Title

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ABSTRACT

Smart home technology has been gaining traction in recent years, especially since the introduction of intelligent personal assistants such as the Amazon Echo or Google Home. With smart devices replacing manual controls in homes, utilities and policymakers need to understand the potential of this technology to save energy or shift load to identify whether/how they can support it. While most of the current industrial research on smart home technology focuses on non-energy benefits, there is a clear need to identify products and features that hold promise to support home energy management (HEM) functions. This paper presents a framework for identifying use cases for home energy management systems (HEMS). Our analysis draws on data from a multi-method research study on HEMS that included interviews and surveys with consumers and stakeholders, as well as a technological assessment of over 300 HEM products. The framework inventories and categorizes opportunities to reduce or shift home energy consumption, then maps these opportunities to specific strategies a HEM product user can enact, or allow, and specifies the required product/system features and user interactions. These use cases can support the design of smart home products that better enable HEMS, the development of educational tools to promote the energy management uses of smart home products to consumers and can guide the creation of policies, regulations, and programs.

Introduction

Smart home technologies that facilitate remote operation or automation of household appliances are becoming increasingly prevalent (McKinsey & Company 2018). These technologies include upgrades of conventional appliances, such as thermostats and refrigerators, to include sensing, communication, and actuation components, as well as completely new products that enable innovative interactions with one's home, like Amazon Echo and Google Home (Ford et al., 2016). Smart home products and systems, combined with the smart grid, create opportunities to leverage two-way communication between energy utility and customer, facilitating real-time data transmission, analytics, and control. This offers potential to support users in demand side energy management efforts while providing benefits such as enhanced convenience, comfort, and security (Wilson, Hargreaves, Hauxwell-Baldwin 2017).

To date the energy saving features of smart home products have not been a central focus of product design, marketing, and consumer adoption (Ford et al. 2016). Conflicting value propositions and enhanced service expectations from home automation could limit or negate the demand side energy management potential of the smart home; a desire to improve home security, comfort, or convenience could even result in increases in energy use (Darby 2017). For this reason, utilities, policy makers and other stakeholders should articulate better how those products could also be used to save energy. Indeed, although non-energy benefits are driving adoption, consumers are almost universally appreciative of energy savings as an additional benefit (Sanguinetti et al. 2018a, 2018b).

In order to enable, promote, evaluate, and ultimately realize the full potential of smart home technologies to contribute to demand side management, it is necessary to identify and articulate why and how they might deliver energy benefits to users in parallel with other values. By developing a series of use cases that explore how home energy management opportunities can be realized, it is possible to define product requirements and user interactions to deliver a smart *energy* home. The present research provides a framework for inventorying HEM use cases of smart home technologies. This framework can be used by smart home product designers to maximize features conducive to energy benefits, and by retailers, utility program managers and policy-makers to educate and motivate consumers to use smart home products for energy management.

Background

The framework proposed in this paper is based on a multi-faceted research project focused on HEM technology, conducted on behalf of Pacific Gas & Electric Company (Ford et al. 2016). The project included a technology assessment (an inventory and analysis of available HEM technologies), a stakeholder analysis, and consumer research. Insights from the technology assessment and customer research were the impetus for developing our HEM use cases framework. We briefly describe each of these research efforts and their findings that led to the current work.

The technology assessment aimed to provide insight into the range and capabilities of smart home products that enable energy management. We conducted a content analysis of smart home product information, coding 308 products on 96 unique attributes (e.g., software and communication features) to inventory functionalities, determine key differences within and between product categories, and explore their potential for delivering energy savings and demand shifting. Data collection built on prior work (Karlin et al. 2015) and used four strategies to find products: (1) review of websites across key actors including retailers (e.g. Lowes), service providers (e.g. ADT), and product manufacturers (e.g. Honeywell); (2) Internet search of online markets for smart home products (e.g. SmartHome); (3) lists from personal contacts, and (4) review of key media sites and newsletters focused on smart home technologies (e.g., GreenTechMedia). See Ford et al. (2017) for full methodological details and Pritoni et al. (2017) for the complete raw data set.

