmation Stage, particularly concerning their satisfaction with features and performance.

Satisfaction with features Remote control and monitoring capabilities were favorite features for all smart HEM product categories among reviewers. Reviews also revealed the desire for a balance between opportunities to engage with the technology (via remote control and monitoring, customization, tips, and notifications) and opportunities for automation (via presets, scheduling, learning, and demand-response). For example, reviewers appreciated the high degree of customizability of some smart lights, but in the absence of presets that are easily implemented (e.g., off and on at dawn and dusk, respectively, and the ability to extend a setting to multiple lights) options could be overwhelming. As one reviewer lamented, "I now really wish I'd just stuck with inexpensive dimmers instead of a system that wants me to make a career out of lighting control."

As with the above example of presets for smart lights, some desired features were present in some but not all products within a given category, or present to varying degrees (i.e., differentiating features). Other differentiating features of smart lights included color-change, precise dimming control, ability to synchronize with music, and sound effects. Differentiating features of smart thermostats included subjective preference for esthetics of hardware design, an indoor temperature indicator on the device, and the inclusion of remote sensors. General differentiating features across product categories included the degree of integration possible and the protocols used—e.g., remote control away from home was a valued feature only available for products or systems using Wi-Fi.

Desired features for hubs included the ability to program with IFTTT commands, remote control away from home, and the ability to connect lots of devices. Regarding the latter, one hub reviewer remarked, "I wish these home automation companies would get on a standard. It is too confusing for consumers."

Reviewers wanted to integrate their products with a variety of other products and platforms. The most frequently mentioned integration was with the Amazon Echo. Reviewers of the Belkin WeMo Switch were especially keen to integrate with the Echo, sometimes indicating this was a primary motivation for their smart plug purchase. Reviewers also wanted to use their smart thermostats and smart lights with the Echo. Wink was also popular; reviewers mentioned integrating (or wanting to integrate) smart thermostats and smart lights into a Wink eco-system. Other desired integrations can be seen in Table 2.

Satisfaction with performance When reviewers were satisfied with product performance, they appreciated ease of use (including intuitive software), accuracy, reliability, and of course the delivery of anticipated outcomes (e.g., increased comfort). Most reviewers who mentioned cost conveyed contentment with the value of the product, with the exception of some smart light and plug/switch reviewers who mentioned the cost was high for the value. Smart thermostat reviewers were also generally satisfied with their return on investment due to energy savings.

Disappointments regarding performance across categories featured connectivity problems, causing unreliability; this was a pronounced and prevalent issue. There were also reports of poor quality hardware and poorly designed app interfaces across multiple product

categories. Smart light reviewers were sometimes disappointed in the flexibility of their products. Specifically, some smart lights can only be controlled remotely and not by conventional switches. This was problematic for some adopters and led to discontinued use.

Smart thermostat reviewers were generally satisfied with product performance in terms of the precision of programming and simplicity of scheduling. The intelligent learning function received mixed reviews. Some felt it was accurate in learning their preferences, whereas other complained about lags after adjustments and insufficient "smartness," one claiming there would be a negligible return on investment compared to programming a programmable-controllable thermostat. Other complaints included inaccurate temperature readings and erratic behavior.

Discussion

This paper triangulated multiple research methods to explore how energy management factors in to smart home adoption, and barriers to smart HEM product uptake and associated energy benefits.

It was difficult to ascertain consumers' knowledge of energy management as an aspect of the smart home from our data because knowledge levels of smart home technology in all respects were relatively low. Consumers were largely unfamiliar with smart HEM products, with the exception of smart thermostats (particularly Nest), but also unfamiliar with smart home products unrelated to HEM. There is a need for accessible information to help consumers navigate this market. If utilities provided such resources and partnered with retailers, they could ensure consumers learn about the HEM products, capabilities, and use cases of the smart home, and not just about non-energy benefits.

