Title

Smart home products with energy management implications: Characterizing and comparing adoption, experiences, and outcomes

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Smart Home Energy Management (HEM) Products: Characterizing and Comparing Adoption, Experiences, and Outcomes

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ABSTRACT

The smart home market includes several different types of products that enable energy management: smart lights, plugs, thermostats, and appliances. While pilot studies have been conducted across these categories, little is known about the actual market adopters of these product types and how they may (or may not) be using the products to manage their energy use. This paper reports results from a survey of over 300 California residential utility customers who own smart home energy management (HEM) products. In order to better understand how and for whom each product is, or is not, contributing to home energy management, we characterize and compare the user experience of different product types. Smart thermostats were the most popular among our sample, with highest levels of ownership and highest reported intention to continue use compared with other product categories. Smart thermostats were also most frequently reported to result in energy savings, although about one-third of owners of each other product type also reported energy savings. Smart thermostats and plugs were most commonly purchased online, whereas smart lights and appliances were most often purchased in home improvement stores. We also highlight interesting differences among owners of smart lights, plugs, thermostats, and appliances in terms of demographics, household characteristics, and attitudes about energy management and smart home technology. Our findings have implications for market segmentation, utility programs, and product development to better leverage the energy management potential of smart home products.

Introduction

Smart home energy management (HEM) products, such as lights, plugs, thermostats, and appliances, enhance households' control over energy-consuming devices via remote access, scheduling, or learning algorithms (Ford et al. 2017). For utilities, these products hold promise for supporting demand-side management (DSM) goals, driven by government regulation and economic interests. HEM technologies can also enhance power grid visibility, enabling utilities to understand and alter consumption patterns.

Although "smart homes" are often discussed as one thing, a great deal of variability exists in what constitutes a smart home, depending on the products and how they are adopted and used by household members (Darby 2018). Different products may be more attractive to certain demographics, they may elicit different patterns of use, and they may have different effects on energy use. This paper investigates similarities and differences in adoption, user experience, and energy outcomes between four types of HEM product: smart lights, plugs, thermostats, and appliances; implications for product design and marketing are discussed.

Literature Review

While research has identified significant potential for energy savings and demand response through the adoption and use of HEM technologies, market uptake has failed to meet projections and studies of how products are actually used by adopters are lacking, and savings estimates are difficult to calculate. This section reviews past literature on home energy management products' adoption, user experience, and energy savings.

HEM Adoption and User Experience

Despite the variety of products and high expectations, awareness and adoption of smart home technology — and particularly HEM products — remains low. For example, in a market characterization survey in 2015 (Icontrol Networks 2015), 50% of the sample (North Americans) said they were likely to purchase a smart home product in the next 12 months. However, a similar study found that only 12.5% of American households owned a smart home device by the end of 2016 (Paxton 2017).

This is likely due to a combination of factors. Past research has identified some negative user experiences with smart home products, notably reliability issues and security concerns (Tsukayama 2016). Additionally, there has been a high degree of turnover in the availability of products on the market, which could be causing uncertainty among potential consumers (Karlin, Ford, et al. 2015).

Little research has investigated HEM early-adopter demographic profiles and how early adopters use these products. Karlin, Sanguinetti, et al. (2015) compared active adopters (i.e., people who bought and/or used a product outside of a formal study) of energy feedback technologies with non-adopters and found that adopters were more likely to be male, older, married, and homeowners. They were also likely to have a higher income, more liberal political ideology, greater environmental concern, and higher consciousness of their energy bill. Adopters used feedback products to track energy consumption over time or to learn discrete facts about their energy use (e.g., the energy consumption of particular appliances). To our knowledge, this study is the first of its kind to investigate these elements of HEM product adoption.

Energy Savings

While there is a great deal of evidence demonstrating the savings potential of providing energy feedback to consumers (Ehrhardt-Martinez, Donnelly, and Laitner 2010; Karlin, Zinger, and Ford 2015), research on the savings potential of smart HEM products is limited. The product category with the largest body of empirical research is smart thermostats. For example, Greentech Media (2014) reported that Nest thermostats lead to load reductions of 1.18 kW per thermostat during demand response (DR) events and average AC runtime reduction of about 5%.

