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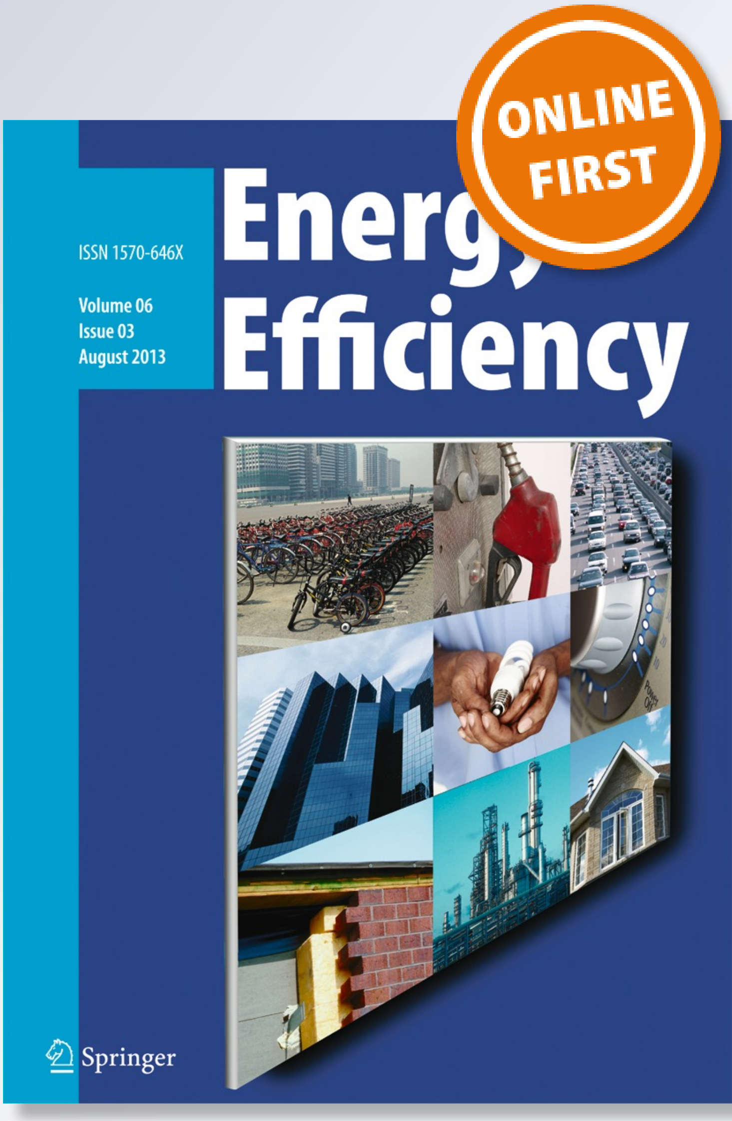

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ORIGINAL ARTICLE

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Abstract Feedback is a promising strategy for energy conservation, and many energy feedback products (i.e. technologies with hardware) and platforms (i.e. technologies without hardware) have emerged on the market in recent years. Past research suggests that the effectiveness of feedback varies based on distinct characteristics, and proposes categories to better understand and distinguish between these characteristics. A review of existing categories, however, identified the following issues: (1) current structures group feedback technologies into four (or fewer) categories, making device distinction and selection onerous; (2) current categories often ignore technical and psychological distinctions of interest to researchers; and (3) none provide a systematic description of the specific characteristics that vary by category. This paper presents a classification structure of feedback technology, derived theoretically from a review of relevant literature and empirically via content analysis of 196 devices. A taxonomy structure of feedback technology was derived based on the characteristics of hardware, communications, control, display, and data collection. The resulting taxonomy included the following nine categories: (1) information platform, (2) management platform, (3) appliance monitor, (4) load monitor, (5) grid display, (6) sensor display, (7) networked sensor, (8) closed management network, and (9) open management network. These categories are mutual exclusive and exhaustive of the identified technologies collected and are based on characteristics, which are both stable and important to feedback provision. It is hoped that this feedback classification will be of use to both researchers and practitioners trying to leverage the potential of these technologies for energy conservation.

Keywords Feedback · Conservation · Electricity · Technology

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Feedback refers to the process of giving people information about their behaviour that can be used to reinforce behaviour and/or suggest behaviour change. It is considered an important dimension of behaviour change (Skinner 1938; Bandura 1969) and has been used to influence behaviour in a wide variety of fields, including education, public health and consumer research.

This emphasis has received increasing attention in recent years due to the rapidly changing energy infrastructure in the developed and developing world. Advances in data sensing, storage and dissemination have made it possible for information about behaviour to be collected, stored, and presented to consumers at speeds and on scales that were previously impossible. "Adding sensors to the feedback equation helps solve problems of friction and scale. They automate the capture of behavioural data, digitising it so it can be readily crunched and transformed as necessary. And they allow passive measurement, eliminating the need for tedious active monitoring" (Goetz 2011). Such

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changes in data collection also require changes in data storage—Austin Energy, for example, increased yearly data storage from 20TB to 200TB for just 500,000 m (Danahy 2009). Finally, changes in data presentation are being seen in the form of ambient displays, gamificaiton strategies and innovative dashboard designs for both mobile and web platforms.

Within the realm of energy efficiency, changes in infrastructure are enabling this transition on a wide scale. Countries are spending billions of dollars upgrading the current electrical grid with what is referred to as the "smart grid"; a network of controls, computers, automation and new technologies that enable sensing of and response to conditions on the transmission lines, as well as two-way communication between utilities and customers. One important component of this is the replacement of traditional electricity meters with advanced metering infrastructure, or "smart meters", which are defined as "a metering system that records customer consumption (and possibly other parameters) hourly or more frequently and provides for daily or more frequent transmittal of measurements over a communication network to a central collection point" (Federal Energy Regulatory Commission 2008, p. 5). Currently, <10 % of the world's meters are considered "smart", but this number is expected to change rapidly. In the USA alone, smart meters have already been installed in over 25 million homes and an estimated 65 million will be installed by 2020, serving over 50 % of US Households (Institute for Electric Efficiency 2011). Likewise, the European Union Directives aim for 80 % coverage by 2020 (Faruqui et al. 2010; Sánchez 2012).

Both the public and private sectors have recognised the potential for increased information provision and are creating and supporting new technologies to provide feedback about energy use to consumers. The US White House recently launched the Green Button Initiative to encourage utilities to provide consumers with real-time access to their energy information and promote private sector development of technologies that integrate with this initiative (Chopra 2011). Additionally, a variety of companies, ranging from major players such as General Electric and Panasonic to start-ups such as OPOWER and Navetas are creating new technologies to provide energy feedback to consumers, both directly through hardware as well as through integration with smart meter technology.

Programs like the Green Button Initiative, as well as the 200+ feedback products (i.e. technologies with hardware) and platforms (i.e. technologies without hardware) that have emerged, are based on the idea that receiving information about energy use leads to better decisions about energy use. As the use of electricity in the home is "abstract, invisible and untouchable" (Fischer 2008, p. 80), feedback has been hypothesised to serve a vital function in making this energy use visible and interpretable to the consumer. Reviews of energy feedback research have found that the provision of feedback leads to average savings of 10 % (r=.1179, p<.001), with effects ranging from negative effects (i.e. increase in energy consumption) to up to 20 % in energy reduction (Darby 2006; Ehrhardt-Martinez et al. 2010; EPRI 2009; Fischer 2008; Karlin and Zinger 2013); others argue that a realistic effect may be closer to 3–5 % (McKerracher and Torriti 2013). These studies suggest that the effectiveness of feedback varies based on type, and propose categories to better understand and distinguish between these types. However, current classifications of feedback lack the technological sophistication to account for the diversity in available products and platforms. The goal of this paper is to analyse current energy feedback technologies in the marketplace and present a comprehensive taxonomy of feedback technology based on product characteristics.

We start by introducing past psychological and technical approaches to understanding feedback. Next, we review previous literature on energy feedback, focusing on past attempts to define, describe and categorise feedback. Then, we introduce and describe our study methodology, which is a content analysis and classification of currently available feedback technology. Using data collected from 196 feedback technologies (both products and platforms), we present a list of energy feedback characteristics and identify key characteristics for categorization. Finally, we present a taxonomy structure of energy feedback that incorporates these key characteristics.

As feedback technologies are becoming increasingly ubiquitous in our society, with a growing capacity to leverage personalised energy information, there is an urgency to ensure that they are utilised to their full potential. Whilst there is a growing body of research and evaluation on the potential effectiveness of feedback in consumer trials, there has been little research into the actual products and platforms available in the marketplace. This paper extends previous literature in that the taxonomy presented is derived both theoretically and empirically and all categories are designed to be mutually exhaustive and mutually exclusive, given current technological capabilities. It is hoped that this report will assist both researchers and practitioners in the fields of energy efficiency and conservation and that it may serve as the basis for publicly available product information on feedback technology as this market grows in future years.

Literature review

Early feedback—cybernetics

Feedback has been studied in both the physical and social sciences for decades (e.g. Skinner 1938; Wiener 1948). The basic premise is simple: Feedback enables the output of a dynamic system or process (i.e. one whose behaviour varies over time) to be compared to a goal or reference point, in order to enable improved control over that system or process (Goyal and Bakshi 2008). Figure 1 illustrates the difference in the structure and control of a process when no feedback is provided (a), and when feedback is provided (b).

