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**Publication date**
2009

**Document Version**
Accepted author manuscript

**Published in**
First European Energy Efficiency and Behaviour Conference

**Citation (APA)**
van Dam, SS., Bakker, CA., & van Hal, JDM. (2009). The mediating role of Home Energy Management Systems. In *First European Energy Efficiency and Behaviour Conference* (pp. 1-20).

# The mediating role of home energy management systems

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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.

In the Netherlands more than half of the CO2 emission of households is caused by energy using products while not in use, or by those designed to function in the background of people's daily lives, with little direct interaction between the user and the product. Research has hardly paid attention to the role that HEMS can play towards energy conservation of these background products. HEMS that manage energy at product level can mediate better with background products than those that measure at household level. However, these HEMS often function in the background themselves, countering the effects of user's behavior by assuming control of devices. Others are designed to create awareness; motivating or engaging users to change behavior through feedback. However, there is evidence that HEMS which only give feedback at household level, gradually fade into the background, jeopardizing energy reduction and undermine their existence. These findings have several implications for the mediating roles of HEMS, which are elaborated in this paper. If HEMS are to become truly effective, future research needs to focus on improving longitudinal effects and studying the influence of design.

***Keywords:*** *energy monitor, energy management, conservation, household, background relation*

HEMS: Home Energy Management System

# Introduction

Households and their energy use play an important factor in the sustainability of a country as a whole. In 2007 the Dutch government reached an agreement on their climate goals for 2020. The ambitious aim is by the year 2020 to have reduced the amount of C02 emissions by 30% in comparison to 1990. 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 (Passive House Institute, 2009).

Household energy consumption is caused by an array of different appliances. Western household commonly have a range of 28 to 67 appliances (Milieu Centraal, 2005, Ellis, 2009), 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 (Stevels et al., 2001). 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 (Terpstra, 2008). An energy efficient product does not guarantee energy efficient utilization by its users (Derijcke and Uitzinger, 2006) as housekeeping rituals change over time and change under influence of shifting social norms (Shove, 2003). Reducing the energy consumption of one appliance or technical installation will not make a whole household sustainable.

Home Energy Management Systems (HEMS) can help households reduce energy consumption while taking 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 (Hutton et al., 1986, van Houwelingen and van Raaij, 1989, Ueno et al., 2006b). 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 mediating roles can HEMS play and what further research is needed in this area? 2) What is known from past research on the influence of design on the (long-term) effectiveness of HEMS?

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.

## 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., (Abrahamse et al., 2005) 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 (2006). 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 (2008) 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 (2002) 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. There are however some limitations as HEMS research is a quickly developing area, with language barriers and confidentiality issues concerning recent empirical studies. As far as possible, data is given in these areas.

## 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. Feedback can be useful for raising awareness of energy consumption that is not easily traceable to a given appliance because the appliance or its energy consumption is ‘invisible’ to users. Yet not all types of feedback or all types of HEMS are as suitable for this purpose. To create suitable HEMS, their design needs to be considered. Feedback closely intertwines with the interface or architectural design of HEMS, and this paper will therefore 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.

## Feedback and the use of technology

Feedback is the central operating principle of HEMS. Though there have been mixed results (Hutton et al., 1986, Seligman et al., 1978), feedback has in general proven its merits in several researches (van Houwelingen and van Raaij, 1989, Mountain, 2006, Staats et al., 2004).

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 (1979) were forerunners in the use of an in-home display for attaining electricity reduction. Van Houwelingen and van Raaij (1989) were pioneers in using the Indicator that gives feedback on residential gas consumption. Others have used HEMS for peak-shifting purposes (Sexton et al., 1987, Nexus Energy Software, 2005), which will not be discussed in further details. In recent years HEMS research has really taken flight with numerous studies underway, often in cooperation with utility companies (Mountain, 2006, Mountain, 2007).

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 (Brandon and Lewis, 1999, Midden and Ham, 2009), and the addition of other interventions such as goal setting or information (McCalley and Midden, 2002). Furthermore, Increased effectiveness through disaggregated feedback at appliance level rather than household level also seem to be present (Ueno et al., 2006b), but currently there is a disturbing lack of further research on direct feedback at appliance level. The mentioned differences also result in usability issues and have consequences for the mediating of HEMS. The next sections will discuss these issues.  However, first a backdrop on contextual aspects of household energy consumption that are relevant to the discussion of the mediating role for HEMS will be given.