For the other three product categories, studies have mainly included simulations, manufacturer studies, or small sample pilots ($n < 10$). Chua and Chou (2010) found that CFLs coupled with smart lighting save up to 7% of residential electricity consumption. However, savings were not attributable to smart lighting alone and estimates were based on assumptions of user behavior. A report for San Diego Gas & Electric (NegaWatt Consulting 2012) installed

smart plug strips and found an average instantaneous drop of 5.5 kW in response to a simulated DR event. However, this was based on a sample of six homes.

Smart appliances have mainly been studied in terms of demand shifting, rather than overall energy savings. Southern California Edison (2012a) found demand reduction of 100 W for a smart refrigerator during brief demand response events, but power increased during longer demand response events. A second lab study found that a smart dishwasher can achieve demand reduction up to 1 kW (SCE 2012b) but this finding was not tested in a field setting.

As such, we still know relatively little about how people are buying and using HEM products and whether they are being leveraged in customer homes to shift or reduce demand. In the current paper, we aim to characterize and compare the user experience of different product types in order to better understand how and for whom each product is, or is not, contributing to home energy management.

Method

The data presented in this paper were part of a broader research project (Ford et al. 2016) conducted on behalf of Pacific Gas and Electric Company (PG&E) to investigate the role of HEM technology in energy savings. The overall project included interviews, a survey of stakeholders, four consumer studies (two retail ethnographies, a content analysis, and a consumer survey), and a technical inventory of over 300 products. The present research focuses on the online consumer survey, which was conducted in March 2016 using PG&E's Customer Voice Panel, a voluntary pool of more than 15,000 customers who agreed to be contacted for research. Stratified sampling was used to increase the representativeness of the sample in terms of region (Northern, Central Valley, Central Coast, Bay Area), gender, age, income, and homeownership. The survey assessed product ownership and user experience with smart thermostats, appliances, lights, and plugs. These four categories were selected based on the typology in Ford et al. (2016), which identified types of "smart hardware" that have independent capacities to support HEM.

The survey instrument included infographics (Figure 1) to illustrate each HEM category for those who might own the product but be unfamiliar with the terminology. Each infographic was presented directly before questions about ownership and user experience with that product category. For each product, the survey asked: *Do you own a smart [appliance / thermostat / plug / light]?* For smart appliances, an additional question asked owners to specify, *Which, if any, of the following smart appliances do you own (please select all that apply)?* Response options were: *Smart washing machine; Smart dryer; Smart dishwasher; Smart refrigerator; Smart oven; Other (please specify);* and *None of these / not sure.* Individuals who selected these last two options were not included in our sample of smart appliance owners since we were particularly interested in the specified white goods.