Exploring energy savings and demand response potential for our assessed products proved difficult. Technical documentation for HEM products often describes a multitude of features offered by each device and claims the capability of achieving large savings. Studies utilizing energy simulations frequently use overly simplified assumptions, resulting in highly uncertain results (Urban et al. 2016). Such studies do not consider how products will be used by home occupants, which is a key aspect when considering expected - rather than maximum - potential energy savings. On the other hand, field demonstrations - in which users do interact with products in their homes - tend to treat products as black boxes and just measure their energy performance in a specific setting (e.g., brand, climate zone, type of house, home demographics; Aarish & Jones 2016), producing results that are difficult to generalize and which typically deliver smaller savings than highlighted in technical documentation. These trials do not explore how HEM products are being used and the implications this has on energy savings. They fail to explore the gap between potential and actual energy demand management, or identify opportunities to use smart home products in ways that can deliver energy savings alongside other benefits. A simple yet comprehensive framework to assess savings potential for different technologies, accounting for how they are used, is missing in the literature.

The consumer research in the HEMS project aimed to provide insights into end-user knowledge, attitudes, and experiences about smart home products and their HEM implications. We conducted a number of studies, including a survey of PG&E customers, customer observation and interviews at two smart home product retailers in the California Bay Area, employee interviews at these same retailers, and content analysis of HEM product customer reviews on Amazon.com. For full methodological details see Sanguinetti et al. (2018a,b).

This research revealed that many consumers, including early adopters, are not fully aware of the HEM possibilities afforded by smart home products. Furthermore, early adopters reported experiences with these products (including smart thermostats, plugs/switches, and lights) did not strongly feature HEM use cases. Our research suggested that although non-energy benefits related to nurturing and protecting one's household are driving adoption in this space, customers almost universally appreciate energy and related cost savings as a secondary benefit. Without such practical benefits consumers often see smart home products as frivolous. In the retail context, it often was not until a salesperson described a relatable use case for a product (e.g., smart plug can turn off appliances when the house is empty) that a customer would realize its value. Thus, making the ways in which people interact with energy through HEMS more salient, is valuable to the customer. Use cases may also prevent some of the potentially negative energy impacts caused by enhanced service expectations (e.g., improved comfort and convenience) associated with home automation. However, there is currently no readily accessible inventory of HEM use cases for smart home technology to support product design, utility programs, policy development and consumer choices. Thus, the goal of this paper is to provide a framework for identifying and inventorying HEM use cases.

HEM Use Cases Framework

Here, we propose a simple framework to characterize different strategies of demand side energy management. The framework has four parts: (1) energy services model, (2) HEM strategies, (3) HEM-enabling features, and (4) HEM use cases. The first three parts are mostly technical, while part 4 develops the use cases. We link the saving strategies to HEM product features and use them to illustrate HEM use cases.

Energy Services Model

Figure 1 depicts a model of energy services, which serves as the foundation of our framework. An *END USE* device (e.g., a light) provides a service for the user (*Service Output*; e.g., illumination) consuming energy (*Energy Input;* e.g., electricity). The end use device generates *Conversion Waste* (e.g., waste heat) as a result of some internal energy conversion process. The *Efficiency* of the device is the conversion ratio between [*Energy Input – Conversion Waste*] and *Energy Input*. The energy use can be shifted in time using internal *Storage* (e.g., a computer battery). Other examples of services include thermal comfort, washing clothes, and refrigerating food. *Useful Service* is required or desired by the user (e.g., light in occupied rooms), whereas *Superfluous Service* is not (e.g., light in the empty rooms). Sometimes the user can take advantage of *Free Service* (e.g., natural light through a window). The *HEMS* controls and/or exchanges information with the *END USE* and may gather information about *Energy Cost* from some source (e.g., utility meter). The *USER Experiences* the *Service* through the environment, while receiving *Feedback* and setting *Service Preferences* through the *HEMS*.

