Smart and usable home energy management systems

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Abstract

This paper reviews research into Home Energy Management Systems (HEMS). These are intermediary products that can visualize, manage, and/or monitor the energy use of other products or whole households. HEMS have lately received increasing attention for their possible role in conserving energy within households. However, an analysis of the problem areas within household energy consumption along with a review of case studies and commercially available HEMS reveals some research gaps. If HEMS are to become truly effective, future research needs to focus on improving longitudinal effects and studying the influence of design.

Key words: *household energy consumption, home energy management system, energy monitor, conservation,*

1. Introduction

Dutch households are responsible for 19% of the total CO_2 emissions in the Netherlands. Total electricity consumption of households has increased structurally over the years, caused both by new appliances and changing consumer behavior. While overall gas consumption figures show a slight decline, they belie the great difference in energy demand existing between houses of different ages and quality. Furthermore, the energy bill for two identical houses can differ immensely due to the behavior and lifestyle of its inhabitants [1]. Household energy consumption is caused by an array of different appliances. Western household commonly have a range of 28 to 67 appliances [2, 3], with this number increasing each year. The amount of technical installations, such as heaters, solar panels and ventilation systems, is also increasing due to their relevance in meeting energy efficiency and comfort standards. The energy use of a household is dependant on the sum of these products. Energy consumed by an appliance during its use-phase is responsible for 50%-85% of the total environmental impact of common electronic products [4]. Technological solutions can achieve great reductions in energy consumption. A-label refrigerators, high efficiency heaters and a number of other appliances have become the standard in homes in the Netherlands with drastic energy reductions declared.

Yet this solely technical/design approach has not achieved the reductions theoretically stated as possible [5]. An energy efficient product does not guarantee energy efficient utilization by its users [6] as housekeeping rituals change over time and change under influence of shifting social norms [7]. Reducing the energy consumption of one product will not make a whole household sustainable.

Home Energy Management Systems (HEMS) can help households reduce energy consumption while take into account these key areas. HEMS are intermediary products that can visualize, manage, and/or monitor the gas, water or electricity use of other appliances or of a household as a whole. Most HEMS *monitor* energy consumption and give feedback through a (visual) representation of energy consumption. Visualization is commonly achieved with the help of a display (so-called energy monitors) and can either be for individual appliances or a complete household. A select group of HEMS can also *manage* the energy consumption of (groups of) appliances, controlling if or when they use energy.

A number of scientific researches have shown positive results for implementing HEMS to reduce energy consumption [8, 9, 10]. However, some research gaps are revealed when making an analysis of the problem areas within household energy consumption along with a review of case studies and commercially available HEMS. The main challenge to be addressed here is 1) what is known from past research on the influence of design on the (long-term) effectiveness of HEMS and 2) what other fields of research are relevant for improving design and increase effectiveness?

Scientific literature has little attention for HEMS's design and its influence on effectiveness in reducing energy consumption. Furthermore little is known on the longitudinal effects and how to influence or improve these.

The purpose of this current review is to study previous research on the effects of HEMS and the role for design with an evaluation of areas that have been neglected. It concludes with a proposal for directions for future research with the aim to develop effective HEMS that stimulate lasting energy reductions of households and considers three key areas that are essential in understanding home energy consumption.

1.1. Method

In the past, researchers have reviewed studies in energy related behavior change strategies for households. The current paper however has a singular focus on researches studying energy reduction by applying technological feedback devices to give direct feedback. Whereas Abrahamse et al., [11] focused on behavior intervention strategies for households such as information, feedback, rewards and goal setting with an eye for long-term effects, Darby went on to specifically study feedback intervention [12]. She categorized feedback into 5 main categories according to the amount of control and the immediacy to the energy user. There is also a difference in frequency in which the feedback is given. Fischer's review [13] theorizes on "why and how feedback works". She tries to clarify the differences in achieved results through a more elaborate and detailed comparison. All three conclude that though results have been somewhat mixed, effectiveness often increases with increased frequency and in combination with other interventions. On the other hand, it has been disputed by Mccalley and Midden [14] whether feedback in itself is effective or only in combination with goal setting. Therefore feedback in itself will not be questioned again as such, but rather a focus will be given on its use within technology.