First applied to steam engines and other mechanical systems in the eighteenth century, feedback systems are based on control theory; which has three key aspects: (1) a goal or reference point to which the system is controlled with respect to, (2) a means to compare actual performance to the goal or purpose, and (3) a process to enable information about the output of the system to be communicated back to the input to enable modification of the process (Duffy 1984). Improved control over dynamic systems is thus enabled by the presence of feedback loops and the communication of information (Åström and Murray 2009). A simple example of this type of system is a home heating, ventilating, and air conditioning system. The system is set up with a desired temperature. The temperature sensor on the thermostat enables the temperature of the building to be measured and compared to this desired state. The difference and direction between the desired and actual temperature is then communicated back to the controller, which in turn activates the system to minimise any differences between the actual and desired state.

In the 1940s, Norbert Wiener explored how these types of communication and control theories might be extended to human systems. This, he argued, called for a new science of feedback, human behaviour, and information, which was coined "cybernetics" (Wiener 1948). Cybernetics is fundamentally concerned with the study of how information may be manipulated and communicated around dynamic systems for the purpose of control, with a particular focus on behaviour, processes and

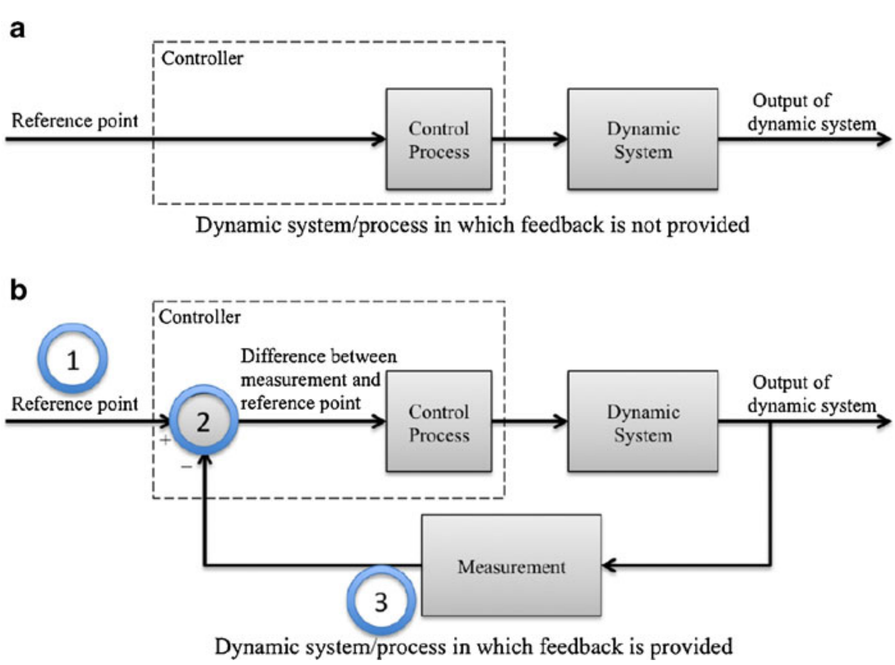

Fig. 1 Control of dynamic systems with and without feedback, adapted from Goyal and Bakshi (2008)

circular communication (Duffy 1984). In cybernetic systems that integrate humans into the control process, the resulting system is often non-mechanical and more flexible than machine-only control counterparts, but although it is more complex it operates in much the same way (Klein 1989). The movement towards goals or reference points requires individuals to identify their current behaviour with respect to the established reference, which may require more than just a simple mechanical sensing of the existing environment. The discrepancy between their current behaviour and reference point needs to be evaluated, and a mechanism needs to be employed to reduce this discrepancy (Klein 1989; Lawrence et al. 2002).

In the past 40 years, the use of cybernetic systems for feedback and control have been implemented and validated across many disciplines, including psychology, epidemiology, environmental studies, engineering, economics and more (Goetz 2011). Although they have proven to be very popular methodologies, there are concerns with their use in social systems, particularly in cases where goals or references points may not exist, where accomplishments may not be measurable, or where the information provided cannot be used (Hofstede 1978). Psychological theory may, therefore, serve to integrate system principles of cybernetics with the complex systems related to human behaviour. The next section will discuss this integration.

Psychological theories of feedback

The earliest cited psychological theory of feedback is Thorndike's Law of Effect (1927), which asserts that those behaviours that produce a positive effect are more likely to be repeated and behaviours that produce a negative effect are less likely to be repeated. Skinner's model of operant conditioning (1938) expanded on this, stating that knowledge of positive results could be seen as a positive reinforcement and knowledge of negative results as a punishment, thus serving to encourage or discourage subsequent behaviour. Albert Bandura (1969) is also noted for seminal theoretical work on feedback; he found that providing a goal and information about progress towards that goal could serve as a form of behaviour modification, much like a reward or punishment. Subsequent theories based on this early work include control theory (Carver and Scheier 1981), goal setting theory (Locke and Latham 1990), and action identification theory (Vallacher and Wegner 1987).

Kluger and DeNisi (1996) conducted a meta-analysis of feedback interventions across a wide variety of behaviours and introduced the Feedback Intervention Theory (FIT) based on their analysis of past empirical and theoretical contributions. FIT argues that behaviour is regulated by comparisons to pre-existing or intervention-provided goals or standards. These standards can be personal goals or comparisons to past behaviour or others in a social group. This is a common concept in previous feedback theories, including goal setting theory (Latham and Locke 1991) and control theory (Carver and Scheier 1981), which both assert that behaviour is generally goal directed and that people use feedback to evaluate their behaviour in relation to their goals. When behaviour differs from the standard, this creates what they call a feedback-standard gap, and it is the desire to decrease this feedback-standard gap that mediates the effectiveness of feedback.

Four options are available to individuals when provided with a feedback-standard gap. They can respond by changing behaviour to match the standard, changing the standard to match behaviour, rejecting the feedback or leaving the situation altogether. Both the strength of the goal and the size and direction of the feedback-standard gap can impact this choice. As control theory would suggest, negative feedback is more likely to lead to behaviour change than positive feedback (Campion and Lord 1982; Podsakoff and Farh 1989).

However, it is also possible for positive feedback to lead to behaviour change. Action identification theory (Vallacher and Wegner 1987) asserts that people identify actions with specific meaning related to their identity. Thus, the action of taking a test in class can be construed as answering exam questions or as working towards future career success. As people learn a task and develop mastery, performance becomes automatic and they are able to begin thinking about it in terms of higher levels of meaning. This is presented in contrast to a strictly control theory, or cybernetic, model of feedback, in which the goal of reducing the feedback-standard gap remains constant. This explains why positive feedback can also impact behaviour even though it does not serve to reduce a feedback-standard gap. In such a case, a higher-level goal can be created and therefore create a new standard.

Finally, FIT suggests that feedback is effective insofar as it changes the locus of attention of the individual to the feedback-standard gap. Feedback may direct attention to a specific goal or behaviour that was not previously the focus of attention. Thus, it can serve not only to provide information about a behaviour-standard gap but also to draw attention to a specific behaviour in the first place. The visibility and availability of feedback is also an essential element and serves as a key factor in its effectiveness.

This framework provides an introduction to the different components involved in feedback that have clear implications for feedback interventions across a wide variety of behavioural domains. Applying these principles to energy feedback can increase our understanding of the most important variables upon which to categorise such technologies. The next section reviews previous literature on feedback in an attempt to link basic feedback theory to the specific case of energy feedback.

Past research on energy feedback

Over a hundred empirical studies of energy feedback have been conducted over the past 40 years and over 200 articles have been published about energy feedback during that time. Reviews of this research have found that feedback is effective, on average, with effects ranging from increases in energy use to savings of over 20 % (Darby 2006; Ehrhardt-Martinez et al. 2010; EPRI 2009; Fischer 2008). However, definitions, descriptions and categorisation of feedback vary from report to report. Operational definitions for energy feedback, as well as key characteristics and categories, are lacking. Before presenting our own analysis, we review past attempts to define, describe and categorise energy feedback. For the purposes of our discussion, we define a characteristic as a single variable with two or more levels, and a category or type as a group of products or platforms that share one or more characteristics.

Definitions of feedback

Whilst research on energy feedback is abundant, there seems to be gap in the literature regarding a specific operational definition of energy feedback. Both Darby (2006) and EPRI (2009) rely on dictionary definitions of feedback; although technically accurate, they are not specific either to energy or to consumer-facing information (e.g. that which involves people in the process). EPRI (2009) and Abrahamse et al. (2005) further characterise energy feedback as household-specific electricity consumption information and Ehrhardt-Martinez et al. (2010) define feedback in the context of consequence strategies for behaviour change, which "attempt to change behaviour by influencing the determinants of a behaviour after the behaviour in question has been performed" (p. 38). These definitions focus the definition on home energy use and incorporate motivational element of feedback, but are still vague with regards to what kind of information constitutes feedback.

Without a clear operational definition, it is difficult to determine what exactly distinguishes feedback from energy information or control. Areas of ambiguity include (but are not limited to) *estimated* feedback (e.g. carbon calculators, based on user input) and *automated* systems (e.g. appliances that receive and respond to feedback directly, removing the user from the loop). Within the literature, the feedback system relates to the energy consumption of a dwelling; therefore, an *energy* feedback technology is one that receives information about the actual energy consumption of the dwelling (or part of the dwelling). Likewise, definitions focus on the role of feedback in informing consumers and affecting behaviour; therefore, a definition should include provision of this energy data back to the consumer. Therefore, we define energy feedback as information about *actual energy use* that is collected in some way and provided back to the *energy consumer*.