Table 2 Product integrations reviewers' implemented or desired

Smart hardware product	Desired integrations
Smart thermostats	Amazon Echo, HomeSeer, Wink, Comcast router, IFTTT
Smart plugs/-switches	Amazon Echo
Smart lights	Amazon Echo, Wink, Samsung SmartThings, other types of smart lights
Hubs	Blink camera, MyQ garage door opener, sensors, lights, Z-Wave, Nest, Siri, Harmony universal remote, Hunter Douglas blinds, Belkin outlets

Once introduced to smart home technology, consumers were generally less interested in their energy management functionalities compared to benefits related to protecting and nurturing their household. That said, they almost universally appreciated energy/cost savings, if only as a secondary benefit. When consumers did not perceive these practical benefits, they saw smart home technology as unnecessary, excessive, gimmicky, and promoting laziness. If smart home companies placed greater emphasis on HEM, e.g., by including energy-saving defaults and presets in their products, it might mitigate those negative perceptions and HEM could assume a more prominent role in the smart home.

Once convinced of the value of smart home technology, consumers face a host of barriers to the decision to purchase, including doubts about performance, high cost, and data security. Those who adopt smart HEM products in the face of these barriers are often confronted with the realities of poor performance, unreliability, and lack of value. Perception of the value of some smart HEM products might increase if they were bundled with more popular products/values (e.g., home security systems), which we are starting to see. However, this raises issues for measuring energy savings since any demand reductions from the HEM products would be bundled with additional demand to power the security products.

Use cases described by adopters did not suggest high energy savings potential with current smart HEM products. For example, many use cases were reported for smart thermostats that could have resulted in increases or decreases in energy consumption depending on user behavior before adopting the smart thermostat. Smart light adopters were predominately using their products for entertainment. Smart switch and plug users were predominately concerned with convenience and control. Energy management did not feature strongly, if at all, in adopters reported motivations and experiences.

Those who owned products were often unaware of the extent of opportunities for multiple product integration. There was also confusion about how hubs operate. While product integrations and hubs in and of themselves do not offer home energy management benefits, interconnectivity is key to unlocking the potential of the smart home. Systems of integrated, coordinating products is where the real opportunities for HEM lie, but also

the most expense and effort for consumers to purchase, install, and set up.

Limitations Our research was limited by the products sold at our retail partners' smart home displays, e.g., neither retail space featured large smart appliances (washer, dryer, dishwasher, refrigerator). Additionally, products with a high number of reviews on Amazon.com may not have represented the actual current market profile due to product discontinuation and newer products having less time to accumulate reviews. Our methods enabled a broad assessment of the complex adoption process for multiple product categories, but future studies on particular product categories and particular stages of adoption would be informative (e.g., ethnographies to assess smart plugs/switches in the Implementation Stage). It is critical that further research explore the actual energy savings and demand management outcomes among early adopters of all HEM-related smart home products.

Conclusion HEM technologies have the technical potential to deliver a variety of benefits to both users and utilities. The products themselves can deliver demand reductions (e.g., through more efficient delivery of services such as heating, cooling, lighting, etc.), and can support users in reducing or shifting loads, saving both energy and money. Growth in the smart home and Internet of Things market and the alliances already emerging whereby smart home platforms incorporate both HEM technologies and non-energy related smart home devices suggest that the future of HEMS could be highly intertwined with the wider connected home. This confluence compounds the value of smart home technology for consumers, enabling home energy management while increasing security and comfort, but also makes it difficult to anticipate the net energy impacts of smart home technology. HEM-enabling smart home products, if adopted for non-energy benefits and/or integrations with other smart home technologies that consume but do not help manage energy, might just as easily result in net energy consumption increases.

This research provided insights into the multi-stage process of smart home adoption. The approach was designed to offer a critical perspective on the potential for the smart home to deliver energy benefits. Implications of this research could help industry, regulators, utilities, and retailers shape the future of these technologies and support consumer adoption in ways that will better promote power demand reductions and load shifting at scale for the smart home and smart grid of the future.

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Compliance with ethical standards

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