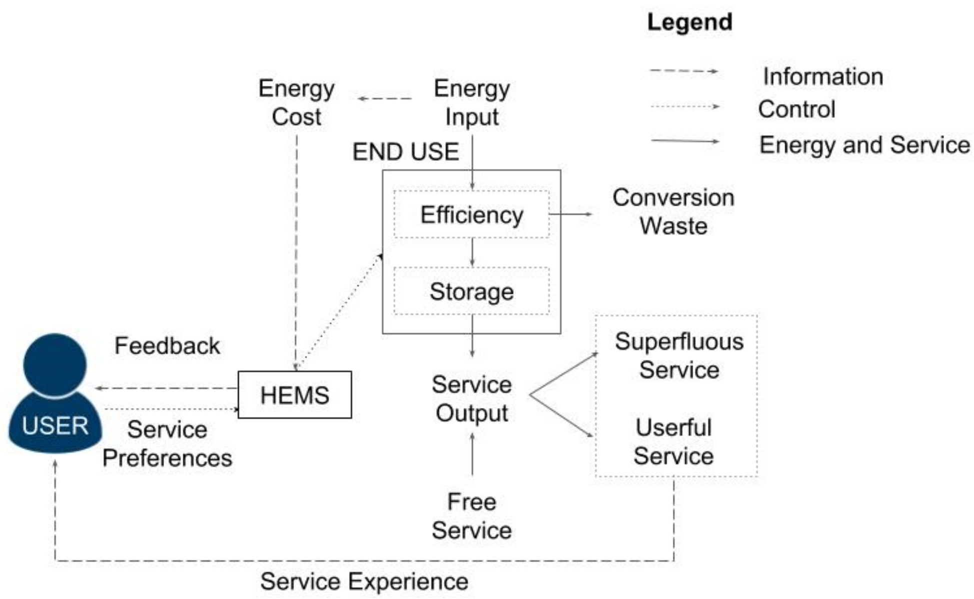

Figure 1: Energy Services Model

It is important to note that the concepts of useful and superfluous service are subjective and context dependent. People will have different and changing preferences, for example, desired level of illumination may be different depending on the time of day, the time of year, their physiology/age, or depending on their other activities (e.g. reading a book vs. entertaining dinner guests). HEMS offer the opportunity to automate control of service provision to support demand management and other objectives (e.g. reducing HVAC operation during a demand response event in return for financial gains), but it is crucial that users remain satisfied with the level (e.g., comfort) and quality (e.g., convenience, reliability) of service. While this can be challenging, it is possible to overcome these issues through enabling users to opt out of automated responses - providing them with the ability to "set and forget" preferences for autonomous demand management while also retaining a degree of control over the operation of their home.

HEM Strategies

Based on our Energy Services Model and HEMS technology assessment, we identified six HEM strategies. Figure 2 defines these strategies. All of these strategies can be performed without the use of smart home technologies, as the examples in Figure 2 illustrate. However, the feedback and control capabilities provided by smart home products support users in delivering savings through these strategies (detailed in the next section).