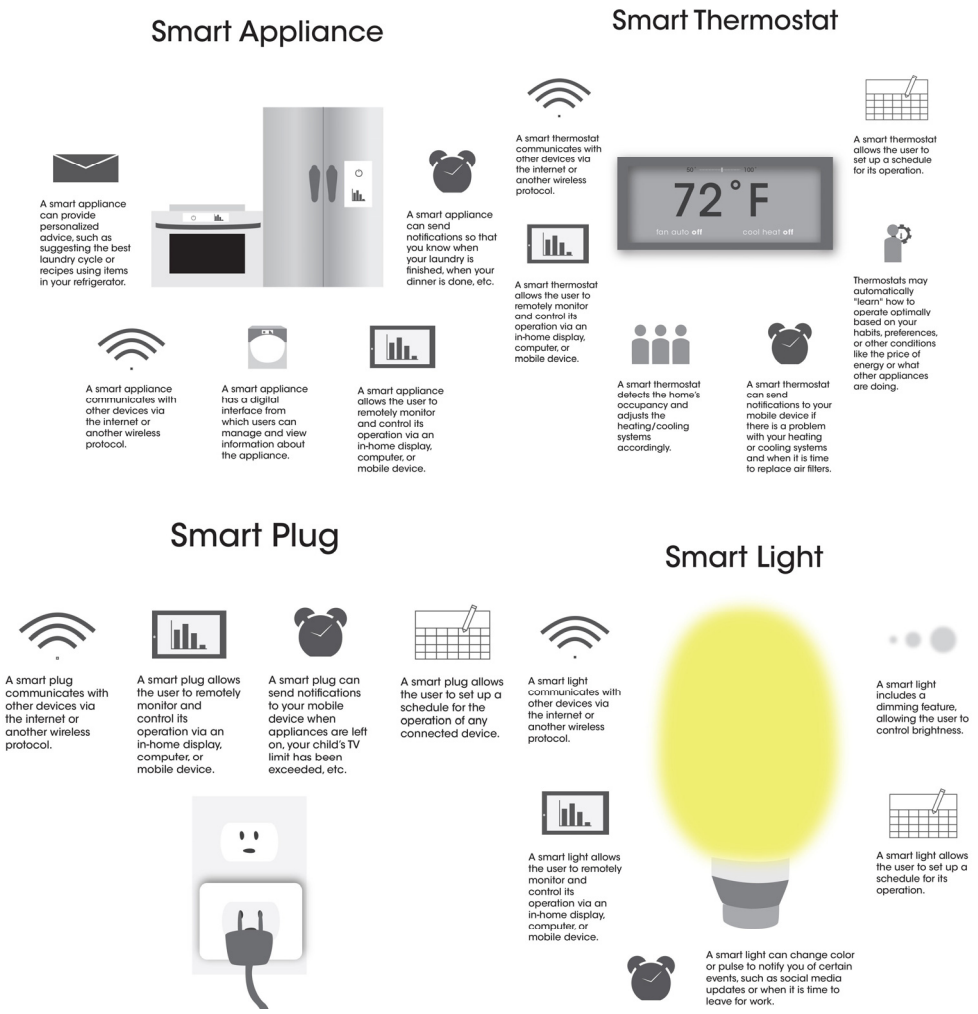

Figure 1. Smart product infographics shown before asking about ownership

Respondents who indicated they owned a particular product category were provided with an additional series of five questions pertaining to user experience. These questions were the same for each product category. They proceeded as follows:

1. *Where did you acquire your smart [appliance / thermostat / plug / light]?* Response options: *Store (specify); Online (specify); Gift from (please specify); Borrowed from (specify); Came with my home; Other (specify); None of these / not sure*
2. *What, if anything, do you like about your smart [appliance / thermostat / plug / light]?*
3. *How, if at all, did your energy use change as a result of using your smart [appliance / thermostat / plug / light]?* Response options: *Decreased; No change; Increased; Not sure*
4. *Do you intend to keep using smart [appliances / thermostats / plugs / lights]?*

The survey also included questions about household characteristics and basic demographics, e.g., gender, age, homeownership, number of years in home, and household income.

Results and Discussion

Product Adoption

Out of 1,414 survey respondents, 21% (n = 303) reported owning one or more HEM product. In order of prevalence: 14% of all respondents (n = 203) owned a smart thermostat, 7% (n = 92) owned a smart light, 5% (n = 72) owned a smart appliance, and 5% (n = 70) owned a smart plug (Figure 2).

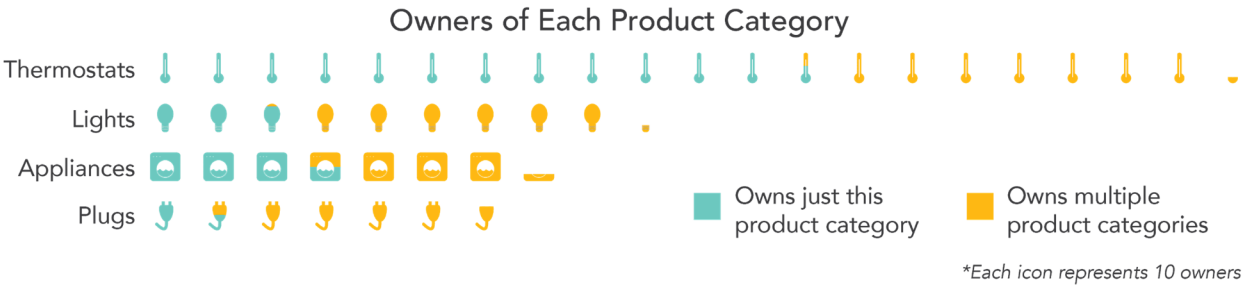

Figure 2. HEM ownership patterns

We also asked respondents where they acquired their HEM products (Table 1). Appliances and lights were most often purchased in retail stores (77% and 54%, respectively), whereas thermostats and plugs were primarily purchased online (34% and 49%, respectively). Retail stores most commonly cited include Home Depot, Best Buy, and Lowe's (also Apple Store for lights). Most common online retailers were Amazon and Smarthome.com (also Nest and eBay for thermostats).

