Home Energy Management: Products & Trends

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ABSTRACT

Home Energy Management (HEM) describes a class of technologies including sensors, smart thermostats, and feedback devices seeking to manage residential energy consumption profiles to reduce peak electric demand and consumers' electric bills. A growing number of HEM products and companies have emerged over the past decade, ranging from basic energy displays to whole-home control systems and smart phone apps. The great diversity of HEM product features and types is indicative of the nascent state of the HEM industry. Despite research showing that HEM products providing feedback on electricity consumption can reduce household electricity consumption by 4 to 12%, these products still face relatively low market penetration. We discuss some of the challenges facing the industry, including barriers to consumer adoption. We further present a taxonomy for residential HEM products with three basic categories: Control Devices, User Interfaces, and Enabling Technologies. This taxonomy provides a framework for future discussion about what areas of HEM have the most potential to result in widespread deployment, consumer engagement, and energy savings in the future.

Introduction

Because of its potential to save resources, the home energy management (HEM) field to date has received considerable research and development. Residential energy consumption currently accounts for approximately 22% of the nation's total energy demand (Ehrhardt-Martinez et al. 2010; DOE 2011). Ongoing technology trends include decreased sensor, computation, and display costs, as well as pervasive integration of device-level information processing capability and communications. These trends, along with increased interest in electric demand response and the rollout of smart utility meters have greatly increased opportunities for market viability of HEM systems.

To exploit this growing market, numerous products and companies have emerged over the past decade. These range from single control devices, such as smart thermostats and powerstrips, to centralized home automation systems. This product class also includes various types of user interfaces providing energy consumption feedback such as home energy displays (HEDs), web portals and smartphone applications.

The diversity in the HEM market is indicative of the nascent state of an industry that currently has low market penetration. Despite significant potential for home occupants to manage their energy consumption more effectively, technology-enabled efficiency measures often stumble due to the uncertainty in human interaction with technology. In fact, some of the most significant players on the market (i.e. Google, Cisco) have decided to exit the industry, citing a lack of scalability and consumer interest.

In the following paper we present a taxonomy to help describe the HEM market and to guide our discussion of specific challenges facing the industry as a whole. Are there scalable, effective market solutions for utilities and consumers? We further discuss general HEM product trends and classes with the highest potential for wide-scale deployment.

Taxonomy

We have devised the following classification system for all types of HEM products available in the residential market. The three basic categories are:

1. Control Devices
2. User Interfaces (UI)
3. Enabling Technologies

These categories are meant to capture the key aspects of typical HEM devices and are not mutually exclusive, i.e. individual products may fit into multiple categories. For a list of HEM companies and products please see the Appendix. Table 1 summarizes the HEM taxonomy.

Table 1. HEM Taxonomy

Category		Description	Examples
Control Devices allow the consumer or utility to actively control energy use, with varying degrees of automation/ human-in-the-loop.	Centralized Control	Communicates with multiple control devices in the home and allows the user to manage them from a single location	Home automation systems, whole-home lighting control systems, may build on security systems
	Device-Level Control	User controls a single device or function, standalone control	Lighting control with motion sensors and remotes, scheduling; thermostats; smart plugs; smart power strips
	On-Board Control	Control functionality integrated in the device	Smart apliances, e.g., that respond to grid instability; office equipment power management; smart light bulbs
User Interfaces (UI) provide energy feedback to consumers and can display both raw and processed data. *Raw data* provide basic information such as real-time data on energy consumption (kWh, $/hr, watts/hr, etc.). *Processed data* give users the personal significance of raw usage data and how to act upon that information (budgets, historical comparisons, tips, goal setting, etc.).	Home Energy Display (HED)	Stand-alone in-home display; often portable	Many HEDs on the market have compatible web dashboards or are able to connect to third party freeware. Utilities implementing smart meters often provide their customers with web dashboards.
	Web Dashboard/ Portal	Online interface accessible from any Internet-enabled device	
	Smartphone Application	Device-specific interfaces for iPhones, Android phones, and others.	Current roducts typically pull information from an HED and generate processed data (but may also provide raw data).
	Other (e.g., TV)		Multimedia approaches include combinations of display/web/phone feedback.