This current review is conducted by studying both peer reviewed scientific literature using HEMS and grey literature such as white papers, company reports and personal communications. The grey literature gives more insight in HEMS design compared to scientific research over the past 30 years. The main focus here is on the effects over time and on design.

2. Findings

The following sections review research applying HEMS in case studies. First a short introduction is given on the effects of feedback and the use of HEMS in research. Feedback seems effective in most cases, but researches have conducted mainly short term case studies and those researches that have been long term have indecisive results. Furthermore the type of feedback and manner in which feedback is given seems to have distinct influence on the effectiveness. As this is closely intertwined with the interface or architectural design of HEMS, this paper will then continue on the topic of the role for design on the effectiveness and usability of HEMS. Research applying HEMS pays disturbingly little attention to how the HEMS are designed and if this can influence long-term effectiveness. Furthermore, barely any between- or within-subject research designs have been applied comparing different HEMS within one research.

Afterwards the possibilities that persuasive technology can have for HEMS in increasing usability and effectiveness are discussed with a conclusion on further directions for research.

2.1. Feedback

Feedback is the central operating principle of HEMS. Though there have been mixed results [8, 15], feedback has in general proven its merits in several researches [9, 16, 17].

Feedback needs a medium to be transported through. While at first researches on feedback often used written messages to relay feedback or written requests to participants to self report meter readings, the opportunity to use technical systems soon became apparent. The advantages of a HEMS is that it can give real-time feedback at any moment of day, whenever the user chooses. This gives additional possibilities to users in their utilization of feedback and has vantages over feedback presented at fixed points in time that have been unnaturally orchestrated by a researcher.

When considering the development of the use of HEMS in research, McClelland and Cook [18] were forerunners in the use of an in-home display for attaining electricity reduction. Van Houwelingen and van Raaij [9] were pioneers in using the Indicator that gives feedback on residential gas consumption. Others have used HEMS for peak-shifting purposes [19, 20]. In recent years HEMS research has really taken flight with numerous studies underway, often in cooperation with utility companies [16, 21].

Most researches have concentrated on applying a HEMS that only gives factual feedback or, in other words, only measures and displays energy consumption numerically. Different case studies have varied in types of feedback and the manner in which it has been given: E.g. how real-time, accurate, detailed, or at which level the feedback is given, as well as the possible addition of other interventions. Though a comparison between researches is difficult, a distinct effect on energy reduction effectiveness can be ascertained in a number of these areas: The type of feedback such as comparative, factual or social [22, 23], and the addition of other interventions such as goal setting or information [14]. Increased effectiveness through disaggregated feedback at appliance level rather than household level also seem to be present [10], but currently there is a disturbing lack of further research on direct feedback at appliance level. In other researches these differences result in usability issues which will be discussed in the next section.

2.2. Usability

HEMS have been introduced from a social and behavioural point of view as a means to give people feedback. But it is important to study how people use HEMS in actual life from a usability and design perspective so that the design can be improved to increase both usability and effectiveness.

Certain studies have found that users use the HEMS (in hand) to track down pronto the appliance that is at that moment in time causing the high energy consumption being displayed. [24, 25] Knowing this, designing the HEMS to give accurate and real-time feedback becomes essential. Only then is this type of utilization really advantageous to users. However, with HEMS giving feedback at household level, this tracing back by consumers to appliances can also provoke a single-minded concentration on peaks [24] thus neglecting continuous lower energy consumers that use more in the long run. Attention should be paid to delays or infrequent data transmission, as this can have negative effects for understandability, leading to inexplicable peaks usages for users.