Reviewing this definition helps to provide some clarity to ambiguous areas in the past literature. Estimated feedback, which collects approximated energy usage information from the user (therefore not actual energy use), and automated systems that completely remove the user from the feedback loop (i.e. not providing data back to the energy consumer) are, consequently, not classified as a feedback technology.

Characteristics of feedback

Several authors over the past decades have discussed specific characteristics of feedback that may be most effective in promoting energy conservation or distinguishing between types of feedback technologies (see Table 1). The most commonly cited characteristic was immediacy (Darby 2001, 2006; Donnelly 2010; Ehrhardt-Martinez et al. 2010; EPRI 2009; LaMarche et al. 2011; Stein and Enbar 2006), which breaks down feedback into the two categories of direct (immediate) and indirect (not immediate). Additional characteristics

Table 1 Characteristics identified during literature review

Characteristic name	Characteristic levels	Characteristic definition	References
Immediacy[a]	Direct, indirect	How soon after an action feedback is provided	Darby 2006; Donnelly 2010; Ehrhardt-Martinez et al. 2010; EPRI 2009; LaMarche et al. 2011; Stein and Enbar 2006
Data collection[a]	Estimated Feedback, Sensor	How feedback information is collected	EPRI 2009; Hochwallner and Lang 2009; LaMarche et al. 2011
Frequency	Continuous, daily, weekly, monthly, bimonthly	How often feedback is given	Fischer 2008; Fitzpatrick and Smith 2009; Froehlich 2009
Duration	Weeks, months, years	How long feedback is provide	Fischer 2008
Content (Measurement unit)	Electricity, cost, environmental impact, temperature, utility messages	The units of measurement the feedback is given in	Fischer 2008; Fitzpatrick and Smith 2009; Froehlich 2009; Herter and Wayland 2009; Stein and Enbar 2006
Breakdown (Data granularity)	Room, appliance/device level, time of day, building, indoor/outdoor, rate period	The resolution of the feedback data	Fischer 2008; Fitzpatrick and Smith 2009; Froehlich 2009; Herter and Wayland 2009; Hochwallner and Lang 2009
Presentation mode (Visual design)	Numeric, graphic, ambient, artistic	The format feedback is presented in	Fischer 2008; Fitzpatrick and Smith 2009; Froehlich 2009; Wood and Newborough 2007b
Presentation medium	Electronic media, written material, in home display, mobile apps, web portals and social media	The medium through which feedback is presented	Fischer 2008; Froehlich 2009; Hochwallner and Lang 2009; LaMarche et al. 2011
Comparisons	Historical, normative, forecast, other buildings, other appliances, other rates, other rate periods, personal goals	Whether feedback is measured against some standard	Wood and Newborough 2007b; Fischer 2008; Fitzpatrick and Smith 2009; Froehlich 2009; Herter and Wayland 2009
Additional information and other instruments (Recommending action)	Incentives, goals, personal commitments, advice	Whether information other than usage	Fischer 2008; Froehlich 2009; Shutlz 2010
Location	Activity-based displays, embedded displays, central displays, localised, independent	Where the feedback display is found	Wood and Newborough (2007b); Fitzpatrick and Smith 2009; Froehlich 2009
Push/Pull	Push, pull	Whether the feedback is sent to the user or the user navigates to it	Froehlich 2009
Control device (Automation)	Central, device level, on-board, low automation, high automation, no automation	Whether the feedback system enables control	Donnelly 2010; Ehrhardt-Martinez et al. 2010; LaMarche et al. 2011
Feedback level	Low-level feedback, high-level feedback	Whether the feedback is specific to an action or summative	Froehlich et al. 2010
Communications	Fixed, wireless, gateways, range extenders, home area networks	Devices used to enable data transformation	Hochwallner and Lang 2009; LaMarche et al. 2011
Communication protocol	X10, UPB, Insteon, Z-Wave, Zigbee	Standards used to enable data transmission	LaMarche et al. 2011

[a] Characteristic names not used explicitly by authors

relate to the frequency and duration of feedback collection and provision, the type of information provided and the messages used, and variables related to both the visual display and hardware components of feedback.

It is important to note that non-technology factors can also impact the effectiveness of feedback. Literature reviews have identified several such factors, including study duration, sample size, and recruitment method (Darby 2006; Ehrhardt-Martinez et al. 2010; EPRI 2009; Fischer 2008). Statistical meta-analysis of 42 feedback studies support many of these claims, identifying several non-technological variables that moderate the effectiveness of feedback, including study duration, frequency of provision, combination with goal-setting and incentives and the population from which the study sample was drawn (Karlin and Zinger 2013). As most of these analyses are conducted from between-study (vs. within-study) comparisons, further research is needed to clarify the role of these non-technological variables, both apart from and in conjunction with any identified difference in treatment effect associated with the type of feedback, as discussed in this paper.

The current paper focuses on the type of feedback product or platform used, which has been identified as one of the key variables moderating the effects of feedback. Several authors have proposed specific categories, or types, of feedback to help distinguish among the many available technologies available. Although specific terms are used to describe different types of energy feedback systems, they are not always clearly defined and authors may use different terms to describe similar functions, or similar terms to describe different functions. Before developing and presenting our taxonomy structure of feedback technologies, we discuss current types and typologies of energy feedback.

Types of feedback

The most commonly cited types of feedback are *direct* and *indirect* feedback. Darby (2001, 2006) uses the term *indirect feedback* to refer to frequent utility bills, based on accurate usage data. EPRI (2009) uses it to categorise both standard and enhanced billing (billing with additional information and advice) as well as estimated appliance specific feedback (e.g. through the use of home audit software). The American Council for an Energy Efficient Economy (ACEEE) (Ehrhardt-Martinez et al. 2010) distinguishes between indirect feedback provided by the utility (offering improved customer service, better outage, power quality, more frequent meter readings and feedback to customers), and indirect feedback provided by vendors (offering improved feedback information, advice, estimated disaggregation, goal setting capabilities and social and historic comparisons).

In contrast to indirect feedback, Darby (2001, 2006) defines direct feedback as feedback that is "immediate, from the meter or an associated display monitor" and "available on demand". EPRI (2009) defines direct feedback as "feedback that is provided real-time or near-real-time". The ACEEE build on this to further state that direct feedback systems "provide energy use information at the time of consumption (or shortly after consumption)" (Ehrhardt-Martinez et al. 2010). The terms *direct* feedback and *real-time* (or near real-time) feedback are therefore taken to be synonymous.

The terms *in-home display*, in home energy display (Ehrhardt-Martinez et al. 2010), and home energy display (LaMarche et al. 2011), are all used to refer to an independent display that provides real-time energy consumption information. These systems tend to be comprised of a sensor as well as a display, which communicate wirelessly. The sensors tend to use current clamps to monitor the home's main circuit panel, though some systems use optical sensors to track the power meter. They tend to provide whole home energy feedback, though some systems have extra clamps for measuring individual circuits and are therefore capable of providing a breakdown by circuit (Donnelly 2010). Darby (2006) uses the terminology *direct displays*, which depicts a free-standing display, supplemental to the electricity meter, providing information on electricity and gas consumption.

Wood and Newborough (2007a) use the term *Energy Consumption Display* to refer to anything that provides energy feedback using a technological format. They further distinguish between central displays (i.e. displays placed in a central location in the home) and activity based displays (i.e. displays located next to the activity about which feedback is provided). Activity-based displays, defined as devices which sit between the wall outlet and an appliance (or group of appliances) and measure the energy consumption of that appliance (or group of appliances), have also been called plug in electricity usage monitors and watt-meters (Hochwallner and Lang 2009), plug monitors, outlet level monitors and outlet readers (LaMarche et al. 2011), plug-in devices (Fitzpatrick and Smith 2009) and distributed direct sensors (Froehlich et al. 2010). When these *plug-load monitors* also offer control or automation, they are sometimes called smart plugs/sockets/outlets/strips (Donnelly 2010; LaMarche et al. 2011), a type of *smart device*.

Other types of *smart devices* incorporate novel sensing and control algorithms for direct feedback and automation (Badami and Chbat 1998); these include smart thermostats, smart lights and smart appliances (Ehrhardt-Martinez et al. 2010). The most basic smart devices have sensing and/or communicating networking chips, enabling data collection and automation; more advanced options enable higher degrees of automation with wireless two-way utility communication for demand management control, delayed start functions and pricing signal control (Donnelly 2010).

Often, smart devices form part of a Home Area Network (HAN). Donnelly (2010) uses the terms Home Automation Network and Home Area Network interchangeably and states that the simplest HAN is a smart thermostat that enables heating/cooling control and communicates with a central computer and/or the utility's metering system. However, she notes that a complete HAN includes (1) smart devices with embedded/attached networking and/or communicating chips for automation, (2) advanced network systems and software using mesh networks to provide measurement and feedback of appliance specific data, (3) the potential for two-way communication with the utility and (4) some kind of consumer interface for direct, real-time feedback. Hochwallner (2009) defines a *home automation system* as one that "consists of "smart" devices and a communication bus that connects all devices in a home". The communications bus is used to both control appliances, and to receive information from the appliances about their current power consumption.