## Background relations

Many products operate in the background either physically or in the back of our minds. Additionally, energy flows in households are mostly invisible. In the following discussion, there is an assumption that there is a relationship between a.) Visibility of products within a household and b.) User's unawareness of the energy use of products. It is important to understand users intangible relationship with energy and the appliances consuming energy as HEMS are often intended to create awareness of energy consumption. It can therefore shed light on the mediating role for HEMS.

### Background relationship with appliances

Background relations with technology is described from a philosophical point of view by Ihde (1990) who describes products who have an 'absent presence' in households. An increasing amount of appliances, especially technical installations, function autonomously i.e. self-regulate their energy use. Most of these autonomous products are also intended to function in the background of people's attention and daily activities. This means that next to the fact that they function autonomously there is also little to no interaction with the end user. Borgmann (1995) describes this as disburdening but also disengaging technology. Background appliances are a significant contributor to the energy consumption of households. More than half of $CO_2$ emissions of households is caused by background appliances or by 'background energy consumption' used in periods that appliances are not actually in use. Examples of background energy consumption are energy leakages through the use of standby functions with additional losses through the constant energy consumption of transformers and adaptors. While there are a number of important beneficial aspects to users, it also undermines the direct cause and effect relationship between users, their behavior and their energy consumption. For users the relationships between their behavior and their energy consumption is often no longer apparent.

### Background Energy Use

However it is not only the appliance itself that are 'invisible', it is also energy itself. While inhabitants may only realize the presence of certain appliances when they malfunction or breakdown, energy is even more invisible than background appliances. Energy has become a commodity that people have become largely unaware of. Electricity, gas and water are relatively cheap and abundantly available to the extent that the supply is (still) often perceived as being unlimited. This will however likely change in the future with fossil fuels becoming scarcer.

In a qualitative research report by Dobbyn and Thomas (2005) it was noted that "Gas and electricity use operates at the level of the sub-conscious within the home. There is little conscious awareness that lights, heating and appliances within the home are running off fossil fuels extracted from the earth and sea." (pg. 6) They see the main challenge as "raise(ing) people's use of energy in the home from the subconscious to the conscious, and enable them to feel part of the solution." (pg. 2). Two similar quotes in a 10 household case study on energy monitors in Britain (Kidd and Williams, 2008 pg. 11) show similar perspectives "Electricity is very invisible isn't it, you can sort of pretend that it's not doing any harm… (with gas) I feel differently because they drive up in a lorry and fill the tank up" While these cases are situated in England, there is no reason to believe that this is not also the case in the Netherlands. Perhaps it is even more invisible in the Netherlands as gas is also brought to household through an ‘invisible’ network of pipes.

## Mediation role of HEMS

HEMS are valuable for bringing background products to the foreground and thus under attention of the user. They can also contribute to making invisible energy flows visible. However, the degree in which HEMS are currently suitable for these purposes varies considerably and, research has currently only applied a limited number of possible roles and functionalities of HEMS.  Furthermore, while certain appliances are intentionally designed to function in the background, disburdening users of the need to actively monitor or manage a wide assortment of appliances, most HEMS are not. However they can suffer a similar fate. A number of researches have ascertained that HEMS themselves tend to disappear into the background over time or becoming obsolete. This could contribute to why longitudinal research on the effectiveness of HEMS is limited and hard to substantiate. Furthermore this drifting into the background raises questions on how HEMS should be designed.

### Different roles for HEMS

Before discussing the mediating role for HEMS from a design perspective, Ihde’s (1990) philosophy of technology perspective is a good starting point.
What is important to realize is that for HEMS different levels of involvement between users and technology are present: The involvement of users *through* the HEMS with other appliances and the involvement with the HEMS *itself*.
First and foremost, the mediating role that HEMS have between users and other products and their energy consumption is essential. It is difficult, even unwanted, to physically ‘experience’ how much energy an appliance is using. Humans need technology (in the case a HEMS) to see a visual representation of the energy consumption, mentally interpret the given value and in doing so perceive the energy consumption of other products. Ihde calls this a hermeneutic relationship with users. Secondly, an alterity relationship between users a HEMS takes place where the HEMS in *itself* is the continual focal point of attention.
Furthermore, a key area in the energy consumption of households is the background relationship of users with appliances, as discussed earlier. However, it

can happen that, over time, a HEMS itself becomes a background product. When a background relationship between users and HEMS is not intended then it is important that an alterity relationship between users and HEMS is designed to take place. In other words, these HEMS should be designed as ‘foreground’ HEMS. On the other hand some HEMS are designed to function more in the background. Yet these aspects are not considered enough currently in the design or research of HEMS. The following paragraph highlights researches showing that HEMS easily drift into the background of people’s attention or sometimes even discontinue to be used.

