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Smart Energy Management for Households

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Contents (concise)

Preface

In rounding off five years of research and embarking on a new journey, I would like to take the time to thank the people involved. It has been a long marathon, which at times felt more like a roller-coaster ride, and I could not have done it without the help and support of all the people involved both directly and indirectly.

I want to begin by thanking my supervisor and daily supervisor Anke van Hal and Conny Bakker. Thanks for taking the risk with me as your first PhD candidate and helping me grow. Anke, your inventive solutions when I didn't know a way out anymore after yet another letdown in the execution of the case studies were a blessing. Conny, our weekly meeting were inspiring, and the time and effort you put into extensively reading and commenting on everything I wrote is immensely appreciated. Though occasionally the initial shock of finding a paper or chapter completely covered in comments had to wear off.

Within my research, many people and companies were involved, in executing HEMS trials, gathering data, or as participants in case studies or think tanks. This research wouldn't have come about without you: Innovaders, Plugwise, Quby, Alliander, Eneco, and Aurum for your openness and/or willingness to let me come aboard the different initiatives you were undertaking; There are too many employees to name individually, but I would like to thank one person in particular that I worked together for two years, Tako in 't Veld, who has the unique gift and practical approach to see opportunities and what is possible, despite the circumstances; all the participants of the three case studies, and in particular the 50 participants who (repeatedly) gave me so many meaningful insights into their lives, for your willingness, time and, perhaps most of all, patience and endurance; all the participants in the three think tank sessions: Anke van Hal, Conny Bakker, Arno Wayenburg, Norbert Vroege, Pim van Gennip, Gijs Postma, Dirk Smallenbroek, Hanneke van der Horst, David Keyson, Henk Seinen, René Nederhoed, Roelof de Vries, Mark Spee, Pablo van der Laan, Jan Willem Croon, Zeno Winkels, Marie Therese Anderwegen, Patrick Koch, Charlotte Kobus, Harry van Breen, Geert-Jan Dirven, and Dirk te Winkel for your input and feedback; And finally, Han Brezet and the Cartesius Institute for your initial role in giving me the opportunity to embark on this PhD research.

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I began by addressing the people who have been involved in my research, but the most important people in my life and the ways they made it possible for me to conduct this research have remained unmentioned. To my family, in-laws and friends, thanks for your support and for putting up with the stressful moments and accompanying mood swings. There are three people in particular that I would like to thank: To my mom and dad, for your outlook on life, for teaching me how to think for myself and question common opinions, for opening my eyes to our responsibility of managing this earth's resources well, and for your forethoughtfulness that showed through in, for example, implementing solar panels and CFL's in the late 1980's; and, most importantly, to Willem, thanks for your unwavering faith in me and your support and encouragement. I would not be here without you by my side.

To anyone I might have forgotten: it was not on purpose.

Summary

The aim of the research presented in this thesis was to infer design-related insights and guidelines to improve the use and effectiveness of home energy management systems (HEMS). This was done through an empirical evaluation of the longitudinal effectiveness of these devices and an exploration of factors that influence their use and effectiveness. Three case studies executed with three different HEMS in households, a life cycle assessment (LCA) on those three HEMS, as well as a reflection on the challenges of both researching and implementing HEMS in existing housing gave a comprehensive picture of the opportunities and barriers for HEMS. The research revealed five typical use patterns that emerged amongst households. It also revealed average energy savings of 7.8%, which however decreased in the follow-up that was conducted, and factors that may influence the use and effectiveness of HEMS. Nonetheless, the LCA calculations divulged that the HEMS can achieve net energy savings when taking their embedded energy into account.

Problem statement: The goal of reducing the energy consumption of existing housing formed the basis for this research. There are many facets to this energy consumption, including the characteristics of the house, its appliances, and the behaviours of its inhabitants. Because of this complexity, addressing only one of these facets is not effective in substantially reducing the overall energy consumption of households. This called for an interdisciplinary approach, merging the domains of design for sustainability, sustainable housing transformation and environmental psychology. In this thesis, HEMS were chosen as the intervention to address the various elements that contribute to household energy consumption, thereby functioning as a pivot. By giving feedback and/or helping manage consumption they can assist households in changing their behaviour and help save energy. However, in analysing literature on HEMS, four critique points were encountered. Past research tends to be limited in the types of HEMS and energy sources studied. Furthermore, limited knowledge was available on the longitudinal effectiveness of HEMS, the large variances in achieved energy savings and use of HEMS, and factors influencing their use and effectiveness.

Conceptual framework: To address these critique points and explore the influence of the factors: user, HEMS, other people, other products, context, and time; a framework was proposed. It postulated the pivotal role of HEMS and visualized the interdependence of the different elements. This framework structured the findings of the research.

Case studies: Three case studies were conducted. The first case study with an electricity monitor revealed that the effectiveness of HEMS tends to decrease over time. The initial savings in electricity consumption of, on average, 7.8% after four months were not sustained over a period of 15 months. The participants were divided into three groups,

who all had the same rate of fall-back. However, the group that had a daily habit after 15 months of checking the monitor, achieved the largest savings in comparison to the groups that did not have a daily habit after 15 months or that returned the monitor after four months. The second and third case study with a multifunctional HEMS and a energy management device revealed five distinctive use patterns: there was often one main user who varied strongly in their knowledge of, interest in, and affinity with energy and technique in general, resulting in different needs and desires concerning the HEMS. Additionally, the studies revealed that contextual factors, such as the structure of the home and its energy meters, can impede the use and implementation of HEMS.

Lifecycle assessment: The positive result of the LCA was that all three types of HEMS can theoretically achieve net energy savings (where $e_{invested} < e_{saved}$) over the course of five years in the six scenarios that were created. However, it can take up to 24 months to achieve net energy savings, depending on the scenario and type of HEMS. No HEMS achieve a positive return on investment within five years in all six scenarios.

Conclusions: This research found that the role of HEMS in reducing the energy consumption of households is constrained when not taking the factors into consideration that were distilled in the case studies. For one, human factors, such as the characteristics of the user and other household members and family dynamics, may influence the use and effectiveness. Furthermore, physical elements, such as the design of the HEMS (e.g., the type of feedback, the quality of the technique, its usability and applicability) the design and functioning of appliances and the dwelling played a role. Particularly, the interplay between people and these physical elements such as the match/mismatch or compatibility/incompatibility between HEMS, users, appliances and the dwelling were influential, in part due to the complexity of reducing energy consumption and users' preferred type of reduction approach. Based on these factors, design guidelines where formulated for HEMS with the aim to achieve lasting energy savings and increase the usability of HEMS. Examples of these guidelines are: HEMS should not be developed as standalone interventions but should be incorporated as part of a broader, overarching change strategy; one size does not fit all; and careful trade-offs needs to be made with regard to the design of the HEMS, e.g., while a small display size is positive for the LCA, it could limit the potential to influence behaviour.

Relevance: The resulting knowledge of these studies can be employed to inspire the different domains merged within this thesis. For the HEMS industry: in striving to designing HEMS that are capable of influencing users, effective in reducing energy consumption, and easily usable and implementable in everyday life. For the building industry this research illustrated the benefit of considering the behaviour of inhabitants in achieving sustainable housing transformation. Furthermore, lessons were presented in how the building industry can contribute to increasing the ease of implementation of HEMS. HEMS researchers may assimilate knowledge for future research to deepen the knowledge on ways of increasing the effectiveness of HEMS.

Samenvatting

Het doel van dit onderzoek was om ontwerp-gerelateerde inzichten en richtlijnen te ontwikkelen om de bruikbaarheid en de effectiviteit van thuis energie management systemen (HEMS) te verbeteren. Dit werd gedaan door middel van een empirische evaluatie van de longitudinale effectiviteit van deze apparaten in huishoudens en een exploratief onderzoek naar factoren die hun gebruik en effectiviteit kunnen beïnvloeden. Er zijn drie case studies en een levenscyclusanalyse (LCA) uitgevoerd met drie verschillende HEMS, alsook een reflectie gedaan op de uitdagingen van zowel het onderzoeken en implementeren van HEMS in bestaande woningen. Dit gaf een volledig beeld van de mogelijkheden en barrières voor HEMS. Het onderzoek liet vijf verschillende gebruikspatronen van HEMS zien die ontstonden onder huishoudens. Daarnaast werd een besparing van gemiddeld van 7.8% gepresenteerd , die echter wel terugliep in de tijd, en factoren die het gebruik en de effectiviteit van HEMS kunnen beïnvloeden. Uit de LCA berekeningen bleek dat HEMS, in theorie, netto energie besparingen kunnen behalen als de energie die nodig is voor productie, gebruik en afdanking in ogenschouw worden genomen.

Probleemstelling: Het verminderen van het energieverbruik van bestaande woningen vormde het uitgangspunt voor dit onderzoek. Er zijn vele facetten aan energieverbruik, zoals de kenmerken van het huis, de apparaten, en het gedrag van bewoners. Door deze complexiteit is het niet effectief om alleen op een enkel aspect te focussen, omdat daarmee het totale energieverbruik van huishoudens niet substantieel wordt verminderd. Daarom is een interdisciplinaire benadering noodzakelijk, welke werd bereikt door samenwerking tussen de domeinen van 'design for sustainability' en 'sustainable housing transformation', en milieu-psychologie.
In dit proefschrift werden HEMS gekozen als de interventie om de verschillende elementen die bijdragen aan huishoudelijke energieverbruik aan te pakken. Door het geven van feedback, het helpen veranderen van gedrag en/of het helpen managen van energieverbruik kunnen HEMS bijdragen aan het verminderen van huishoudelijk energieverbruik. Tijdens het analyseren van literatuur over HEMS werden echter een aantal kritiek punten ontdekt: Over het algemeen werden maar een beperkte aantal soorten HEMS en typen energie onderzocht. Verder was er slechts beperkte kennis beschikbaar over de longitudinale effectiviteit van HEMS, de grote verschillen in het gebruik van HEMS en de behaalde energiebesparing, en factoren die het gebruik en de effectiviteit van HEMS.

Conceptueel raamwerk: Om deze kritiek punten te adresseren en de invloed van de factoren: gebruiker, HEMS, andere mensen, andere producten en tijd te onderzoeken, werd een raamwerk voorgesteld. Dit raamwerk werd gebruikt om de spilfunctie van

HEMS te poneren, de onderlinge afhankelijkheid van de verschillende elementen te visualiseren en om de bevindingen van het onderzoek te structureren.

Case studies: Drie case studie zijn opgenomen in dit proefschrift. De eerste studie met een 'elektriciteitsmonitor' liet zien dat de effectiviteit van HEMS vaak afneemt in de tijd. De initiële besparingen in elektriciteit van gemiddeld 7,8% na vier maanden, was 11 maanden later sterk teruggelopen. De deelnemers werden onderverdeeld in drie groepen die alle drie dezelfde mate van terugval hadden. Echter, de groep die na 15 maanden een dagelijkse gewoonte had opgebouwd om de HEMS te checken behaalde de grootste besparing in vergelijking tot de groep die geen dagelijkse gewoonte had en de groep die de elektriciteitsmonitor na vier maanden terug ingeleverd had.
De tweede en derde case studie met een 'multifunctionele HEMS' en een 'energiemanagement-apparaat' lieten vijf verschillende gebruikspatronen van HEMS zien die ontstonden onder huishoudens. Er is vaak een hoofdgebruiker van de feedback, die sterk varieerden in hun kennis van, belangstelling voor en affiniteit met energie en techniek in het algemeen. Daardoor hadden zij verschillende behoeften, verwachtingen en wensen ten aanzien van de HEMS. Bovendien bleek in de case studies dat omgevingsfactoren zoals de structuur van het huis, en in het bijzonder de energie meters, het succesvolle gebruik en de implementatie van HEMS kan belemmeren.

LCA: Het positieve resultaat van de LCA was dat, in theorie, alle drie soorten HEMS een netto energiebesparing (waar $e_{\text{geïnvesteerd}} < e_{\text{bespaard}}$) kunnen bereiken. Dit werd berekend over een periode van vijf jaar voor zes ontwikkelde scenario's. Het kon echter tot 24 maanden duren voordat een netto energiebesparing werd behaald, afhankelijk van het type HEMS en de scenario. Geen van de drie HEMS bereikte een positief rendement op de investering binnen vijf jaar in alle zes de scenario's.

Conclusies: Dit onderzoek liet zien dat de rol van HEMS in het verminderen van het energieverbruik van de huishoudens beperkt is als de factoren die uit de drie case studies naar voren kwamen niet in ogenschouw worden genomen. Een facet die het gebruik en de effectiviteit van HEMS beïnvloedt is de mens, zoals de kenmerken van de gebruiker en andere leden van het huishouden en de onderlinge familiedynamiek. Daarnaast spelen fysieke elementen een rol zoals het ontwerp van de HEMS (b.vb. de type feedback, de kwaliteit van de techniek, de gebruiksvriendelijkheid en de toepasbaarheid) en het ontwerp van huishoudelijke apparatuur en de woning. Vooral de wisselwerking tussen de mens en deze fysieke elementen zoals de match/mismatch of compatibiliteit/incompatibiliteit tussen HEMS, gebruikers, apparaten en de woning zijn van belang. Dit ligt onder andere aan de complexiteit van het verminderen van energieverbruik, en de verschillende (gedrags- of technisch gerichte) energiereductie benaderingen van gebruikers. Op basis van deze factoren werden ontwerprichtlijnen geformuleerd voor HEMS met het doel om langdurige energiebesparing te behalen en de gebruiksvriendelijkheid van HEMS te verhogen. Voorbeelden van deze aanbevelingen en ontwerprichtlijnen zijn: HEMS zouden niet als een op zichzelf staande interventie ontwikkeld moeten worden, maar als onderdeel van een bredere overkoepelende veranderingsstrategie; er is niet een HEMS die voor iedereen geschikt is; en het is belangrijk om voorzichtige afwegingen te maken in het ontwerp van HEMS, b.v.b. met betrekking tot de maat van de display. Een kleine maat heeft positieve effecten op de LCA echter zou het de potentie kunnen limiteren om gedrag te beïnvloeden.

Relevantie: De verkregen kennis uit dit onderzoek kan worden gebruikt om de verschillende domeinen die vertegenwoordigd werden in dit proefschrift te inspireren. Voor de HEMS-industrie: in het streven naar HEMS die in staat zijn gebruikers te stimuleren, effectief in het verminderen van het energieverbruik, en gemakkelijk bruikbaar en toepasbaar in het dagelijks leven te maken. Voor de bouw wereld toont dit onderzoek de noodzaak en voordeel van het in ogenschouw nemen van het gedrag van bewoners in het streven naar duurzame woning transformatie. Bovendien werden lessen gepresenteerd hoe de bouw kan bijdragen aan het vergroten van het gemak van implementatie van HEMS. HEMS onderzoekers kunnen voortbouwen op de factoren genoemd in dit onderzoek om daarmee kennis te vergroten over de effectiviteit van HEMS.

Contents (extensive)

PART I Literature review: household energy consumption and the role for HEMS

1 Introduction

A family retrofitted their recently bought home with high-tech installations that had the potential to achieve significant energy reductions. However, after several years, the reductions had still not been achieved. The owners were struggling to understand why their energy consumption was higher than expected, and so they called in experts. Several attempts were made to gain control over their consumption, but to no avail. To measure and receive feedback on their energy consumption, smart meters and a device giving feedback were experimented with, but without success. The owners therefore remained in the dark as to whether their technical installations were not living up to expectations, or whether it was down to their own habits, practices and use of the installations.

This is just one of a range of experiences from practice that gave rise to this research. Had a simple device that gives easily accessible insight into and control over a household's energy consumption been available to the above family, it might have helped them to understand the cause of their higher than expected energy consumption and to achieve the energy savings potential.

As is explained in this chapter, there has been research on such devices – namely home energy management systems (HEMS) – but why they are not always used or effective in practice, remains uncertain. The aim of the research presented in this thesis was to explore how HEMS might, not only in theory but also in practice, better contribute to achieving long-term energy reductions in households. This was done by evaluating the longitudinal effectiveness of HEMS and exploring factors that influence their use and effectiveness. The aim was to infer design-related strategies to improve the use and effectiveness of HEMS.

§ 1.1 Household energy consumption and the potential for home energy management systems (HEMS)

Households are responsible for 20% of natural gas consumption and 24% of the electricity consumption in the Netherlands (Energiezaak, 2011). The average electricity consumption is 3480 kWh and the average gas consumption is 1617 m^3 per household (Energiezaak, 2011). There is strong potential to reduce this energy consumption of households. This is particularly the case for the current housing stock, of which over 50% dates back to before the first insulation regulations were introduced in 1975, and

84% dates back to before the energy performance coefficient (EPC) regulations were introduced in 1995 (MvBZK, 2010). Older dwellings therefore need more energy for heating (NIBUD, 2009, Guerra Santin, 2010, p. 156). As only 1% of the total housing stock is added in the form of new housing each year (MvBZK, 2010), focusing on the existing housing stock is essential for achieving overall reductions in Dutch energy consumption.

Technological solutions, such as switching to the most energy-efficient technologies available, could save up to 40% in residential electricity consumption (IEA, , 2009). However, the focus on technology alone appears to have its limitations. Modern washing machines use significantly less energy, water and detergent, but there are no indications that actual energy consumption for washing clothes is decreasing (Terpstra, 2008, Shove, 2003). Technically identical houses that should theoretically consume the same amount of energy might in practice use vastly different amounts of resources due to the behaviours, heating preferences and lifestyles of their inhabitants. Gill et al. (2010) found factors of difference between 2.5 and 7.75 for various utility resources (either measured in totals or per m2 of housing). Specific for heating, factors of difference of 3–6 have been reported (Gram-Hanssen, 2010, Passive House Institute, 2009). According to the method used by Gill et al. (2010), occupancy behaviour explained 51%, 37%, and 11% of the variation in, respectively, heat, electricity and water consumption. As Crosbie and Baker (2009) state: "*It does not matter how much energy hypothetically could be saved by efficient technologies if no one wants to live in the properties, install or use efficient lighting and heating*." Therefore, it is essential to address the behaviour of households in energy reduction approaches. This is discussed in further detail in Chapter 2.

§ 1.1.1 Introduction to HEMS

In the endeavour to reduce the energy consumption of households and tackle this behavioural dimension, smart metering and home energy management systems (HEMS) are receiving increasing attention both in academia (Table 2) and in commercial enterprises. For example, most major energy suppliers in the Netherlands have a type of HEMS on offer for their clients or are testing them, and the UK government aims to have rolled out smart meters and accompanying HEMS to all British households by 2020 (UK Gov, 2013). HEMS are advocated as having a high potential, with norms for savings reported of between 5 and 15% (Darby, 2006a). HEMS is a generic name for a variety of devices that can be found under such names as energy monitors, eco-feedback devices and energy consumption indicators.

HEMS are defined as intermediary products that can visualize, manage and/or monitor the energy use of products or entire households. They are intended to give households direct and accessible insight into their energy consumption and thus help them to reduce it. This makes them different from smart meters, which are predominantly intended to benefit the gas or electricity supplier and distributor, and generally need a HEMS to give users the intended insight. HEMS come in many shapes and sizes, as discussed in the following section.

§ 1.1.2 Typology of HEMS in relation to past research

This section presents a typology of existing HEMS. Depending on the type of HEMS, their purpose and effects are different. Table 1 gives a brief overview of six variables.

Variables	Explanation
Type of energy measured	Gas and/or electricity
Level of feedback	Differs, e.g. feedback on overall household utility consumption, detailed information for separate appliances (disaggregated) or limited to one appliance.
Type of feedback	Varies from factual (e.g. showing real-time, numerical consumption data) through social (e.g. using smiling/frowning faces) to comparative (e.g. current versus historical consumption data).
Strategies to influence energy consumption	Monitors: only give feedback, leaving it to the user to decide whether to act on the feedback Managers: (also) help users control whether and, if so, when their appliances consume energy.
Architecture of the HEMS	Varies with regard to mono-functional or multifunctional, type of interaction and physical location of HEMS (e.g. local appliance-specific solutions, central in-home touchscreens, online web applications).
Intended purpose	Varies: achieving energy savings within the home or peak shifting of the grid load, i.e. creating a more even grid load.

Table 1
Typology of HEMS

The six HEMS variables in Table 1 are elaborated upon in the rest of this section. Using this categorization, a short overview is given of research on HEMS exemplifying the differences between the HEMS market and HEMS research.

§ 1.1.2.1 Type of energy measured

Most HEMS on the market are intended for electricity, because it is technically less problematic to measure and not all countries provide households access to other forms of energy. But there are also some intended for gas, often in combination with electricity. Certain HEMS also, or only, measure water consumption, although strictly speaking water (not counting the energy needed for heating) is not a form of energy. As such, specific home water management systems were not part of this research.

More research has focused on HEMS intended for electricity consumption (Ueno et al., 2006b, McCalley and Midden, 2002, Wood and Newborough, 2003, Kidd and Williams, 2008, Mountain, 2006) than on those intended for other forms of energy. Two of the few exceptions are van Houwelingen and van Raaij (1989) on gas consumption and Ueno et al. (2006a) on overall consumption (electricity, natural gas and kerosene).

§ 1.1.2.2 Level of feedback

HEMS can give feedback at different levels. Some give feedback on overall household consumption at utility level. These basically relay the information from the gas or electricity meter to the user. Others provide additional detailed information for separate appliances. Work has been done to disaggregate the information from the meter using disaggregation algorithms or non-intrusive load monitoring (Zoha et al., 2012, Gupta et al., 2010), but more commonly the consumption of individual devices is read out using plugs. The number of plugs is usually limited. This might mean that only the high energy consuming appliances are connected, as the number of appliances in homes would otherwise make this a very expensive and perhaps too complex system, but it might also be the case that the HEMS is only capable of giving feedback for one specific appliance.

Research with HEMS has either focused on aggregated feedback at utility level (van Houwelingen and van Raaij, 1989, Brandon and Lewis, 1999, Hutton et al., 1986) or on feedback for one appliance. In some instances, the user could decide which appliance to connect (Lofstrom and Palm, 2008, Liikkanen, 2009), while in other cases the HEMS was integrated into or designed specifically for one appliance, such as a washing machine or a cooker (McCalley and Midden, 2002, Wood and Newborough, 2003). Again, Ueno et al. (2006a, 2006b) are among the few to give disaggregated feedback for several appliances in addition to aggregated feedback.

§ 1.1.2.3 Type of feedback

The most common form of feedback is factual feedback, whereby (often real-time) consumption data are visualized in numerical figures. A limited number of HEMS, mostly prototypes, have included attempts to incorporate persuasive techniques and the use of social feedback, whereby for example the feedback is accompanied with smiling/frowning faces. Others have implemented comparative feedback, by for example comparing current versus historical consumption data. The divide between social and comparative feedback can be obscure, either because the two are sometimes combined, or because comparisons between a household and 'others' or neighbours is sometimes referred to as comparative feedback (Abrahamse et al., 2005).

Most scientific research has dealt with HEMS that give factual feedback (Hutton et al., 1986, Kidd and Williams, 2008, Mountain, 2006). Limited work has been done on incorporating social feedback into HEMS (Midden and Ham, 2009, Al Mahmud et al., 2007), even though studies implementing social feedback in energy bills instead have shown potential (Ayres et al., 2009). Historical feedback has also been implemented (Pyrko, 2011).

§ 1.1.2.4 Strategies to influence energy consumption

HEMS can either monitor energy consumption or (monitor and) manage it. The difference is that monitors only give feedback, leaving it to the user to decide whether or not to act on the feedback, while managers help users to control whether and, if so, when their appliances consume energy. This is done by, for example, switching appliances off according to a pre-set schedule or when they enter standby mode. It should be noted that not all HEMS actually give feedback. Some only help manage energy consumption without reporting how much energy is being used, as is the case with standby killers.