Typologies of feedback

Darby (2001, 2006) proposed a typology of feedback that focused on direct and indirect feedback but also included three additional categories: inadvertent feedback (learning by association, e.g. through microgeneration in the home or community), utility-controlled feedback and energy audits. EPRI (2009) subcategorised feedback into six types: four indirect and two direct. They divide indirect feedback into (1) *standard billing*: traditional source of feedback that households receive from their utility company, generally in the form of a monthly bill or statement; (2) *enhanced billing*: provision of more detailed information about consumption patterns from the utility, such as historical or social comparison statistics; (3) *estimated feedback*: data supplied by the user is analysed to produce estimates of aggregate (e.g. carbon footprint) or disaggregated (e.g. appliance-specific) usage; and (4) *daily/weekly periodic*: presents energy information to the user that is time-delayed by a day or more, but is provided more often than the traditional energy bill. Direct feedback is further categorised as (5) *real time*: delivers overall consumption level on a real-time or near-real-time bill and (6) *real-time plus*: provides disaggregated (e.g. individual appliance) energy feedback and/or allows users to control appliances in the home.

The Ehrhardt-Martinez et al. (2010) typology also begins with Darby's definition of indirect and direct feedback and constructs an analogy based on an onion metaphor. The layers of the onion are defined as: (1) *utility delivered* (utility bill or website), (2) *vendor delivered* (whole home information), (3) *deeper contextual information* (e.g. includes statistical analysis), (4) *in-home energy display* (real time or nearly real time feedback), (5) "*Smart*" *devices* (e.g. provide simple automation), (6) *disaggregated and contextual* (information about individual appliances) and (7) *automation* (whole systems that include disaggregated real-time feedback, home automation and sometimes energy generation and storage systems). The three outer layers of the onion (1, 2 and 3) correspond to indirect feedback mechanisms and the three inner layers (4, 5 and 6) correspond to direct feedback, with home automation at the core (7). As the layers of the onion are peeled away, the feedback becomes progressively sophisticated.

In a meta-review of feedback studies based on these categories, Ehrhardt-Martinez et al. (2010) found "distinct differences in the average and median energy savings associated with different types of feedback". However, they do note that significant variation exists within each of the feedback categories. Whilst the authors attribute this "within category" variation to differences in study methodology, it is also possible that there are significant differences between types of feedback within these broad categories as well. For example, within the real-time plus category, a feedback intervention may or may not be electronic and may or may not provide appliance-specific information, both of which are variables which may impact the effectiveness of the feedback intervention.

The classification "taxonomy" proposed by LaMarche et al. (2011) takes a different approach, consisting of three basic categories intended to capture essential components of a typical feedback device such that feedback can fall into one or more of these categories: (1) *control devices* (allow the consumer or utility to actively control energy use), (2) *user Interfaces* (provide energy feedback to consumers) and (3) *enabling technologies* (underlying support framework). Control devices can be centralised (communicate with multiple devices), device level (user controls a single device) or on-board (control is integrated into the device). User interfaces can provide raw, i.e. direct feedback (e.g. real time or historic usage data), or processed, i.e. indirect feedback (e.g. comparisons, advise, goal setting). Enabling technologies include sensors, communications (e.g. gateways) and communications protocols (e.g. Zigbee).

Limitations of previous research

Whilst the literature to date presents significant evidence supporting the potential effectiveness of energy feedback to promote conservation, further research is still needed to answer the questions of how and for whom feedback works best. As seen in the previous sections, the results of past energy feedback studies have varied, with effects ranging from negative (i.e. increase in energy consumption) to large effect sizes (accounting for nearly 50 % of the variation in energy use). These results suggest that the effectiveness of feedback varies based on the type of feedback received.

In addition, although past literature reviews have proposed categories to distinguish between these types of feedback, current categorisations lack the technological sophistication to account for the diversity in available technologies and are not systematic in their classification of specific feedback technologies. Classification, or categorisation, is the process of grouping like objects into categories based on their properties (Cohen and Lefebvre 2005). Categories within a classification structure should be clearly defined (e.g. new objects can be easily categorised), mutually exclusive (e.g. each object fits in one and only one category) and collectively exhaustive (e.g. all objects fit into a category); the result is that every object within a classification structure fits in one and only one category. When categories are based on a fixed set of characteristics in parallel, the resulting structure is a typology; when these characteristics are considered in succession, the resulting classification structure is a taxonomy (Marradi 1990). A review of existing classifications (see above) identified the following issues:

1. All existing products and platforms are grouped into four (or fewer) categories, which leaves single categories containing upwards of a hundred technologies, making distinction and selection difficult.
2. Categories focus primarily on the type of information provided and ignore physical design and operating differences.
3. None provides a systematic description of the specific characteristics that vary by type, making categorisation of emerging technologies difficult.

The goal of this project is to analyse the current status of feedback technologies in the marketplace with a focus on the specific characteristics of various technologies. This paper presents a taxonomy of technological feedback, derived theoretically and empirically from a review of 196 feedback technologies coded on over 100 device characteristics.

Methods

The study utilised content analysis and classification methodologies to derive a taxonomy of feedback technologies. Content analysis is a technique of compressing large amounts of text into a manageable data set by creating and coding the text into categories based on a set of specific definitions (Neuendorf 2001; Stemler 2001). Descriptive data on over 200 specific feedback technologies were identified and collected from March to August 2011. After similar/identical devices were removed, product information was analysed qualitatively using open coding followed by axial coding; themes were constructed from analysis of the codes in consultation with previous literature (Corbin and Strauss 2007; Creswell 2009). The set of final characteristics were screened for relevance and a taxonomy structure was derived to categorise all products and platforms such that the categories were mutually exclusive and mutually exhaustive to the dataset. The following four sections (data collection, inclusion, coding and analysis) describe the methodology of this study in further detail.

Data collection

The following four methods were used to identify and collect data about feedback technologies: (1) review of relevant literature, (2) Internet keyword search, (3) retail websites and (4) personal contacts. As products and platforms were identified, a raw data file was created for each product with any available information (e.g. user manuals, product summaries, new articles, photos).

Data collection began by compiling a list of identified feedback technologies from the following reports: Anderson and White 2009 (7 devices); Ehrhardt-Martinez et al. 2010 (12 devices); Herter 2010 (49 devices); Herter and Wayland 2009 (35 devices); Hochwallner and Lang 2009 (4 devices); LaMarche et al. 2011 (38 devices); Stein 2004 (11 devices); and Stein and Enbar 2006 (27 devices). One hundred and one unique feedback devices were identified from these reports.

Next, general searches were conducted in Google as well as Amazon.com using the keywords energy and feedback simultaneously. In addition to identifying additional technologies, these searches also uncovered third-party websites that specifically market and/or sell feedback technologies, including: www.powermeterstore.com, www.mymeterstore.com, www.smartgrid.gov and www.home-energy-metering.com.

Further feedback technologies were identified through informal inquiries via email and discussion with colleagues and personal contacts, including colleagues at our universities, researchers at energy-related conferences and colleagues at the ACEEE. The total number of feedback products and platforms initially compiled and reviewed using all four of the above search strategies was 259.

Inclusion

For the purpose of this work, we defined energy feedback as *information about actual energy use that is collected in some way and provided back to the energy consumer*. As such, our inclusion criteria for determining whether a feedback technology meets this definition were as follows:

1. The feedback technology collects information about actual building electricity use.
2. The feedback technology provides this actual usage data back to the user.
3. The feedback technology is an actual product or prototype (not concept).
4. Sufficient information is available to describe the feedback technology.

Additionally, this work considers only those commercial or pre-commercial ventures in which the commercial product or platform provided is energy feedback; feedback systems provided to consumers by electric utilities, whose primary commercial venture is the retail of energy, are not included here. Commercial and pre-commercial feedback technologies that met all four of the above criteria of energy feedback were subject to inclusion in our analysis. Among the initial 259 devices/systems collected, we identified 196 that met all of the above criteria.

Coding

Code development was iterative and utilised the constant comparison method and multi-phase coding (Corbin and Strauss 2007; Creswell 2009). Each feedback technology was treated the unit of analysis for coding and the content analysis utilised a manifest approach, such that the exact information was pulled from the data. An initial set of codes was developed based on previous literature (e.g. frequency, immediacy, content, medium—see review above); additional codes were created, as needed, as technologies were added. Variables relating to key hardware and system properties of the feedback technology were added to ensure that we were able to account for both physical design and operating conditions (and differences). Further characteristics were added in an iterative procedure; opening coding from the 196 products and platforms resulted in a total of 117 distinct codes, divided into five primary categories: development, hardware, system, data collection and data presentation.

In the second round, the 196 technologies were recoded according to these characteristics. All coding was then reviewed for accuracy; discrepancies were resolved through discussion between all three authors. In some cases, information being coded for a particular technology either was not obtainable (e.g. total number of subjects contacted) or was somewhat ambiguous (e.g. random assignment); therefore, not all studies could be coded on every variable. When information was missing in a study and there was no clue to support a reasonable estimate, the information was coded as missing data.

Because the coding process involved some degree of subjectivity, all study variables were coded by at least two authors and results on 10 % of the data were compared for reliability. Inter-rater reliability was acceptably high (kappa >.700) for all variables (Cohen 1960).