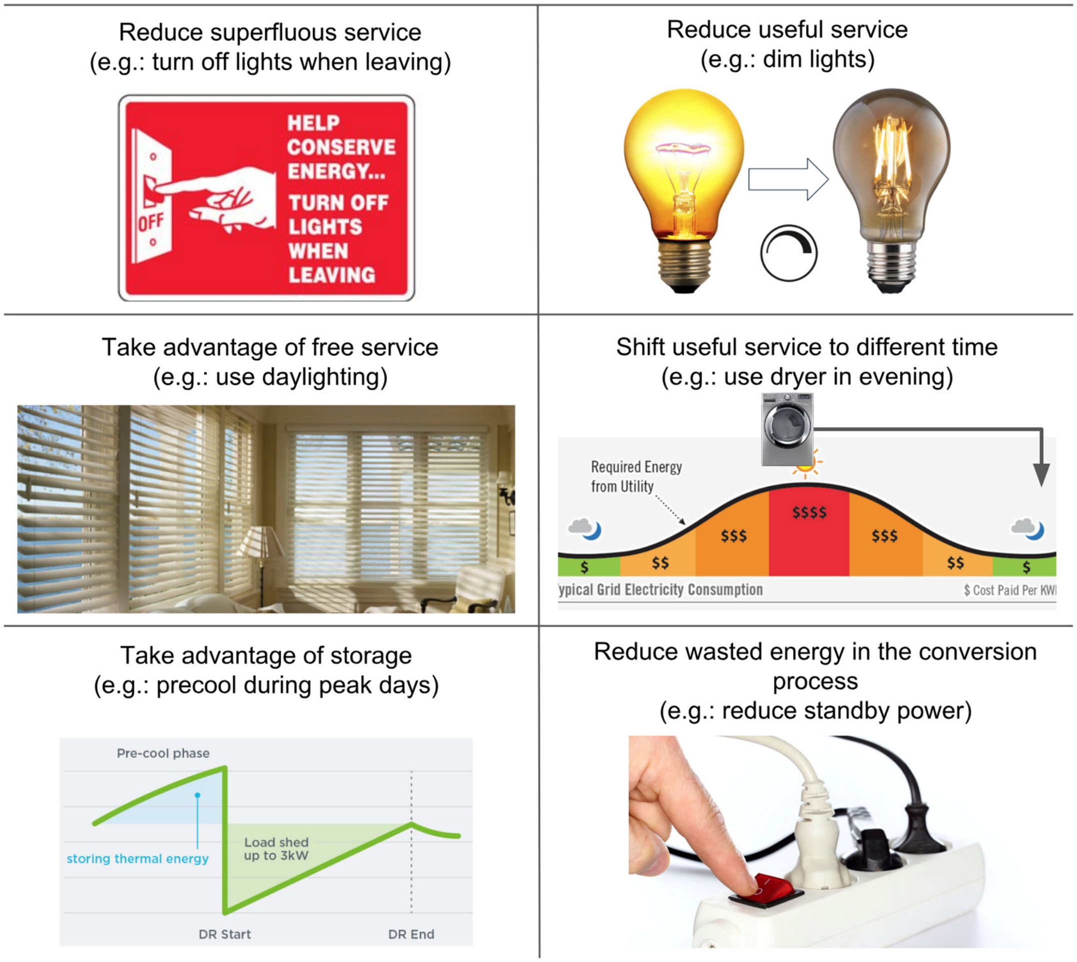

Figure 2: HEM strategies

Reduce superfluous service (RedSup). Perhaps the most obvious HEM strategy is reducing service superfluous to users' desires or needs. One way of achieving this is interrupting or decreasing level of service when the house is unoccupied, e.g., turning off lights or changing HVAC set points when leaving for work (RedSupT, Figure 3). Another opportunity is reducing service areas of the house where service is not needed (RedSupS, Figure 3), e.g., turning off the lights when leaving a room or zoning HVAC operation to implement different temperature profiles in different rooms. While some end uses, such as central HVAC, do not have the capability of providing separate services to different areas in the home, it is still possible to deliver an optimal thermal comfort service with a mix of centralized and localized appliances (e.g., AC and fans). In this case, smart home technology would need to coordinate the operation of the multiple devices.

We also need to consider that it may be difficult to define what part of the service is superfluous. Using the example above, lights turned on in unoccupied rooms are considered unnecessary. However, somebody walking between rooms very often (e.g., doing house chores) may consider lights in the whole house to be useful. Therefore, another dimension of reducing superfluous service (in addition to time and space), is user activity and preference, the determination of which is a significant challenge for HEM technology.

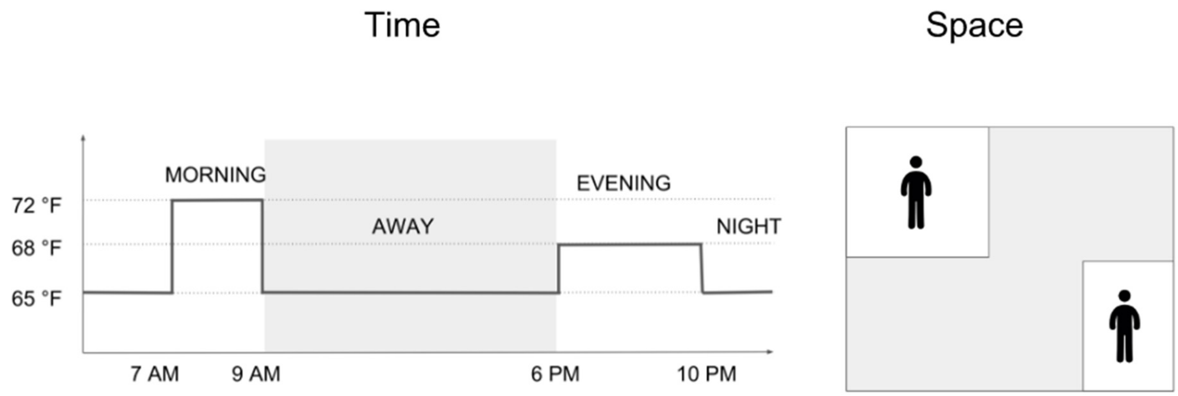

Figure 3: representation of time (RedSupT) and space (RedSupS) dimensions for "reduce superfluous service" strategy. In grey the time periods and spaces where the service is not needed.