Practically all scientific research has focused on electricity monitors (Hutton et al., 1986, van Houwelingen and van Raaij, 1989, Mountain, 2006, Kidd and Williams, 2008), without implementing options to control energy consumption. The results are therefore strongly dependent on the ability of households to adapt their behaviour on the basis of the given feedback.

§ 1.1.2.5 Architecture of HEMS

The architecture – the physical shape and characteristics – of HEMS also varies with regard to their mono- or multi-functionality, portability and physical location. HEMS are commonly dedicated devices that have only one functionality, which is related to the goal of reducing energy consumption. HEMS can also be physically bound to a location or appliance, or be portable. They can vary from local appliance-specific solutions, such as standby killers, to central, fixed or portable in-home screens or touchscreens, to online web applications for smart phones or PCs. Tied into the physical location is a difference in how users interaction with the HEMS. A central screen is rather 'in your face' and you can come into contact with it more by chance in your daily rituals. In contrast, a web application needs a user to actively visit a website.

Researchers have studied a variety of different types, though savings are not always reported. Most of the devices studied have been prototypical and/or dedicated HEMS: HEMS that were still in the prototype phase and/or did not have additional functionalities. They vary from a central display (Mountain, 2006, Kidd and Williams, 2008, Hargreaves et al., 2010), a computer with software (Brandon and Lewis, 1999, Petersen et al., 2007), online web application (Pyrko, 2011), information pages in teletext format on a certain TV channel (Völlink and Meertens, 2006), a local display (Wood and Newborough, 2003), ambient devices (Lofstrom and Palm, 2008), to handheld devices (Wever et al., 2008, Liikkanen, 2009).

§ 1.1.2.6 Intended purpose

The intended purpose of a HEMS can be energy saving or peak shaving. Peak shaving is sometimes more accurately referred to as peak shifting of the grid load, as some research with pricing schemes has shown that the overall consumption is not reduced but rather shifts to cheaper times (Sexton et al., 1987). The environmental benefits of peak shifting are more indirect, as they deal with macro level processes outside the home. With a more even grid load, fewer energy plants – which commonly use fossil fuels emitting more greenhouse gasses – need to be on standby.

Except for in the USA (Sexton et al., 1987, Nexus Energy Software et al., 2005, Pacific Northwest National Laboratory, 2007), most research has been done on HEMS aimed at energy saving. However, with the development of smart grids, more interest is being shown in HEMS that are aimed at peak shifting. The present research focused on energy saving within the home rather than peak shaving. This is because the direct cause–effect relationship of the achieved savings are more apparent for HEMS users, which relates better to the objective of this research to reduce the energy consumption of households.

§ 1.2 Limitations of past research on HEMS

This section goes into more detail about research on HEMS and the measured energy savings. Table 2 provides an overview of the main journal articles on HEMS, with the addition of one report (Mountain, 2006) in order to benefit from its longitudinal nature. This section addresses those aspects that stood out as limitations, and on that basis were chosen to form the starting point for this research.

Four points of critique are explained in this section. The first is related to the typology and concerns the limited overlap between available HEMS and past research on HEMS. Because the typology is not specifically intended to expose the shortcomings of past research, three additional points of critique are addressed based on the studies in Table 2. These are: the short-term focus, the limited scope of past research, and the unknown causes of large variances in savings and the use of HEMS. These formed the main starting points for this research. The scope and the domain of the research are then explained.

Authors	Name of HEMS	Type of measurement	Duration of study	N who recei-ved HEMS	Achieved energy savings
Seligman and Darley (1977), Seligman et al. (1978)	Lucite frame where plastic numbers could be inserted	Overall E consumpti-on for G+E-powered homes	Unclear, 3 weeks or 1 month	29	10.5% in comp. to control
Seligman et al. (1978)	Blinking light indica-ted when airco could be turned off based on outside temp. (+fb)	Overall E consumpti-on for G+E-powered homes	1 month	10 blinking light. 10 blinking light +fb	15.7% for groups with blinking light (+ fb) in comp. to groups with only fb and control group
McClelland and Cook (1979)	Fitch Energy Monitor	Overall E consumption in E-powered homes	11 months	25	12% in comp. to control
Hutton et al. (1986)	ECI (energy cost indicator)	Overall E(+G) con-sumption in E(+G)-po-wered homes	Unclear, possibly 1 year	3 cities with 25 hh each	Between no measurable savings and 5.1%

Table 2
Journal articles and longitudinal research on HEMS, the duration of the study and the achieved energy savings

Authors	Name of HEMS	Type of measurement	Duration of study	N who recei-ved HEMS	Achieved energy savings
van Houwe-lingen and van Raaij (1989)	Residential gas con-sump-tion indicator (IND)	Overall G consumption in G+E-powered homes	1 year with follow-up one year later (w/o IND)	50 (45 at year end, 40 at follow-up)	After 1 year 12.3% in comp. to baseline, however difference from other groups. No longer significant at follow-up
Brandon and Lewis (1999)	PC where users 'could input indivi-dual household data'	Overall G+E consump-tion in G+E-powered homes	9 months	15 in PC group	4.3% for group with PC (12 hh saved, 3 hh did not) in comp. to baseline. Control used 7.8% extra
McCalley and Midden (2002)	fb integrated into washing machine control panel	E consumption of washing machine	20 x In lab	3 x 25	21% fb + personal goal. 9.6% only fb in comp. to control
Wood and Newborough (2003)	ECI (energy-con-sump-tion indicator)	E consumption of cooker	2 months	10 ECI, 10 (-2) ECI + info	group only ECI: 15%. Group ECI+ info 5.7-8.9% in comp. to baseline. Spread of -39% to +9% (+31%)
Mountain (2006)	Blueline Powercost monitor	Overall E consumption in E+(G)-powered homes	1 year	500 at start but unclear how many at finish (382 hh had 1 or more unusa-ble data points)	E-powered homes no significant savings, non-E heated homes 8.2% in comp. to baseline. Within last group, spread of 5.1% (hh with water non-E-he-ated) – 16.7% (hh with water E-heated).
Ueno et al. (2006b)	ECOIS I	Overall + disaggregated E consumption for E+G+kerosene- powe-red homes	40 week-days	9 (-1)	9% in comp. to baseline
Ueno et al. (2006a)	ECOIS II	Overall E, city G (and kerosene) consumpti-on + disaggregated E	28 week-days (dura-tion of study 9 months)	10	12% in comp. to baseline – not corrected for seaso-nal influences
Völlink and Meertens (2006)	Information pages in teletext format on one channel of the TV	Overall G+E+W con-sumption, in G+E-po-wered homes	4 months	29	W 18%, E 15%, G 23% in comp. to control group. Only W 6% in comp. to control group who recei-ved same questionnaires
Petersen et al. (2007)	Competition. Web-site with weekly fb or PC + website with real-time fb	E (+W) in G+E-powered dormitories	2 weeks	2 with PC in lobby 20 (-4) with only website	E 32%, W 3% in comp. to baseline. Group with PC 55%, group with only website 31%
Lofstrom and Palm (2008)	Power-aware cord	E consumption for appliance of choice	2 months	6	Not mentioned
E= electricity G= gas W= water fb = feedback, hh= household					

Table 2

Journal articles and longitudinal research on HEMS, the duration of the study and the achieved energy savings

§ 1.2.1 Limited overlap between available HEMS and past research on HEMS

When reviewing literature in relation to the typology, there is a limited overlap between available HEMS and past research on HEMS: research gravitates towards studying monitors that give factual feedback on overall electricity consumption. Because of this, advances in the HEMS market and HEMS design have only limitedly filtered down into HEMS research. There is also limited knowledge of the influence of the type of HEMS itself, and the role that increased control over household consumption through HEMS might play. Furthermore, gas (39%) is a larger energy source than electricity (25%) for households in Europe (European Environment Agency, 2012), with similar tendencies in other countries that also have colder climates.

§ 1.2.2 Short-term focus

An initial assessment (Darby, 2006a, Abrahamse et al., 2005, Fischer, 2008) of studies implementing HEMS or feedback (without a HEMS) reveals energy savings. However, a more detailed study of the results reveals an important finding, namely that research on energy savings through HEMS has had a short-term focus (Table 2) with little research on energy-related behaviour change in general extending over four months (Abrahamse et al., 2005). Those HEMS studies that did extend for four months or longer have shown mixed results (van Houwelingen and van Raaij, 1989, Mountain, 2006), that is, the results vary with one of the sample groups in the study not achieving significant savings or follow-up measurements negating some of the results. Hutton et al. (1986) are not clear as to exactly how long the HEMS were installed in participant's homes, saying only that "*Energy consumption was recorded for one year preceding and one year following the treatments*". The article seems to indicate that the study lasted a year, but their results were also mixed. The study by Ueno et al. (2006a) lasted nine months, but the researchers do not report savings past the initial couple of months. McClelland and Cook (1979) form an exception due to the savings of 12% that were achieved during their 11-month study with a HEMS in all-electric homes. Brandon and Lewis' (1999) study lasted nine months and also achieved savings of 4.3%, but whether providing a computer with software where users "*could input individual household data*" can be classified as a HEMS is up for discussion. Further research to evaluate the long-term results of HEMS is therefore necessary.

§ 1.2.3 Narrow focus/limited scope

The short-term focus is part of a larger, more important drawback of past research on HEMS: journal articles on HEMS have had a limited scope. The main interest has been in reporting the average savings in energy consumption achieved through the implemented interventions, and in how households respond to those interventions. Feedback has been the predominant intervention, possibly in combination with or in comparison to other interventions such as information (Brandon and Lewis, 1999, Wood and Newborough, 2003) and goal setting (McCalley and Midden, 2002). Feedback has mainly been studied from a psychological perspective, and there has been limited cross-fertilization between the domain of social and environmental psychology and industrial design (Froehlich et al., 2010).

Because of the limited scope, the factors that influence the energy savings achieved by means of a HEMS are not apparent. Past research on energy savings through HEMS has predominantly used technology that was at hand, without looking at variables within and surrounding the applied HEMS that potentially influence the results on energy savings, such as context, family dynamics, usability and design. Yet already in 1986, caution was urged about blindly implementing feedback: "*This study cautions against saying that any type of feedback, under any conditions, directed at any population, will produce positive results.*" (Hutton et al., 1986, p. 336). Too little attention has been paid to how HEMS are used and fit into household practices, the mediating role they play with current appliances and how they can contribute to sustainable housing transformation. This therefore needs to be addressed.

Furthermore, while past research has reported average 'savings' in energy consumption, the extent to which these savings have actually been environmentally beneficial is not apparent. The production, use and disposal of HEMS have environmental impacts. As such, there is embedded energy in HEMS, which might negate savings. It is therefore essential to question whether implementing HEMS makes sense.

§ 1.2.4 Unknown cause of variances in savings and the use of HEMS

Due to the limited scope of past research, there is a lack of understanding of the reasons for the large variances both in the savings achieved with HEMS and in their use. Darby (2006a) reported: "*the norm is for savings from direct feedback (immediate, from the meter or an associated display monitor [i.e. a HEMS]) to range from 5-15%.*" However, a closer analysis of various articles shows greater variances in average savings (Table 2). Few articles have reported the savings of individual households, but a study of individual households reveals even greater variances. These variances are exemplified in the following section using several articles from Table 2.

Next, the variances in the use of HEMS are discussed. The use of HEMS is important because if a HEMS is not used successfully, a household will not receive useful feedback on their energy consumption, the driving principal of most HEMS. So to a certain extent, the successful use of a HEMS is a prerequisite for a HEMS to be effective. This is not to say, however, that successful use guarantees savings, or that a HEMS is a prerequisite to achieving energy savings.

§ 1.2.4.1 Variances in savings

To start with the variances in energy savings, three articles from Table 2 are briefly discussed here to exemplify the differences.

McCalley and Midden (2002) report savings of 21% for a combination of feedback and setting a personal goal. The interventions were integrated into a washing machine and tested in a lab setting. The groups that only received feedback integrated into the washing machine saved 9.6%.

Wood and Newborough (2003) report average savings of 15% over two months for a group that only received a HEMS designed to give feedback for a cooker. The average savings were lower for the other two groups that received the HEMS in addition to energy-saving information or only energy-saving information. Wood and Newborough's study is one of the few to report on the individual savings of households. These showed strong variances, with savings ranging from a 39% decrease to a 9% increase in consumption. The variances in savings of individual households in the other two groups were less strong.

In only one of their three sample groups could Hutton et al. (1986) confirm two of their hypotheses related to energy reductions. The hypotheses for their HEMS (which they called an 'ECI') on overall consumption for all electric or gas+ electricity powered homes were: 'The ECI + Education and Education alone will result in lower (as compared to the Control conditions) energy consumption.' And: 'The ECI + Education will have more impact than the Education alone on consumption.' In the one group where the hypotheses could be confirmed (all-electric homes in Quebec), the savings were 5.1% in comparison to their pre-trial baseline consumption. This amounted to 4% incremental savings in comparison to the control group. In the other two groups, these hypotheses could not be confirmed.

The abovementioned case studies exemplify the variances in energy savings, ranging from averages of 21% to no savings. Possible reasons for the variations have been proffered in the discussion sections of articles. However, a scientific exploration of the reasons for these variances is largely absent. Fischer (2008) has made a first analysis to explain the variances on the basis of a literature review. Her tentative conclusions are that feedback should be disaggregated, longitudinal, frequent, including historical and comparative feedback, be measured rather than estimated, and designed with consideration for its usability and interactions with its user. However, her analysis is specific to feedback rather than HEMS, and it is likely that not only the feedback but also other aspects play a role. Furthermore, she stresses that there are too few data, in particular when using larger samples, to verify and quantify her analysis. The knowledge on the reasons for the variances is therefore still insufficient.

§ 1.2.4.2 Variances in the use of HEMS

The previous section concerned the large variances in achieved savings. Less has been published on the use of HEMS, but those that have reported results on the use of HEMS reveal variances in the amount and duration of the use of HEMS by households. This section discusses the limited findings that are available in the literature.

The research by Ueno et al. (2006a) is singular in visualizing the variances in the use of HEMS by ten individual households over a nine-month period. Large variances are apparent amongst the ten households: the household that used the HEMS the most frequently used it eleven times as often as the household that used it the least. Their research also seems to indicate that HEMS slowly drift into the background as their use by households slowly decreases.

In a study on the use of an electricity monitor (PowerCost) by Mountain (2006), one third of the participants indicated they would no longer use the monitor after the pilot study. Two of the ten participants in a trial with an electricity monitor (Efergy) (Kidd and Williams, 2008) indicated that they had not used the HEMS during the one-month trial.

Likewise, Hutton et al. (1986) report that tracking data revealed that during the first few months of the study, there was a considerable drop in the use of the HEMS. An important detail is that the participants in the sample group in Quebec, which was the only site where energy reductions could be confirmed, used the feedback in the HEMS more than the participants in the other two sample groups.

While only a few sentences were devoted to this finding, it might imply that the use of HEMS is relevant to the achieved energy savings. When a HEMS is not used, then in effect there has been no intervention, and there can be no effectiveness of the feedback. It is, however, possible that households still achieve savings during a case study while not using a HEMS, as happened in the study by Kidd and Williams (2008), which might be caused by the act of participating in the study. While it is impossible to draw decisive conclusions based on these studies, they do justify further exploration into the use of HEMS and how this relates to effectiveness.

§ 1.3 Domain and contribution of this research

The lack of overlap between the typology of HEMS and past HEMS research, the short-term focus and limited scope of past research, and the unknown causes of large variances in savings and the use of HEMS were the starting point for this research. To be able to explore these aspects and to add the body of knowledge from social and environmental psychology that was already present in the literature on feedback, knowledge from different scientific domains needed to be combined. Specifically, a combination of the domains of architecture and industrial design engineering was chosen because of the strong interdependency of these domains with regard to the challenge of reducing the energy consumption of households and the goal of HEMS to reduce this consumption.

This chapter started with an explanation of the energy consumption of existing housing, which is the domain of architecture. HEMS need to be considered in the context in which they are used: the home. HEMS fit into a complex system of energy consumption within the structure of a house. The category 'existing houses' covers an immensely wide palette of building constructions, architectures, construction dates, technical installations, appliances, and inhabitants with their specific behaviours, practices and habits. Each has its own defining characteristics that influence energy consumption and the potential for implementing and using HEMS.

Furthermore, the domain of industrial design engineering is relevant to understanding the influence of the design, usability and context of use of HEMS. Recent developments in the field of interface design and usability, persuasive design and captology (Fogg, 2003, Froehlich et al., 2010) might aid in improving the use and usability of HEMS as well as the achievable energy savings.

To take both the developments in interaction design and the contextual factors of existing housing into consideration, an interdisciplinary approach was chosen in the combination of these two disciplines: an innovative view on interaction design, and a building industry-related view on achieving sustainable housing transformation. This thesis was written within the Sustainable Housing Transformation group, which has the task of improving the quality of existing housing and neighbourhoods in a sustainable way. It builds on the work already present in the literature on feedback. Through a cooperation between the departments of Design for Sustainability and Housing at, respectively, the faculties of Industrial Design Engineering and Architecture, and a combination of the bodies of knowledge present there, cross-fertilization is possible.

The insights that were gathered through case studies on HEMS are thus intended to benefit both the field of HEMS industry and that of specialists in housing transformation. The contribution of this thesis is to widen the scope of current research and deepen the understanding of the effectiveness of HEMS. This exploration and mapping of relevant factors that might influence the use and effectiveness of HEMS can be used as input for future research to better ascertain the true value and effectiveness of HEMS.

§ 1.4 Objectives and research questions

Based on the previous assessment, the four main objectives of the research were defined as:

- To empirically evaluate the mid- to long-term effectiveness of HEMS.
  HEMS are defined as intermediary products that can visualize, manage and/or monitor the energy use of products or entire households. Effectiveness is defined as the extent to which users can maintain significant energy savings in energy consumption over a prolonged period. Mid- to long-term refers to a period of longer than four months, with an emphasis on including all seasons.
- To identify and explore factors that might influence the use effectiveness of HEMS.
  'Factors' is a general term and to manage the scope of this exploratory research, this thesis focuses only on factors within the home. Therefore, the structure of the home should also be seen as the boundary to the elements that are discussed. In other words, the factors referred to in this thesis are related the house, its technical installations and appliances, people living within the home, the HEMS, and the relationships between these elements. Aspects such as legislation, policies and society are excluded because they require a different research approach.
- To infer design-related strategies for industrial designers and the building industry to improve the use and effectiveness of HEMS.

- To reflect on the implications for sustainable housing transformation, the HEMS industry and researchers, and their goal of reducing the energy consumption of households.
  Numerous parties are involved in HEMS and therefore HEMS industry is a comprehensive that includes -but is not limited to- designers, developers, energy companies, installers, and housing associations involved in the development and implementation of HEMS. Here, both practical and scientific implications for the fields of the building industry and industrial design engineering are intended.

To achieve these goals, the following questions were explored:

- What are the medium- to long-term results of HEMS on energy savings?
- What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?
- What factors might influence the use and effectiveness of HEMS?
- What is the overall effectiveness of HEMS when taking their lifecycle and embedded energy into account?
- What can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing households?

The combined answers to these research questions led to the answer to the question: What design-related insights and guidelines can be inferred that influence the use and effectiveness of HEMS?

§ 1.4.1 Methodology

To achieve the objectives and address the four limitations of past research(§ 1.2), the author executed case studies with HEMS. The methodology for this largely exploratory research is discussed in this section.

The first two objectives concerning the mid- to long-term effectiveness of HEMS and factors that might influence the use effectiveness of HEMS, necessitated that HEMS be largely studied in their natural context of use. This allowed for the investigation of real-life household patterns, dynamics, longitudinal use and effectiveness, and changes over time. The HEMS were placed as an intervention in participants' homes, which permitted the empirical evaluation of the mid- to long-term effectiveness of the intervention. However, as explained in § 1.2.4, there were large variances in the use of HEMS and the achieved energy savings; in other words, the outcome of past research on HEMS is not clear or straightforward. Therefore, the second objective lent itself to exploratory case studies. The natural environment supported the exploration of influencing factors rather than focusing on a specified set of variables. In order to study the usability of the HEMS, experiments were also conducted in which participants (from the case studies) were invited to a lab for short sessions. In this way, the usability and first-time use could be studied in a controlled environment and with controlled ways in which the HEMS could be used. The third and fourth objectives concerning design-related strategies and the implications for the different parties could be gleaned from the findings of the case studies.

Furthermore, the design of the HEMS was expected to be an influencing factor on their use and effectiveness, due to the differences that were stated in the typology in § 1.1.2. This warranted the study of distinctly different HEMS in each of the case studies. Therefore, three case studies were set up in the Netherlands in cooperation with HEMS manufacturers, energy providers and TU Delft. Through the cooperation with commercial parties, the drawbacks resulting from the current gravitation of research towards studying monitors that give factual feedback on overall electricity consumption (as mentioned in § 1.2.1) could be addressed. As a result, the three HEMS cover a variety of characteristics: mono-functional and multifunctional, energy monitoring and energy managing, aggregated and disaggregated feedback, and feedback on gas and on electricity consumption.

To achieve the various goals, different methods were applied. The first case study focused on the longitudinal effectiveness of HEMS and therefore used qualitative research methods. The second and third case studies were more exploratory in nature and therefore both quantitative and qualitative research methods were initially applied in a mixed-method approach. The quantitative data was intended to be used to support the qualitative findings. However, due to a number of challenges in the execution of the case studies, the quantitative results from the second and third case studies were either unusable or unobtainable, as is explained in more detail in Chapters 5 and 8. Therefore, the approach used in the second and third case studies was made qualitative during their execution. The initial research objectives and questions were adjusted to correct for the shift in data; the objectives and research questions in § 1.4 reflect the final approach. The research was therefore more exploratory; certain findings can be substantiated with qualitative data but not with quantitative data.

§ 1.4.2 Framework to interpret the findings

The objectives highlight the exploratory nature of this research and reveal an aim to provide an expansive view of the HEMS landscape and the effectiveness of HEMS. To be able to do this in a structured manner within the domains of architecture and industrial design engineering, and with consideration for social sciences, a framework was sought. The framework needed to fit within and give consideration to the multidisciplinary facets of the research. It also needed to be practicable yet comprehensive for the exploration and mapping of the relevant factors. I therefore felt that the human-computer interaction framework in Figure 1 (adapted from van Kuijk (2010) and Wever et al. (2008)) was applicable, as is explained in more detail in Chapter 3.