Category		Description	Examples
Enabling Technologies are the underlying framework supporting *obtaining, processing,* and *communicating* information about energy usage.	Sensing	Acquisition of dynamic variables within the home environment	Smart meters, temperature sensors, occupancy sensors, time of day
	Communications	Physical devices necessary to support the network	Gateways, range extenders, local area networks, wireless routers, and modems
	Communication Protocols	Standards that allow individual nodes within a network to communicate	X10, UPB, Insteon, Z-wave, ZigBee

As seen in the taxonomy, enabling technologies support acquiring and communicating energy information. While the reliability of these mechanisms is crucial for successful HEM products, their relevance to the average consumer is typically low. Importantly, there is a clear difference between feedback (UI) and control technologies. These two solutions have different behavioral and technological factors at play when it comes to consumer adoption.

Perhaps the biggest general barrier to wide-scale deployment of HEM is that consumers currently need to invest in tools (displays, software, sensors, etc.) to manage their energy consumption. Whereas some manufacturers claim that their products can help saving up to, e.g., $200 a year, such claims may not be scientifically supported or clearly achievable for potential buyers. This interplay between human factors and HEM technology effectiveness often results in unpredictable energy savings and return on investment for HEM products. In turn, the unclear cost effectiveness of HEM systems slows uptake by consumers and energy efficiency programs.

Consumer research also suggests that the average user is not yet willing or capable of learning the necessary information to install and navigate current products (SGCC 2011). A clear example of this is that of programmable thermostats, which are typically used successfully only by approximately 50% of U.S. home occupants and do not yield clear energy savings relative to nonprogrammable thermostats (Meier et al. 2011). As shown in Table 2, the complexity of HEM devices impedes their acceptance and effective use by consumers in multiple ways. This further limits the demand for HEM technology among the general population, creating a market filled with early adopters and technology enthusiasts.

Table 2. HEM Complexity

Deployment Complexity	Some HEM systems, particularly home automation systems, require professional installation, increasing cost and user effort.
Complexity of Set-up/Use	Centralized HEM systems and many individual devices such as thermostats require programming.
Complexity of Information Presented	HEM display devices may present information that confuses some consumers instead of enabling them.

Feedback

One available technology for reducing residential energy consumption is providing feedback via displays. Feedback is information about the consequences of household actions that affect energy consumption (Spagnolli et al. 2011). This has been shown as an effective method of making energy information visible to consumers and results in whole-home energy savings ranging from 4-12% (Ehrhardt-Martinez et al. 2010). Importantly, engagement factors that keep the consumer interacting with such information over time need to be further understood before successful market penetration of HEM technologies can be achieved.

The presentation medium and the design of energy feedback devices are two factors that impact consumer engagement. In recent findings, users show a preference for flexibility of display medium and expect to be able to access their energy data across multiple media such as an HED, web dashboard, and smartphone application (LaMarche 2011). In addition, users place a great deal of importance on the clarity of the display interface and do not want to spend a lot of time reading text or interpreting graphs. These findings are in line with Fischer (2008) and suggest that barriers to HEM adoption can be overcome by conveying simple and intuitive information to home energy users for each step of the process from finding product specifications to post-purchase operability. Progress in user-centered interface design is also being made. Companies such as Lucid Design are also creating highly engaging displays through novel information visualization.

Products that have dominated the market in recent years include HEDs that provide raw consumption data (The Energy Detective, PowerCost Monitor, etc.). Research to date suggests that HEDs may not be able to maintain user interest and achieve persistent energy savings (Dam et al. 2010). Other third-party options are coming to market connect to HEDs and transform raw data into more relevant processed data. For example, MyEragy offers energy and cost breakdowns and allows the user to request email or SMS alerts when usage exceeds a threshold set by the user. This highlights another trend, providing multimedia data access. It is likely that a push to create sleeker smartphone applications that may remotely control and monitor energy usage will continue in 2012. This approach is extremely viable for mass markets, but until smart meters are fully deployed it is still necessary for consumers to purchase another device that acquires and posts electricity consumption data to the application. This will inhibit the success of smartphone HEM due to a significant gap between what consumers are willing to invest and what HEM costs. Our focus group participants were not willing to spend more than $50 on HEDs and for many people the upper bound was even lower. The most basic HEDs currently available start at $100 and can cost upwards of $900 for more sophisticated systems. In any case, current solutions on the market such as HEDs that show only raw data at the device-level are not fulfilling the needs of most consumers and thus not scalable market solutions.