Reduce useful service (RedUsf). Another HEM strategy is to reduce quality or quantity of useful service (e.g., dim the lights, adapt to less comfortable temperatures). Users may be willing to do this so long as their needs are met or in response to changes in energy price, but activities and preferences likely play a much stronger role in acceptability of this strategy compared to reducing superfluous service. Some users may prefer to explicitly decide when to accept reduction in useful service, rather than allow HEM devices to choose autonomously (e.g., through automatic demand response).

Take advantage of free service (FreSer). Taking advantage of free sources of service (e.g., daylighting or night breeze in the summer) is another HEM strategy. Energy savings are only achieved if the operation of the traditional end use is corrected accordingly (e.g., switch lights and AC off). HEM devices can automate this strategy only if they can work in a coordinated fashion (e.g., open the blinds and turn the lights off when enough daylight is available in the room).

Shift useful service to a different time (SftTme). In many states in the US and EU, energy prices vary with time of the day or for particular events during the year (e.g., peak hot days during the summer). Operating appliances during peak days or peak hours is more expensive. To reduce energy costs, users can shift the operation of a device (and the delivery of its service) to times when the energy price is lower. For instance, one can do laundry during the evening or the night. Arguably, there is a tradeoff between convenience and cost. HEMS can help automate these responses using timers and schedules in conjunction with price information from the utility (Figure 1).

Take advantage of storage (UseStg). For some end uses there is a time mismatch between service delivery and energy input. For example, there is a time lag between a user requesting heating via a thermostat and when the HVAC system produces the desired effect on the temperature, due to thermal mass[1]. Therefore, efficient management of the thermal environment requires planning in advance. Too often users give up the opportunity of saving energy by adopting constant temperature setpoints (Meier et al. 2011). HEMS can use different control strategies to take advantage of thermal storage and save energy while maintaining occupant

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[1] The thermal mass enables a building to store heat, providing "inertia" against temperature fluctuations.

comfort. Another application of this strategy is pre-cooling a house in anticipation of a demand response event to reduce the energy required to cool during the peak period.

Reduce wasted energy in the conversion process (RedWst). Some end uses have different modes of operation. For instance, heat pumps can heat with a reversed refrigeration cycle or they can use electric resistance to heat more quickly. The latter is much less efficient than the former, and HEMS can help to reduce the energy wasted in the conversion between input energy and output service. For instance, HEMS can sensor data to determine how to deliver the same useful service using the most effective and efficient modes of operation. Another example here relates to standby mode (Lebot et al 2000), during which all the energy is wasted without providing any service. HEMS can reduce conversion waste through the elimination of standby power.

HEM-enabling Features

The current analysis focuses on HEMS that provide users with remote or autonomous control over end uses and the services they provide, including smart thermostats, lights, appliances, and plugs, in addition to less common controllers that automate the operation of blinds/shades, HVAC registers, and windows. We do not discuss feedback-only HEM products, e.g., load monitors and in-home displays that have no control features, though these can also certainly play a role in promoting HEM strategies. The following sections inventory and describe <u>product features</u> that enable *HEM strategies* for various **end uses** (summarized in Table 1).

All end uses. Typically, HEMS can be <u>controlled and monitored remotely</u> via a web or smartphone app, making manual adjustments more convenient and allowing users to control devices when they are away from the home or in another room. Remote control facilitates *reduction of superfluous service (RedSupT)*, when users remember to turn off appliances or systems after leaving the house or when they want to control devices in the house without moving (e.g., sitting on the couch). This feature may also enable *shifting useful service to a different time (SftTme)*, for instance to start the dryer after leaving the house.