For smart thermostats, lights, and plugs, respondents also reported acquiring the products through contractors and/or in conjunction with other upgrades (e.g., security, solar, HVAC, Comcast), per open-ended responses corresponding to the "Other / Not Sure" category in Table 1. Also represented in the "Other / Not Sure" category, 6% of smart thermostat owners (4% of HEMS owners and less than 1% of total sample) reported receiving their device from PG&E (as part of a pilot study). Thus, the prevalence of smart thermostats is only slightly inflated due to utility incentive programs supporting the rollout of this technology.

Table 1. Reported points of purchase for HEM products

	Appliances	Thermostats	Lights	Plugs
Store	77%	22%	54%	26%
Came with home	14%	10%	4%	4%
Online	6%	34%	42%	49%
Gift	2%	7%	5%	9%
Other / Not sure	< 1%	27%	8%	12%

We were also interested in how often owners of each product type owned *just* that product type, as this has implications for spillover (i.e., are consumers likely to adopt single products or multiple products). Most (66%) smart thermostat owners owned *just* smart thermostats and no other product types. Almost half (49%) of smart appliance owners owned *just* smart appliances. The opposite pattern was found for lights and plugs. Most owners of smart lights (69%) and plugs (78%) owned products in more than one HEM product category. Ownership of specific combinations of products is depicted visually in Figure 3 and statistically in Table 2. Lights and plugs were most often owned together (r = .43), while appliances and thermostats were least often owned together (r = .14).