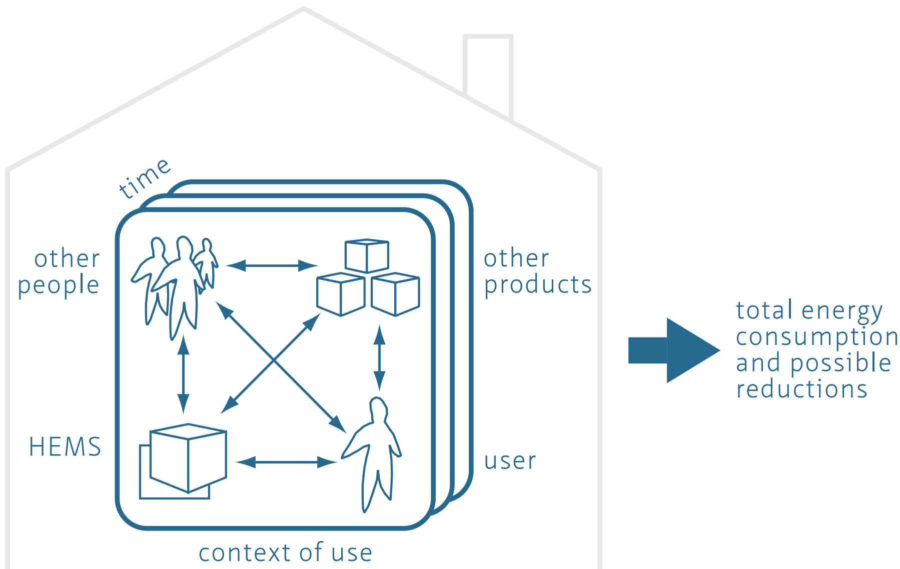

Figure 1
Factors influencing the use and effectiveness of HEMS. Adapted from Wever et al. (2008) and van Kuijk (2010)

The framework visualizes the elements and relational lines -or interactions- that influence the usability of a product. This thesis hypothesises that, specific for a HEMS, both the use and the effectiveness of a HEMS are dependent on the surrounding factors. A HEMS needs to be used and usable to enable households to receive feedback, and feedback is intended to reduce the energy consumption of households.

In this holistic approach, HEMS are discussed in relation to all the elements surrounding their use and household energy consumption, including housing, its technical installations and appliances, its inhabitants' behaviours and social dynamics, and the practices that surround the use of products and energy (Figure 1). The element of time is added to include possible variances in use over time and the uncertainties with regard to the longitudinal effectiveness of HEMS in previous research as discussed in § 1.2.2 and § 1.2.4. Additionally, a home is visualized as the perimeter of the framework. This both demarcates the boundary of the findings discussed in this thesis and also visualizes the context of the use of HEMS. This framework is used to categorize the findings in this thesis and to frame the chapters, as is explained in the following section.

§ 1.5 Thesis Outline

This thesis is divided into four parts (Figure 5). **Part I** – 'The complexity of home energy consumption and the role for HEMS' – explains in further detail the context of household energy consumption, the working principles of HEMS and the framework used in this thesis.

To be able to explain the framework and the importance of the context surrounding HEMS on their use and effectiveness, **Chapter 2** first explains the context of current household energy consumption. It gives a backdrop to the underlying issues surrounding existing housing, its energy consumption, its inhabitants and achieving energy reductions, and advocates the need for an interdisciplinary approach.

Chapter 3 addresses the potential to achieve and the challenge of achieving energy reduction through HEMS by discussing its working principles. It also discusses the relational lines within the framework and past research on HEMS in relation to this framework, including housing, its technical installations and appliances, its inhabitants' behaviours and social dynamics, and the practices that surround the use of products and energy. This framework is used to frame the findings that are presented in the subsequent chapters.

Part II – 'Empirical studies on implementing HEMS within households' – reports the results of case studies implementing HEMS within households over a prolonged period. It consists of Chapters 4, 5 and 6. The chapters address different research goals by reporting on one or more case studies that implemented a different type of HEMS and took a different research approach.

Chapter 4 addresses the first research question by evaluating the longitudinal effectiveness of an energy monitor (Figure 2) in households during a 4-month period and at an 11-month follow-up. The energy monitor gave real-time and cumulative/24-hour feedback on overall electricity consumption. This chapter addresses the elements of HEMS–user interaction and time, and their influence on the use and effectiveness of HEMS from Figure 1. The quantitative data for this first case study were gathered by means of meter readings and four online questionnaires.

Figure 2
The 'Wattcher' energy monitor used in case study 1.

Chapter 5 explains the setup of the second and third case studies. It details the challenges that were encountered and the consequences they had for the research data and the research questions. In the second study, an energy management device (Figure 3) was implemented that gave real-time and historical feedback for individual appliances and helped manage whether and, if so, when appliances consumed electricity. This study lasted five months. The data were gathered by means of qualitative, semi-structured in-depth interviews through house visits with participants. The third case study implemented a multifunctional HEMS (Figure 4) that gave real-time and historical feedback on gas and electricity consumption and lasted 6–12 months. The data in this case study were gathered by means of focus groups, usability studies and interviews.

Figure 3
The 'Plugwise' energy management device used in case study 2.

1 2

Figure 4
Multifunctional HEMS used in case study 3 (picture 1 displays the start screen for the 'smart' meter, picture 2 displays the start screen for the 'dumb' meter).

Chapter 6 addresses the second research question by investigating the ways in which households use the energy management device and multifunctional HEMS and the use patterns that emerge. This chapter explores the interplay between all the elements within the box in Figure 1. It explores the use of HEMS by different household members and the practices that emerge, family dynamics and the interplay with other appliances.

Part III – 'Interpretations: lessons learned from the case studies' – merges the findings from the three case studies and addresses the third research question. **Chapter 7** derives principles and insights concerning the design, use and implementation of HEMS and their effectiveness in reducing energy consumption. The insights are grouped according to the different interactions within Figure 1.

Part IV takes a step back to reflect on the actual effectiveness of HEMS and whether they provide a real benefit. It reflects on the benefits and challenges of HEMS in general, conducting research with HEMS and implementing HEMS in existing housing.

Chapter 8 addresses the fourth research question by reporting on the overall effectiveness of HEMS. It takes into account the whole lifecycle of the three HEMS and the energy invested in them. Based on the literature, several scenarios were developed in order to find the break-even point, where $e_{invested} = e_{saved}$. Here, the HEMS and their 'true' effectiveness in Figure 1 are elaborated on.

Chapter 9 delves into the underlying spectrum of knowledge gained through process of executing research on HEMS and implementing HEMS in existing housing. It probes the aspects concerning the perimeter of Figure 1 and specifically addresses the contextual factors form the third research question and the fifth research question.

Chapter 10 concludes the thesis by combining and answering the research questions. It also presents a discussion and recommendations for further research.

Thesis outline and research questions:
What design-related insights and guidelines can be inferred that influence the use and effectiveness of HEMS?

Chapter 1:
Introduction to HEMS

PART I Literature review: Household energy consumption and the role for HEMS

Chapter 2:
The context: household energy consumption and energy reduction approaches

Chapter 3:
Influencing behaviour through HEMS: explaining the framework

PART II Empirical studies on implementing HEMS within households

Chapter 4:
Case study 1:Home energy monitors: impact over the medium term

What are the medium- to long-term results of HEMS on energy savings?

Chapter 5:
Setup of the 2nd and 3rd case studies and a revision of their research questions

Chapter 6: Exploring use patterns through a classification of users and their use and application of HEMS

What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?

PART III Interpretations: Lessons learned from the case studies

Chapter 7:
Insights into reducing household's energy consumption through HEMS

What are the medium- to long-term results of HEMS on energy savings?

PART IV Reflections on HEMS

Chapter 8:
Do HEMS make sense? Assessing the overall lifecycle impact of HEMS

What is the overall effectiveness of HEMS when taking their lifecycle and embedded energy into account?

Chapter 9:
Reflections on implementing HEMS in existing houses and conducting research with HEMS

What can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing households?

Chapter 10:
Conclusions and recommendations

Figure 5
Thesis outline


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PART I Literature review: household energy consumption and the role for HEMS

Part I of this thesis 'household energy consumption and the role for HEMS' lays the foundation for this thesis by delving into the issues touched upon in chapter 1. It explains the context of household energy consumption, the working principles of HEMS, and the framework used in this thesis in further detail. To achieve this ,Part I is split into two chapters.

Chapter 2 explains the context of household energy consumption. A breakdown is given of households' gas and electricity consumption in order to ascertain the influence of various appliances and technical installations. Furthermore, the influence of building characteristics and the characteristics, demographics and behaviours of its inhabitants on their' gas and electricity consumption are addressed. It concludes with the pivotal role that HEMS play in household energy consumption and reasons for studying HEMS.

Chapter 3 then narrates the reasons for the use of the framework of Wever et al., (2008) and van Kuijk (2010) for this research on HEMS. Consecutively, the framework and the different interactions and elements that are visualized within along with the working principles of HEMS are explained. The chapter draws on knowledge from various sciences.

2 The context: household energy consumption and energy reduction approaches

§ 2.1 Introduction

The high energy consumption of existing households forms the challenging starting point for this thesis. To be able to address and reduce this energy consumption through HEMS, it is important to first assess the factors that contribute to this energy consumption. Therefore, this chapter explains the context of household energy consumption and past energy-reduction approaches.

The chapter reveals the complexities of household energy consumption and thereby advocates the need for interdisciplinary research by including the human factor to achieve energy reductions in households. It concludes by proposing HEMS as a viable approach that merges various disciplines. These disciplines can play a pivotal role in household energy consumption and its influencing factors, as discussed in this chapter: they can be implemented in existing households and with current appliances. They can also mediate between users and their appliances, creating awareness of background appliances and making invisible energy flows visible. Furthermore, they can influence behaviour. However, to be able to fully study the potential of HEMS, first the determinants of household energy consumption are detailed in the following sections.

§ 2.2 A breakdown of household energy consumption

Households are responsible for 20% of natural gas consumption and 24% of the electricity consumption in the Netherlands (Energiezaak, 2011), as was explained in Chapter 1. This section breaks down this figure according to the sources of consumption in order to provide a better understanding of the context and complexity of household energy consumption.

This gas and electricity is consumed by nearly 7.4 million households (CBS, 2013), which amounts to an average of 3480 kWh of electricity and 1617 m^3 of gas per household (Energiezaak, 2011). Figure 6 visualizes the overall energy consumption expressed in CO_2 emissions. It shows that there has been a slight overall decrease in emissions per household in the past 20 years due to the slow decrease in gas consumption.

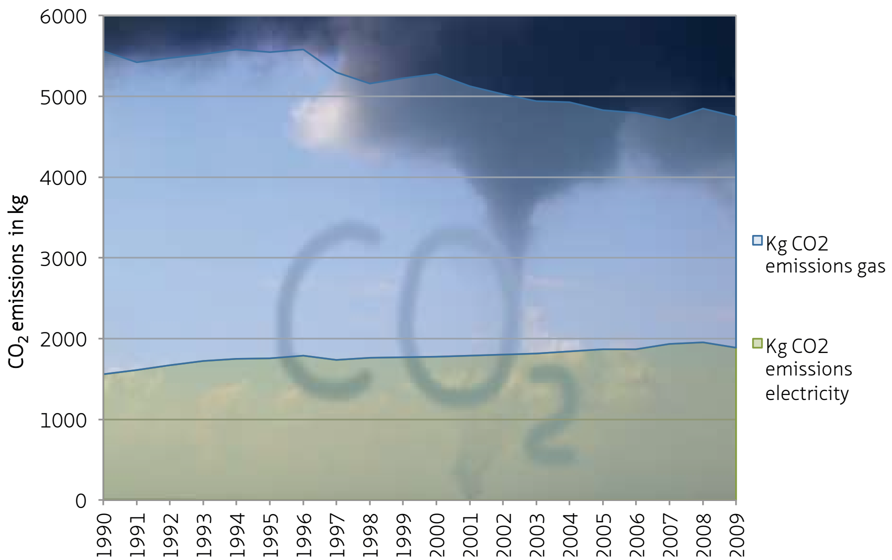
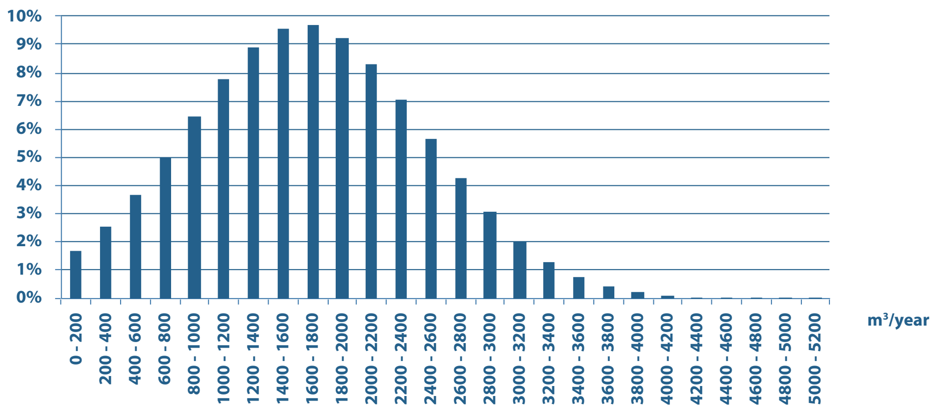


Figure 6
CO_2 emissions per households during the past 20 years in the Netherlands (EnergieNed, 2009).

However, the figure also shows that the electricity use of households has been steadily increasing over the years. This same negative effect can be seen worldwide, where electricity consumption has been increasing at an average rate of 3.4% annually since 1990 (International Energy Agency (IEA), 2009). Averages per household are generic and hide the large spread in household energy consumption that is visible in Figure 7.

Spread in gas consumption



Spread in electricity consumption

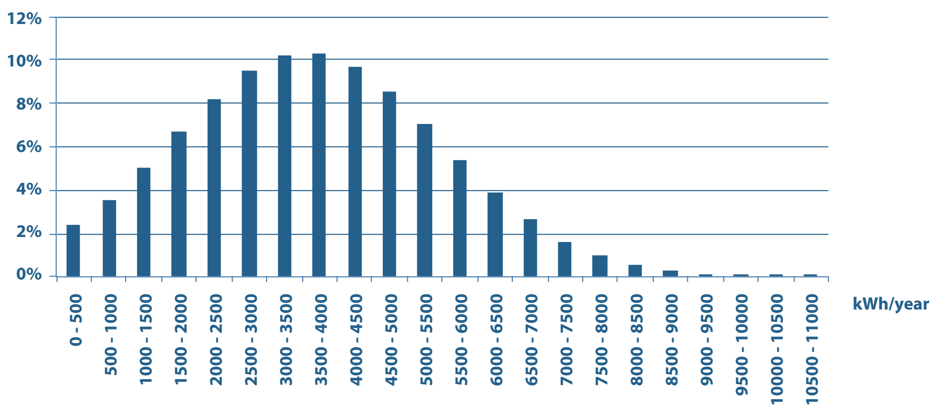


Figure 7
Spread in Dutch household energy consumption (source ECN (2012)).

§ 2.2.1 A breakdown of energy consumption according to its sources of consumption

To explain the average energy consumption of households and these variances, a first step is to unravel the statistics according to their sources of consumption.

§ 2.2.1.1 A breakdown of gas consumption according to its sources of consumption

Gas is responsible for around 60% of household emissions in the Netherlands, mainly because gas is the main source for heating. Spatial heating accounts for nearly 73% of total gas consumption (Figure 8), with warm water and cooking accounting for far less (23% and 4%, respectively). Thus, spatial heating is an important area to address in order to reduce the gas consumption of households.

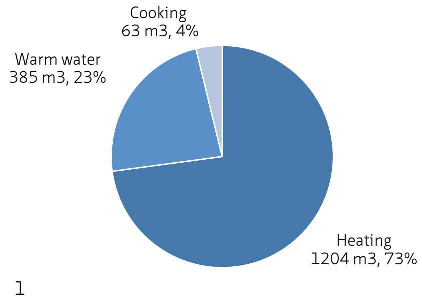


Figure 8
Breakdown of gas consumption per household (Milieu Centraal, 2008).

§ 2.2.1.2 Breakdown of electricity consumption according to its sources of consumption

Various appliances and sources are responsible for the electricity consumption (Figure 9), rather than the one major source (heating) that can be seen with gas. Similar figures can be found in neighbouring countries (Leefmilieu Brussel – BIM, 2009, Zimmermann et al., 2012). Influencing the electricity consumption of households therefore means addressing the large number of sources of the consumption.

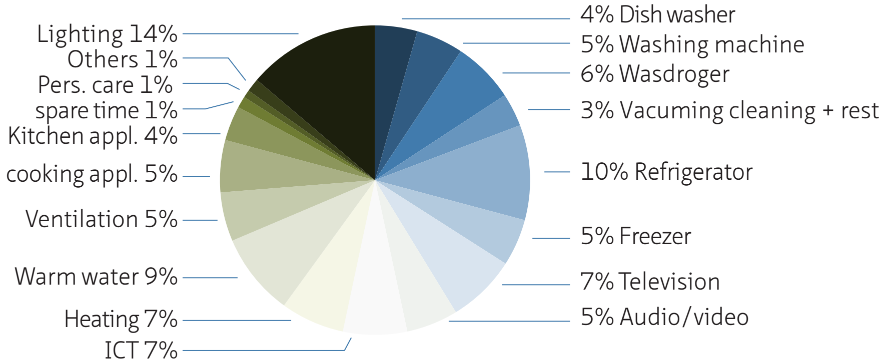


Figure 9
Breakdown of electricity consumption per household (ECN, 2012, using HOME)

§ 2.2.1.3 Implications regarding the breakdown

The figures present a breakdown for gas and electricity consumption for an average household. However, which appliances (or sources) are the largest contributors varies per household (ECN, 2012, Leefmilieu Brussel – BIM, 2009, Owen, 2012). Appliances that are the largest contributors in one house might not be present in other houses, which are likely to have other high energy consumers instead. Other underlying factors, besides the appliances, contribute greatly to the actual energy consumption of households; these are explained in the following section. The figures represent the appliances as being the responsible subject. Yet it is not only the physical appliance as such that is responsible for the energy consumption. For example, the energy needed for heating greatly varies per household and is dependent on a number of factors outside the appliance using the energy, such as building characteristics and household characteristics, demographics and behaviour. It is essential to take a bird's eye view and recognize these factors. Therefore, the influencing factors for gas and electricity consumption are discussed in further detail, starting with dwelling characteristics.

§ 2.2.2 The influence of building characteristics

First the contributors to gas consumption are discussed, because in the Netherlands building characteristics are more important to gas consumption than to electricity consumption (NIBUD, 2009).

§ 2.2.2.1 The influence of building characteristics on gas consumption

One important aspect contributing to the emissions of households, and thus to their energy consumption, is the age of the dwelling. There are approximately 7.1 million independent dwellings in the Netherlands (MvBZK, 2010). More than 50% of all housing dates from before the first insulation regulations were introduced in 1975, and more than 84% dates from before the overall energy performance regulations (EPC) were introduced in 1995 (MvBZK, 2010). While a certain number of retrofits (insulation of roof, floor, walls and windows) have taken place, dwellings built before 1995, and especially before 1945 (Guerra Santin, 2010), still consume more gas. Nibud (2009) found a significant difference in gas consumption between houses built before 1945 and after 1980. Nonetheless, home insulation improvements to existing dwellings and particularly the installation of high-efficiency condensing boilers/furnaces (Sijbring and Overman, 2011, Energiezaak, 2011) have contributed to the decrease in gas consumption that was seen in Figure 6.

Other building characteristics that influence gas consumption are the type of housing (e.g. detached, terraced, flat), the size of the dwelling and its useful living area, the number of rooms, and the presence of a shed, garage or basement, all of which contribute to the energy consumption for heating (Guerra Santin et al., 2009, NIBUD, 2009).

§ 2.2.2.2 The influence of building characteristics on electricity consumption

Contrary to gas consumption, the influence of building characteristics on electricity consumption is less (NIBUD, 2009). In the Netherlands, only [a minority of households have electric or other types of non-gas heating (ECN, 2012) and air conditioning (milieu Centraal, 2011) which decreases the contribution of building characteristics. There is a slight relationship between electricity consumption and the number of rooms and the type of house (NIBUD, 2009), but these are not very strong determinants. Firth et al. (2008) found notable differences in electricity consumption and suggest "*that built form is not a strong determining factor in household electricity use and instead factors such as number of occupants, number and type of appliances, and occupancy patterns may be more relevant*". These are discussed in § 2.2.3.

§ 2.2.2.3 Implications with regard to building characteristics

Building characteristics mainly influence gas consumption. Particularly the gas consumption of older dwellings is important in the endeavour to reduce the overall energy consumption of households. Legislation concerning new housing is being increasingly tightened in an effort to increase the energy efficiency of such housing (Guerra Santin, 2010). However, only 1% of the total housing stock is added each year in the form of new housing (MvBZK, 2010). This has been relatively constant in recent decades, and from a natural resources point of view it is not feasible to simply tear down existing housing. So while new housing deserves attention to make it as energy efficient as possible, this cannot be justified as the main solution to the current high consumption of households. A focus on the other 99% – the existing housing – is therefore essential. The existing housing stock comprises a variety of dwellings each with its own characteristics. Therefore, there is no single, universally implementable solution, which makes achieving gas reductions a complex task.

Furthermore, the energy consumption for heating identical dwellings can also differ (Gram-Hanssen, 2010, Passive House Institute, 2009). For electricity consumption, where building characteristics only play a minor role, there are other, stronger contributing factors such as household demographics, characteristics and behaviour, and the type and number of appliances. The influence of household characteristics and demographics on gas and electricity consumption is discussed in the following section.

§ 2.2.3 Influence of household characteristics and demographics

Dwellings are not just a physical enclosed structure. The inhabitants of a home contribute to the energy consumption. The following section discusses their influence on first gas and then electricity consumption.

§ 2.2.3.1 Influence of household characteristics and demographics on gas and/or heating consumption

The number of adults and children, and particularly the amount of time they spend at home during the week and at weekends (Guerra Santin et al., 2009), influences the amount of energy used for heating. An average household in the Netherlands consists of 2.4 persons (MvBZK, 2010), a figure that is slightly lower than that for most other European countries. Additionally, households with higher incomes use more gas than those with lower incomes. Another factor is the age of the inhabitants: people over 65 use more gas than younger people, probably because they are at home more or prefer higher temperatures (NIBUD, 2009).

§ 2.2.3.2 Influence of household characteristics and demographics on electricity consumption

Age and increasing family size not only influence the amount of energy needed for heating, but also correlate to the total amount of electricity consumption (NIBUD, 2009, Brandon and Lewis, 1999). Households with more children or older children use more than smaller households; a family of five uses over 50% more than a family of two (NIBUD, 2011). Furthermore, family size is related to the number of appliances a household owns. And the number of appliances in turn also contributes independently to the amount of electricity consumption. However, a different study found that single-person households use more energy each year for certain applications, such as washing clothes and lighting. Owen (2012) reported a higher number of washing cycles among a group of non-pensioners. Likewise, the energy that singles use for cooking in this study was roughly the same as that used by three- and four-person households.

A research conducted in the Netherlands on the acquisition, possession and recycling of electrical appliances found that families with older children owned the most electrical appliances (GfK Panel Service Benelux, 2007). Table 3 shows the large differences between different family situations. On average, Dutch households have 51 appliances (excluding lighting), either working or defective. Owens (Owen, 2012) found an average of 34 light sources and 41 appliances in homes in Britain. These figures fit into the worldwide trend in which western household own between 28 and 65 appliances (IEA, 2009). This increase in the number of appliances and technical installations correlates with the worldwide increase in electricity consumption.

	Total	Kitchen, washing, cleaning and personal care appliances	Visual/audiovisual equipment	Computers and ICT appliances
Total	51	30	14	7
Young singles	37	21	11	6
Middle-aged singles	42	24	13	6
Elderly singles	38	24	9	4
Young couples	52	29	15	8
Middle-aged couples	61	34	18	9
Elderly couples	52	33	13	6
Families with young children	59	33	18	9
Families with older children	69	37	22	11

Table 3
Number of appliances per household in the Netherlands (GfK Panel Service Benelux, 2007)

Income also has an effect on the number of appliances households own. But the effect of income on electricity consumption is only indirect, in contrast to gas consumption (NIBUD, 2009). This is because the number of appliances is the direct cause of the increase in consumption. Brandon and Lewis (1999) found a direct effect between income and consumption, but they did not compensate for the number of appliances.