Low adoption of current products on the market may be caused in part by a lack of actionable information specific to the occupant's own behavior. Customization is likely to become more sophisticated in the next few years with advances in networking, data acquisition, and standards in communication protocols that will allow homes to be more connected. We already see this taking shape in 'cloud' platforms aiming to connect energy providers, customers, and the devices in their homes (e.g. Tendril). The next step in successful HEM feedback includes providing more timely, and actionable, information. Already, emerging smart meters promise a tighter temporal coupling between energy usage and feedback (Froehlich et al. 2011). Companies like IBM and Oracle are pushing progress in data analytics to enable smart meters to become more effective for both utilities and consumers. In addition, advances in disaggregation techniques could allow energy saving recommendations to leverage more detail at minimal additional cost. Disaggregated data will enable utilities to assess and prioritize energy saving potentials of various initiatives (Froehlich et al. 2011). Companies like Powerhouse Dynamics (eMonitor) offer circuit-by-circuit breakdown of energy consumption in addition to diagnostics, but at a significant consumer investment of around $600.00 and a monthly fee. Other approaches to disaggregation, such as non-intrusive load monitoring, have proven difficult to develop reliable algorithms and often require training.

We are also seeing trends toward open access to energy data. For instance, some California utilities have launched a "Green Button" enabling utility customers to easily and quickly download their consumption data. Further, the Department of Energy has sponsored an app design competition, which allows any member of the public to submit ideas for different feedback interfaces. By empowering people in this way, it may be possible to create a more meaningful relationship between the energy consumer and their usage. Other trends in this area include embedding games or social competitions into energy dashboards. Joulebug is a social mobile game where users can earn badges for making energy efficient adjustments. People Power allows users to set energy budgets, compare their usage to state and national averages, view recommendations to lower energy bills, and take energy efficiency quizzes or post scores to Facebook.

Control

Control systems hold a lot of promise for utilities and consumers that prefer not to engage with energy-related feedback technologies. However, an overarching question is the role of automation in HEM technology; to what extent should occupants be involved? While success in reducing energy use with feedback devices depends on how energy consumers interpret and act upon the information provided by HEM devices, when HEM systems are fully automated their effectiveness depends, rather, on the balance between preserving human trust in the technology while allowing occupants to exercise control over them if they so desire (see Parasuraman & Riley 1997). It is critical that automation of tasks be carried out in a way that does not inconvenience inhabitants (e.g., inadvertently shutting down devices still in use, diagnosing false positives).

Because of its potential to manage electricity consumption and demand for multiple end uses, centralized home automation is an integral HEM subsector. Erhardt-Martinez et al. (2010) states that the future of HEM is likely to involve a complex network of wireless, consumer-controlled, home automation "set and forget" systems. This is evident in the new generation of smart thermostat devices that have appeared on the market and communicate via the home area network. For example, the Nest returns to the adjustable ring design of earlier thermostats and uses interaction history and sensor inputs to learn heating and cooling preferences. Moreover, feedback companies such as Opower are partnering with control-based companies like Honeywell to create a more effective wireless thermostat with HVAC feedback capabilities. These are examples of how innovative design and product aesthetics could rapidly alter the HEM marketplace.

Leveraging HEM with home entertainment and networking is another trend in HEM controls. Verizon, for example, recently launched a commercial-scale home automation line of business, by offering energy management and security to their customers via subscription services. In addition, design innovators like EnergyHub are creating software platforms that can function in embedded systems like TVs, home security, or smart thermostats. Embedding energy monitoring functionality into pre-existing household systems, or adding non-energy benefits like security or comfort, will likely be the types of features that appeal to a much wider audience.

As it stands, many companies with centralized control capabilities suffer from 'vaporware,' i.e., products in the early stages of development that are not typically available for purchase. Intel and Microsoft have debuted proof of concepts for HEM consoles that will have their own 'stores' where users can add apps that compatible with devices in their homes. This approach is extremely viable for user customization and engagement; however, these products were not yet available at the time of this paper. Vague specifications on pricing, release date, and full home requirements for models are barriers for consumers looking for information about HEM control products online.

Other companies like Control4 provide users with one centralized hub for managing all automated aspects of their home. GE also has launched their "Nucleus home energy manager," which has similar functionality to Control4 and can also control GE home appliances with built-in communication capabilities. Users decide what aspects of their home to control and can add on more functionality for an increased price. These home systems move towards homogenous home control, but despite their innovative features their cost (Control4 up to $5,000.00 with installation, GE requiring consumer investment in specific appliances) prevents them from delivering widespread adoption outside of the luxury market.

Plug-level solutions offer monitoring, control, and even automation at the level of individual sockets (see Ecos 2009). For example, smart power strips such as the Belkin Conserve also have a "control" appliance that automatically turns off all of the other plugged-in devices when the control appliance is turned off. Products such as this might be a way for users to transition into a home automation lifestyle with minimal investment (products in this class range from about $20-$200), making outlet solutions one scalable way to provide preliminary control capabilities for users. However, awareness for this product class will need to be raised before such market adoption can take place, as we found approximately 75% of survey respondents had not heard of smartstrips.