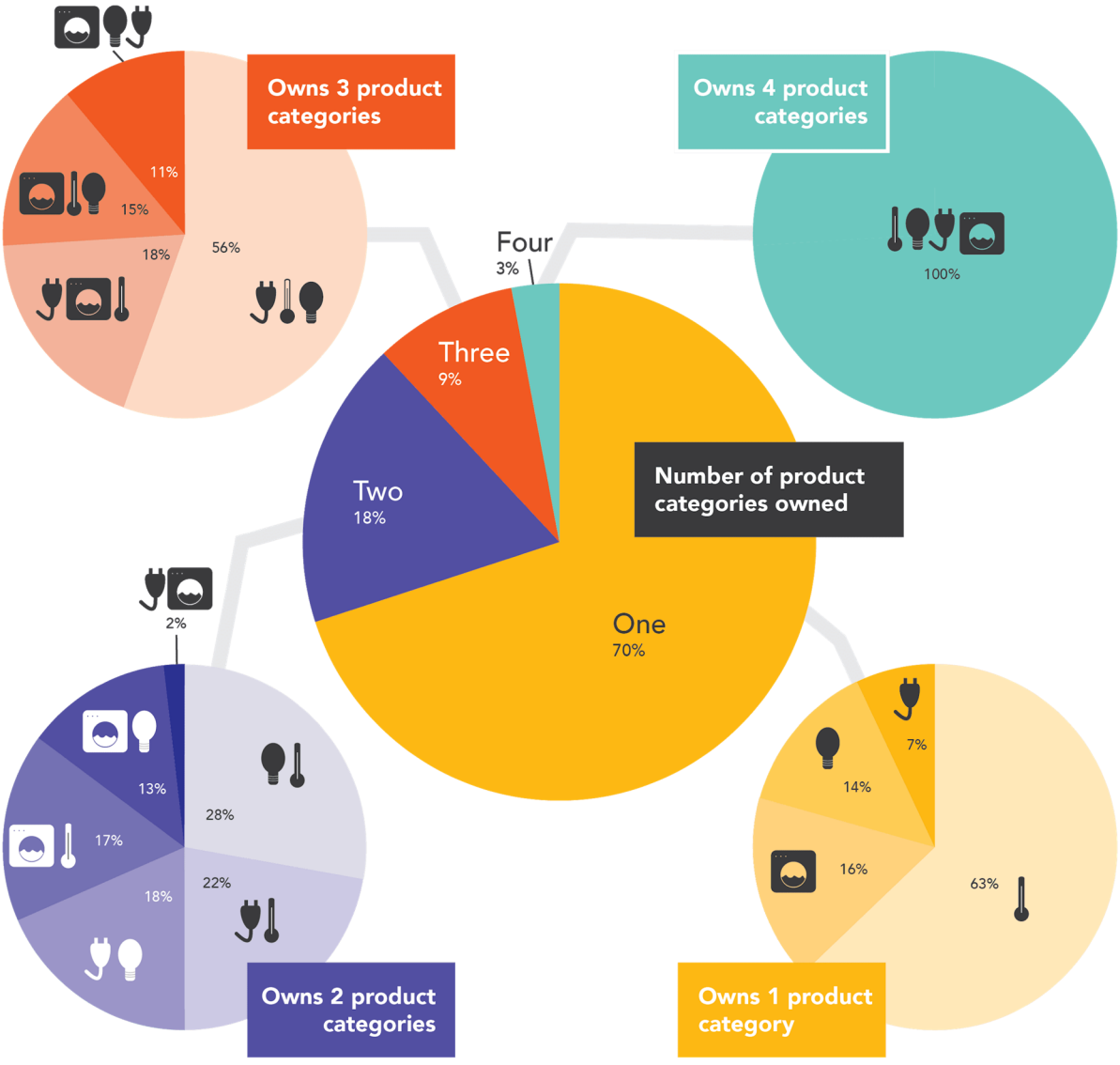

Figure 3. Variation in ownership of different HEM product categories

These relationships could be related to the higher cost of smart thermostats and appliances: Owners who get their feet wet with smart home technology by investing in these more expensive products might hold off on additional purchases. Another hypothesis is that appliances and thermostats have a stronger independent value proposition, whereas lights and plugs have increased functionality — and a stronger value proposition — when they are owned in multiples or as part of a system of multiple product types. This latter hypothesis was supported in other research we conducted with retail shoppers and smart HEM product reviewers on Amazon.com (Ford et al. 2016; Sanguinetti, Karlin, and Ford 2017).

Many implications for HEMS marketing and education flow from these findings. Since smart thermostats have been most widely adopted, highlighting their HEM functionalities could increase consumer awareness and adoption of smart thermostat HEM features. Highlighting smart thermostat interoperability with other products (especially those with HEM features) could promote HEMS adoption.

Product bundling can also help subsidize HEM products with insufficient independent value propositions (e.g., single smart lights, plugs, and switches). For example, some companies provide kits of multiple smart lights, switches, or plugs, sometimes along with a hub, which is a promising approach per our findings that customers prefer more than one of these products. Product bundling can also be used to leverage popular products with a strong independent value proposition, such as smart thermostats, or even smart products without HEM features (e.g., smart door bells or security cameras). Less popular HEM products could be combined with these "hook" products in kits or via partial incentives (e.g., rebated hub and/or HEMS kit with the purchase of "hook" product).

Table 2. Correlation coefficients representing the degree of association between ownership of different product types.

	Appliances	Thermostats	Lights	Plugs
Appliances	--			
Thermostats	.14**	--		
Lights	.23**	.24**	--	
Plugs	.20**	.29**	.43**	--

**Correlation is significant at the 0.01 level (two-tailed).

Characteristics of Product Owners

We compared smart HEM product owners to non-owners, and owners of specific smart HEM product types, to understand how their demographic profiles may differ (Table 3). Because so few participants owned only lights or plugs and ownership of these two were highly correlated, we grouped them together for this analysis. When comparing single-product-category owners, we excluded individuals who owned more than one product category (counting plugs and lights as a single category) in order to have mutually exclusive groups for comparison.

Overall, smart HEM owners (of any product type) were more often male, younger, with higher income, and more likely to own their home. They were also likely to have a larger home,

be planning to stay in their home longer, and have solar panels for home electricity and/or a plug-in electric vehicle. These are typical characteristics of early adopters of innovative technologies (Rogers 2003). However, results revealed different profiles for owners of different HEM product types.

In general, smart appliance owners did not match the overall HEM product owner profile. In fact, they did not differ significantly from non-owners in any way. This could indicate that smart appliances have more diverse and stronger value propositions for the general population, in contrast to other HEM products that have a greater appeal to the more technophilic early-adopter type. This could be because smart appliances serve the same basic functions as their "non-smart" counterparts, in contrast with the other HEM categories that are not responsible for the quality of basic services and thus perceived as discretionary add-ons. Once the price points of smart appliances drop, there may be significant opportunity to leverage them as a gateway to multi-product HEMS adoption (e.g., through product bundling).