Analysis

During axial coding, the 117 distinct codes were reviewed and collapsed into 36 primary characteristics. For example, codes that represented multiple levels of the same characteristic were condensed (e.g. Linux, Mac, and Microsoft combined as levels of the characteristic, "operating system compatibility"). The next phase of analysis distinguished those codes related to the primary goal of the study (e.g. categorising feedback devices) from others related to the quality of personal preference (Corbin and Strauss 2007). A taxonomy classification structure based on these characteristics was then constructed and all technologies were reviewed for fit. Final categories were derived based on an integration of analysis results with previous literature as well as data regarding the most important device characteristics for consumers.

Findings

Feedback characteristics

After both open and axial coding, 36 feedback characteristics within five broad categories were identified; these characteristics grouped by category are listed in Table 2.

From this list of characteristics, we identified both *typing* characteristics and *quality* characteristics; *quality* characteristics are those that pertain to the quality of the feedback system whilst *typing* characteristics are those variables necessary to distinguishing between categories of feedback. For example, some individual technologies provide feedback data at multiple levels of granularity, so it made sense to amalgamate the different levels of granularity for categorisation purposes, and instead use this variable to define the quality of the feedback technology within type. To determine the categories for our taxonomy, we identified those that were:

1. Stable and inherent to the technology in itself
2. Consistently identifiable for at least 80 % of the devices
3. Theoretically relevant
4. Had an even distribution of products/platforms across the variable options (i.e. no more than 80 % of devices belonging to one type).

Those that met these criteria are identified in bold text in Table 2. These were further grouped into six primary taxonomy characteristics: product hardware (sensor units, external transmitters and physical displays), communications (communication protocol), control (appliance control), display (medium of presentation), collection (collection point) and protocol (communication protocol). These characteristics, their definitions and levels are listed in Table 3, and further information is provided below.

Hardware

Hardware describes the physicality of the feedback technology, asking whether or not the technology requires the purchase of any new sensors, transmitters and/or displays. Any system that provides feedback via existing channels (i.e. does not require the user to purchase new hardware devices) and collects data via existing sources (e.g. utility meters, data loggers) does not have hardware. Any system that requires the purchase of a device or devices, such as a display or a sensor, has hardware.

Communications

Communications refers to whether or not the physical component or components of feedback systems are able to communicate with each other and/or pre-existing electronic devices. These communications can be either wired or wireless. Feedback systems that consist of various hardware components that communicate with one another, or consist of a single hardware component that communicates with other electronic devices in the household or building have communications capabilities. Individual feedback products that collect and provide data within the same device do not have communications capabilities. This characteristic does not apply for feedback systems that have no physical components (i.e. have no hardware).

Control

Control refers to whether or not the feedback system enables remote control of electronic devices within the home and/or building. This includes automation, i.e. setting devices to turn on or off or change setting at a

Table 2 Characteristics identified during coding

Category	Attribute	Category	Attribute
Development	Status of technology	System	Technology requirements
	Cost[a]		OS compatibility[a]
	Target audience		Amount of memory[a]
Hardware	Sensor units		Memory location[a]
	External transmitters		Integration w/other systems
	Physical displays		Documentation availability
	Power supply options	Data collection	Data granularity
	Measurement capabilities[a]		Collection point
	Monitoring channels[a]	Data presentation	Medium of presentation
	Measurement resolution[a]		Display update frequency[b]
	Voltage/current ranges[a]		Temporal granularity[b]
	Collection update frequency[a]		Comparison messages
	Power factor correction[a]		Units of measurement
	Communication channels[a]		Appliance control
	Communications range[a]		Visualisations used
	Communication protocol		Level of configurability
	Installation protocol		Recipient of feedback[b]
	Additional components		Provision of advice

[a] Insufficient data—missing data for 20 % or more of dataset

[b] Insufficient variation—over 80 % of dataset fell into one category

specified time, as well as the ability to manually turn devices on and off from a remote location.

Display

Display refers to the physical medium on which the feedback data is presented to the user. When feedback is displayed via existing channels, such as a utility bill, website, computer software or phone, it has no display. When feedback is presented on an independent display, whether it is wall mounted or portable, it has an autonomous display. When the display is built into the device that collects feedback data (i.e. the sensor), it is classified as an embedded display.

Table 3 Taxonomy characteristics

Characteristic name	Characteristic definition	Characteristic levels
Hardware	Does it have physical hardware?	No (platform)
		Yes (product)
Communications	Does it have communications abilities?	No (monitor)
		Yes (network)
Control	Can it be used to control electronic devices remotely?	No (information)
		Yes (management)
Display	What type of display is feedback presented on?	None (existing channels)
		Embedded (within device)
		Autonomous (standalone display)
Collection	Where does the data come from?	Grid
		Sensor
		Appliance
Protocol	Does the system use proprietary communications protocols only?	Yes
		No

Collection

Data collection describes where the feedback information comes from. Data collected by a meter or provided by the utility is classified as grid. Data collected by the feedback product is classified as sensor. Data that comes from an existing home appliance or device, such as refrigerator or home thermostat, is classified as appliance.

Protocol

Protocol refers to whether or not the feedback system uses only non-standard communication protocols such that it can only communicate with itself. Feedback systems that are capable of using public communications standards can communicate with other devices, such as smart meters or smart appliances that use the same communication protocol. Feedback systems that use only proprietary communications cannot.

Feedback taxonomy

The six characteristics described in Table 3 were analysed with the dataset in order to identify meaningful categories. Although a simple factorial typology of the six variables reveals a possible 144 combinations, many of these are not possible (e.g. feedback technologies that do not have hardware by definition do not have sensors to collect data); therefore, a taxonomy structure was derived to create mutually exclusive and exhaustive categories whilst retaining parsimony in the final construction. Figure 2 presents the final taxonomy structure of feedback technology, which was constructed from analysis of these characteristics with respect to both existing technology as well as past literature on the most meaningful characteristics of feedback.

Our taxonomy of feedback technology is comprised of nine categories, which are divided into two groups, *platforms* and *products*. A platform does not require the purchase of any new hardware; instead, it integrates with existing hardware that users already have (e.g.