HVAC. While <u>scheduling</u> features have been available in thermostats for decades, smart thermostats and other HVAC controllers can make this functionality easier. When they setback the temperature during unoccupied hours, they can *reduce superfluous service in time (RedSupT).* Smart thermostats can also use sensors and other sources of information to <u>determine occupancy</u> in the house. When the house becomes unoccupied, the thermostat automatically sets the temperature back, *reducing superfluous service in time (RedSupT).* Operation of the HVAC tends to be affected by the <u>thermal</u> mass of the system[2] , therefore thermostats and other HVAC controllers can be used to *take advantage of storage (UseStg)*. <u>Fan overrun</u> forces the fan to run for up to a few minutes at the end of each heating or cooling cycle, harvesting residual heat (or “coolth”) in the HVAC system that would otherwise be lost. As such, this feature *reduces conversion waste (F)*. <u>Learning and optimization</u> features vary in their capability, but overall, they try to *reduce superfluous service in time (RedSupT)* and *take advantage of storage (UseStg)* by using energy models developed from data collected from each house. An example of learning is <u>smart recovery[3],</u> that adaptively determines the optimal time to start heating or cooling the house to recover from setback (depending on the specific house and outdoor conditions). This

[2] Not a feature of the HEM device, rather a characteristic of the house structure and the HVAC systems
[3] Some non-connected thermostats have similar features

allows users to just specify the time and temperature desired (e.g., 70 °F at 7 a.m.) instead of having to anticipate the required start time. Smart recovery *reduces superfluous service in time (RedSupT),* in days with shallow setback or mild temperature, because it causes the HVAC to start at a later time. In **heat pump or multi-stage HVAC** systems, optimization algorithms can also *reduce wasted energy in the conversion process (RedWst)*, by selecting the operation mode that minimizes energy use (e.g., avoiding use of resistance heating), but also preserves comfort.

Dedicated ventilation systems (e.g., whole-house fans) and **smart vents** are less common HVAC components that can also reduce energy use. Typically, ventilation systems exchange air with the outside independently from the central HVAC[4] and can be used to *take advantage of free service (FreSer)* using outdoor air to cool the house instead of the AC. While the service is not entirely free (i.e., the fan consumes power), the system requires significantly less energy. To optimize their operation, ventilation systems need to coordinate their operation with the central HVAC by measuring outdoor conditions. Smart Vents allow the user to modulate the airflow into different rooms, effectively creating separate thermal zones in the house. These devices *reduce superfluous service in space (RedSupS)*, by stopping the conditioned air from flowing into rooms that are not occupied, therefore reducing the amount of heat that needs to be delivered to reach the setpoint[5]. Occupancy and room temperature are typically determined via additional sensors. Smart vents need to coordinate with the thermostat to achieve better performance.

Lighting. Lighting can be controlled through smart switches, smart light sources (e.g., bulbs) and smart outlets. These HEMS typically offer remote control and some offer occupancy-based control to help *reduce superfluous service in time (RedSupT)* and *space(RedSupS)* (at unoccupied times or in unoccupied spaces). Schedules and timers can be useful to *reduce superfluous service in time (RedSupT),* for example by planning the operation of outdoor lights. However, since the effect of lights is instantaneous, occupancy and light sensors are often preferred to schedulers. Dimming capabilities can help *reduce superfluous service in time (RedSupT) and space (RedSupS)* or to *reduce useful service (RedUsf)* when users want to save energy, for instance during demand response. Finally, **smart blinds/shades**, especially with sensors and coordinated with smart lights and HVAC, *take advantage of free service (FreSer*) (Urban et al. 2016).

Appliances and Others. Appliances that are not required to operate all the time (e.g., washer, dryer, dishwasher) and use a large amount of power offer a good opportunity to *shift useful service to a different time (SftTme)*, because their impact on demand is large. To do so, some smart appliances offer scheduling capabilities. Smaller appliances tend not to have inbuilt "smarts", but smart plugs/powerstrips connected to **electronics** (e.g., TV, game console, set-top boxes) can save energy by *reduce wasted energy in the conversion process (RedWst)* (i.e., eliminating standby power) when not in use. **Water heaters** with tanks can be also turned off to *reduce superfluous service in time (RedSupT)* in case of long absence from the house, although care should be taken in not wasting more energy than what it is saved at the startup (e.g., by triggering the use of resistance heating in heat pumps). Their *Storage (UseStg)* capabilities can also be used to shift demand. Further, optimization algorithms can *reduce wasted energy in the conversion process (RedWst)* for heat pump water heaters, by selecting the most efficient modes of operation. Other less frequent end uses, such as **pool pumps** and **electrical vehicles** also have