Despite the small sample size, there were significant differences between smart appliance owners and owners of other HEM product types. Smart appliance owners were older than smart thermostat and smart light/plug owners. They had a lower income than smart thermostat owners, but were similar to this group in other ways. Both smart appliance and smart thermostat owners were less likely to rent (and more likely to own) their home, and expected to remain in their home longer compared to light/plug owners. This could be explained by the relative permanence of smart thermostats and smart appliances when compared to smart plugs/lights; while renters typically own their own plug-in appliances/devices and are responsible for replacing/maintaining light bulbs, they tend not to own white or fixed goods associated with the rental property.

Table 3. Characteristics of smart HEM product owners.

	Non-owners (1,111)	All owners (303) v. non-owners	Thermostat owners (134)	Light/Plug owners (54)	Appliance owners (35)	Single-product owners v. non-owners
Gender	45% Male	68% Male $\chi^2 = 49$***	68% Male	70% Male	54% Male	$\chi^2 = 35$***
Age (mean)	45	42 $\chi^2 = 11$**	35 15% 65+	40 6% 65+	50 31% 65+	$\chi^2 = 29$***
Income (median)	$50-74,999	$75-99,999 t = 9***	$75-99,999	$75-99,999	$50-74,999	$F = 17$***
# yrs plan to stay in home	3.9	4.1 t = -2*	4.2	3.6	4.5	$F = 4$**
# bedrooms (mean)	3.7	4.0 t = -5***	4.1	3.7	4.	$F = 9$***
Owns home	58%	75% $\chi^2 = 30$***	84%	50%	74%	$\chi^2 = 39$***

Owns PV (solar)	11%	20% $\chi^2 = 17$***	18%	19%	20%	$\chi^2 = 10$*
Owns PEV (plug-in vehicle)	6%	13% $\chi^2 = 20$***	9%	17%	6%	$\chi^2 = 13$**

*, **, *** indicates significance at the 95%, 99%, and 99.9% level, respectively

User Experience

This section explores users' experiences with smart HEM products, based on survey participants' open-ended responses about their likes and dislikes of each product type owned. Understanding strengths and limitations of products from a consumer perspective can shed light on barriers to broader adoption and continuation of use, as well as implications for energy use.

Common preferred features across product categories include remote access to information and control. For example, a smart thermostat owner liked how they could "adjust the temperature from wherever... without having to get up and physically touch the thermostat." A smart light user liked "the ability to control the lighting in our house remotely including, for example, if we forgot to turn off the lights before bed, or for security reasons while travelling." A smart plug owner remarked, "[The smart plug] lets me control some products without having to be next to a switch." The ability to schedule appliance operations was also a common preferred feature across thermostats, lights, and plugs.

Common dislikes across products included problems with performance, reliability, ease of use, and cost. For example, some smart thermostat owners reported that their device did not always operate as programmed, had glitches or erratic behavior, or was too difficult to program. Some smart light owners also had difficulties with installation and programming and characterized their products as "glitchy." One remarked, "These early generation products are being constantly worked on but they are still not 100%." Regarding the complexity of setup, one smart light owner remarked, "I have low confidence that if I die my wife (or anyone else) will be able to use the system, especially if there's any power/network/etc. disruption and things get out of sync." An owner of multiple smart plugs noted, "They sometimes turn on without my knowledge." High cost was noted for smart appliances (the most expensive product category), but was more often mentioned by owners of smart lights and plugs, with some noting that they needed to buy so many to make them truly useful in the home that it made the total price expensive.

Unique likes and dislikes for each product category were also revealed, particularly regarding their respective unique features. For example, the learning feature of smart thermostats featured strongly as both a like and dislike. A proponent explained, "I love that it learns our habits and then becomes essentially self-operating"; whereas another owner complained, "It notices patterns that aren't indicative of our actual habits and then incorporates them into daily settings." Smart appliance owners in particular liked information features, such as receiving notifications and the ability to monitor feedback related to performance and maintenance. For example, a smart refrigerator owner said, "I like that it can notify me if the fridge has been left open, it counts the gallons that goes through the water filter, and came with LED lights." Smart

plug owners enjoyed opportunities to integrate smart plugs into a smart home ecosystem, whereas smart appliance owners were dissatisfied with the interoperability of their products.