§ 2.2.3.3 Implications of household characteristics and demographics

As stated in § 2.2.3, in addition to building characteristics (§ 2.2.2), household characteristics and demographics influence energy consumption. In short, age, family size and number of appliances are contributors to the electricity consumption of households. Likewise, age, income, family size and the amount of time household members spend at home influence the gas or other energy needed for heating. These are important facts to consider and have implications for making appliances and dwellings more energy efficient. Yet there are still other aspects that influence energy consumption. Household characteristics are strongly intermingled with household behaviour, as inhabitants make choices to buy and use appliances or to retrofit their homes. The following section discusses the importance of paying attention to behaviour.

§ 2.2.4 Influence of behaviour

As inhabitants and their behaviours are important, one needs to study specific, individual households in closer detail. The figures previously given on the energy consumption of households were obtained by dividing the overall consumption figures by the number of households. However, a drawback of this approach is that it gives averages per household. Averages can be deceitful as there are variances between identical dwellings with similar households that cannot be explained by demographics, building characteristics or other hard facts. An energy-efficient product does not guarantee energy-efficient use by its users. Technically identical houses, which should theoretically consume the same amount of energy, might in practice use vastly different amounts of resources due to the behaviours, heating preferences and lifestyles of their inhabitants, as the following section shows.

§ 2.2.4.1 Influence of behaviour on energy consumption

Several studies have found that the behaviours and lifestyles of inhabitants contribute to household energy consumption. Firth (2008) found notable differences in electricity consumption over a two-year period for 72 new dwellings spread over four different types of properties that were all gas heated. The electricity consumption varied from 902 kWh to 8775 kWh, suggesting that building demographics were not the most important factor. Likewise, for new, energy-efficient and award-winning estates, Gill et al. (2010) found factors of difference between 2.5 and 7.75 for different gas, water and electricity consumption when measured in totals and per m2 of housing. Using a method implementing the theory of planned behaviour, Gill et al. (2010) found that occupancy behaviour explained 51%, 37%, and 11% of the variation in, respectively, heat, electricity and water consumption. Brohus et al. (2009) found occupant behaviour to be the major contributing factor to energy consumption. They measured air leakage, room temperature, heat load of occupants and appliances, and water, electricity and district heating consumption.

Specific for heating, factors of difference of 3 (Gram-Hanssen, 2010) to 6 (Gram-Hanssen, 2010, Passive House Institute, 2009) have been reported. Figure 10 shows the significant differences in energy consumption for the spatial heating of identical dwellings. This was corrected for household size.

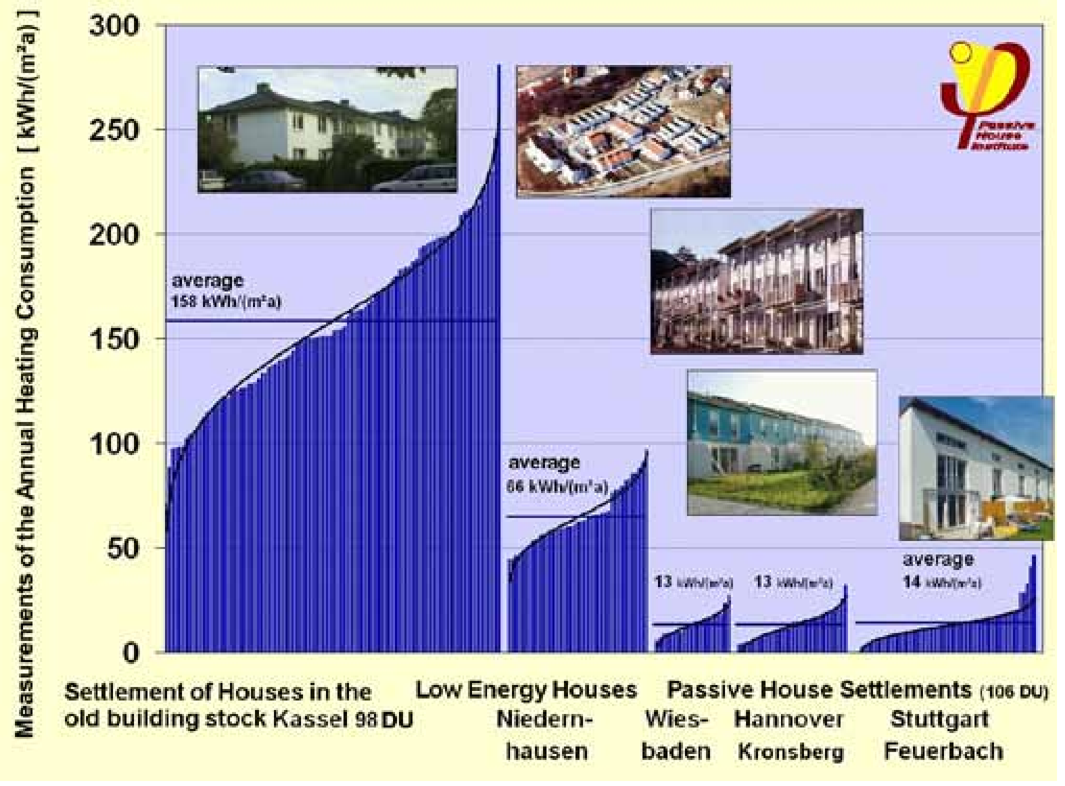


Figure 10
Annual heating consumption of differnt types of housing (Passive House Institute, 2009)

All five studied types of housing have the same basic s-shaped curve. However, for each dwelling type, the highest energy-consuming household uses around six times as much as the lowest consumer.

The examples given concern new housing stock. Therefore, there have been little to no adjustments, retrofits or extensions to the properties, as there have been with older housing stock, that might pollute the data. While it might be more difficult to distil the influence of behaviour in older housing stock due to the adjustments that have been made over the years, the example in Figure 10 indicates that the influence of inhabitants is even more important for older housing stock: the differences between the highest and the lowest energy-consuming household in the older building stock (on the left in Figure 10) are far more extreme in absolute consumption figures.

§ 2.2.4.2 Implications of household behaviour

The energy consumption of households comes about though a combination of building characteristics, appliances, and household demographics, behaviour and lifestyles. Therefore, the behaviour of inhabitants adds an extra dimension to the complexity of household energy consumption. The large variances in energy consumption and the influence of behaviour thereupon cannot be ignored. However, this behavioural dimension has not always been given proper consideration in architecture and industrial design. This is explained in more detail in the following section.

§ 2.3 The importance of paying attention to behaviour

This section addresses the limitations and drawbacks when the behavioural dimension of energy consumption is not taken into consideration. Attention to the behavioural dimension attracted interest only after energy consumption itself had attracted interest. And energy consumption during the use phase of a product's (and a building's) lifecycle became important only relatively recently, with an increase in overall energy consumption stimulated till the early 1970s (van Overbeeke, 2001). Pascual et al. (2003) analysed 850 papers published between 1998 and 2002 at eco-design community conferences and found that the emphasis was often lopsidedly placed on technicalities, validation and end of life. This approach has centred on developing ways in which to decrease production impact, toxicity and overall material use, to increase the recyclability and performance of products, and to harness renewable energy sources. One of their main conclusions was that "*Research on energy consumption of products receives little attention, when it is a dominating factor on the environmental impact at product lifecycle and it will become a future issue due to international agreements (Kyoto)*".

In recent years, however, the energy consumption of appliances and technical installations has received increasing attention – and with good reason. For most home appliances, the use phase has the most impact. In a benchmarking study done by Philips (Stevels et al., 2001) to ascertain the lifecycle impact of around 50 electronic products, energy consumption was responsible for 50–85% of the total environmental impact of these products. A research by Rüdenauer et al. (2005) showed that the use phase was responsible for 80–90% of the total environmental impact of a refrigerator during its complete lifecycle. However, in practice the energy consumption of appliances and buildings can differ from the expected, theoretical consumption due to the behaviour of its users/ inhabitants. The following sections discuss experiences in various fields where energy-related behaviours have not been given enough attention.

§ 2.3.1 Consumer goods

Technological solutions can theoretically achieve significant reductions. Large improvements have been made to the energy (and water) consumption of appliances such as refrigerators, ventilation units, washing machines, dishwashers and high-efficiency condensing furnaces/boilers. Yet in practice, this approach has not achieved the reductions theoretically stated as possible. Plug-in hybrids are expected to save significant amounts of gas, but the first results show that, on average, they use 80% more than calculated due to driver's behaviour (Dekker, 2012). In the same line, even though modern washing machines use 45% less energy, 60% less water and 40% less detergent, there are no indications that actual energy use for washing clothes is decreasing (Terpstra, 2008). The only possible explanation Terpstra sees is that people had changed their behaviour since the acquisition, with the laundering frequency increasing over the years. Shove (2003) confirms the trend with clothes laundering rituals. She explains that the social norms surrounding laundry have changed, resulting in people washing their clothes more frequently. Terpstra (2008) concludes that even though on a technical basis a product should be able to attain a certain energy reduction, this is not a good indicator for actual reduction in practice.

§ 2.3.2 Housing

Similar cases from building improvement are also present. Terpstra (2005) found that for solar boilers, only half the households were actually using less gas in both consecutive years after installation and that the overall savings were half of the expected reductions (Terpstra, 2008). In the European EBOB project, Zeiler et al. (2009) found that the expected savings of 20–30% for an office building were not achieved in real life "*due to 'incorrect'* [single quotation marks added] *behaviour of the office users*". Likewise, in research among the inhabitants of new, sustainable housing estates, Derijcke and Uitzinger (2006) found that 25% of the inhabitants did not use the flush stops on their toilets, and that 'a reasonable share' of all residents did not even know that their toilet had a flush stop. As Crosbie and Baker said: "*It does not matter how much energy hypothetically could be saved by "green" housing developments or energy-efficient heating and lighting systems if the energy-efficiency measures are unwanted*" (2009, p. 3).

§ 2.3.3 Background appliances

Many products operate in the background either physically or in the back of our minds. Ihde (1990) describes this relationship with products as their being an 'absent presence' in households. An increasing number of appliances, especially technical installations, function autonomously, that is, they self-regulate their energy use (Figure 11).

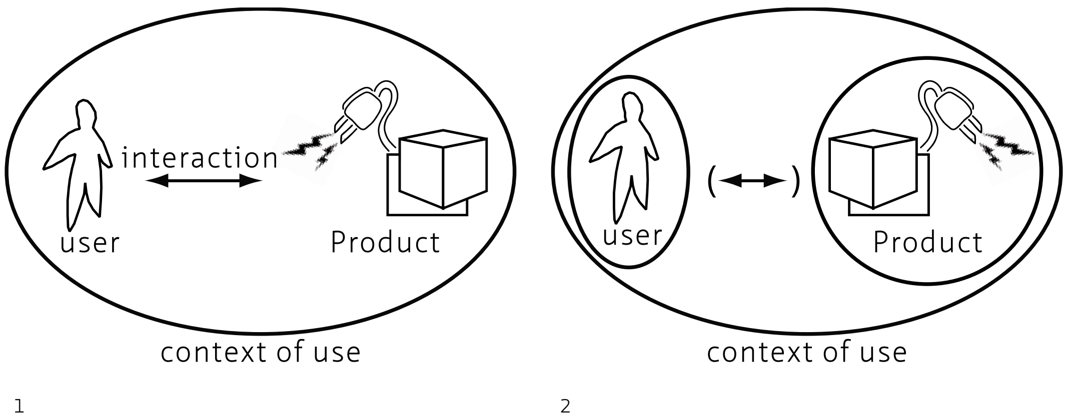


Figure 11
Changing relation between the user, his/her appliances and the energy consumption of those appliances (graphics derived from Wever et al., 2008, van Kuijk, 2010).

A user's energy consumption was historically directly dependent on his or her interaction with a given product or appliance (left side of Figure 11). A woodstove would heat up when a user fed it wood, and a shrinking pile of wood next to the stove was the tell-tale sign of the amount of energy consumed. Nowadays, however, an increasing number of products (such as heaters, close-in boilers, programmable thermostats, pumps, refrigerators, water beds, modems, security alarms) function autonomously and there is little to no direct relation between the interaction of a user with a product and its energy consumption (right-hand side of Figure 11). The heater is usually hidden away in the attic or utility room, and an automated thermostat adjusts the temperature and sends a signal to the heater to switch on. Borgmann (1995) describes this autonomous functioning as disburdening but also disengaging technology. Schuitema and Steg (2005) found that people underestimate the energy consumption of appliances that self-regulate their energy consumption and function unseen in the background. Background appliances are a significant contributor to the energy consumption of households. More than half of the CO_2 emissions of households (derived from Milieu Centraal, 2008) are caused by background appliances (heaters, cooling appliances) and by background energy consumption in periods that appliances are not actually in use. Examples of 'background energy consumption' are energy leakages and the use of standby functions with losses through the constant energy consumption of displays, transformers and adaptors. Specifically, standby functions were found to make up 9–16% of households' energy consumption in England (Zimmermann et al., 2012), and even 19–20% for continuous and standby (Firth et al., 2008).

§ 2.3.4 Invisible energy consumption

Energy flows in households are mostly invisible. To stay with the analogy of the heater, there is no longer a pile of wood next to the stove. Gas or electricity is transported automatically to the heater through a system of pipes and only once a year is an indication given on the bill about how much has been used. Energy has become a commodity that people have become largely unaware of. Dobbyn and Thomas (2005) 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*." (p. 6) People's perception of energy consumption can differ from reality, with people thinking that larger appliances use more energy (Schuitema and Steg, 2005). It can be difficult or even seemingly impossible for householders to understand what is consuming their energy and, even more so, to know what they can do about it.

§ 2.3.5 Implications

Householders' behaviours, preferences and lifestyles are therefore important for the actual energy consumed in dwellings and by appliances, in particular due to the number of background appliances and the invisible nature of energy consumption. To achieve energy reductions, users and their behaviours have to be taken into account. However, this means understanding the underlying reasons why the expected energy consumptions of appliances and dwellings are not achieved in practice. This is briefly explained in the following section.

§ 2.4 Explaining energy-related behaviour

A number of theories have been developed to explain the energy-related behaviours of households mentioned in the previous section, and the reasons for those behaviours. The rebound effect and lock-in and social sciences perspectives are discussed here.

§ 2.4.1 Rebound effect

Some of the phenomena mentioned in the previous section, such as the examples concerning washing machines and solar boilers, can be ascribed to the rebound effect, which is the lost part of the energy efficiency improvement potential (Berkhout et al., 2000). There is very little consensus as to the actual size of the rebound effect, with figures ranging from 0 to 30% of the possible energy reduction (Berkhout et al., 2000). Some even argue that a 'backfire' can occur, whereby people end up using more rather than less energy. This is in part due to the "*various behavioural responses which are commonly grouped under the heading of rebound effects*" (Druckman et al., 2011). Direct rebound effects are directly related to the increased efficiency of a product; for example, households use a CFL light more because it is energy efficient and costs less to run, while indirect effects affect the use of other products. With this latter 'income effect', people have more income at their disposal due to a decrease in product running costs or energy prices, and use this money on other energy consuming appliances or services. Druckman et al. estimated for a specific household situation that the cumulative direct and indirect rebound effect, combined in the "*overall or economy-wide rebound effect*", is around 34%, but it can vary from 12% at best, to a backfire with an increase of 515% in the worst case.

§ 2.4.2 Lock-in

Another explanation for the high energy-consuming behaviour of households is that we live in a consumption-based society. Some of the answers that social science gives are that we consume for wellbeing, to satisfy needs and desires, as a means for achieving personal identity or in pursuit of meaning and self-worth. Others state that households have little choice in the matter and that people are 'locked-in' to behaviour. As Jackson (2005) states:

... far from being able to exercise deliberative choice about what to consume and what not to consume, for much of the time people find themselves 'locked in' to unsustainable consumption patterns. Consumer 'lock-in' occurs in part through the architecture of incentive structures, institutional barriers, inequalities in access, and restricted choice. But it also flows from habits, routines, social norms and expectations and dominant cultural values.

Jackson also states that there are two distinct, opposing approaches to understanding the behaviour of consumers. Internalists view behaviour as mainly originating from a person's attitudes, values, habits and personal norms. Externalists see behaviour as dependent on the environment and context surrounding an individual, that is, dependent on aspects such as incentives, institutional constraints and social norms.

§ 2.5 An interdisciplinary approach to reducing the energy consumption of households

In conclusion, diverse aspects influence the energy consumption of households and it is important to take a holistic approach. It is not only housing (the domain of architecture) or only the things that people put in houses (the domain of industrial design) that are responsible for the overall energy consumption of households: inhabitants and their behaviour are also an essential component. This is the domain of social and environmental psychology.

A purely technological approach has its drawbacks because the theoretical savings are not always achieved in practice. Therefore, it not possible to focus only on one product or aspect, because it all ties in together. Focusing on reducing the energy consumption of one product will have limited effect on the overall consumption.

The behaviour of inhabitants and their interactions with their appliances and homes are essential to the actual energy consumption of households. However, a purely socio-psychological approach also has its shortcomings. There is no one, specific, energy-consuming behaviour in households. Energy consumption can be attributed to a series of different behaviours of individuals as well as to the practices that make up daily life. If we wish to reduce significantly the energy consumption of households, we must address – and influence – numerous behaviours and practices.

All the mentioned elements interplay with each other, as can be seen in Figure 12.

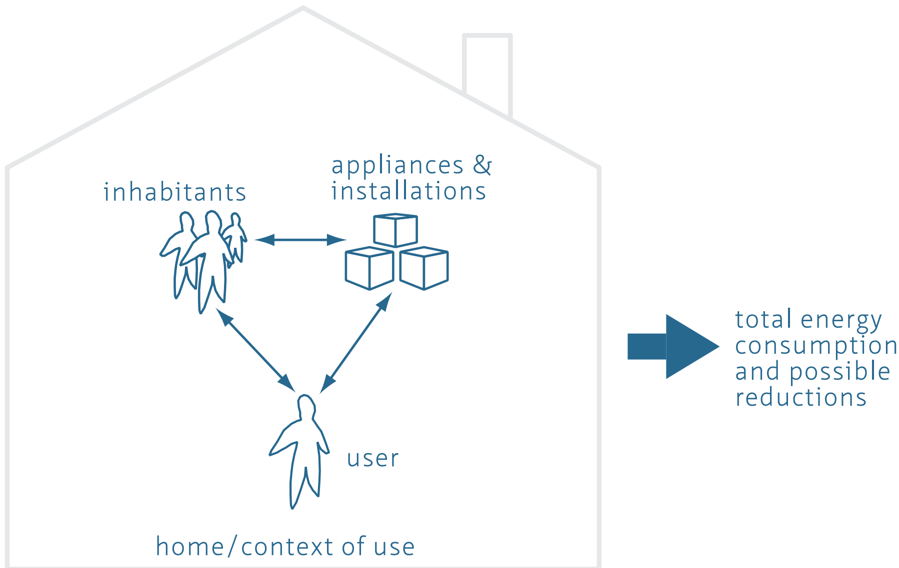


Figure 12
Factors influencing the energy consumption of households (graphics derived from Wever et al., 2008, van Kuijk, 2010)

Figure 12 shows that a household is a system of elements that intertwine and interact with each other. This means that the relationship between the various elements, and therefore also the usability of those elements, is essential. As stated in § 2.3.1 and § 2.3.2, if people do not use an energy-saving appliance component or technical installation correctly, the energy reduction is not achieved. As such, choosing an effective strategy to influence energy consumption means the strategy needs to be effective across the line. This calls for an interdisciplinary approach that is able to address the different aspects in Figure 12 and intersects the different elements.

§ 2.6 Influencing the energy consumption of households through HEMS

The intervention that was chosen in this research to address the various elements in Figure 12 is home energy management systems (HEMS). Feedback is commonly the main working principle and form of intervention used in HEMS. They are therefore sometimes classified as 'eco-feedback technology', that is, technology that provides feedback on individual or group behaviours with the aim of reducing the environmental impact (Froehlich et al., 2010 adopted from Midden et al., 2002).

What makes HEMS so interesting is that they have the capability to address the elements discussed in this chapter. HEMS can function as the pivot in household energy consumption, as can be seen in Figure 13.

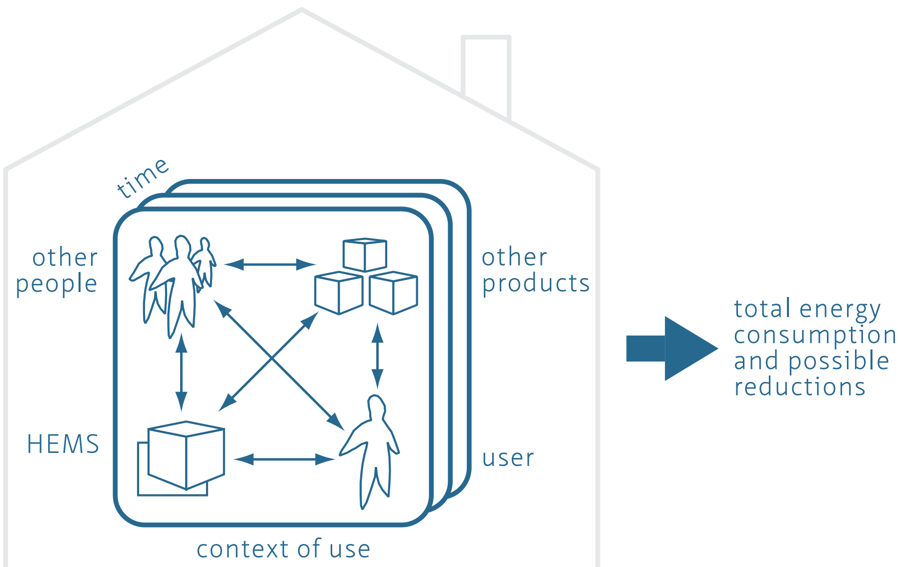


Figure 13
Pivotal position of HEMS in household energy consumption (Adapted from Wever et al., 2008, van Kuijk, 2010)

HEMS have the singular capacity to solve a number of key issues surrounding home energy consumption. They are implementable in existing households and with current appliances. They can also mediate between users and their appliances. This is of particular importance in the creation of awareness of background appliances and energy consumption, making invisible energy flows visible, as discussed in § 2.3.3 and § 2.3.4. They can influence both behaviour and practices, especially in combination with the use of persuasive techniques. Besides feedback, they can easily implement other behaviour change and influence strategies.

§ 2.7 Conclusions of Chapter 2 and moving on to Chapter 3

This chapter has analysed the context of household energy consumption. It has assessed the influencing factors and revealed the complexity of household energy consumption. A breakdown was given of households' gas and electricity consumption in order to ascertain the influence of various appliances and technical installations. The influence of building characteristics and household characteristics, demographics and behaviour on households' gas and electricity consumption was discussed. This gave a comprehensive picture of the context and complexity.

To address this complexity, an interdisciplinary approach using HEMS was proposed. HEMS were positioned within a framework that postulates the relationship between HEMS and energy consumption. HEMS address the various elements within the framework and their influence on household energy consumption, implying that these elements in turn influence the use and effectiveness of HEMS. To come to a fuller understanding of the possibilities of and opportunities for HEMS, Chapter 3 goes into further detail on the framework in Figure 13. It addresses the various elements within the framework and the working principles of HEMS

3 Influencing behaviour through HEMS: explaining the framework

§ 3.1 Introduction

Chapter 2 assessed the importance of considering the human factor in reducing the energy consumption of households and concluded that HEMS have the potential to influence household energy consumption. HEMS fit into the puzzle surrounding energy reduction because they are intermediary devices that can function as a pivot in household energy consumption, merging the various aspects addressed in Chapter 2. HEMS were positioned within the framework in Figure 14.