[4] Some dedicated ventilation systems are compatible with central HVAC
[5] Results from lab and field test of "smart vents" are mixed because they can cause drop in system efficiency (Urban et al. 2016)

large potential to *shift useful service to a different time (SftTme), take advantage of storage (UseStg) and reduce wasted energy in the conversion process (RedWst).*

Table 1: Relationships between end uses, HEMS devices, features, and HEM strategies

End Use	**HEM Device**	**HEM-enabling Features**	**HEM Strategies**						
			RedSupT	*RedSupS*	*RedUsf*	*FreSer*	*SftTme*	*UseStg*	*RedWst*
All[6]	All[7]	- remote control	X				X		
HVAC	-	(thermal mass)[8]						X	
	Thermostat	- schedules	X						
		- occupancy-based control	X	X					
		- fan overrun							X
		- learning: smart recovery - learning: preferred setpoints - optimization: use of house dynamics	X					X	
HVAC (heat pump or multi stage)		- optimization: smart management of HVAC stages - optimization: heat pump algorithms							X
HVAC (dedicated ventilation)	Ventilation Controller	- “free” cooling (outdoor air) - coordination with thermostat - operate during periods that minimize heating/cooling loads				X	X		
HVAC (duct system)	Vents Controller	- system zoning - room-level sensing - coordination with thermostat		X					

[6] All End Uses: HVAC, Lighting, Large Appliances, Electronics, Water Heaters, Pool Pumps, Electric Vehicles
[7] All HEMS: Smart Thermostats, Vent, Light, Blind/Shade, Appliance, Plug,
[8] Not a feature of the HEM device, rather a characteristic of most HVAC systems/houses.

End Use	HEM Device	HEM-enabling Features	HEM Strategies						
			RedSupT	*RedSupS*	*RedUsf*	*FreSer*	*SftTme*	*UseStg*	*RedWst*
Lighting	Light controller[9]	- remote control - occupancy-based control	X	X					
		- schedule/timer	X						
		- dimming	X	X	X				
	Smart Blinds	- illuminance-based control				X			
Large Appliance	Smart appliance control	schedule/timer	X				X		
Electronics	Smart Plug	- occupancy or power level sensor							X
Water Heater		- schedule/timer - optimization (especially for HP)	X					X	X
Pool Pump		- remote control - learning and optimization					X		X
Electric Vehicle		- remote control - optimization					X	X	X

HEM Use Cases

The analysis thus far has been purely technical, focused on energy processes and product features. Our consumer research highlighted a need to frame HEM strategies in the context of user interactions with smart home products, i.e., use cases, to convey them to smart home product owners and prospective owners. Use cases should be descriptions of HEM strategies from the user's perspective, in layman's terms, e.g., *Why should USER Do X* (specify user-product interaction) *under Y circumstances*.
There are at least two approaches to use our framework to develop use cases. One possible process is to begin with a specific product or combination of products then work through available features, end uses, and HEM strategies, as follows:

1. Identify the smart home product(s) of interest
2. Identify the HEM-enabling features of the product(s)
3. Identify relevant end uses
4. Map available features (2) and end uses (3) to related HEM strategies
5. Describe the use case in these terms: Under X circumstances, do Y (specify user interaction or automated process) for Z reason (to enact HEM strategy)

[9] Smart switch, smart bulb or smart outlet (for lights plugged into an outlet)

A more user centered approach could begin with a particular routine activity (e.g., bedtime, leaving for work, household chores) or event (e.g., short vacation), perhaps specific to a demographic or lifestyle (e.g., family with young children, retired couple, working professional), then identify relevant HEM strategies and product and feature combinations that would be most appropriate, including consideration of other value propositions (e.g., home security, convenience, comfort). These would be the main steps for using our framework in this process:

1. Identify user activity
2. Identify relevant end uses/services
3. Identify relevant HEM strategies
4. Map HEM strategies to enabling products and features
5. Describe the use case in these terms: Under X circumstances, do Y (specify user interaction or automated process) for Z reason (to enact HEM strategy)

We now offer one example using this second approach illustrated in Figure 4.