### HEMS drift into the background

The most detailed research into change and decrease in usage of HEMS over time and how HEMS fade into the background has been done by Ueno et al. (2006a, 2006b). Both studies reported drastic decreases in use during the first couple of weeks, after which stabilization took place. The second study is one of the few who monitored HEMS use over a prolonged period of time. A precise record was kept of how often the HEMS was used during the course of 9 months and which controls were pressed. Yet their research only portrays the results on how often their HEMS was *used* for the full extent of the nine months. Reports on energy reduction are only for the 28 representative weekdays after installations, which is compared to the 28 representative weekdays before installations and a control group. It is questionable why energy reduction was only reported for the first representative 28 weekdays, while the research ran a full 9 months.
Likewise, respondents in the ‘PowerPlayer’ pilot (Firet L.T., 2009) used the different screens 1.6 times per day on average, with the amount greatly varying between a total of 41 to 256 times per household over the course of three months. Total use could be higher as no records were kept when the PowerPlayer was only switched on from standby mode to the start screen. In the follow-up questionnaire, participants indicated that at a certain point in time they knew their energy use, and used the ‘PowerPlayer’ less. Respondents did add that they would use it again when buying new appliances. However no data was present of how the use of the PowerPlayer actually changed during the course of the case study.
In the five month case study of the Wattcher in the Netherlands (Wayenburg, 2009) 23% of participants stated in the survey at the end of the case study that

they used the energy monitor more while 57% stated they used in less. On the contrary, Dobson and Griffin (1992) shortly mention that in the follow-up interview participants stated to have increased their use of the Residential Electricity Cost Speedometer (RECS).
Lofstrom (2008) addresses the use of a Power-AwareCord, which is basically an energy monitor at product level. She tested it for two months with six households and found that the interaction changed over time. Whereas in the beginning people were enlightened by the energy use of an appliance, after a certain point in time the Power-Aware cord 'just' became a decorative element likened by all participants to Christmas lights.

It is also apparent that  under a limited group of users certain habits develop around HEMS (Kidd and Williams, 2008, Wayenburg, 2009), yet strengthening these (positive) habits through design considerations has not been studied. Habits can be devised as a strategy to prevent HEMS from drifting into the background since they imply a continuing use. However, to study habits around HEMS and long-term energy reduction effects, longitudinal studies are necessary. Yet, the amount of longitudinal studies are limited (Abrahamse et al., 2005) and in the cases that they have been conducted they are somewhat indecisive (van Houwelingen and van Raaij, 1989, Mountain, 2006) or reduction results remain unmentioned (Ueno et al., 2006a). Follow-ups, in the period after the case study is discounted, are even rarer with some indecisive results (van Houwelingen and van Raaij, 1989, Abrahamse et al., 2005). A follow-up of the Wattcher case study is currently being undertaken, but it is to early to publish results here.

## Relation of HEMS to background appliances

In the discussion of background appliances and HEMS, the level at which feedback is given becomes significant. When giving disaggregated feedback of the energy consumption of (background) appliances, it becomes much easier for users to ascertain the cause and effect relationship between their behavior and the energy consumption of specific appliances. Disaggregated feedback can also be useful for signaling problems concerning the (energy consumption) of background appliances that would otherwise go unnoticed much longer. Especially for technical installations such as PV panels, heaters, ventilation systems and the

likes, it would be worth considering. Yet extremely limited research has implemented HEMS giving feedback of *actual* consumption at product level as discussed previously in the section on feedback.
Certain studies have already found that users utilize a HEMS giving feedback at household level (in hand) to track down pronto the appliance that is at that moment in time causing the high energy consumption being displayed. (Kidd and Williams, 2008, Wayenburg, 2009) Knowing this, designing the HEMS to give accurate, real-time, and possibly disaggregated 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 (Kidd and Williams, 2008) 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. Giving disaggregated feedback can also solve (part of) the problem.

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 (1995). HEMS that can control energy use of appliances also implicitly function more as background HEMS, subtly correcting unwanted behavior of users in a way that does not hinder their daily routines and activities. If this is advantageous to lasting energy reductions is however yet to be studied.

In conclusion it is believed that HEMS can alter the relationship people have with energy-using products (EuP’s) and decrease energy use. The effects that a HEMS can have on that relationship, but also the choice for it’s design, is dependant on the type of human-product relationship that is present but most likely also linked to the issue of the commodity of energy.