This chapter first explains why this framework was chosen and how it builds upon insights from social and environmental psychology, computer–human interaction and sustainable product design. It then discusses the framework itself in more detail by explaining its usability background. The various relational lines within the framework and which elements have been studied by different sciences are then detailed. Because the main body of current knowledge is from social sciences and centres on the feedback itself – which is the behaviour change mechanism generally used in HEMS – this is discussed first. After this, the other lines within the framework and reasons for including are discussed.

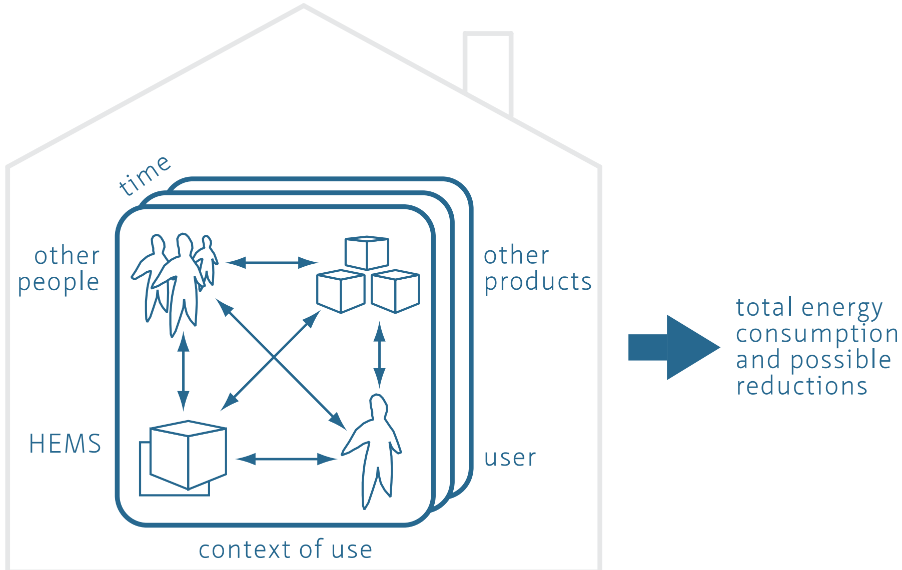


Figure 14
Framework on factors influencing the use and effectiveness of HEMS. Adapted from Wever et al. (2008) and van Kuijk (201a0)

§ 3.2 Choice of framework

This chapter first explains the reasons for using the conceptual framework of Wever et al. (2008). Prerequisites for the framework were that it needed to fit within and give consideration to the multidisciplinary facets of the research and the aspects addressed in Chapter 2. It also needed to be practicable yet comprehensive for the exploration and mapping of the relevant factors within the domains of architecture and industrial design engineering, and with consideration for social sciences.

Few models and frameworks are available in the literature on HEMS. The following section explains four models that are in the literature and addresses why they were not suitable for this research. The reasons for using the human–computer interaction framework of Wever et al. (2008) are then explained.

§ 3.2.1 Brandon and Lewis's model on factors that influence the energy consumption of households

Brandon and Lewis (1999) present "*an illustrative model of hypothesized factors influencing the energy consumption of households*" (Figure 15). This includes income constraints, behavioural and structural potential for change, environmental attitudes, feedback and socio-demographics. These are predominantly human-related characteristics. In their case study on implementing various types of feedback, Brandon and Lewis hypothesized that the factors in Figure 15 influence both energy consumption and energy savings.

Brandon and Lewis found that several of the factors did indeed either influence energy consumption or achieve savings, or both. Of the factors that were analysed, income, age, number of occupants and tenure were the only factors that had a significant influence on historical consumption, but they did not have a significant influence on savings. With regard to savings, whether households were high, medium or low users of energy had the most significant effect, whereas feedback and environmental beliefs and attitudes were marginally significant.

However, they did not consider factors other than behavioural and demographic characteristics that may influence energy consumption and achievable savings. This made the model too limited for this research, which aimed to also explore the influence of contextual factors. Furthermore, their study was on feedback and not specifically on HEMS. As mentioned in Chapter 1, it is questionable whether the PC they implemented in one of their samples qualifies as a HEMS, because the article suggests that households had to enter their energy consumption data into the software themselves.

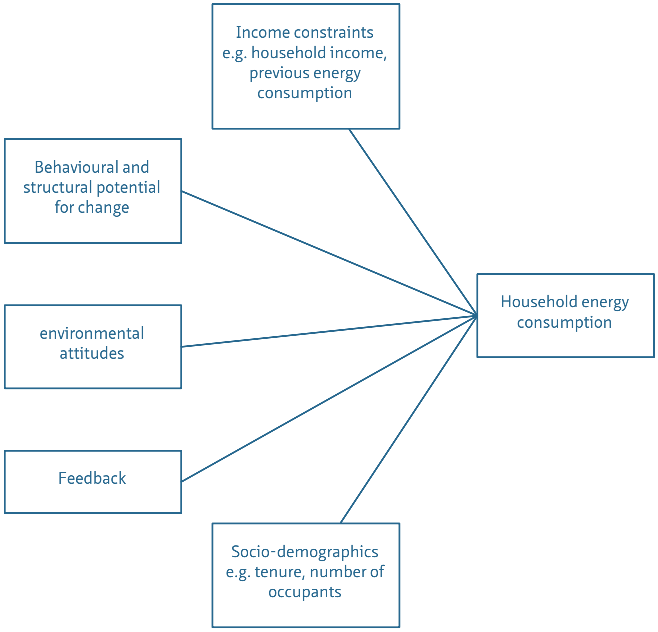


Figure 15
An illustrative model of hypothesized factors influencing the energy consumption of households (Brandon and Lewis, 1999)

§ 3.2.2 Framework Hutton for feedback

Hutton et al. (1986) present *"four components of a conceptual framework for feedback"* in table format (Table 4). According to their review, aspects that influence whether household are responsive to energy saving measures are: environmental factors, behaviour change strategies, mediating variables, and consequences (how household respond to the measures). Their framework lists the diverse possible influencing factors.

The framework shows that many factors may affect a household's conservation response. However, there are also a couple of drawbacks to the framework: the external mediating variables are listed as fuel type, geographic location, housing stock and demographics. In doing so, they merge a diverse list of aspects into one category, which does not do justice to the diverse nature of those aspects. Moreover, physical environmental factors and mediating variables within the home and their possible influence on the effective of the HEMS and its feedback are barely addressed. Lastly, in essence, it sums up findings in the literature on behaviour change. It is therefore not very suitable for exploring additional factors (within the home) that may influence the effectiveness of feedback or the use of HEMS and the interrelationship between various elements. While they explain that the mentioned aspects are not exhaustive, their framework was not deemed suitable enough for the, in part, exploratory nature of this research.

Four components of a conceptual framework for feedback			
Environment	**[Interventions] Strategies**	**Mediating variables**	**Consequences**
Energy concerns	**Antecedent**	**External**	**Conservation response**
- Price	- Education:	- Fuel oil type	**Product response**
- Consumption	- Conservation booklets	- Geographic location	- Knowledge
	- Feedback manual	- Housing stock	- Attitudes
Consumer information		- Demographics	- Intentions
- Government programmes	**Consequence**		- Behaviour
- Education	- Feedback:	**Internal to feedback**	
- Utility bills	- Learning	- Kind	
- Advertising	- Motivation	- Amount	
		- Immediacy	
Predispositions		- Format	
- Household			
- Public policy			
- Private sector			

Table 4

Four components of a conceptual framework for feedback (Hutton et al., 1986)

§ 3.2.3 Wood and Newborough's frameworks on factors that influence the design and feedback process during case studies

Wood and Newborough present two frameworks. One is of factors that influence the design of HEMS (2007) (Figure 16). It includes the place of the display, the motivational factor used by the HEMS, the unit of measurement, how the consumption is visualized, the timescale of the given feedback and how the feedback is categorized. These concern the design of the HEMS and are therefore internal to the HEMS. One partial exception is the motivational factor that the HEMS uses, which relates to the way in which the HEMS communicates to its user. Almost all these factors are specific to the HEMS itself in the framework adapted from Wever et al. (2008), but they do provide a relevant analysis of the specific elements within HEMS.

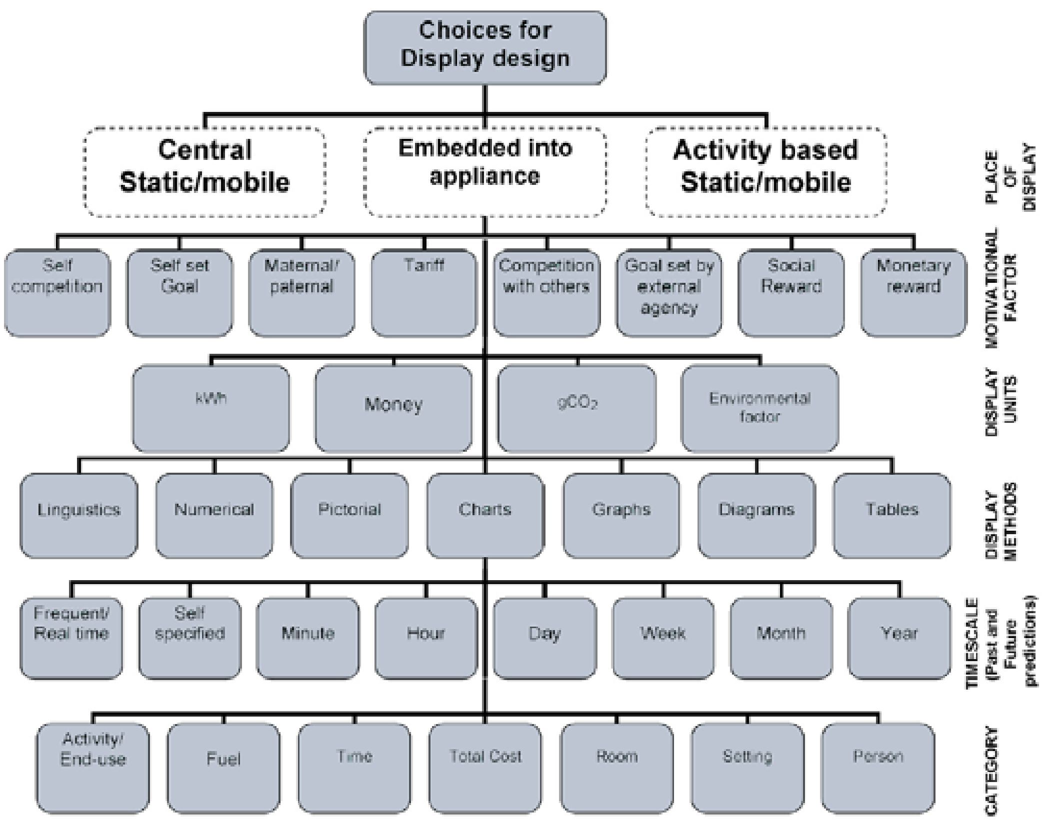


Figure 16
Framework of factors influencing the design of HEMS (Wood and Newborough, 2007)

Their second framework is on a more abstract level. In Wood and Newborough (2003), they discuss several factors that influence the feedback process during case studies and present a feedback loop, as displayed in Figure 17. Limited clarification of the framework is given, but they explain that the 'uncontrolled environment' and the experimenter/installer may be influential when interacting with the HEMS, because they may distract users or influence their perceptions. It has some similarities with the framework of Wever et al. (2008) in that it visualizes some identical elements and interactions.

However, the framework and feedback loop (at the bottom of Figure 17) is specifically designed for feedback integrated in an appliance, and as such the HEMS (labelled 'ECI' (energy consumption indicator) in the figure) and appliance are merged into one system. Additionally, the framework is specifically for case studies and as such the experimenter is included. It was therefore deemed to be unsuitable for the purposes of this thesis.

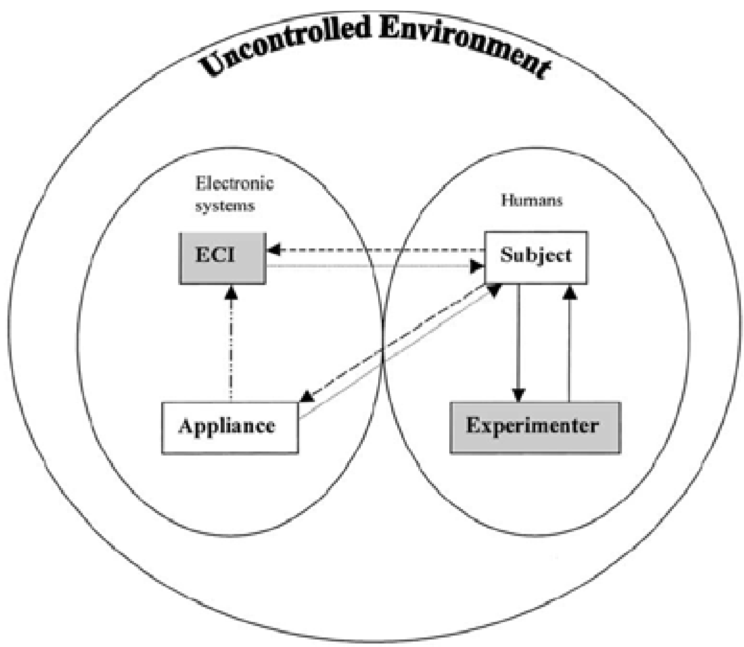


Figure 17
Factors influencing the feedback process (Wood and Newborough, 2003)

§ 3.2.4 The framework of Wever et al. and van Kuijk and its usability background

In conclusion, the scope of the abovementioned frameworks or models is too limited and does not give a comprehensive overview of influencing factors. In past research, limited consideration was given to the surrounding elements and contextual factors within the home. Finally, only a limited number of articles on HEMS have actually tried to explore and frame the factors that might influence the use and effectiveness of HEMS. Because the frameworks within the field of HEMS did not seem suitable enough, a framework outside this field was sought.

The framework of Wever et al. (2008) and van Kuijk (2010) (Figure 18), which has its origins in industrial design engineering and the usability of products, was therefore explored. The foundations of this framework lie in the work of Shakel (1984), who visualized four elements in human–machine interaction. Shakel explains that the usability of a product is related not only to the direct human–product (or tool) interaction, but also to the task (or goal) and environment. Wever et al. and van Kuijk expanded and updated Shakel's framework to make it more applicable to electronic products, stating that "*today's products are often product–service combinations, function in networks with other products, and that other people are also involved in or affected by a person's product use*" (Wever et al., 2008, p. 12). Because a HEMS is a mediating device, visualizing the energy consumption caused by other appliances, the network of other products that Wever et al. include in their framework is particularly relevant. As with the usability of a product, a HEMS cannot be viewed on its own. The context is important, as both Hutton (1986) and Darby (2006a) state: "*Feedback covers a wide range of practices and these are best analysed and understood in context*" (Darby, 2006a p. 8). That is why HEMS should be seen as a part of the system of a household, as the central interaction point concerning the practices surrounding energy consumption.

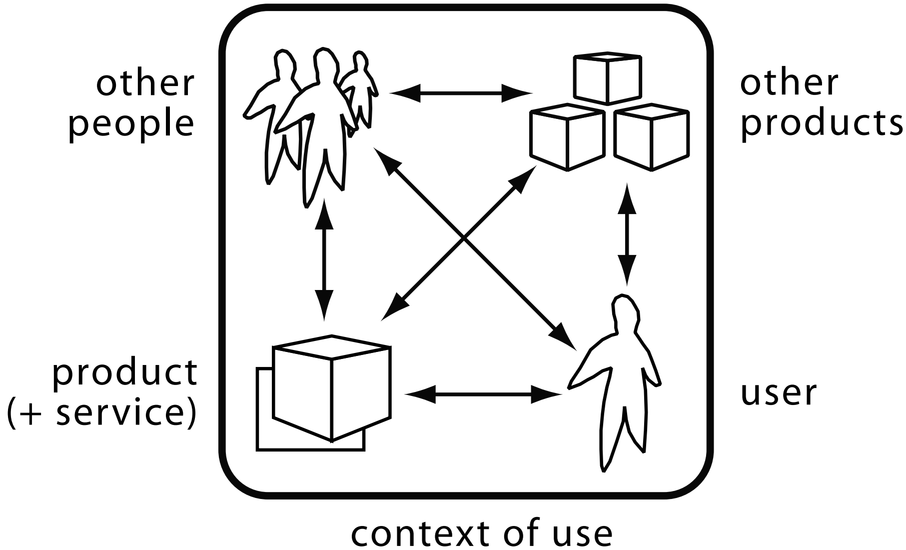


Figure 18
Original human–computer interaction framework of Wever et al. (2008), van Kuijk (2010)

In addition, the framework inherently provides the opportunity to study factors that influence the use of HEMS. If a HEMS is not used or not used successfully, a household will not receive feedback on its energy consumption – the driving principal of most HEMS. So to a certain extent, the successful use of a HEMS is a prerequisite for a HEMS to be effective. The successful use of HEMS is tied in with its usability: "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (ISO, 2006).

When specifically applying the framework in Figure 18 to HEMS, as was done in Figure 14, this visualizes the interactions between a HEMS, its user, other household members and other products that affect the use of HEMS. The following briefly define what the different elements encompass within this research.

- Van Kuijk (2010) explains that most electronic products are a system that consists of a set of three components, namely a core product, the extended product and the ecosystem. For the HEMS, this means that:
  - The hardware and interface of the HEMS form the core product. In other words, the HEMS is the product that the user primarily interacts with.
  - The extended product differs per HEMS but usually includes the manual, the box in which it is presented and, in the case that it is attached to an energy meter, the sensor and transmission unit.

- The ecosystem is also HEMS dependent, but may include the meter/smart meter, attached appliances, PC software, a router and services.

- 'Other people' relates to the presence of other household members, and the social context of these family dynamics.
- 'Other products' relates to the other energy-using products, such as household appliances and technical installations.
- 'Context of use' is defined as the architecture of the home and the energy structures embedded within it. This environment includes physical and environmental aspects such as the floor plan and spatial layout of the home. To visualize the context of use in which a HEMS is used, a house was drawn around the framework (Figure 14).
- For the purposes of this thesis, the framework was further expanded to include the element of time, which was one of the shortcomings in previous research, as stated in § 1.2.2.

§ 3.2.5 Benefits of the framework of Wever et al. and van Kuijk

The framework of Wever et al. and van Kuijk (Figure 14) seemed to be more fitting than the other frameworks because it is able to visualize the interdependence of the different elements that influence the energy consumption of households, as discussed in Chapters 2. It displays the appliances, users, other inhabitants and the context, including the home itself, and visualizes how these elements interplay. It also displays the pivotal position of HEMS and how it influences and relates to the other elements in the diagram. Furthermore, it combines and visualizes various scientific fields that can contribute to reducing the energy consumption of households, rather than focusing on only one individual element or relational line. In doing so, knowledge can be drawn from these fields for the current discussion, merging and expanding on previous literature. In conclusion, the framework presented in Figure 14 seemed to be more applied and give a more comprehensive overview of the factors to explore concerning their possible influence on use and effectiveness of HEMS in reducing the energy consumption of households.

§ 3.3 Focus of different scientific fields and practitioners within framework

This section explores the framework step by step by discussing each interaction (or 'relational line') separately. The two elements that make up the relational line are discussed integrally alongside the line itself. First, a short explanation is given of why the given interaction is relevant. Then the scientific field(s) that is/are relevant for influencing this relational line and knowledge that can be gleaned for HEMS is discussed. The first part of the framework explained in more detail is the user and the interaction with other people. This is because the main body of knowledge on issues surrounding HEMS is from social sciences and centres on influencing behaviour.

§ 3.3.1 User <-> other people: the fields of social and environmental psychology: Relevance of the interaction between the user and other people

This interaction is relevant because a household often consists of more than one person and all household members contribute to the overall household energy consumption, as discussed in § 2.2.3 and § 2.2.4. A HEMS is intended to influence the energy consumption and behaviour of different household members, either directly or possibly also indirectly through the interactions and dialogues between different household members. How many people use the HEMS within the household and how they use it is a factor that is explored in this research.

The fields of social and environmental psychology have attempted to influence the energy-related behaviours of household in various ways, as is detailed in the following section. In particular, feedback is viewed as an important or core element in lowering the environmental impact of households, and therefore this research is grounded within the fields of social and environmental psychology. However, social and environmental psychology has predominantly been interested in influencing the behaviour of household members through the intervention feedback, and has been less interested in the medium by which feedback is given, the HEMS. That is why feedback and its working principles are discussed within this relational line.

§ 3.3.1.1 The field of social and environmental psychology

Two strategies to influence behaviour that are commonly used within the fields of social and environmental psychology are addressed in this thesis, namely using interventions to achieve behaviour change and using influence tactics. These are not strictly disparate strategies, but they do represent different schools of thought. Influence strategies are not completely dissimilar to interventions, but they have a different accent or work on a different scale with several influence strategies being applicable to just one intervention strategy. The following section discusses both in more detail. A brief overview of the various strategies applied within social and environmental psychology, along with their applicability to HEMS, is given, with a particular focus on feedback – the core principle of HEMS.

A Intervention strategies

Interventions are commonly used in the fields of social and environmental psychology and medical/health sciences to help people change a certain behaviour or habit or its context. There is also quite an extensive body of knowledge on the role that interventions can play in achieving pro-environmental behaviour. Within this field there are two main types of interventions: structural interventions – which are aimed at altering the context and conditions in which a behaviour takes place – and psychological (or 'behavioural') interventions, which aim at altering "*already existing perceptions, knowledge, attitudes, norms and values*" (Abrahamse, 2007). Structural interventions are commonly divided into "*financial–economic measures, physical/technical alternatives* [which design interventions can be a part of] *and legal regulation*" (ibid.).

Abrahamse et al. (2005) divide behavioural interventions used in research on household energy consumption into two subcategories, namely antecedent interventions (preceding a targeted behaviour) and consequence interventions (succeeding a targeted behaviour). The main forms of antecedent interventions are goal setting (setting a specific target to reach), commitment (participants say they will commit to doing 'something' sustainable), modelling behaviour (participants are shown role model behaviour) and information. Feedback is the main form of consequence intervention. Another form is rewards, whereby a participant is promised a reward for either participating or achieving a certain behaviour. Of these different types of intervention, feedback seems to have a high potential for success, particularly in combination with other interventions and with increasing frequency (Abrahamse et al., 2005, Fischer, 2008). In addition, feedback is a prerequisite for certain interventions, such as those using goals or rewards. These depend on feedback in order to set a certain goal or level at which a reward will be given.

Working principles of feedback

Feedback is basically "*the transmission of evaluative or corrective information about an action, event or process to the original or controlling source*" (Merriam-Webster, 2013). In this thesis, feedback relates to information about a user's energy consumption. This can be current, real-time consumption or historical consumption, that is, energy consumed over a previous period such as a day, a month or a year. Extrapolation to the future, based on past consumption, is commonly called feed-forward or a prognosis.

According to Abrahamse (2007), feedback may increase a user's perceived possibilities to conserve energy (also called 'self-efficacy'), which can then encourage the user to actually conserve energy. Similarly, Darby (2006b) explains that feedback can be seen as part of a learning process. She has visualized this process (Figure 19). Darby notes that while the figure is not complete and that real life does not follow such a smooth curve, it does highlight the elements that are involved in the energy learning process.