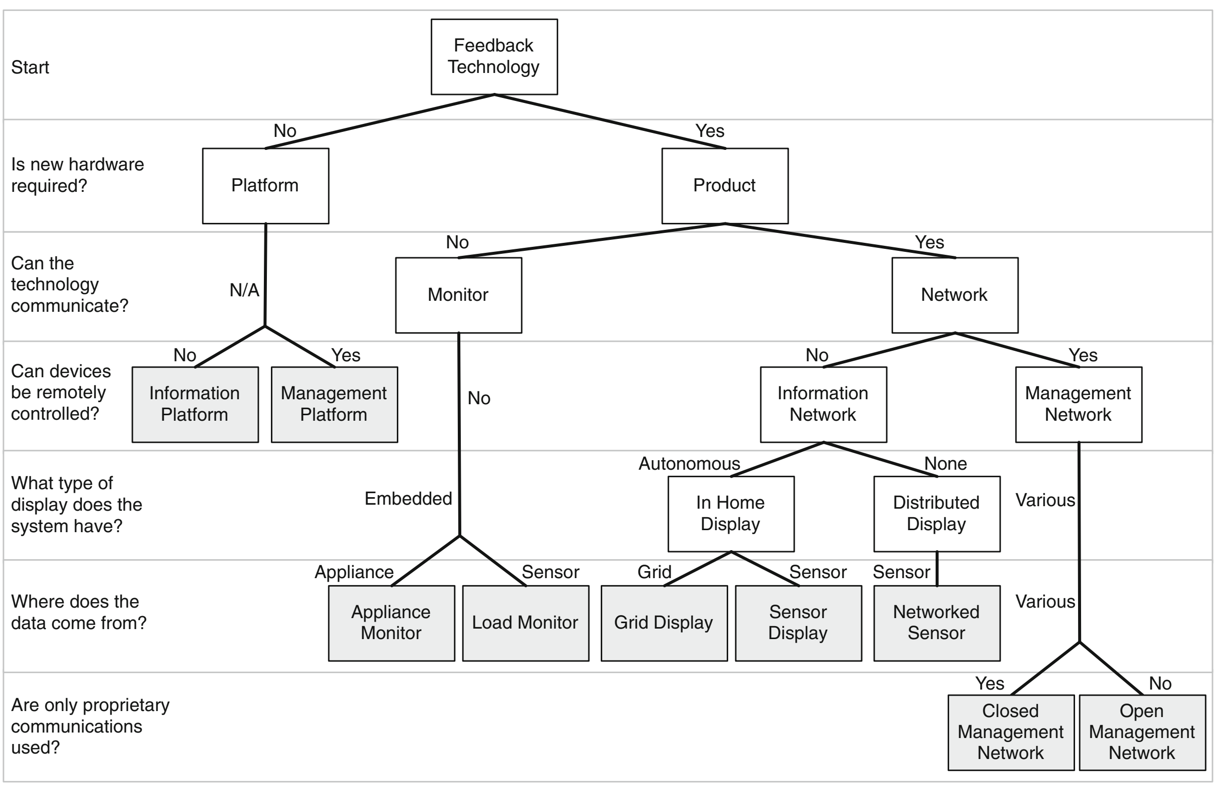

Fig. 2 Taxonomy of energy feedback technology

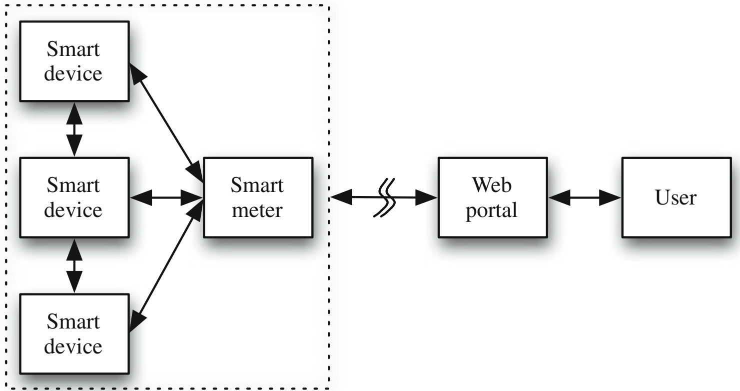

Fig. 3 Network architecture of a management platform

smart appliances, smart meter) and provides energy use data to consumers via enhanced energy bills or reports, mobile apps, web browsers or computerised software. Feedback platforms are broken down further into two groups: information platform and management platform. The key difference between an information platform and a management platform is that a management platform can be used to remotely control appliances and an information platform cannot. Examples of information platforms include forms of feedback such as enhanced energy bills and customer web portals, provided by companies such as Opower and Efficiency 2.0 PEER. Both of these platforms rely on smart meter data from a partner utility, which is then processed and presented to consumers in a paper-based report and via an online web portal. Additional services such as comparisons to other users, advice about energy saving behaviours, indications of approximated appliance energy consumption and potential savings and rewards programs are other characteristics of this type of feedback and can be used to distinguish between the different information platforms available to users.

Management platforms allow the user to automate "smart" electronic devices connected to the platform, including smart lights, a smart thermostat or smart appliances. Examples of management platforms include Silver Spring Network's Smart Energy Platform and the FutureDash Greendash Hub. These technologies rely on smart meters and smart devices already in the home for information and control. The information is provided to consumers via a web-based portal, and users are able to remotely control their smart devices via the web interface. These devices may also be controlled via a utility delivered demand response program. Figure 3 illustrates the type of network architecture involved. Different companies use different protocols to transmit information from the smart meter and smart devices to the consumer portal. The Silver Spring system provides information to consumers via the utility, whilst FutureDash is aims to work with consumer electronic manufacturers to skip this link and enable data transfer over the Internet.

Feedback products, unlike platforms, do require the user to purchase some sort of hardware, and are further subdivided into two categories based on whether or not

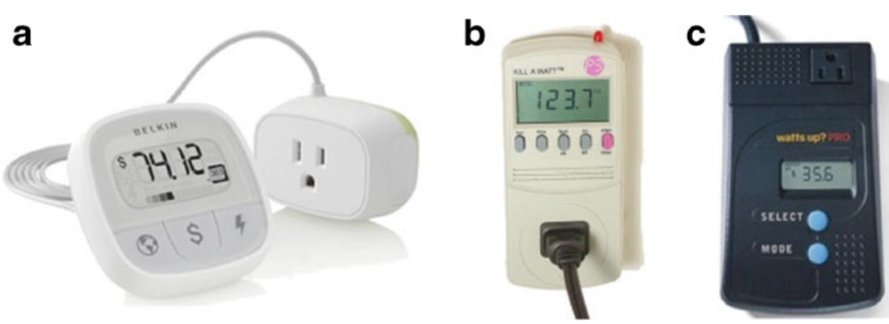

Fig. 4 Examples of energy load monitors

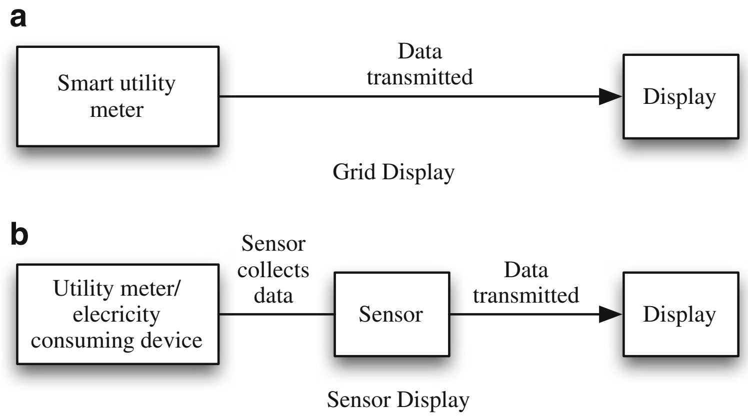

Fig. 5 Basic system architecture of in-home displays

they have communications capabilities. A product consisting of a single hardware component that does not communicate data with any other electronic device is a *monitor*. Feedback monitors contain sensors (to collect energy use data) and a display (to provide data back to users) in a single piece of hardware. A product with multiple hardware components that communicate with each other, or that are able to communicate with third-party electronic devices, is classified as a *network*. These networks tend to be confined to a physical space within a single building and may therefore be thought of as local area networks, or, in the residential setting, as home area networks (Donahue 2007).

Feedback monitors are further broken into two categories, appliance monitors and load monitors, both of which contain inbuilt sensors and embedded displays. Because they are not capable of communications, they do not enable remote control of appliances; however, some products are fitted with timers that can be pre-programmed to allow some amount of automation.

An appliance monitor collects data from and displays data about an individual appliance (i.e. the appliance has inbuilt energy sensors and an embedded display showing this information). Fridges, freezers, washing machines and tumble driers that have an embedded display to present their energy use to consumers, are all classified as appliance monitors.

A load monitor is a separate piece of hardware that serves as a proxy between the energy source and energy-consuming device. Most load monitors collect data at the plug level (although some collect data at the meter level), and sit between the socket on the wall and the appliance plug. Some load monitors offer the option of additionally viewing the data on accompanying computer software (facilitated via a USB or SD card connection). These features, and others such as the viewing options (i.e. ability to see instantaneous power consumption, total energy use, energy use over a predefined period), memory availability and cost, distinguish different products in this feedback category. Examples of load monitors include Belkin's Conserve Insight Monitor, the Kill-a-Watt, and Watts Up, as illustrated in Fig. 4a–c, respectively.

Networks are feedback products that have communications capabilities. Similar to platforms, networks are broken down into two categories based on whether or not they enable the user to remotely control appliances. *Information networks* do not enable remote control of appliances whereas *management networks* do. Information networks are further broken down into in-home displays (grid displays and sensor displays) and networked sensors, and management platforms are broken down into open management networks and closed management networks.

In-home displays are feedback products that have a physical display providing energy usage information to users in real (or near real) time and collect data from either a sensor (sensor displays) or the user's electricity

Fig. 6 The TED 5000G, including (*left to right*) one set of current clamps and measuring transmitting unit for breaker panel installation, and one gateway to transmit data externally

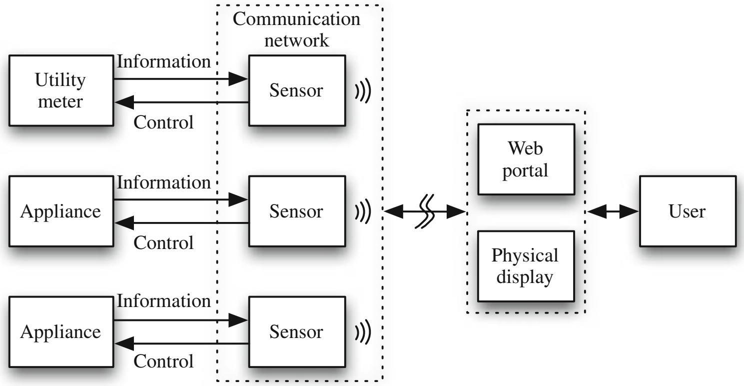

Fig. 7 Basic system architecture of closed management networks

meter/utility (grid displays). The basic architecture of grid displays and sensor displays are shown in Fig. 5a and b, respectively. Some in-home displays offer the option of additionally viewing the data online or via accompanying software.

All grid displays provide whole-home level energy usage information and some receive and display peak demand pricing and other messages from the utility. AzTech's In-Home Displays, Ambient's Energy Joule, and GEO's Duet II for Smart Meters are all types of grid displays. The main difference between these displays is how the information is presented to users (including the units used, the availability of historical data, features of the display in terms of size and colour, and so on) and what additional features the display provides, such as pricing information from the utility.

The most common type sensor display consists of at least one pair of CT clamps, a transmitter, and a portable display. Whilst most sensor displays transmit data from sensor units to displays using wireless or powerline communications, some rely on wired communications, using, for example, CAT-5 LAN cable installations. Examples of sensor displays include Current Cost's ENVI, Ewgeco's Electricity Monitor, and the TED 1001. Of all the types of feedback identified in this research, sensor displays formed the largest category, containing 61 separate products.

Networked sensors, the third type of information network, are feedback products that have a sensor or sensors, but no physical display. Physical sensors collect energy usage data and communicate it to external servers where it is processed for viewing on a web browser, app or computer software. The TED 5000 G series, depicted in Fig. 6, falls into this category.