The next steps in successful HEM control products will include larger efforts particularly in the area of demand response. This is an appealing area for utilities want to mitigate peak loads, but may be less appealing for consumers who could be worried about inconvenience, personal privacy, or security. Nevertheless, such features would take advantage of low-cost electricity data from smart meters, benefitting utilities and consumers. While smart meter technologies are still not the norm for most homeowners in the United States, some appliance companies like Whirlpool are developing appliances that do not need a smart meter. For example, Whirlpool's smart dryers incorporate an embedded system to sense and respond to grid distress by cycling heat on and off.

At this point, further fieldwork is needed to understand market opportunities in home automation as it relates to consumer acceptance. It is still unclear whether consumers will be willing to invest larger amounts of money in such products unless incentive is offered or until return on investment can be successfully demonstrated.

Conclusions

HEM technologies hold great promise to make home occupants' life both more comfortable and sustainable. But, for any HEM system to achieve mass-market penetration, the industry must overcome current challenges for easily selling, installing, managing, and securing HEM solutions (Cisco 2010). As we have expressed throughout this paper, research on market scalability will need to address data acquisition barriers to providing actionable and reliable information, as well as maintaining customer engagement and satisfaction.

We have seen that many products that exist currently in raw user interface, particularly in the HED medium, do not fulfill the needs of most consumers who desire an intuitive and flexible feedback approach. Also, while it is accepted that people react to energy efficiency products and measures very differently, the cost, ease of use, and product complexity need to be significantly improved before large-scale adoption is feasible. There is still a clear need for more research feedback design as an important parameter for occupant motivation.

We have also seen great promise in device-level controls particularly in new well-designed smart thermostats, and plug-level controls that provide basic home automation without significant consumer investments. Finally, we see widespread development in device-level home automation and demand response to mitigate peak loads; areas that will possibly change the centralized and on-board control consumer markets in a few years.

Rigorous evaluation of the energy savings potential per end-use for different HEM types is crucial for the future of both feedback and control technologies. If utilities could reliably incorporate proven cost-effective HEM solutions into their energy efficiency programs, this could help the HEM market achieve scale, lowering product costs overall. This goal is clearly within reach, but cannot be achieved only via technological advancement. Human factors play a crucial role in determining the market success of this class of products.

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APPENDIX

This appendix alphabetically lists companies that have HEM offerings, their taxonomic category, and what kind of HEM products they offer. For details regarding pricing and extended functionalities see LaMarche et al. (2011). Note that 'Availability' refers to access of products on the consumer market.

Company	Taxonomic Category	Product Listing	Availability	Target Market
2 Save Energy	UI; multimedia	OWL, OWL Micro displays, OWL intuition-e software	Yes	Residential
ADT	Control; centralized / UI; phone	ADT Pulse security and home automation system with feedback application	Through dealer	Residential
AlertMe	UI; multimedia	SmartEnergy display and software suite	Yes, in UK	Residential
Ambient Devices	UI; HED	Energy Orb, Energy Joule displays	Through Consumer Powerline	Utilities
AzTech	UI; HED	AzTech In Home Display	No	Utilities
Belkin	Control; device-level / UI; HED	Conserve series for plug monitoring and control	Yes	Residential
Black and Decker	UI; HED	Home Power Monitor	Yes	Residential
Blueline Innovations	UI; multimedia	PowerCost monitor, PlotWatt software for third party posting	Yes	Residential
Brultech	UI; HED	ECM-1240 Home Monitor	Yes	Residential
Control4	Control; device level / Control; centralized	Remote control lighting, smart thermostat, home automation hub, entertainment	Through dealer	Residential
Current Cost Ltd	UI; multimedia	ENVI, EnviR, TREC displays with feedback software, IAMs individual outlet monitor	Yes	Residential
Digi	Control; device-level	Smart powerstrip	Yes	Residential
DIY KYOTO	UI; multimedia	Wattson display, Homes software	Yes, but not U.S.	Residential
Eco-eye	UI; HED	Elite 200, Eco-Eye Mini displays, Plug-in individual outlet monitor	Yes, but not U.S.	Residential
Ecobee	Control; device-level / UI; web/phone	Smart thermostat with feedback software	Through contractors	Utilities
EcoDog Inc	UI; HED	FIDO home energy monitor	Yes	Residential
Efergy	UI; HED / Control; device-level	Elite, E2 displays, remote-control powerstrip and outlet monitors	Yes	Residential
eGauge	UI; web	eGauge monitoring kit	Yes	Resdential
Energate	Control; device-level / UI; HED	Energate Companion smart thermostat and energy manager	No	Utilities, Service Providers
Ener$ave	UI; web	Third party posting software	Yes	Residential