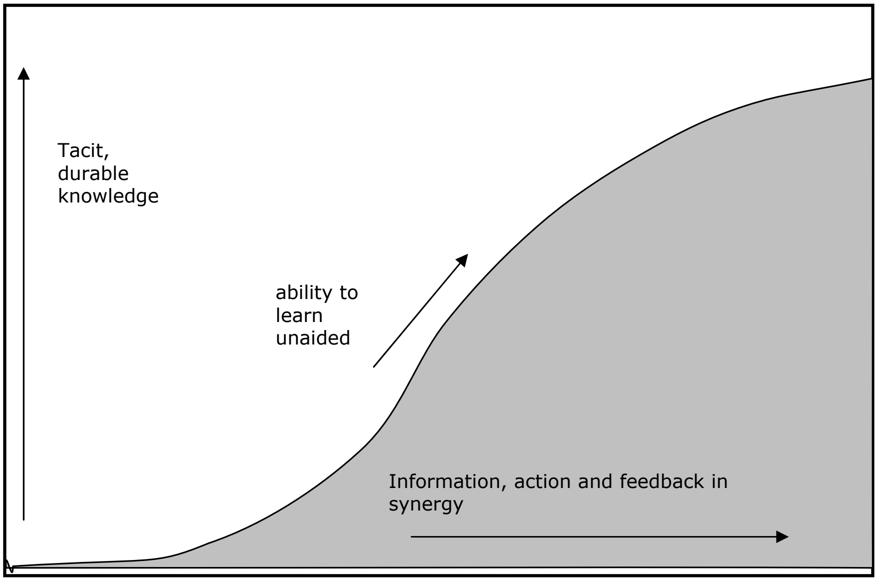


Figure 19
A model for the development of tacit, durable knowledge (Darby, 2006a)

Darby explains that within this process, feedback increases a user's ability to find the needed information and sources more independently. She also explains that feedback contributes to "*building up of a body of 'tacit knowledge' or know-how about the supply and use of energy. In this, people take in information concerning their energy use, they act (change their behaviour in some way) and they gain understanding of what has happened by interpreting any feedback that is available*" (2006a). However, the learning process of people can be hindered. People need to be able to interpret the feedback for it to have an effect, and 'affective factors', such as attachments to certain practices, can inhibit people's willingness to change.

B Influence strategies

Besides intervention strategies, there is also a school of thought on influence or persuasion strategies, which are commonly used in marketing. Cialdini's (1993) work draws on ethology, where fixed action patterns describe the automated behaviour of animals. He calls these automated responses "*click–whirr*" responses, where 'click' activates the appropriate tape and 'whirr' results in a pre-set sequence of behaviours. He distinguishes six principles, or 'weapons', of influence.

- Reciprocation – This is based on the tendency of people to return a favour.
- Commitment and consistency - If people make a commitment, they want to fulfil it so that they are not perceived as being inconsistent. This is strongly related to cognitive dissonance, whereby people do not want to contradict themselves.
- Social proof – In other words, normative conduct or looking at what other people do. People are basically copycats. If a number of people are looking up at the sky, other people will imitate this behaviour even though they cannot see what is being looked at.
- Authority - People tend to believe and obey authority figures.
- Liking – If a person finds another person agreeable, the latter is more likely to be able to persuade the former.

- Scarcity – If something is perceived as scarce, then people will want to have it.

Cialdini and colleagues also studied which of these subconscious motives is relevant to pro-environmental behaviour. They especially studied the possibilities for social proofing. Practical examples of the implementation of influence strategies can be found in, for example, Goldstein et al. (2008), where messages encouraging the reuse of hotel towels were altered to appeal to people's normative conduct, with success. Additionally, Nolan et al. (2008) tested the effects of four messages (save money, benefit society, protect the environment, the neighbours conserve energy). They found that the descriptive normative message that a majority of the neighbours conserved energy was the most effective in motivating people to reduce energy, even though people indicated that this was the least important. This implies that the way in which a message is put across is significant to its effectiveness.

An energy billing company (Opower) has recently been implementing Cialdini's work by combining persuasion strategies with feedback on energy consumption (Ayres et al., 2009). Both descriptive norms (what most people do) and injunctive norms (what people ought to do) were combined with monthly feedback on overall energy consumption, and the results showed that there is good potential here. It was done by giving feedback in comparison to similar households and giving smileys according to how well the participants had done. The study consisted of two large-scale pilot projects amongst 75,000 households; savings of 1.2% and 2.5%, respectively, were achieved. This shows that feedback is also an important component for some persuasion strategies; however, the manner in which it is given needs to be considered, which is relevant to the interface of HEMS.

§ 3.3.1.2 Application of the knowledge from the field of User <-> Other People and psychology to HEMS

Various influence and intervention strategies are implementable within the design of HEMS. For example, goal setting and feedback can be combined within HEMS and presented using commitment & consistency along with social proofing tactics. Opower's energy bills are, in essence, already a product, but Opower has also implemented these influence principles in online tools and energy alert platforms for smart phones and tablet PCs. However, more work could be done to implement different intervention and influence strategies within HEMS.

The most relevant and commonly implemented strategy for HEMS is feedback (page 92). Both the abovementioned intervention and influence strategies attribute value to feedback and see it as one of the important elements, or the core element, in lowering the environmental impact of households. Feedback is both an effective intervention strategy and an important precondition for several influence strategies. As Midden (2006) says concerning feedback, "*One might say that the system persuades the user in a certain sense to make more energy-efficient choices.*" He states that to be effective, feedback needs to fit with user's goals that are in effect at the point in time when feedback is given, and that it needs to be presented on the level of the task that the user is executing.

An important characteristic of feedback for this research is that it ties in with two major issues addressed in Chapter 2. One is that the energy consumption of households is caused by many different appliances, technical installations and the structural characteristics of the home, as well as by behavioural and demographic factors. It is therefore important to view households as systems, and not aim at altering only one of these aspects. Feedback is capable of addressing these different factors of energy consumption.

The second issue is the invisibility of background appliances and energy flows. Most households receive a bill only once a year and it may even be based entirely on estimates. Kempton and Layne (1994) draw a parallel with shopping: "*consider groceries in a hypothetical store totally without price markings, billed via a monthly statement like 'US$527 for 2362 food units in April'. How could grocery shoppers economize under such a billing regime?*" Feedback is a necessary element to make energy consumption visible, just like a receipt in a supermarket does.

As explained at the beginning of this section, social and environmental psychology have predominantly been interested in the effects of the intervention on the behaviour of household members rather than the medium (HEMS) by which feedback is given. Feedback was discussed within this section because of the focus on the person rather than on the HEMS or the interaction between the HEMS and the user. However, it is part of the HEMS and therefore this chapter continues by shifting towards the relational line HEMS <-> user, discussing the interaction between the user and the HEMS as well as the design of the HEMS.

§ 3.3.2 HEMS <-> user and the design of HEMS: Relevance of the interaction between the HEMS and its user

The interaction between the HEMS and its user is important because the HEMS is the physical device that gives the feedback to the user. However, far more than only the feedback itself plays a role. The design and architecture of the HEMS – including the interface, functionalities, and physical characteristics and location of the HEMS – affect how users can interact with and experience the HEMS, and may thereby influence its potential effectiveness, as discussed in § 3.2.5. The dynamics between the HEMS and the user and how people respond to the HEMS is relevant because it may help explain the variances in achieved savings, as discussed in § 1.2.4. The interaction between the user and the HEMS is therefore worth exploring.

§ 3.3.2.1 The field of computer–human interaction

HEMS have recently attracted some interest within the field of computer–human interaction (CHI). Articles on HEMS used to be published mostly in energy, environment, building and psychology related journals (see Table 2 on page 39). A number of design related papers have recently emerged, although most date from after the commencement of this research. These recent studies from the CHI community have focused either on the design of the HEMS itself or on evaluating its design, the appeal of HEMS and increasing the usability of HEMS, rather than on the effects on energy savings (Froehlich et al., 2010). The CHI community has gravitated towards developing prototypical HEMS, with short-term, small-scale and qualitative testing at home or in the lab (Petkov et al., 2011, Froehlich et al., 2010, Kjeldskov et al., 2012, Petersen et al., 2009). While feedback has its roots in the fields of social and environmental psychology, the amount of cross-fertilization and building upon each other's work so that all fields benefit is still limited (Froehlich et al., 2010). The use of

HEMS is an important topic to explore further, preferably with larger samples over a prolonged period of time in a home setting.

Nonetheless, the papers do reveal that households have difficulty understanding the data provided by the HEMS (Strengers, 2011) and energy consumption units in particular (Kjeldskov et al., 2012). They indicate that in the design of feedback, consideration should be given to the differences between people (Ai He et al., 2010), as people appreciate and respond differently to comparative feedback (Petkov et al., 2011). Furthermore, users do not always use the HEMS (Pierce et al., 2010) or stop using them because of the irrelevance of the feedback (Strengers, 2011).

§ 3.3.3 HEMS <-> other people: Relevance of the interaction between HEMS and other people

The relational line between HEMS and other people is relevant for two reasons. The first is that it remains to be explored how many people within the home use the HEMS. This could mean that the HEMS <-> other people line may, to a certain extent, overlap with the HEMS <-> user line. The second reason is that even if not all household members use the HEMS, it is likely that they will be affected by the presence of the HEMS in their household. It may be the case that a user of the HEMS influences the behaviour of other household members, or that other household members influence the extent to which a user uses the HEMS or achieves savings. This is not a specific field of research, although it does tie in with social psychology, as discussed in § 3.3.1. This is therefore explored in this thesis.

§ 3.3.4 HEMS <-> other products: Relevance of the interaction between HEMS and other products

HEMS are mediating devices. They mediate between users and other electronic products. In this mediating role, they give feedback to the user and/or manage the energy consumption of other appliances for the user, with the aim of influencing the user and/or the energy consumption of appliances. This line visualizes this relationship. For energy monitors that give feedback on overall consumption, this relational line is indirect, as a certain amount of deductive reasoning is required to understand the relationship between overall electricity consumption and the consumption of an individual appliance. This relational line is direct for both HEMS that give disaggregated feedback and energy management devices, although it plays the largest role in the latter group. Energy management devices are intended to directly control the consumption of other appliances. However, these devices have received little attention in the literature, as explained in § 1.2.1, and therefore perhaps this interaction between HEMS and other products has not been probed.

§ 3.3.5 Users <-> other products and the field of sustainable product design: Relevance of the interaction between users and other products

Because HEMS are mediating products, the interaction between users and other products is also relevant. The utilization of appliances by the user influences the energy consumption of households, as was explained in Chapter 2. If a HEMS is to reduce the energy consumption of households, it must directly or indirectly influence the interaction between a user and his or her other energy-using products.

§ 3.3.5.1 The field of sustainable product design

Although influencing behaviour is inherent to product design, purposefully doing so, in particular concerning influencing sustainable behaviour, has only recently gained interest (Bhamra et al., 2011). There are a number of lessons that can be learned from this field. Three approaches are discussed here, one from mainstream product design, the others from sustainable product design. These are persuasive technology, design for sustainable behaviour (DfSB) strategies and the design with intent toolkit, all of which partly draw on knowledge from social and environmental psychology. They are discussed because of their broad scope and their applicability to the interaction between user and other products as well as HEMS themselves.

Fogg (2003) coined the term persuasive technology for a set of influence strategies implementable within product design. Some persuasive strategies overlap with Cialdini's influence strategies, which were discussed in § 3.3.1.1, but others are more specific to the realm of computer–human interaction. Fogg's work is strictly limited to persuasion rather than coercion. As a means of implementing persuasive technology in products, Fogg (2009) developed a behaviour change model. He defines three principle factors within the model, namely motivation, ability and trigger. If a target behaviour is to occur, each of the three factors must be simultaneously present. However, not all factors are equally easy to manipulate from a product design point of view. He advises starting with the trigger, especially 'sparks' and 'facilitators'. If this does not result in the intended behaviour, the next step is to increase the ability by creating simplicity.

Ability can be achieved quicker than motivation, which people are more likely to resist. The main value in Fogg's model is the direct applicability in products.

Bhamra et al. (2011) distinguish seven strategies for change behaviour through product design, namely eco-information, eco-choice, eco-feedback, eco-spur, eco-steer, eco-technical intervention and clever design. They indicate that the *"The seven design approaches fall into three levels of interventions starting from where the power in decision making lies completely with the user, and therefore the intervention aims to provide a conversation with which to guide the change through to the other extreme where the power in decision-making is just with the product (or system) and it is trying to force the change."* Basically, coercion is the final stage in this spectrum, but they indicate that there are ethical and user acceptance dimensions to be considered.

Perhaps the most comprehensive overview is given in Lockton's 'design with intent' toolkit (2009), which attempts to address the different ways to design for behaviour change, merging a wide range of scientific fields. He draws from the fields of cognitive, social and environmental psychology, and incorporates knowledge from persuasive technology and sustainable product design approaches. Basically, the toolkit addresses questions intent on enabling, motivating and constraining behaviour through eight 'lenses', namely architectural, error-proofing, interaction, ludic, perceptual, cognitive, Machiavellian and security.

§ 3.3.5.2 Applicability of knowledge from the field of user <-> other product and influencing people through products to HEMS.

Findings from sustainable product design and persuasive technology are relevant to the design of the HEMS itself. The following section briefly discusses how the abovementioned approaches can be implemented in HEMS.

If one implements Fogg's (2009) line of thinking into HEMS, this could mean creating the right triggers at the right moment and/or increasing the simplicity (of both the HEMS itself and the energy reduction possibilities) in order to increase the ability of household members to reduce their energy consumption. Awareness of energy consumption through feedback can increase motivation, but it does not necessarily increase ability or simplicity. Fogg's approaches could therefore be considered.

Several of Bhamra et al.'s (2011) strategies are directly applicable to HEMS because they concern different forms of feedback. The power in decision making and whether the HEMS or the user is in control is particularly relevant to the energy influence strategies used by HEMS, ranging from monitoring to managing, as discussed in § 1.1.2.4.

Lockton's (2009) toolkit is a practical approach that can be utilized in different dimensions of the HEMS including the architectural, locational and interface design of the HEMS. Different design strategies for HEMS could be formulated and experimented with using the eight lenses.

§ 3.3.6 Other people <-> other products: Relevance of the interaction between other people and other products

This interaction is relevant for the same reasons that the interaction between users and other products is relevant. The accumulated use of appliances by all household members strongly contributes to the household's overall energy consumption. Therefore, a HEMS also needs to influence the interaction between other household members and other appliances in order to achieve its intended purpose. Whether and, if so, how a HEMS is able to do this is an area to delve into. The scientific field discussed in § 3.3.5.1 on influencing behaviour through products also applies to this relational line.

§ 3.3.7 The context of use and its relevance: the fields of architecture and the building industry

Chapter 2 assessed that the context (i.e. the home) contributes to the overall energy consumption of households. It is therefore likely that it also contributes to the use and effectiveness of HEMS. Housing developers and the building industry have mostly aimed at improving the environmental impact of this context: they have addressed the issues of the house itself but not what happens inside the home, so little is known about how the home influences the use and effectiveness of HEMS. This is explored in Chapter 9.

§ 3.4 Conclusions and moving on to part II: Empirical studies on implementing HEMS within households

This chapter has delved into the various relational lines in the framework (Figure 14) postulated in Chapter 1. It has addressed reasons for using this framework and explained its usability background. In doing so, a number of scientific fields and their contribution to the current discussion were also addressed. Insights from the fields of social and environmental psychology and from the computer–human interaction community, persuasive technology and sustainable product design were discussed. The relevance of each type of interaction and the perceived gaps, which have either not been addressed in the literature or are worth giving more attention to, were pinpointed.

To explore the framework and the influence of the different interactions and give a comprehensive perspective on the potential for HEMS, case studies are necessary. Part II of this thesis therefore presents the results of three case studies conducted with HEMS. These also focus on the gaps addressed in Chapter 1 and resolve these issues.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PART II Empirical studies on implementing HEMS within households

This part presents the empirical results that were obtained through the execution of three case studies between 2008 and 2011. The case studies were carefully selected to allow the study of the factors discussed in Chapters 1, 2 and 3. By implementing three distinct types of HEMS over a prolonged period of time, a wide range of knowledge could be gathered on the design, use, context and implementation of HEMS and their mid- to long-term effectiveness. The cases were executed in the Netherlands due to the various new start-ups underway there, the intended crossover between industry and academics, and the manageability of the number of variables through the exclusion of cultural differences.

The first case study involved 189 participants between 2008 and 2009. It is discussed in **Chapter 4**. The participants used an electricity monitor for four or 15 months with both groups followed up on at the end of the 15 months. The monitor gave real-time and cumulative/24-hour feedback. The quantitative data for this study were gathered by means of four online questionnaires and meter readings.

Chapter 5 discusses the setup and execution of the second and third case studies. In the second study, ten semi-structured, in-depth interviews were conducted with households that used an energy management device in 2010 for five months. It gave real-time and historical feedback for individual appliances and helped households manage whether and, if so, when appliances consumed electricity. The third case study was executed between the summer of 2011 and that of 2012 with an all-in thermostat giving real-time and historical feedback on gas and electricity consumption. Sixty-nine participants used the all-in thermostat for one year at home, while an additional 22 participants used the all-in thermostat only on a one-off basis in a lab setting. The data in this case study were gathered by means of three online questionnaires, five focus groups and two usability studies. A number of challenges were encountered in the execution of the second and third case studies, which are also be detailed in this chapter. As a result, the quantitative data that were gathered on energy consumption and the use of the HEMS were not usable, which led to a revision of the research questions.

Chapter 6 combines the qualitative data from the second and third case studies in order to delve into the differences between households and their use of HEMS. It explores how HEMS are used, the use patterns, and the consequences this has for the design and implementation of HEMS.

4 1st case study: Home energy Monitor: Impact over the medium term

van Dam, S. S., Bakker, C. A. & van Hal, J. D. M., 2010. Home energy monitors: impact over the medium-term. Building Research & Information, 38(5),pp. 458 - 469.

One of the issues pointed out in chapter 1 was that research up to now in the area of Home Energy Management Systems (HEMS) has had its shortcomings, especially concerning the study of the long-term effects. This next chapter aims to address this shortcoming. The dark blue elements in Figure 20 visualize which aspects will be addressed in this chapter, namely the element of time, HEMS-user interaction and the influence this has on the use and effectiveness of HEMS.

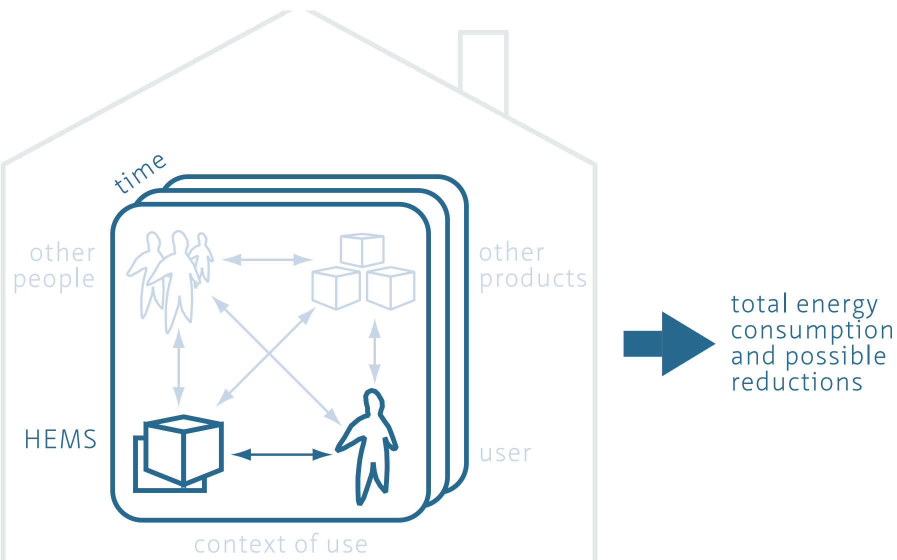


Figure 20
Aspects of the framework addressed in chapter 4

HEMS increasingly receive attention for their role in energy conservation in households. A literature review and a case study examine the mid-term effectiveness (more than 4 months) of HEMS. The case study presents the results of a 15-month pilot with a domestic energy monitor in the Netherlands. It explores the extent to which participants manage to sustain their initial electricity savings over time, with a special focus on the development of habitual energy-saving behaviour. The results show that the initial savings in electricity consumption of 7.8% after 4 months could not be sustained in the medium- to long-term. A second finding is that certain groups of people seem more receptive to energy-saving interventions than others. These participants quickly develop new habits and exhibit larger savings than other participants. Obviously, a 'one-size-fits all' approach for home energy monitors cannot be justified. For HEMS to be effective, a deeper understanding is needed that embraces social science, contextual factors, usability, and interaction design research.

§ 4.1 Introduction

Residential electricity consumption has been growing in all regions of the world at an average of 3.4% per year since 1990. Although some of this growth is a result of more people with access to electricity, the majority is caused by the increased consumption of electricity by individual households(International Energy Agency (IEA), 2009). Western households commonly own a growing number of appliances that currently range in number from 28 to 67 (Milieu Centraal, 2005, IEA, 2009). Also, the number of technical installations for space heating, cooling and ventilation is increasing. Technological solutions, such as switching to the most energy-efficient technologies available, could save up to 40% in residential electricity consumption (IEA, 2009). However, the focus on technology alone appears to have its limitations. With regards to energy, for instance, occupant behaviour was found to be the major contributor to the variance in domestic energy consumption (Brohus et al., 2009, Crosbie and Baker, 2009). As Crosbie and Baker (2010) state: *"It does not matter how much energy hypothetically could be saved by efficient technologies if no one wants to live in the properties, install or use efficient lighting and heating." (p. 1)*

In the endeavour to tackle this behavioural dimension, smart metering and Home Energy Management Systems (HEMS) are being given increasing attention both in academia and in commercial enterprises. HEMS are much advertised and promoted as 'high potentials' for domestic energy savings, with some (commercial) energy monitors claiming 10 – 20% savings. For the authors, this was the starting point for a critical examination of these seemingly optimistic claims.

HEMS are defined as intermediary devices that can visualize, monitor and/or manage domestic gas and/ or electricity consumption. Their main purpose is to give users direct and accessible insight into their energy consumption. This makes them different from smart meters, which are predominantly intended to benefit the gas or electricity supplier and generally need a HEMS to give users the intended insight.

HEMS come in many shapes and sizes and they vary in six significant areas. The first is the type of energy for which they are intended: gas and/or electricity. Second, they differ at the level at which feedback is given. Some give feedback on overall household (utility) consumption, some provide detailed information for separate appliances (disaggregated), and yet others limit feedback to just one appliance. Third, they vary according to the type of feedback they provide, such as factual (e.g. showing real-time consumption data as shown in picture 1 in Figure 21), social (e.g. using smiling/ frowning faces, as shown in picture 2 in Figure 21), or comparative (e.g. current versus historical consumption data, as shown in picture 3 in Figure 21). A fourth characteristic is whether they only monitor or also manage energy consumption. The difference is that monitors only give feedback, leaving it to the user to decide whether or not to act on the feedback, while managers help users control if and when their appliances consume energy. Fifth, the type of interaction and physical location of HEMS varies from local appliance-specific solutions, such as standby-killers, to central in-home touch screens, to online web applications. Finally, their intended purpose can be energy saving or peak shaving (peak shifting of the grid load).