Figure 4: Illustration of a use case, *Waking up,* developed using our framework

1. User activity: Waking up on a cold winter morning
2. Relevant end use/service: Warmth, light, coffee
3. Relevant HEM strategies:
    a. *Reduce superfluous service* of heater running through the night to avoid being too cold in the morning, or guesswork of programming conventional programmable thermostat to turn on at the right time[10] in the morning;
    b. *Take advantage of free service* of daylight instead of, or to supplement a lesser amount of, artificial lights;

[10] considering special cases for heat pumps, condensing boilers or other special equipment

    c. *Reduce conversion waste* (standby) of coffee pot being powered all night
4. HEM-enabling products-features:
    a. Smart thermostat with scheduling and smart recovery features
    b. Smart shades with scheduling and/or light sensor features
    c. Smart plug with scheduling feature
5. Use case: Early morning on a winter day, while the sun starts rising outside, in both the master bedroom and the kids' bedrooms smart shades rise to wake up the family with natural light. In the kitchen, a smart plug switches on and the coffee machine starts brewing. The thermostat has been slowly warming up the house after the nighttime setback.

The use case shows that a set of HEM devices could deliver comfort and convenience (features consumer look for), but at the same time save energy (secondary benefit for the consumer, but primary benefit to other stakeholders, e.g., utilities).

Discussion

The HEM use case framework presented in this paper can be expanded as more smart home products and HEM-enabling features emerge. The use case presented in the previous section is just a simple example of how our framework (service model, HEM strategies and product features) can be used to convey home energy management opportunities to smart home users, using simple language related to everyday life. There are a variety of practical applications of the use case framework, for multiple stakeholders.

For smart home product designers, and the technology industry more broadly, our framework highlights HEM-enabling features that may be desirable to incorporate into product design to maximize opportunities for HEM strategies. Such features help to distinguish between products within a category, which may be important to customers when choosing which product to purchase. For example, dimming is available with some but not all smart lights, and some but not all smart thermostats come with occupancy sensors. Other HEM-enabling features that are not universal, but have implications on HEM strategies include cloud connectivity and high degree of interoperability across multiple products. The former enables remote control away from home, the latter offers users flexibility to interact with their systems in different ways (e.g., voice control) and opens new possibility of coordination between devices (e.g., smart blinds and smart lighting) that can achieve larger energy savings. Unfortunately, interoperability in current devices is hindered by the lack of standard communication protocols and incompatibility between different software platforms. In addition, similar products adopt widely different user interaction models in terms of user commands and expected results. Better interoperability and more standardized interaction methods would help realize the true potential for the smart home.

Our HEM use case framework can also be used in educational strategies and to market energy benefits in addition to non-energy advantages, that typically drive adoption. Use cases can be packaged as user scenarios (a design concept) for particular user groups (e.g., shift workers with irregular home occupancy patterns) by considering time, space and activity dimensions relevant to those user groups, and articulating non-energy value propositions of HEM use cases (e.g., smart blinds opening in the morning in lieu of artificial lights saves energy *and* the sunlight provides health benefits). Utilities could use the same logic for educational strategies to promote HEM use cases to smart home adopters who are already using products for only their non-energy benefits. Utilities can also encourage industry to include HEM-enabling features by specifying those features in incentive programs (e.g., a rebate for smart thermostat products that include occupancy sensors). Energy auditors can be trained on HEM use cases so they recognize the potential of smart home devices they may find in customers' homes. Online marketplaces for energy efficiency and smart home products can also highlight HEM use cases to educate consumers at the point of purchase.

Conclusion

In order to enable, promote, evaluate, and ultimately realize the full potential of smart home technologies to contribute to demand side management, it is necessary to identify and articulate why and how they might deliver energy benefits to users. In this paper we presented a framework for developing home energy management (HEM) use cases for smart home technologies. The framework categorizes opportunities to reduce or shift home energy consumption, then maps these opportunities to specific strategies a HEM product user can adopt, and specifies the required product/system features and user interactions. These use cases can support the design of smart home products that better enable HEM and the development of marketing or educational tools to promote the energy management uses of smart home products to consumers.

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