Energy Savings and Continuation of Use

Respondents were asked whether their energy use had decreased, increased, or stayed the same after using the smart home products (Table 4). Thermostats were rated highest in self-reported energy savings (51%): "Improves how much I save on heating and air conditioning electric/gas usage." However, nearly a quarter of people with thermostats said that they didn't know if it saved energy and a few (6%) said that it could lead to more energy use. Some noted that energy savings for a smart thermostat depends on what technology it replaces: "It probably hasn't saved me much energy, because I already had a very energy-efficient schedule on my previous programmable thermostat."

Respondents reported very similar energy savings for smart lights and plugs, with 35% saying they decreased energy usage and just under half reporting no change in energy usage for both products. Some of the comments about energy savings for lights were focused on the energy efficiency of the light itself and not the "smart" component of it: "saves money on energy bills and they last 10 years plus". In general, when talking about lights, respondents discussed factors such as convenience and aesthetics more than energy savings. Appliances had the lowest reported changes in energy use, with just 29% saying their energy usage decreased and 72% saying they were not sure, didn't notice a change, or saw an increase in energy usage. This could perhaps be due to lack of information and control relating to energy consumption that is provided to users; typically smart appliances focusing on enhancing the primary function of the appliance, rather than providing additional functionality related to energy management (Ford et al. 2017).

Table 4: Survey responses of HEM product adopters regarding energy impact and continuation

	Smart thermostats (n = 203)	Smart appliances (n = 72)	Smart lights (n = 92)	Smart plugs (n = 70)
Impact on energy consumption	51% decreased 20% no change 6% increased 23% not sure	29% decreased 46% no change 5% increased 21% not sure	35% decreased 40% no change 3% increased 22% not sure	35% decreased 44% no change 4% increased 17% not sure
Continuation of product use	95% yes 3% not sure 2% no	85% yes 11% not sure 4% no	89% yes 10% not sure 1% no	80% yes 17% not sure 3% no

Most HEM product owners reported an intention to continue using their products (Table 4). Smart thermostats had the highest rates of continued use, with 95% of owners saying they would continue using it, 2% saying they would not, and only 3% who were not sure. The product rated lowest for continued use was the smart plug, with 80% saying they would continue using it, 3% saying they would not, and 17% who were not sure.

Conclusion

Overall, our findings suggest that a discussion of "smart home" or "HEM" products in general, either to customers or about the consumer experience, is not sufficient to account for the variation between product types. The distinct demographic profiles, likes and dislikes, and self-reported outcomes all point to a diverse product landscape. For example, the demographics of HEM adopters in general (compared to non-adopters) did not map on to the demographics of examining each separate product type. Specifically, adopters of smart appliances appear to have a distinct profile, and there also appears to be a difference between those adopting more permanent devices (i.e., older, homeowners, more likely to stay in their homes for longer) and devices that can be easily moved, such as lights and plugs. In addition, smart thermostats are seen to have a clearer energy-saving value proposition than the other HEM product types, whereas smart appliances are liked for their ability to support performance and maintenance related to the primary function of the appliance. While these findings are limited by a relatively small sample size, they nevertheless point to the fact that characterizing HEM adopters generally, rather than by product type, may oversimplify and/or mischaracterize customer segmentation efforts.

Despite differences between product types and their specific value propositions, there are some common themes that could inform opportunities for more widespread adoption. For the most part, smart home technology is seen as benefiting users by making their household tasks easier to carry out, whether by, for example, adjusting the thermostat from the sofa, turning lights off from bed, or controlling appliances without having to be right next to the switch. However, performance is critical to user satisfaction; complex installation procedures, difficulties in setup, glitches in use, or a lack of reliability can turn users off.

Thus, collecting and comparing data on how HEM products are used by naturalistic adopters, as well as on the unique attributes and experiences between these products has implications for product design and marketing. Developers must be sure that products work well in homes (as well as in the lab), and can be easily set up and used by non-experts. Marketing should focus on the specific value propositions presented by different product categories. To support energy-related goals, utility and/or government programs must create, emphasize, support, and evaluate use cases for load shifting or reduction to promote the use of HEM products for demand-side management.

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