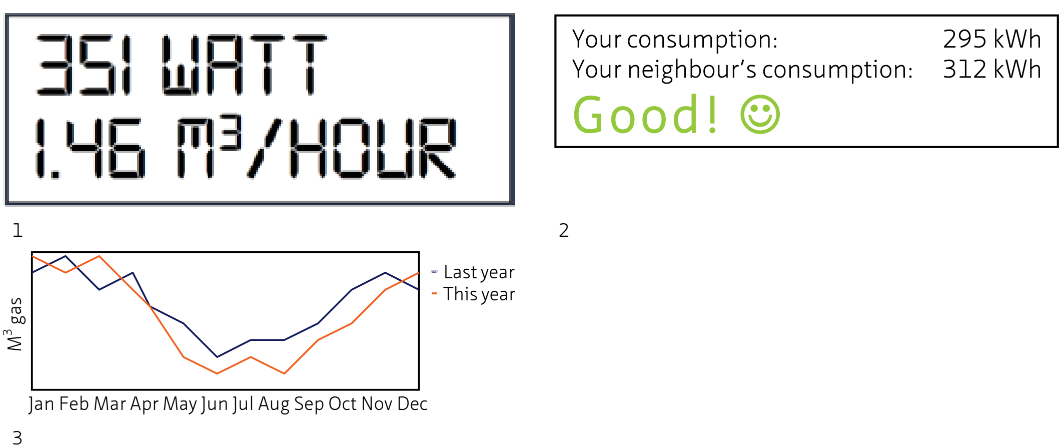


Figure 21
Different types of feedback. Picture 1: factual Feedback, picture 2: Social (comparative) Feedback, picture 3: historical comparative feedback

The type of HEMS that has been commercially available since the 1970s is the energy or electricity monitor, which solely gives inhabitants feedback on electricity consumption at the utility (household) level. This energy monitor has been dominating the market for years, and it is also the type of HEMS that has featured most in academic research. Recently, other kinds of HEMS have entered the marketplace and future studies will hopefully broaden their perspective to include these.

§ 4.2 Research objectives and method

The general objective of this paper is to achieve a better understanding of the effectiveness of HEMS. A literature review will focus on HEMS in general, whereas the second part of this paper – the case study – will focus on energy monitors, considering their medium-term use and effectiveness (more than four months). Effectiveness is defined here as the extent to which users can maintain significant energy savings over these prolonged periods.

Most of the previous studies on HEMS have asked the same basic question: how effective are they in helping people save energy? Although this question has been answered many times and often with a positive result (for instance, Ueno et al., 2006b; Midden and Ham, 2009), the majority of these studies have only assessed the use of energy monitors over relatively short periods (four months or less). The few studies that have taken a long(er) view show indecisive results (van Houwelingen and van Raaij, 1989). This uncertainty is the focus of this paper:

- What are the medium- to long-term results of HEMS on energy savings?
- What happens to the energy savings after the initial four months of HEMS usage?
- What is the influence of the design quality and usability of HEMS?
- Is there a relationship between the amount of HEMS usage and achieved energy savings, and what role does the development of habitual behaviour play?

This paper explores these questions through a literature review and a case study.

§ 4.3 Literature review on issues related to medium- to long-term use of HEMS

§ 4.3.1 Background relations between users and their appliances

Background relations with technology are described from a philosophical point of view by Ihde (1990) who identifies products with an 'absent presence' in households. They operate in the 'background' either physically or in the back of our minds. Even more so, an increasing number of these background appliances, especially technical installations, function autonomously. They self-regulate their energy use, which is consequently imperceptible to users. While some products might drift into the background over time, most background products are intentionally designed to operate this way: there is deliberately little to no interaction with the end user. Borgmann (1995) describes this as disburdening but also disengaging technology. As a negative side-effect, these background products significantly contribute to the energy consumption of households and the invisibility of energy flows in homes. More than half of carbon dioxide (CO_2) emissions of households are caused by background appliances and 'imperceptible' energy consumption like phantom loads (derived from Milieu Centraal, 2008).

While the disburdening effect also brings important beneficial aspects to users, it tends to undermine the direct cause-and-effect relationship between users, their behaviour and energy consumption. This is where HEMS come in: in their mediating role, they provide people with a (visual) representation of the energy consumption, and help them mentally interpret the actual energy (or monetary) figures and perceive the energy consumption of other products. Ihde (1990) calls this relationship between users and products a hermeneutic relationship. An alterity relationship between users and HEMS takes place when the HEMS itself is the continual focal point of attention. However, some instances have been recorded where HEMS slowly drift into the background of people's attention, thus undermining their core purpose of giving recurrent feedback and ultimately becoming obsolete. When a HEMS drifts into the background, a shift from alterity relation to background relation takes place.

Several case studies have shown this change from alterity to background. The most detailed studies were performed by Ueno et al (2006a, 2006b). These reported drastic reductions in the usage of a display giving disaggregated feedback during the first two to four weeks, after which stabilization took place. In the three-month pilot of the 'PowerPlayer' (interview with L. T. Firet concerning PowerPlay pilot Nuon, SenterNovem and UCPartners, 29 June 2009) participants indicated that at a certain point in time they understood their gas and electricity usage patterns, and used the PowerPlayer less. Respondents did add that they would use the monitor again when buying new appliances. In a study on the use of an electricity monitor (PowerCost) by Mountain (2006), one-third of the participants indicated they would not use the monitor any more after the pilot. Lofstrom and Palm (2008) addressed the use of the Power-Aware Cord, which can visualize the electricity use of a single socket. They tested it for two months with six households and found that whereas in the beginning people were enlightened by the energy use of an appliance, after some time the Power-Aware Cord 'just' became a decorative element, likened by all participants to Christmas lights.

Although it is impossible to draw decisive conclusions based on these studies, the general trend seems to be that feedback devices slowly drift into the background. The exact cause of this finding has not been studied, although it is conceivable that people simply lose interest.

This raises the question how to prevent HEMS from drifting into the background. One possible answer lies in the increased interaction with HEMS, e.g. when people develop habits around them. Another possibility is the improved design of HEMS and their feedback, as several design strategies have been created to influence behaviour through products (Lockton et al., 2008). A third option would be to view a background relation as a potential strength by implementing HEMS that not only monitor, but also manage energy. Energy management devices operate more in the background, programmed (by users) to switch off appliances that are not in use. They are therefore less dependent on behavioural change for energy savings than monitors. Whereas monitors only give feedback, energy management devices additionally give participants the ability to control their energy consumption. Perceived control is claimed to have a positive influence on users (Geller, 1995 and Allen and. Ferrand, 1999), although raising awareness through feedback still remains essential. However, there has been no scientific research into energy management devices to validate their effectiveness (especially in comparison with energy monitors). This is therefore a potential area for future research. As past studies do give some insight into the possible role for design and habits, these will be discussed in the following sections, starting with habits.

§ 4.3.2 Why habits pose a problem for energy reduction

Within psychology, habits are mainly approached as a barrier which prevent the development of new behavioural patterns and act as a cause of fallback. Existing habits, such as leaving the lights on, are seen as major obstructions to the development of new, sustainable behaviours. Even after months of trying to adopt a new pattern, users can still fall back into the old pattern. Habits take time to develop. Therefore, studies on feedback, intent on changing energy-related behaviour, need to have a long-term perspective. However, most of the studies on feedback were conducted over a period of less than four months and often without follow-up (for an extensive review see Abrahamse et al., 2005). In the rare cases that medium- to long-term studies have been conducted, the outcomes were indecisive (van Houwelingen and van Raaij, 1989, Mountain, 2006) or the studies failed to record long-term energy reduction results (Ueno et al., 2006a).

A different approach to habit development is studying the development of new habits or rituals around HEMS so that users receive recurrent feedback. In this approach, habits are used as a strategy to prevent feedback devices from drifting into the background. While drifting into the background alludes to decreased use, to the point of abandonment, habitual use implies ingrained, regular use. Past research has not given specific attention to the habitual use of HEMS, but it is apparent in some studies that under a limited group of users, regular usage does take place at any rate. In Mountain (2006), 38.9% of the participants in the case study indicated that they looked at the PowerCost monitor at least once a day. Kidd and Williams (2008) describe how participants develop certain habits around the energy monitor 'Efergy'. Matsukawa's (2004) study implies a relationship between amount of use of the energy monitor and energy saving. Though by no means a conclusive answer, it does warrant further research on the question if a relationship between (habitual) use of HEMS and savings exists.

While it can be left to chance whether users develop habits around Hems, it can also be part of HEMS's design strategy. For their design to enable habits, they need to fit into people's daily lives and users should want to use them. Attention for design is not only beneficial to habit development; it is also important for its influence on effectiveness, which brings us to the next topic.

§ 4.3.3 Past research on feedback and the design of HEMS

When considering the influence of design on the effectiveness of HEMS and prevention of non-use, it is important not only to focus on the physical appearance. Associated elements such as type of feedback, the architecture, the interface, the interaction between users and product, and the context in which it is used need to be included. As feedback is the core functionality and dominant 'behaviour intervention mechanism' in most HEMS, it poses a good starting point for the discussion. While feedback is approached by social scientists as strictly a behavioural intervention, it is inherently intertwined in the design of HEMS. A designer would consider certain aspects of feedback, e.g. presentation style, a smiley (emoticon) or the colour usage, as a means of making the interface understandable for the user.

Several researchers have reviewed studies on feedback. In their review, Abrahamse et al. (2005) conclude that feedback tends to be more effective when combined with other strategies, and also with increased frequency (e.g. real-time feedback instead of feedback at fixed points in time). Darby (2006a), in reviewing the effectiveness of feedback, comes to the same conclusion: immediate direct feedback could be extremely valuable, as long as it is provided through a user-friendly display. Likewise, Fischer (2008) concludes that the most successful feedback should be given frequently and over a long time, that an appliance-specific breakdown is provided, and that it is presented in a clear and appealing manner using interactive tools. Mccalley and Midden (2002), in much the same vein, conclude that product-integrated feedback, when coupled with the possibility to set an energy conservation goal, is a potentially highly successful means to save energy.

Some studies have found that people use feedback devices to track down a particular appliance at a specific point in time that is causing the rise in energy consumption (Kidd and Williams, 2008). One such study classified users accordingly as 'seekers, detectives, and judges' (Liikkanen, 2009). Knowing this, designing HEMS to give accurate and real-time feedback becomes essential. Likewise, considerations should be given whether to design portable or fixed HEMS, and if they should give disaggregated feedback. With energy monitors that only give feedback on overall household consumption, tracing back energy consumption to individual appliances can provoke a single-minded concentration on peaks by users (Kidd and Williams, 2008). The pitfall is that users consequently neglect continuous lower energy-consuming appliances that use more in the long run. Also, attention should be paid to delays or infrequent data transmission as this can lead to inexplicable peaks for users. Kidd and Williams (2008) noted, furthermore, that some participants switched types of energy being used, for instance heating water on the gas stove rather than using an electric kettle. Feedback on both gas and electricity consumption is therefore desirable, in particular given the fact that gas is responsible for a larger proportion of CO_2 emissions of households in the Netherlands (EnergieNed, 2008). In other words, these examples show that the design of the feedback given by HEMS should afford a certain type of use.

Feedback is one element in the design of HEMS. This section discusses to what extent researchers have taken into account other aspects of the design, in particular the design of the human – HEMS interaction. This human – product interaction concerns the 'use, understanding and experience' of products. This is broader than the straightforward use of a product as it includes the 'physical, cultural, technological, and societal contexts' in which they are used (Delft University of Technology, 2009).

The assumption is that using specific design strategies and design knowledge can help make HEMS more effective, particularly in the long run. Although some researchers acknowledge the importance of a user-friendly display (see above), few studies actually report implementing knowledge from the design of human – computer interaction field. Commercially available monitors have a predominantly 'high-tech' design, and studies regularly implement these monitors. This can lead to usability problems, as was documented for one participant with the use of the Efergy monitor (Kidd and Williams, 2008): *"I certainly haven't used it ... I certainly am not techno..."*.

One journal article on HEMS by Wood and Newborough (2007) does detail a number of human – computer interaction aspects to consider when designing what they call 'energy consumption indicators'. In answering five questions concerning measurement units, categorisation and visualization of information, and the amount of possible interaction, Wood and Newborough emphasize the need for consideration of users and their use of HEMS to achieve energy savings. Outside the field of HEMS, in, for example, interaction design research, new strategies for influencing behaviour through design have also been developed in recent years. One such approach looks at 'persuasive techniques'. There are numerous similarities in the way people interact with each other and the way they interact with (the interface of) a product. People talk to products, show affection, or get angry with them, just as 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 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 behaviour change model (Fogg, 2009) to assist designers in creating persuasive products. Motivation, ability, and trigger are the three principal factors herein.

Merging persuasion theories and combining them with work from other (design) fields, Lockton is developing the Design with Intent (DwI) method (2008, 2009). DwI is defined as 'design that's intended to influence, or result in, certain user behaviour' through six 'lenses' or strategies, that can motivate, enable or constrain a certain behaviour. Persuasive technology and DwI techniques are valuable for the design of the interface and architecture of HEMS. It can help strengthen habits, increase usage, and heighten effectiveness. Implementing Fogg's line of thinking into HEMS, the first step would be to create the right triggers at the right moment. Another step could be to increase simplicity to heighten peoples' ability to save energy. Like Fogg, Cialdini's (1993) work teaches that the manner in which something is presented to a user is very significant, but has given particular attention to normative social influence (the importance of what other people do) in recent years (Goldstein et al., 2008). HEMS are well suited to compare the consumption of a household with that of other households, and in doing so implement both descriptive and injunctive social norms through different visualization techniques. Knowing which strategy is the most effective and which is preferred by different types of user is complicated, however, and needs to be studied in more detail.

§ 4.3.4 Conclusions from literature review

This review poses directions for future research. It highlights several focal points that deserve more attention and are key to creating effective HEMS and reducing energy consumption. Background appliances are an important factor in energy consumption, which makes accurate, traceable feedback valuable. Additionally, the usability, with instances of decreased use and non-use of feedback devices, needs to be addressed. Implementing insights from interaction design to develop user-friendly interfaces can help. But this needs to become a focal point in research, and research needs to study various types of HEMS, e.g. monitors as well as managers, to compare effectiveness. Finally, there is too little attention for medium- to long-term research. This is needed to see whether energy-saving behaviours become lasting habits and whether routine use can contribute to increased effectiveness. Not all can be studied within one research process, though, but the following case study will focus on one aspect, medium-term effectiveness, in relation to the habitual use of energy monitors.

§ 4.4 Case study: a 15-month pilot with a home energy monitor

A 15-month pilot study occurred during 2008 – 2009 in the Netherlands. The pilot consisted of a four-month initial trial, instigated by several commercial parties, to assess the effectiveness of a newly developed home energy monitor, and a follow-up study by researchers from Delft University of Technology. The follow-up study took place 11 months after the initial trial ended, making the total trial period 15 months. The case study was anonymised due to sensitivities surrounding the commercialization of this newly developed product.

The energy monitor consists of a sensor, a sending unit, and a display. The sensor and sending unit are attached to the electricity meter. The sending unit sends a radio signal to the display unit. The display has three settings. In its standard setting, it shows the power consumption in watts (W) in real time (with a short delay of up to 10 seconds). It can also indicate daily consumption (over the past 24 hours), and can compare daily consumption with a personal savings target. The daily target was corrected to the individual's fluctuations in consumption throughout the week. The monitor was designed to be simple to use; and users acknowledged this as only 5% gave the monitor a 'negative' or 'very negative' score on ease of use after installation. A website with energy-saving tips accompanies the monitor, as well as a voluntary e-mail service ('learn and save') with more tips.

The objectives of this case study were, firstly, to gain insight in the effectiveness of the energy monitor in the 11 months after the initial four-month pilot. Effectiveness was defined as the extent to which having the monitor at home contributed to sustained electricity savings. The second objective was to explore whether a habit of checking the monitor daily had a positive influence on sustaining the electricity savings over the trial period.

Based on results from previous studies (see the literature review), the research team had certain expectations and assumptions about the outcomes of this case study. The electricity savings were expected to be considerable after the four-month initial trial, consistent with other short-term research. However, over a longer period it was expected that some of the initial savings would be lost as a result of the monitor 'drifting into the background'. Also, it was expected that people who developed a habit around the monitor (checking it at least once a day at fixed times) would better manage to sustain their electricity savings, as opposed to those who did not develop habitual behaviour.

The resulting hypotheses are therefore:

- At the end of the initial four-month trial, participants have an overall mean electricity saving.
- Participants' initial (four-month) electricity savings are not expected to be sustained over the entire 15month period. However, participants who kept the monitor at home after the four-month initial trial are expected to sustain better their electricity savings than those who returned the monitor.
- There is a positive relationship between having a daily habit of checking the monitor and sustaining the electricity savings over the 15-month period.

§ 4.4.1 Method

Participation in the case study was on a voluntary basis. The initial four-month trial started in the last week of June 2008 and ran until the first week of November 2008. A total of 304 participants received an energy monitor with instructions for its use and installation. Most participants also filled out the three online surveys that were sent out at the beginning, halfway and at the end of the trial. As a reward for their participation, at the end of the four-month period people were given the option either to keep the energy monitor or to return it and receive a gift certificate of €25 instead.

Follow up study			
Nr of participants	Kept monitor	Returned monitor	
Raw data	189	93	96
All electricity data available	54	26 (group A)	28 (group B)

Table 5
Overview of number of participants in follow-up study (4-15 months)

In September 2009, 11 months after the initial trial, 264 participants who had completed at least one of the surveys received an e-mail asking them to participate in an online follow-up questionnaire. Of the 189 respondents, 93 had kept the monitor after the four months trial, and 96 had returned it. The electricity meter readings of the 189 respondents were checked for completeness and inconsistencies. All meter readings were self-reported at five different occasions approximately one year before and during the case study, which unfortunately introduced quite a large number of reporting errors and missing data. Participants with incomplete data were eliminated, as well as those with changes in family circumstances (e.g. moves, divorces, babies, children moving out). This left 54 participants for whom all meter readings were present and consistent. Of these, 26 had kept the monitor after the initial trial, and 28 had not. Within the group that had kept the monitor (group A), a distinction was made between those who had developed a daily habit after 15 months and those who had not (Table 5 and Table 6).The electricity consumption during baseline, initial trial and follow-up was corrected for seasonal influences and extrapolated to yearly consumption.

Group A	Nr of participants (total = 26)
A, with daily habit (AH)	14
A, without daily habit (ANoH)	12

Table 6
Subdivision of group A

§ 4.4.2 Findings

From the questionnaires and the meter data, a number of results were obtained. First, the main results from the questionnaires are discussed after which an analysis of the meter data is elaborated on.

§ 4.4.2.1 Demographics

The demographics showed no exceptional data: the baseline consumption of 3614 kWh was the same as the Dutch average (which increased at an average rate of 1.1% per year between 1998 and 2008) (EnergieNed, 2008), while the household size of 2.4 was slightly above the Dutch average of 2.3. The large majority (n = 43) were homeowners. Household size, income, and tenure were spread evenly between groups A and B.

§ 4.4.2.2 Habits

The responses to the questionnaires (n = 189) were analysed to understand the process of habit formation with the monitor. Of the 93 respondents who kept the monitor (Table 7), 80 indicated they still had a functional monitor in their homes, which was also in use. Seventeen of the 80 respondents indicated they used the monitor less than during the initial four-month trial, but 53 respondents said they checked it daily at a fixed moment in time.

Participants with functional energy monitor	80
Use monitor less during follow-up	17
Report habitual behaviour	53

Table 7
Majority of participants develop habitual behaviour

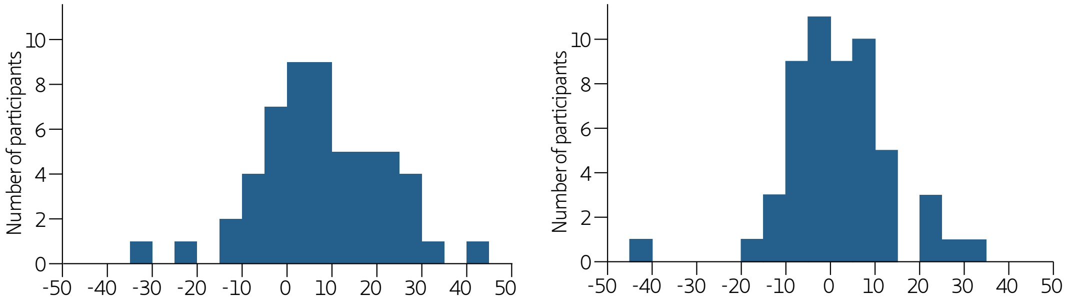
If one looks specifically at the habits formed, then checking the monitor before going to bed was by far the most common routine. Second most popular was after getting up in the morning. Less common were before going out, or while using a specific appliance or space. It is interesting to note that the living room was by far the most common place to have the monitor, followed by the kitchen. None of the participants had chosen to place the monitor in the bedroom. Knowing that checking electricity consumption before going to bed is a common ritual can have design implications. Designers could consider fitting an 'energy check' into an existing bedtime ritual, such as turning down the thermostat, turning off the television or lights, locking up the house, or setting the alarm clock. This could influence the monitor's design and functionalities as well as its favoured location.

§ 4.4.2.3 Savings

To understand the effects of the interventions with the energy monitor, the electricity savings were studied. A first observation is that household electricity savings varied widely (Figure 22). The household that saved the most (a family of three) saved 42.6% of electricity during the pilot and 30.4% during the followup. By contrast, the worst performer (a family of two) used 33.6% more electricity during the initial trial and 40.6% more during the follow-up.

The reasons for these extremes were quite straightforward. The 'high spender' (initial electricity consumption of 3985 kWh/year) had just purchased an airconditioner, whereas the 'top saver' (initial electricity consumption of 2673 kWh/year) followed a strict regime: writing down the electricity meter data twice a day, recording how often the washing machine and dishwasher were used, replacing all incandescent bulbs, limiting the use of the tumble dryer to the bare necessity, decreasing the use of the dishwasher, and placing a timer on the pump of the garden pond. He made an extra note that he was "*very proud*" of his achieved savings.

By far the most commonly noted responses for the expected savings with other participants were less use of appliances and unnecessary lighting and switching appliances off rather than leaving them in standby. Compact fluorescent lights (CFLs) and light-emitting diodes (LED) were also an easy target. Buying new energy-saving appliances sometimes occurred, but this fact was mentioned less often and mainly consisted of new washing machines, fridges and freezers. One participant purposefully noted not buying a flatscreen television. In a couple of instances, a spillover effect to gas consumption could also be noted as a participant turned the heater down, adjusted the thermostat time schedule, or installed double-glazing. Whether this was directly caused by the interventions cannot be confirmed.



1 2

Figure 22

Histograms of achieved savings (%). Picture 1: after 4 months (Mean=7.8 SD=13.8, N=54), Picture 2 after 15 months (Mean=1.9 SD=11.8, N=54).

To analyse the data further, a mixed between-within subjects analysis of variance (ANOVA) was conducted to assess whether there was a difference in the percentage of electricity saved across two time periods (a four-month trial and an 11-month follow-up). The participants were split up in three groups:

Group A consisted of participants who had kept the monitor after the initial trial, and was subdivided in two subgroups:

- Participants who had developed a habit (AH).
- Participants who had not developed a habit (ANoH).

Group B consisted of participants who had returned the monitor after the initial four-month trial.

The electricity savings were corrected by using the baseline consumption as covariate. This was done to correct for large variances in individual electricity consumption of households.

There was no significant interaction effect between the three conditions and the time (Wilks lambda =.97 $F(2, 50)=.67$ $p=.52$). This means that the savings of all 3 groups (AH, ANoH and B) declined at the same rate during the course of the follow-up, in spite of the steeper decline that might seem apparent for AH from Figure 23. On the basis of the second hypothesis it was expected that the fallback would be less for participants who had kept the monitor, and in particular for those who had formed a habit.