The two forms of management platforms, closed management networks and open management networks,

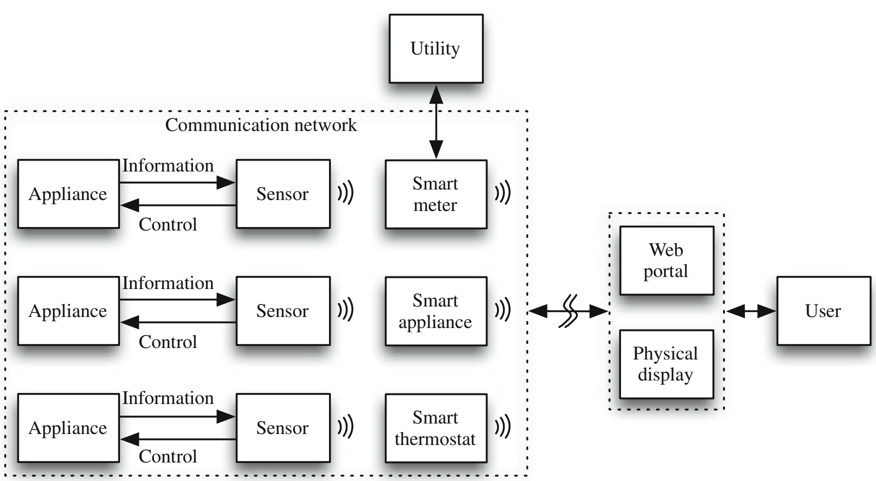

Fig. 8 Basic system architecture of open management networks

Table 4 Characteristics of each feedback type

Feedback type	Hardware	Communications	Control	Display	Collection	Protocol
Information platform	No	NA	No	–	–	–
Management platform	No	NA	Yes	–	–	–
Appliance monitor	Yes	No	No	Embedded	Appliance	–
Load monitor	Yes	No	No	Embedded	Sensor	–
Grid display	Yes	Yes	No	Autonomous	Grid	–
Sensor display	Yes	Yes	No	Autonomous	Sensor	–
Networked sensor	Yes	Yes	No	None	Sensor	–
Closed management network	Yes	Yes	Yes	Various	Various	No
Open management network	Yes	Yes	Yes	Various	Various	Yes

are feedback products that enable users to remotely control connected devices. Data are collected from a variety of sources, including smart meters, sensors and smart appliances, and presented to users on a combination of physical displays and existing channels (i.e. web portals, computer software or mobile app). The defining feature that distinguishes between closed management networks and open management networks is the type of communication protocol utilised by the system. Closed management networks communicate using only proprietary protocol and form closed communication networks to which only proprietary devices can join. Open management networks may use proprietary communication protocols on some layers, but they are also capable of using public communication protocols to form open networks to which any device communicating with the same protocol (e.g. smart meters, smart appliances, etc.) can join. This also means that utilities can send demand response signals to devices and appliances on the network via the smart meter.

The majority of closed management networks, such as AlertMe Smart Energy, Plugwise and thinkeco Modlet, use plug-in sensors to measure and control the energy usage of plug-in devices, as shown in Fig. 7.

The majority of open management networks (see Fig. 8), such as EnergyHub and Greenwave Reality, have a physical display and sensors, and some offer control to both users and third parties, thus enabling utilities to manage large connected loads such as pool pumps.

Table 4 summarises the characteristics of each of the nine types of feedback with respect to hardware, ability to communicate data, options to control appliances remotely, display options, data collection and the communications protocol used by the system.

Conclusion

Although feedback has been widely studied and is a much-anticipated part of our national and global transition to the Smart Grid, there have been few attempts to clearly distinguish among the hundreds of feedback technologies and their unique characteristics. This study is a vital first step towards an energy feedback "market", in which consumers can feel confident to select and purchase products and platforms that help them understand their energy usage in the home.

This work provides a novel contribution to the energy feedback literature by linking together the theoretical underpinnings of feedback technologies with actual commercial or pre-commercial ventures. However, it must be noted that the energy feedback market is a fast paced sector with many companies entering and leaving the market each year. This taxonomy was derived empirically from data collected in 2010–2011; since then, a number of players have left this space (e.g. Google) and others have entered (e.g. Chai Energy, Bidgely). This is not a problem in itself, as the main aim of this work was development of a taxonomy of energy feedback technologies and not to compile a current and complete list of them. However, a potential knock on effect is that these changes could result in the creation or disappearance of whole categories of feedback technologies. The feedback technology market does not present a unique situation in this respect and problems can be managed here by reviewing key characteristics and resulting categorisations as technologies develop over time, as has been done for classification structures of other technologies. For example, as camera technology has advanced in recent years additional categories, such as Megazoom" and "Interchangeable-Lens Camera (ILC)", have been added to existing categorisations to account for the differences in key camera characteristics described by the new technologies. This means that the taxonomy must be viewed as dynamic rather than static, requiring regular reviews and revisions to ensure that the categories describing commercial and pre-commercial feedback technologies remain fully representative of the marketplace. Although this presents a potential time sensitivity to the uselessness of the current categorisations, without them it would be much harder for consumers and reviewers to compare different models and determine which is most appropriate for a given situation. Furthermore, the identification of key characteristics development of the taxonomy structure provided in this work can help guide the creation of additional categories as needed.

This work is distinct from much of the existing literature; rather than try to evaluate the effectiveness of a particular type or characteristic of feedback, we instead aim to develop a categorisation to assist practitioners and researchers organise future work on energy feedback. This research does not provide a comparison between technologies, which we envisage as an additional research project. Rather, we have developed a categorisation that can serve as the basis for publicly available product information on feedback devices and systems, much like that which is available for other consumer electronics (e.g. televisions, cameras, etc.). This work did exclude home energy management technologies that gave users control of appliances without feedback. Whilst this study was aimed specifically at feedback technologies due to the potential savings that can be induced from increased awareness and knowledge about personal energy use, an extension to other types of home energy management system offering automation and control would be a useful next step.

A consolidation of all available data on energy feedback devices will be useful, not only to the average consumer but also to researchers interested in energy feedback technology. There is currently a great deal of redundancy within the research community, with multiple teams across the country (and world) collecting this information on their own in order to test and compare devices or systems. Our taxonomy report and subsequent database allows researchers to focus on designing and implementing studies, rather than attempting to scour the web looking for basic information about these devices.

Feedback has become ubiquitous in many other areas of our lives (e.g. food, transportation), and there is a clear indication from policy leaders and private industry that energy information should and will be made readily available to consumers in the coming decade. A better understanding of the diversity and similarity of devices is vital to this growing field.

Appendix A

Name	Developer or retailer	Type
4Home	Motorola	Open management network
Aclara's ENERGYprism Customer Care Solutions	Aclara	Information platform
The Agentis Platform	Agentis	Information platform
Acuview Energy Recording & Reporting Software	Accuenergy	Information platform
Agilewaves Building Optimization System	Agilewaves	Open management network
Akuacom Demand Response Automation Server	Akuacom	Information platform
AlertMe SmartEnergy	AlertMe	Closed management network
AmWatt Appliance Load Tester	Reliance Controls	Load monitor
AzTech	AZ Tech Associates, Inc.	Grid display
Battic Door Home Energy Monitor	Battic Door	Sensor display
Belkin Conserve Insight Monitor	Belkin	Load monitor
Black & Decker Power Monitor	Black & Decker	Sensor display
Blue Line PowerCost Monitor and Energy Meter II	Blue Line Innovations	Sensor display
Brand Electronics 20-CTR Whole House	Brand Electronics	Sensor display
Brand Electronics Digital Power Meter 4-1850	Brand Electronics	Load monitor
Brand Electronics Digital Power Meter 20-1850	Brand Electronics	Load monitor

Name	Developer or retailer	Type
Brand Electronics Digital Power Meter 20-1850CI	Brand Electronics	Load monitor
Brand Electronics Digital Power Meter 21-1850CI	Brand Electronics	Load monitor
Brand Electronics ONE meter	Brand Electronics	Sensor display
Brultech ECM-1220	Brultech	Sensor display
Brultech ECM-1240	Brultech	Networked sensor
Brultech GreenEye Monitor	Brultech	Networked Sensor
Cent-a-Meter	Island Power Pty Ltd	Sensor display
Centralised Electricity Energy Management System	Shenzhen Sailwider Electronics	Closed management network
Cisco Business Energy Management Services	Cisco	Information platform
Control4 Energy Management System 100	Control4	Open management network
Current Cost EnviR	Current Cost	Sensor display
Current Cost The Classic	Current Cost	Sensor display
Current Cost TREC	Current Cost	Sensor display
Customer Interface Display	Dent Instrument	Grid display
CustomerIQ Energy Portal	Silver Spring Networks	Information platform
Digi X-Grid Solutions	Digi	Open management network
DreamWatts	Makad Energy	Open management network
E-Mon Energy Software	E-Mon Energy	Information platform
E-Watch	Secure Together	Information platform
Ease II Manager	Secure Together	Information Platform
Eco-Eye Elite	Modern Moulds and Tools Ltd's	Sensor display
Eco-eye Elite 100	Modern Moulds and Tools Ltd's	Sensor display
Eco-eye Elite 200	Modern Moulds and Tools Ltd's	Sensor display
Eco-Eye Elite Mini	Modern Moulds and Tools Ltd's	Sensor display
Eco-eye Elite Mini 2	Modern Moulds and Tools Ltd's	Sensor display
Eco-Eye Plug-In	Modern Moulds and Tools Ltd's	Load monitor
Eco-Eye Smart	Modern Moulds and Tools Ltd's	Sensor display
Eco-Eye Smart PC	Modern Moulds and Tools Ltd's	Sensor display
Eco-Eye Smart PV	Modern Moulds and Tools Ltd's	Sensor display
EcoDog's FIDO Home Energy Monitoring System	EcoDog	Networked sensor
EcoManager	EDF Energy	Closed management network
ecoMeter	Ampy Email Metering	Grid display
EcoView Commercial	Advanced Telemetry	Closed management network
EcoView Residential	Advanced Telemetry	Closed management network
Efergy E2	Efergy Technologies Ltd	Sensor display
Efergy Elite Wireless Monitor	Efergy Technologies Ltd	Sensor display
Efergy Energy Monitoring Socket	Efergy Technologies Ltd	Load monitor
Efficiency 2.0's PEER	Efficiency 2.0	Information platform
eGauge	eGauge Systems	Networked sensor
ELOGsoftware	Dent Instruments	Information platform
EM 2500	Energy Mointoring Technologies	Load monitor
eMonitor	Powerhouse Dynamics	Closed management network
EMS-2020	Energy Cite	Grid display
Energate Home Energy Managament Suite	Energate	Open management network
Energy Engage	eMeter	Information platform
EnergyFlow Monitor	Noveda Technologies	Networked sensor
EnergyHub Home Base	EnergyHub	Open management network
Energy Joule	Ambient	Grid display
Energy Manager EXT Software	Electro Industries/ GaugeTech	Information platform
Energy Master	eQ-3	Load monitor
EnergySmart Monitor	British Gas	Sensor display
EnergyView Online	Schneider Electric	Information platform