Company	Taxonomic Category	Product Listing	Availability	Target Market
Energy Inc	UI; multimedia	TED-5000, TED-1000 displays, Ted-O-Meter, Footprints software	Yes	Residential
Energy Hub	Control; device-level / UI; multimedia / Control; centralized	Smart thermostat, smartplug solutions, Energy Hub home base with feedback and software suite	Yes, but varies by product	Residential, Utilities, Service Providers
Eragy	UI; web	Third party posting software	Yes	Residential
GE	Control; centralized / UI; multimedia	Suite of appliance controls, smart thermostat, multimedia feedback with centralized hub	No	Utilities
Google	Control; on-board	Android-controlled lighting	No	Residential
Green Energy Options	UI; multimedia	GEO In Home Displays ranging from basic to advanced in feedback capabilities	No	Utilities
HAI	Control; centralized / Control; device-level / UI; web/phone	Home lighting control system, thermostats, appliance modules with feedback software	Yes	Residential
Honeywell	Control; device-level	Programmable and smart thermostats	Yes	Residential
iControl	UI; web/phone / Control; device-level	OpenHome software platform, smart thermostat	No	Utilities, Service Providers
Intel	Control; centralized / UI; HED	Home energy management console with feedback and home automation	No	Residential
Joulebug	UI; phone	Feedback application	Yes	Residential
Kamstrup	UI; phone	Feedback application	Yes	Utilities
Landis + Gyr	UI; HED	ecoMeter display	No	Service Providers
LG	Control; on-board	THINQ smart appliances	No	Residential
Lucid Design	UI; multimedia	NETWORK and KIOSK feedback displays for third party posting	Through representative	Utilities, Service Providers
Lutron	Control; device-level	Lighting controls	Yes	Residential
Microsoft	Control; centralized / UI; HED	HomeOS console with feedback and home automation	No	Residential
Motorola	Control; centralized / UI; multimedia	4Home platform with lighting control, home automation and entertainment	No	Service Providers
Navetas	UI; multimedia	Navetas energy display and smart hub with feedback applications	No	Residential
Nest	Control; device-level / UI; multimedia	Smart thermostat with control and monitoring sofware	Yes	Residential
Onzo	UI; HED	Onzo display	Yes, only in UK	Residential, Utilities
OPower	UI; web/phone / Control; device-level	Suite of feedback applications, smart thermostat with HVAC feedback	Yes, but not smart thermostat	Residential, Utilities

Company	Taxonomic Category	Product Listing	Availability	Target Market
P3 International	Control; device-level / UI; HED	Kill A Watt series for outlet monitoring and feedback	Yes	Residential
PeoplePower	UI; phone	Feedback application	No	Residential
Plugwise	Control; device-level	Circles suite for outlet monitoring	Yes	Residential
PowerHouse Dynamics	UI; multimedia	eMonitor kit with monitoring and software	Yes	Residential
Simple Energy	UI; web/phone	Feedback applications	Yes	Residential
Smarthome	Control; device-level	Remote control lighting, appliance control, thermostats, general home automation products	Yes, but may vary	Residential
Tendril	Control; device-level / Control; centralized / UI; multimedia	Smart thermostats, smart outlet, HED, load controls, Energize cloud platform suite	No	Utilities, Service Providers
Tenrehte	Control; device-level? / UI; web/phone	PicoWatt outlet monitoring with sofware	No	Residential
ThinkEco	Control; device-level / UI; web/phone	Modlet kits for outlet monitoring and control	Yes	Residential
TrickleStar	Control; device-level / UI; phone	Smart powerstrip with feedback application	No	Utilities
Verizon	Control; centralized / UI; web	Home energy management kit including monitoring and control	Requires subscription	Residential
Visible Energy, Inc	Control; device-level / UI; phone	UFO Power Center with feedback application	Yes	Residential
Vivint	Control; centralized / UI; web/phone	Go!Control security and home energy management system with feedback application	Requires subscription	Residential
WattsUp?	UI; multimedia	Smart Circuit Controller outlet monitors with feedback	Yes	Residential, Utilities
Wattvision	UI; multimedia	SaveOmeter display, third party posting software	Yes	Residential
Whirlpool	Control; on-board	Appliances with control capabilities	No	Residential