Another usability aspect is the apparent change and decrease in usage of HEMS over time. Two studies by Ueno et al., [10, 26] reported drastic decreases in use during the first couple of weeks, after which stabilization took place. Similarly, respondents in the 'PowerPlayer' pilot used it 1.6 times per day on average over the course of three months, but indicated that at a certain point in time they knew their energy use, and used the 'PowerPlayer' less [27]. Respondents did add that they would use it again when buying new appliances. It is also apparent that under a limited group of users certain habits develop around HEMS [24, 25], yet strengthening these (positive) habits through design considerations has not been studied. Furthermore, to study habits around HEMS and long-term energy reduction effects, longitudinal studies are necessary. However, the amount of longitudinal studies are limited [11] and in the cases that they have been conducted they are somewhat indecisive [9, 16] or reduction results remain unmentioned [26]. Follow-ups, in the period after the case study is discounted, are even rarer with some indecisive results [9, 11].

Furthermore, there is a profound lack of research on directly increasing the participant's ability to reduce energy consumption through giving possibilities to control energy consumption at the same moment the feedback is given. In other words; implementing a HEMS that not only measures but also manages energy consumption. Giving people direct ability to control their energy consumption once they have received feedback has strong benefits. It fits in well with the motivation-opportunity-abilities (MOA) behavioral model by Ölander and Thøgersen [28].

2.3. Influence of Design

If one continues along the line of usability to the design of HEMS, then it is striking that few scientific researches display (or describe) the HEMS that are used in their case study, with a few exceptions that give a visualization to a certain extent [8, 26, 29]. It appears that most scientific researches [16, 19, 21, 24] have used an existing HEMS that was at hand rather than develop a HEMS according to certain behavioural principles or design criteria [8]. White papers often do give mention to design [20] as a development company is commonly involved. These papers often have a more product testing focus.

No researches could be found in which side-by-side comparison of differently designed HEMS was conducted. McCalley and Midden[14] and Midden and Ham [23] are more or less an exception as their studies implement device embedded feedback (rather than a separate HEMS) and, in the second instance, do this in comparison with a robotic agent. Their study implicitly shows that feedback through a HEMS can not be seen separate from the architectural and interface design of HEMS.

Wood and Newborough [30] have given a tentative overview of aspects to be considered in the design of HEMS, using knowledge from Human-Computer Interaction (HCI). These aspects are: categorisation of energy consumption, units, frequency and timescale, (graphical) representation methods, and type of interventions or motivator. They then make a distinction as to where the feedback display is placed, either local, i.e. embedded in individual appliances, or a central HEMS. For these types of placements they indicate which of the abovementioned aspects are important. Furthermore an activity based design is also suggested as more than one appliance is often needed to complete an activity such as laundry or cooking.

Though their research is a good start to recognize the importance of design, their evaluation misses an extensive review of past research applying HEMS for underpinning. It also has a limiting assumption of only using an interface to display feedback while other forms are also possible [23, 31].

Certain companies do realize the impact that HEMS design can have. The Wattson's design [31, 32] is specifically intended to draw attention in the periphery of a user's sight through the movement of the scrolling kWh digits, in contrast to the frozen digits of common LCD displays of HEMS. Additionally, the colour of the ambient light changed according to consumption levels accommodating visually inclined users. Similarly, the Wattcher [25] was specifically designed and tested to be an appealing product. It was tested under 300 households for 5 months, reducing energy consumption by 7%. However in both cases, it can not be said what the specific influences of the design on the effectiveness are. The company Positive Energy is implementing persuasion tactic together with scientist R.B. Cialdini. There are positive results in the implementation of improved energy bills [33] and ongoing developments in product design in the form of smart meter web applications [34]. This leads to the next key area which is the use of persuasive technology in HEMS.