Name	Developer or retailer	Type
eSight	eSight Energy	Information platform
Ewgeco B100	Tayeco Ltd.	Sensor display
Ewgeco B200	Tayeco Ltd.	Sensor display
Ewgeco B300	Tayeco Ltd.	Sensor display
Ewgeco H300 EEE	Tayeco Ltd.	Sensor display
Ewgeco H300 ERG	Tayeco Ltd.	Sensor display
Ewgeco H300 EWG	Tayeco Ltd.	Sensor display
Ewatch 100—Secure	Secure Together	Information platform
Flukso	Flukso	Networked sensor
Home Energy Controller (HEC)	Secure Together	Open management network
Freedom	Secure Together	Grid display
GEO Chorus	Green Energy Options	Open management network
GEO Duet	Green Energy Options	Grid display
GEO Ensemble	Green Energy Options	Closed management network
GEO Minim	Green Energy Options	Sensor display
GEO My Energy	Green Energy Options	Information platform
GEO Npower Monitor	Green Energy Options	Sensor display
GEO Prelude	Green Energy Options	Sensor display
GEO Quartet	Green Energy Options	Sensor display
GEO Solo	Green Energy Options	Sensor display
GEO Solo II	Green Energy Options	Grid display
GEO Trio & Trio+	Green Energy Options	Open management network
Google PowerMeter	Google	Information platform
Greendash Hub	FutureDash Corp.	Management platform
GreenWave Reality Energy Management Platform	Greenwave Realitty	Open management network
Greenwire Energy Monitor	Greenwire LLC	Grid display
GridPoint Energy Manager	Gridpoint	Management platform
Home Energy Management Solution (Cisco)	Cisco	Open management network
iControl OpenHome—Utility	iControl Networks	Open management network
In2MyHome	In2Networks	Information platform

Name	Developer or retailer	Type
Insteon Energy display	Insteon	Sensor display
Insteon HouseLinc	Insteon	Closed management network
Insteon SmartLinc	Insteon	Closed management network
Intamac	Intamac	Open management network
Intel Home Energy Dashboard	Intel	Open management network
Kill-A-Watt	P3 International	Load monitor
Kill A Watt EZ	P3 International	Load monitor
Kill-A-Watt Graphic Timer & Plug Power Meter	P3 International	Load monitor
Kill A Watt Power Strip	P3 International	Load monitor
Kill-a-Watt Wireless	P3 International	Sensor display
LS Research RateSaver display	LS Research	Grid display
Lucid Design Group: Dashboard	Lucid Design Group	Information platform
Lucid Building Dashboard—B	Lucid Design Group	Networked sensor
Lucid Building Dashboard—C	Lucid Design Group	Networked sensor
Mi Casa Verde SmartSwitch & Vera	MiCasaVerde	Closed management network
Microsoft Hohm	Microsoft	Information platform
Navetas Energy Monitor	Navetas Energy Management	Sensor display
Navetas Smart Hub	Navetas Energy Management	Sensor display
Needy Needs Inc Wireless Energy Monitor	Needy Needs	Sensor display
Nokia Home Control Center	Nokia	Management platform
Nucleus	General Electric	Open management network
Onzo	Onzo	Sensor display
OpenFrame 7E (OpenPeak)	OpenPeak	Open management network
OPOWER Energy Reports	Opower	Information platform
OPOWER Web portal	Opower	Information platform
People Power 1.0	People Power	Information platform
	People Power	

Name	Developer or retailer	Type
People Power Energy Services Platform+Surf Module		Closed management network
PICOwatt/Tenrehte Plug	Tenrehte	Closed management network
Plugwise	Plugwise	Closed management network
Power Aware Cord	Static!	Load monitor
Power Cost Display Monitor	Energy Control Systems	Sensor display
PowerLogic EPO Energy Profiler Online	Schneider Electronics	Information platform
PowerLogic ION EEM Software	Schneider Electronics	Information platform
PowerLogic ION Enterprise Software	Schneider Electronics	Information platform
PowerLogic PowerView Software	Schneider Electronics	Information platform
PowerLogic SCADA Software	Schneider Electronics	Management platform
PowerLogic System Manager Software	Schneider Electronics	Information platform
PowerLogic Tenant Metering Software	Schneider Electronics	Information platform
PowerPal Meter with Customer Interface Display	Dent Instruments	Sensor display
Power Player	Quby	Grid display
PowerStat	Brunswick Electric Membership	Grid display
PowerWatch-DR	PowerWatch Inc.	Open management network
Pulse Energy Manager	Pulse Energy	Information platform
Pulse Check	Pulse Energy	Information platform
RCS Whole home monitor & control	RCS Technology	Closed management network
San Vision Mobile Energy Assistant (MEA)	San Vision Energy Technology Inc.	Open management network
San Vision Power Dashboard	San Vision Energy Technology Inc.	Sensor display
SaveOMeter	Eco1	Sensor display
Scroller—Secure	Secure Together	Information platform
	Seasonic Electronics	Load monitor
Seasonic PowerAngel Monitor		
Senquentric System	Sequentric	Open management network
Shaspa Smart Home	Shaspa	Open management network
Silk	Powertech IST Otokon	Information platform
Silver Spring Network's Smart Energy Dashboard	Silver Springs	Management platform
SMARTware by Dent	Dent Instruments	Information platform
SolarCity's PowerGuide	SolarCity	Information platform
SRP M-Power Meter	Salt River Project	Grid display
Stanley 77–028 Energy Meter EM100	Stanley	Load monitor
SunPower Monitor	SunPower	Sensor display
Talking Plugs	Zerofootprint	Closed management network
Techtoniq Energy Station	Techtoniq	Information platform
TED 1001	Energy Inc.	Sensor display
TED 1002	Energy Inc.	Sensor display
TED 5000-C	Energy Inc.	Sensor display
TED 5000-G	Energy Inc.	Networked sensor
TED 5002-C	Energy Inc.	Sensor display
TED 5002-G	Energy Inc.	Networked sensor
TED 5003-C	Energy Inc.	Sensor display
TED 5003-G	Energy Inc.	Networked sensor
TED 5004-C	Energy Inc.	Sensor display
TED 5004-G	Energy Inc.	Networked sensor
Tendril	Tendril	Open management network
The Energy Stick	Quby	Grid display
The Energy Valet	Trilliant	Management platform
The PowerTab	Energy Aware Technology Inc.	Grid display
The Owl Electricity Monitors	2 Save Energy Limited	Sensor display
UPM Dual Rate Energy Meter-EM130	UPM Marketing	Load monitor
UPM EM100 Energy Meter	UPM Marketing	Load monitor
	UPM Marketing	Load monitor

Name	Developer or retailer	Type
UPM Plug-in Energy Meter and Electricity Cost Calculator		
UtiliFlex Juice	UtiliFlex	Information platform
UtiliFlex Joule	UtiliFlex	Networked sensor
U-Vue	U-VUE	Sensor display
WANF Electricity Energy Watt Usage Meter	WANF	Load monitor
Watts Up Standard	Electronic Educational Devices	Load monitor
Watts Up .Net	Electronic Educational Devices	Closed management network
Watts Up Pro ES	Electronic Educational Devices	Load monitor
Watts Up Pro	Electronic Educational Devices	Load monitor
Watts Up Smart Circuit 21	Electronic Educational Devices	Networked sensor
Wattson 01	DIY Kyoto	Sensor display
Wattvision Energy Sensor	Wattvision	Networked sensor
Wilting Flower	Carl Smith	Sensor display
Wireless Uni-directional Electrical Energy Saving Monitor	Shenzhen Sailwider Electronics	Sensor display
Wireless Bi-directional Electricity Energy Saving Monitor & Control System	Shenzhen Sailwider Electronics	Closed management network
thinkeco Modlet	thinkeco	Closed management network
Wattsclever Compact	wattsclever	Sensor display
Wattsclever Energy Monitor	wattsclever	Sensor Display
Wattsclever Energy Monitor for Smart Meter	wattsclever	Sensor display
Wattsclever Energy Watch Monitor	wattsclever	Load monitor

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