However, it is not to be forgotten that although certain products are designed to be interacted with in a particular manner, this does not guarantee that actual relationship of users with products will develop as intended by a designer (Verbeek, 2006). Furthermore, this relationship is strongly dependant on the context of use and can thus vary. It is also highly plausible that psychological characteristics of individual users play are role, and that some HEMS are more suitable than others depending on the user. Certain HEMS appeal to users who enjoy playing ‘detective’, tracing back feedback of overall energy consumption to individual appliances, and expecting users to change their own behavior. Others HEMS are designed to give disaggregated feedback providing bite-size pieces of information that are easier to understand but can also additionally take control and counter certain unwanted behaviors. This will perhaps appeal to other user. The following section will discuss design aspects in further detail.

## The role for design

The next section discusses to what extent researchers have taken into account the design of HEMS, in particular the design of the human-HEMS interaction. In this explorative discourse the hypothesis is that using specific design strategies and design knowledge can help make HEMS more effective, particularly in the long run.

The literature review shows that the design of HEMS has been mostly ignored, with some notable exceptions. In general, the quality of the design was low compared to the current state of the art and knowledge in the interaction design world. For instance: acknowledged design principles such as persuasive technology have not applied and designs are too technical.

### Influence of Design

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. This human-product interaction concerns the “use, understanding and experience” of products with respect to the “physical, cultural, technological, and societal contexts” in which they are used (DUT, 2009).

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 (Van Houwelingen and van Raaij, 1988, Ueno et al., 2006a, Hutton et al., 1986). It appears that most scientific researches (Sexton et al., 1987, Mountain, 2006, Mountain, 2007, Kidd and Williams, 2008) have used an existing HEMS that was at hand rather than develop a HEMS according to certain behavioural principles or design criteria (Hutton et al., 1986). Grey literature often does give mention to design (Nexus Energy Software, 2005) 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 (2002) and Midden and Ham (2009) 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 (2006) 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 (Midden and Ham, 2009, Sawdon Smith, 2008).

If one looks at commercially available HEMS then a technical design can be commonly noted. This can lead to usability problems for some users. As was documented for one participant with the use of the Current Costs monitor (Kidd and Williams, 2008) "I certainly haven't used it … I certainly am not techno..." This can perhaps be explained by the background and type of companies that traditionally mostly dominated the HEMS market. These are commonly engineering or electronics firms with a background in business to business markets or the sensor industry.

Certain younger companies do realize the impact that HEMS design can have. The Wattson's design (Sawdon Smith, 2008, 2009) is specifically intended to draw attention in the periphery of a user's sight through the movement of the scrolling kWh digits. In contrast, the digits on common LCD displays of HEMS are usually devoid of motion, apart from the split second when a number changes on screen. Additionally, the colour of the ambient light changed according to consumption levels accommodating visually inclined users. In a sense these aspects plays on a more positive notion of 'absent presence'. Similarly, the Wattcher (Wayenburg, 2009) was specifically designed and tested to be an appealing product that people would want to buy and display. 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 tactics together with scientist R.B. Cialdini. There are positive results in the implementation of improved energy bills (Carroll et al., 2009) and ongoing developments in product design in the form of smart meter web applications (Positive Energy, 2008). This leads to the next key area which is the use of persuasive technology in HEMS.

## Persuasive Design

As discussed before, there are many ways to give feedback, and feedback is just one of several antecedent or consequence interventions. This is one field of knowledge. Another approach to influencing behaviour is through 'persuasion techniques' (Cialdini, 1993), 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. (1984) 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 (Goldstein et al., 2008, Nolan et al., 2008), 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 people’s 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 (2003) who has also developed a behavior change model (Fogg, 2009) 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 (2008, 2009) 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 HEMS, 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.  However, these tactics are of the most use for ‘foreground’ HEMS as these are intended to be interacted with regularly.

## Conclusions

Feedback using HEMS was first mainly introduced by social scientists, and HEMS engineers have linked technical solutions with market potential. In this process the effectiveness of HEMS has been proven but neither of these actors have had explicit knowledge on design and usability nor studied their effects. Feedback through a HEMS can not be seen separate from the physical design of the HEMS.Therefore it is now time to study and develop HEMS that have higher effectiveness because people want, understand and continue to use them.

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. However the opportunities for HEMS have not yet been optimally utilized. HEMS can assist in the key areas in households as they have the opportunity to be implemented in existing households, possibly assisting in raising the awareness for the need for home improvements, and, more directly, drawing attention to the energy consumption of sum of the appliances that are present.

A significant 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 for their technical lifespan) or for a limited period of time, perhaps justifying a lease construction. This also has implications for how HEMS should be designed, whether in the foreground, as persuaders, or more in the background, as managers subtly correcting the undesired 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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