2.4. Persuasive Design

As discussed before, there are many ways to give feedback, and feedback is just one of several antecedent and consequence behavior change interventions. This is one field of knowledge. Another approach is influencing behaviour through ‘persuasion techniques’ [35] as classified by Cialdini. Some of these subconscious motives are instruments usable within the design of a single intervention, while others intrinsically are an intervention according to intervention taxonomies. Their use as instruments for both shaping environmental behaviour change interventions and especially for designing products is significant. Early on, Kantola et al. [36] already proved that appeals to a participant’s cognitive dissonance has impact on the effectiveness of feedback. Cialdini and colleagues have studied possibilities for social proofing and normative conduct [37, 38], and he is now also moving into implementation in product design as discussed before.

Persuasion strategies are not reserved to human interaction alone. There are numerous similarities between the manner in which people interact with each other and the manner in which they interact with (the interface of) a product. People talk to products, show affection, or get angry with products in a very similar fashion to the way they do with other people. The manner in which products are designed can effect peoples emotions and the manner in which they act. Knowing this, it is but a small step to reason that the aforementioned influence tactics could be integrated into products to persuade people into acting in a certain way. This has been coined ‘captology’ by Fogg [39] who has also developed a behavior change model [40] to practically assist designers in creating persuasive products. Motivation, ability and trigger are the three principle factors herein.

Merging these theories and combining them with work from other (design) fields, Lockton [41, 42] is developing the Design with Intent (DwI) method. DWI is defined as “design that’s intended to influence, or result in, certain user behavior” through six ‘lenses’ that can motivate, enable or constrain a certain behavior.

The work of the aforementioned authors is decisive for the design of HEMS and is a strategy to implement alongside the use of interventions. Persuasive technology is significant for how the feedback and given information is designed within the interface and architecture of HEMS. It can help in strengthening habits, increasing use, and heightening effectiveness. If one implements Fogg’s line of thinking to Home Energy Management Systems, then the first step would be to create the right triggers at the right moment. Another step could be to increase the simplicity to heighten ability. Cialdini, like Fogg, teaches that the manner in which something is presented to a user is very significant. Plucking the right snare however is the hardest part which needs to be studied further. Certain influence tactics have already been implemented in commercially available HEMS, but the consecutive step needs to be to test the actual benefits on attained energy reduction.

3. Conclusions

All the above mentioned areas are relevant to the design of HEMS. The focus is on testing and finding the right balance in types of intervention and persuasion tactics and how the interventions are brought across to the user. Especially the long-term effects need to be studied more.

A significance observation is that many researches in scientific literature do not visualize or name the HEMS that has been used within the research. To a lesser extent this also holds true for grey literature that has not been peer reviewed. While some do state that research has gone into the HEMS used, the lack of explanation of the type of HEMS and its design within research articles implicitly states the lack of attention given to the design. Not much can be concluded on the effects of design as the design has not been made explicit nor has the design of HEMS been part of the research methodology, but the lack of mention of the design in itself is telling.

Furthermore practically no variations in the design of HEMS have been tested within one case study. Rather, only comparisons between groups with HEMS and groups without HEMS have been studied. In these studies additional groups receiving other (feedback) interventions have however sometimes also been monitored. While this is positive for understanding the added value of HEMS there is now a need to move on to the following level and consider the differences between HEMS.

In closing, a main area of consideration is the long-term perspective for usage of HEMS. The slowly evolving place or role of HEMS within households needs to be considered, along with the implications this has for the design of HEMS. An additional consideration is whether they are intended to be used ‘forever’ (or at least their technical lifespan) or for a limited period of time, justifying a lease construction? This has implications for how HEMS should be designed, whether in the foreground, as persuaders, or more in the background, as managers subtly correcting the unwanted behavior of users. Most intervention, persuasion and other strategies focus on attaining behavior change, for which product design can be used as shown in the previous sections. These tactics are useful for foreground HEMS. However, not much research has been done on the design of a 'don't-interact-with' or 'background' product, though some, like "Eternally Yours", try to attain the opposite. Therefore more research is needed on the mediating role for HEMS that achieve energy reduction to inhabitants of both old and new houses in the Netherlands.

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