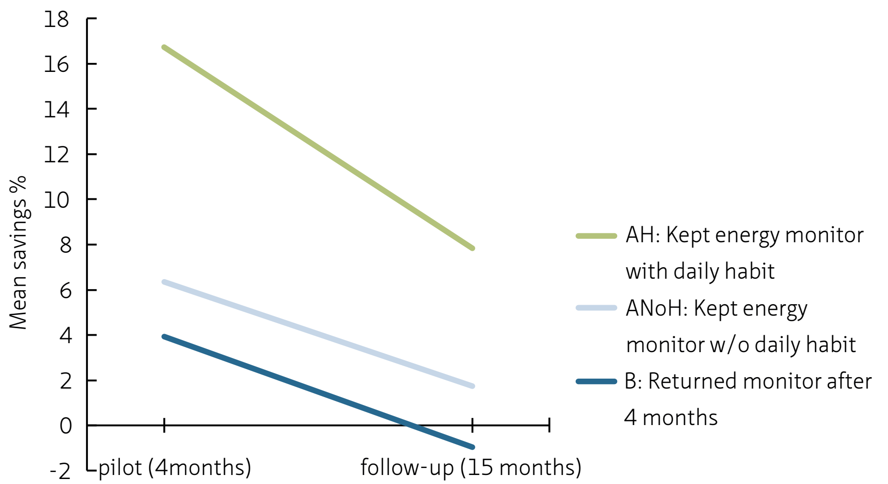


Figure 23
Mean Savings (%) after 4 and after 15 months

Condition	Time	Mean	95% Confidence Interval	
			Lower Bound	Upper Bound
ANoH: kept monitor but no daily habit (N=12)	Pilot	6.320a	-1.198	13.838
	Follow-up	1.740a	-4.985	8.464
B: handed monitor in (N=28)	Pilot	3.910a	-.953	8.772
	Follow-up	-.993a	-5.342	3.356
AH: kept monitor with daily habit (N=14)	Pilot	16.713a	9.747	23.679
	Follow-up	7.816a	1.586	14.047

a. Covariates appearing in the model are evaluated at the following values: baseline Consumption = 3614.52kWh.

Table 8
Estimated Marginal Means (% energy savings)

There was a marginally significant effect over time (Wilks' lambda = 0.94, $F(1, 50) = 3.30$, $p = 0.075$, partial eta squared (ε^2) = 0.06) with the savings of all groups decreasing over time.

All groups sustained savings during the initial trial (Table 8). However, this appears to be due to subgroup-specific characteristics as there is a significant between-subjects effect ($F(2, 50) = 4.63$, $p = 0.014$). As shown in Table 9, the difference in savings for households who had kept the monitor and developed a daily habit (AH) was already significantly different during the initial trial in comparison with households that handed back the monitor (B) ($p = 0.004$), but also in comparison with households who kept the monitor but did not develop a habit (ANoH) ($p = 0.050$). After the follow-up, the difference is only significant between B and AH ($p = 0.024$). The group that formed a habit still had significant savings after follow-up. Even though this cannot be conclusively attributed to the interventions with the energy monitor, it is highly likely that these contributed to the high savings of the receptive households that formed a daily habit; however, the effects are still relatively short-term as the same rate of fallback still occurs.

.					95% Confidence Interval	
	Parameter	B	T	Sig	Lower Bound	Upper Bound
Savings pilot	Intercept	22.061	3.963	.000	10.880	33.241
	baseline consumption	-.001	-1.081	.285	-.004	.001
	ANoH: kept monitor w/o habit	-10.393	-2.012	.050	-20.769	-.018
	B: handed monitor back in	-12.804	-3.025	.004	-21.306	-4.301
	AH: kept monitor with habit	0a	.	.	.	.
Savings follow-up	Intercept	10.848	2.179	.034	.848	20.848
	Pre-pilot consumption	.000	-.686	.496	-.003	.002
	ANoH: kept monitor w/o habit	-6.077	-1.315	.194	-15.357	3.203
	B: handed monitor back in	-8.810	-2.327	.024	-16.415	-1.204
	AH: kept monitor with habit	0a	.	.	.	.

Notes:
a. This parameter is set to zero because it is redundant.
AH,Group A with a daily habit;
ANoH,Group A without a daily habit;
B, group B only possessed the energy monitor during the initial four-month trial.

Table 9
Parameter estimates (in % energy savings)

§ 4.4.3 Conclusions

The first hypothesis: 'At the end of the initial four-month trial, participants have an overall mean electricity saving', is confirmed. During the initial trial, the average savings that were achieved for all participants was 7.8% (standard deviation (SD)=13.8). If the study had ended there, as most studies do, it would have been a sizeable outcome for the interventions. As stated in the Introduction, certain energy monitors advertise with similarly achieved figures.

A subgroup of highly motivated people (the same people that later reported the development of habitual behaviour with the monitor) even managed to reach an initial electricity saving of 16.7% in comparison with 6.3% and 3.9% for the other groups (Table 8).

The second hypothesis was: 'Participants' initial (four-month) electricity savings are not expected to be sustained over the entire 15-month period. However, participants who kept the monitor at home after the four-month initial trial are expected to better sustain their electricity savings than participants who returned the monitor.' This hypothesis is falsified. None of the groups sustained their savings, and the fallback rates in electricity savings of the three groups (AH, ANoH, and B) do not differ significantly from each other. Participants who kept the monitor, though having liked it enough to retain it, did not manage to sustain their electricity savings any better than those without a monitor.

Finally, the third hypothesis: 'There is a positive relationship between having a daily habit of checking the monitor and sustaining the electricity savings over the 15-month period', could not be confirmed. Although the group that developed a habit (AH) still had significant savings after the 15-month period (compared with group B), this cannot be attributed to habitual behaviour, as this group (AH) already showed more than average savings during the initial four-month trial. A more likely interpretation is that the savings were due to subgroup-specific characteristics (i.e. personality traits): these participants were probably predisposed and more receptive to the interventions with the energy monitor than the other participants.

It should be noted that other variables outside this study could have contributed to the participants' electricity savings, such as government campaigns, or the economic crisis. It is, however, highly likely that the energy monitor was an effective trigger for those who saved electricity. Although it is hard to generalize these findings to other household energy monitors, based on the results of this case study, the authors would like to draw the following tentative conclusions:

- Interventions that focus on energy monitors are mainly successful if they are targeted at a specific niche of users who are highly motivated to incorporate the use of the monitor into their daily lives. The exact personality traits of these users are yet to be determined.
- An energy monitor is not effective over a longer period (more than 4 months) for a majority of users. The participants involved in the case study could not sustain the initial reductions in electricity consumption over a period of 15 months.

Possible explanations for the lack of sustained savings may be one or a combination of the following:

- People revert to their old behaviour patterns.
- Over time, people add new appliances to their household. There is some evidence of this in the online surveys (reports of buying plasma screens, air-conditioning, and electric heaters). Even if people have developed a habit of electricity saving

behaviour, these new products may lead to an overall increase in electricity consumption, as an energy monitor mainly curtails existing behaviour.
- The so-called rebound effect. People who replace inefficient products with more efficient ones sometimes increase the use of these more efficient products (Terpstra, 2008), thus negating the savings.

§ 4.4.4 Discussion

Certain shortcomings in the design of the research could not be prevented within this study. The case study was conducted in joint cooperation with commercial parties, which has benefits for directly implementing research into practice, but it also posed some scientific limitations. For instance, it could not be ascertained, beyond probable cause, that the chosen intervention method (energy monitor) was completely responsible for the savings. As in many other studies, this case study also had to deal with convenience sampling. Participants' awareness that their electricity consumption was being monitored during the initial trial might have contributed to the higher savings (Hawthorne effect), although four months is a long time to register this consciously. In contrast, participants did not know that their electricity consumption would be monitored in the period after the initial trial (the follow-up). Furthermore, relying on questionnaires and self-reported meter data introduces a high error rate in the raw data. Tracking the real-time usage of energy monitors in future studies would give more reliable insights.

§ 4.5 Overall Conclusions chapter 3

Both the literature review and the case study highlighted a number of focal points that have implications for future research. The case study confirms the need for longitudinal research, as it shows how the initial effectiveness of feedback tends to wear off over a longer period of time (more than four months). A second finding is that certain groups of people seem more receptive to energy-saving interventions than others. Obviously, a 'one-size-fits-all' approach for home energy monitors cannot be justified. In the development of energy monitors, their design should take into account the fact that users' responses to a type of intervention are divergent.

However, the effectiveness of energy monitors could potentially be enhanced by using insights from interaction design research, such as persuasive technology (as discussed in the literature review) or by considering the night-time ritual of checking the monitor (as discussed in the case study) as part of the design strategy. The understanding of user habits that were formed can have design implications by, for example, fitting an ‘energy check’ into an existing bedtime ritual. The differences in savings between households are of such a magnitude that interventions tailored to individual households are also recommended.

Likewise, the differences in achieved – and sustained – savings between users indicates that a fuller understanding of the influence of contextual factors, design, usability, and users’ characteristics and/or ecological attitudes is highly desirable. Within social science, attention to a participant’s characteristics and attitudes is evident, but other factors receive too little attention. As Abrahamse et al. (2005) also concluded, demographics have repeatedly served as a classification, but other attributes are less well documented. The exchange of knowledge between designers, Home Energy Management Systems (HEMS) practitioners, and social scientists when instigating studies and campaigns therefore needs to be encouraged.

Further research should also consider the development and testing of HEMS that manage energy (rather than ‘just’ monitor it), as was introduced in the section on background relations (§ 4.3.1). These allow users control when appliances and installations consume energy, while subtly correcting their undesired behaviours. This leads to the question: To what extent does more active control by users result in more persistent savings?

Finally, the case study did not allow for the testing of variations in the design of the energy monitor. However, this is definitely an avenue worth further exploration.

While several leads have been introduced both in the literature review as well as in the case study, the focus should be on testing and finding the right balance in the types of intervention and HEMS’s design strategy, coupled with a clear idea of the kind of user the monitor is serving.

§ 4.5.1 Acknowledgements

The authors are grateful for the valuable comments of the four anonymous referees and the editors. Many thanks also to the companies who participated in the trial.

Reason for the 2nd and 3rd case studies in Chapter 5

Chapter 4 took a quantitative approach in assessing the long-term effectiveness of HEMS. The conclusion of the chapter highlighted a number of aspects that had been left unaddressed, two of which in particular were a.) the lack of understanding of other factors influencing the use and effectiveness of HEMS, and b.) knowledge on the user the monitor is serving. To gain more knowledge in these areas, Chapters 5 and 6 present the setup and results of two case studies that looked more in detail at how HEMS are used by households. As the setup of the previous case study provided little space to study the underlying factors that influence effectiveness and issues contributing to the acceptance, implementation and use of the HEMS involved, richer and more in-depth qualitative and mixed-method approaches were chosen for the ensuing case studies.

5 Setup of the 2nd and 3rd case studies and a revision of their research questions

§ 5.1 Introduction

Two additional case studies were set up to follow up the conclusions presented in Chapter 4 and to address the additional research gaps, as stated in Chapter 1. Previous chapters concluded that more research was needed on factors that influence the use and effectiveness of HEMS, on the user the monitor is serving and on different types of HEMS. Therefore, the case studies were intended to continue on this note.

The data gathered from both studies gave insights into how HEMS were and were not used. However, for a number of reasons – which are explained in this chapter and further elaborated upon in Chapter 9 – only the qualitative data became available for research. This resulted in a shift in answerable research questions. The main research question for the combined case studies became 'What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time, and how do users differ in this respect?' – which is answered in Chapter 6. Chapter 9 was added to provide a means of conveying the unexpected range of insights that were gathered by answering the question: 'What can be learned from implementing HEMS and conducting research with HEMS in existing households?'

In this chapter, the original and the revised setup of both studies and the data that remained usable and available for research are explained. It briefly concludes on the benefits and challenges of working with commercial and social enterprises

in scientific research, although Chapter 9 is dedicated to addressing these insights in full. Chapters 5 and 9 are not intended to criticize the parties involved, as a large amount of effort was put into the execution of the studies, and some of the challenges that were encountered were hard to avoid. This chapter does, however, highlight some issues that should be given consideration in future studies.

§ 5.2 Setup of the second case study

In the spring of 2010, the second case study was executed in the Netherlands to study the effects of an energy management device over a period of five months. The initial objective was threefold:

- To study the effectiveness of disaggregated/device-specific feedback.
- To study the effects of not only giving feedback but also of including functionalities that give households more control over their energy consumption.
- To study how the feedback and control functionalities of the energy management device were used and incorporated by households.

A network operator instigated the case in cooperation with the manufacturer of the energy management device. The author was responsible for the content of the interviews but made only a limited contribution to the setup of the case study and questionnaires. The network operator was responsible for the setup and execution of the pilot study, the questionnaires and the analysis of the data.

§ 5.2.1 The HEMS: an energy management device

The energy management device consisted of nine individual plugs in a Zigbee mesh network (Figure 3 on page 52). The plugs of the household appliances were inserted into the plugs of the energy management device, which were inserted into the wall sockets. One plug was wired to transmit the data from all plugs to a USB flash drive either inserted into an 'Eee Box' – which communicated with a participant's personal computer – or a 15" 'Eee Top' touchscreen PC. The energy management device gave real-time and historical feedback on the electricity consumption of individual appliances in euros or kWh. The provided software could be used to schedule whether and, if so, when the connected appliances consumed electricity. This was done by scheduling at what times the power would be cut with possible consideration for whether the appliance was on standby. Participants were free to choose which appliances they connected or removed and the use of the schedules, though a list of devices with potential for high energy savings was given. There was no advised or fixed location for the PCs, although participants who had to use their own PCs in general naturally resorted to the location of their PCs.

§ 5.2.2 Participants

The intention was to recruit 250 participants. All participants received the same energy management interface, but they were to be split into two even groups with regard to the hardware. Group E receive the Eee Top PC, while Group P (only plugs) did not.

Households were recruited by means of a letter sent to 2500 households at the beginning of 2010, and later on with the help of a call centre because the letter did not produce enough participants. Initially, participants with teenage children, a higher than average income, and an affinity with high-tech appliances were recruited on the basis of a database, but participants were not limited to this category. Due to logistical challenges and cancellations, 198 received the energy management device. Additionally, there was a high dropout rate of people who returned the device during the course of the pilot study. This was particularly the case amongst the participants recruited via the call centre, which the network provider thought was probably partly caused by the targets set for the call centre and the need for self-installation. The final tally of the number of participants who received the energy management device and retained it throughout the pilot study was 141.

§ 5.2.3 Setup of the pilot study

The pilot study lasted five months and started with the delivery of the energy management device to the participant's door. During the study, all participants filled in one questionnaire at the door and received three online questionnaires. The author conducted interviews with ten households, namely three from group P and seven from group E. These were recruited by means of the first online questionnaire as a privacy measure. The plan had been to interview five households from both groups, but fewer people from group P volunteered. All adults within the homes were requested to participate in the interview. The interviews were held at participants' homes around five to ten weeks into the pilot study and lasted 1-1½ hours. The aim of the interviews was to explore how households used the energy management device and incorporated it into their daily lives, and to gain an understanding of the households' motivations and wishes concerning HEMS and energy consumption.

The study was split into two parts. The first two weeks were used to establish a baseline measurement with which to compare the energy consumption during the remaining 4½ months. At the start of these two weeks, the participants were to install the energy management device and connect nine appliances. During this period, households were requested to use the appliances as normal. The feedback that was presented was minimized. At the end of the two weeks, the households were automatically requested to download an update that would give them the full functionalities of disaggregated feedback and scheduling software. The energy consumption of individual appliances as well as the use of the software was tracked by means of remote tracking software.

§ 5.2.4 Challenges

The interviews provided useful insights into the use of HEMS, but also highlighted barriers to their successful adoption by households. However, there were a number of technical and organizational challenges that made the quantitative data from the pilot study unreliable and/or unusable. No measurements could be made of the overall electricity consumption of households at the start and the end of the pilot study, and a control group was not put in place. Initially, a small group of participants were to receive a smart meter so that overall consumption could be measured. However, this did not go through because the technique was not done in time. Some of the data on the historical energy consumption of households were based on estimates rather than actual data, which left only the first two weeks of the pilot study as a baseline measurement with which to compare the potential energy savings during the study. While the amount of feedback that households received during the initial two weeks was kept to a minimum, the Hawthorne effect cannot be disregarded, because the participants knew they were being monitored. Additionally, it could not be guaranteed that the energy consumption during these two weeks was representative of the rest of the study, for example due to short holidays and work shifts.

Furthermore, a significant portion of the households had technical difficulties that hindered their use of the energy management device: 38% of the respondents to a questionnaire indicated that they had contacted the helpdesk for help. The majority of calls had to do with the installation, a system error that occurred when updating, and the use of the energy management device. Moreover, the tracking data on the use of the energy management device did not provide enough information about individual households and were not available for all households. Due to privacy concerns with regard to the energy consumption data, HEMS usage data and results from the questionnaires – the raw quantitative data of individual households – did not become available for scientific research. This left only the data from the ten interviews for use in this dissertation.

§ 5.3 Setup of the third case study

The third case study involved the implementation of a multifunctional HEMS in households in the Netherlands in order to study both the long-term effectiveness of HEMS and the use of HEMS and how this changes over time. A mixed method approach was chosen in which both quantitative and qualitative data were to be gathered to gain a solid understanding of both the effectiveness over time and the underlying reasons for the obtained results. The initial setup of the case study is shown in Figure 24.

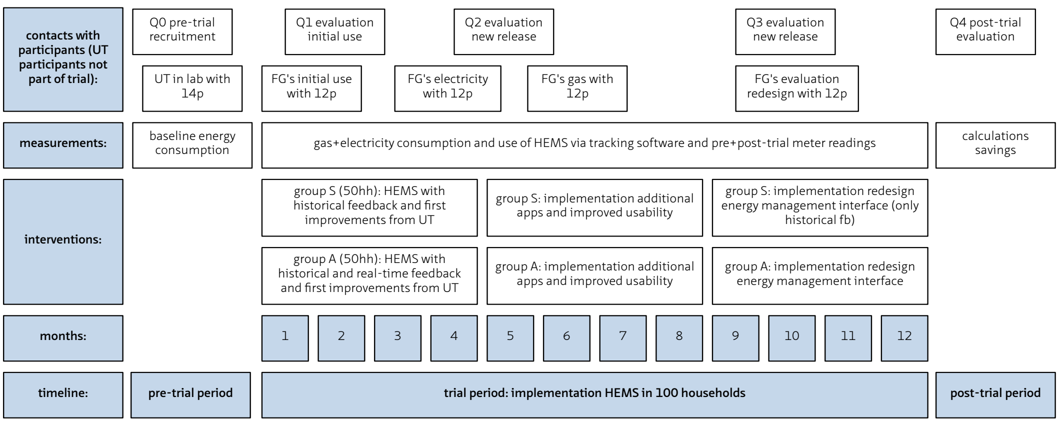


Figure 24
Initial setup of case study 3.

The case study was instigated by an energy provider in the Netherlands and their subsidiary, in collaboration with the HEMS manufacturer. It was to start in January 2010 and last six months. In consultation with TU Delft, the trial was lengthened to 12 months to include all seasons. An extra design iteration process with a usability test (UT) was also included to improve the interface prior to the commencement of the study.

§ 5.3.1 The HEMS: a multifunctional HEMS

The multifunctional HEMS consists of an 8" touchscreen, 0–2 sensors for the gas and electricity meter (depending on whether a smart or a 'dumb' meter was installed), 1–2 transmitting units for, respectively, the meters and the heater (i.e. furnace for the central heating system), an adapter and 0–3 repeaters, depending on the house (to increase the signal strength of the wireless communication between transmitting unit(s) and the display). Communication between the parts happens by means of z-wave, but a wireless router was also installed for communications with the energy provider and the manufacturer. There was an accompanying website where more information on the energy bill and energy savings advice could be found.

All households were to receive the same hardware, although there were variations in the peripheral devices due to the types of meters installed. The specifications of the different meters were also the reason to design two energy management interfaces and divide the households accordingly. A visualisation of the HEMS can be found in Figure 4 on page 52. A fitter installed the multifunctional HEMS at the same location as the home's previous thermostat because of the existing wiring. This was almost always in the living/dining room and often near the entrance from the hallway, although the HEMS was occasionally installed in the hallway.

§ 5.3.2 Participants

One hundred households evenly divided over the two groups were to participate in the trial. Group S was to have smart meters and receive historical feedback on the cumulative, daily gas and electricity consumption in whole kWh/m^3 or euros. Group A was to have 'dumb' (i.e. analogue) meters and would receive real-time feedback on electricity consumption and feedback on gas consumption over the past hour in addition to historical feedback on gas and electricity consumption, all in kWh/m^3 or euros. Both groups would also have programmable thermostats.

For the recruitment of households, the client database of the company was used to send out a questionnaire with questions on the household's technical installations, demographics and environmental predispositions. The initial plan was to use the questionnaire to obtain background information on demographics and to select households that had a suitable heater, gas meter and electricity meter, and that also represented a good sample population for statistical analysis. However, during the rollout it emerged that certain heaters and meters were unsuitable, contrary to earlier tests. As a result, additional households had to be recruited purely on the basis of their technical installations. In the end, only 69 households could be recruited, two of which were employees, and this number was only reached seven months into the pilot study. The two employees pretested all software and hardware. In addition, in the remaining five months, four households dropped out due to technical problems. Of the final 69 households, 36 were in group S (the smart metering group) and 33 in group A (the analogue metering group).

Participants for the usability study were recruited amongst acquaintances of the team. They were selected on the basis that they formed a distributed mix of the Dutch population as regards age, gender and schooling. Additionally, they did not have specific affinity with energy consumption through their work, as was also the case with trial participants. Participants for the focus groups were recruited amongst trial participants via the call centre of the energy provider's subsidiary.

§ 5.3.3 Setup of the trial

A number of interventions and contacts with clients were planned, including the implementation of the multifunctional HEMS, two partial redesigns of the multifunctional HEMS, five online questionnaires (Q0–Q4), a usability study (UT) in a lab setting, and four focus groups (FGs) in a lab setting. The trial was initially split up into three 4-month sections to implement redesigns of the HEMS in participants' households.

The usability study was executed in February 2010 and gave an insight into people's first-time use of the multifunctional HEMS. Over the course of one hour, participants were introduced to the HEMS, asked to imagine that the HEMS had just been installed in their homes, and given the freedom to explore the new product as they would in their own homes. A number of assignments were given to discover the thermostat and energy management interface functionalities, in as far as they had not already covered the assignment when exploring the HEMS. A number of usability issues were pinpointed. The most urgent and easily resolvable issues were dealt with before the HEMS were implemented in households.

Four months into the trial, the first partial redesign was planned in which the functionalities were to be expanded and improved to include weather and traffic apps as well as the remaining usability improvements from the usability test. After eight months, a redesign of the energy management interface was to implement the lessons learned from the previous months and the input from participants.

The focus groups were to be used as input for the redesign and to gain a better understanding of the quantitative data that were measured. The sessions were to be held in the evening and were to last two hours. The first focus group would be on the initial use of the HEMS, with a cultural probe being sent to participants a week before the focus group as preparation. The second would be on electricity consumption and how HEMS can assist in reducing it. Likewise, the third would be on gas consumption and reduction through the HEMS, and the fourth focus group would evaluate whether the redesign was an improvement and successful in implementing the ideas, desires and needs of participants. The questionnaires would be used to, for example, verify the findings from the focus groups and measure whether there were certain correlations between energy consumption, use of the display and answers to questions.

The effects of the interventions were to be measured by means of tracking households' energy consumption and their use of the HEMS. The energy provider had historic energy consumption data of the participating households over the previous year. A control group was to be formed from their smart metering clients, whose demographic data were also available. For the trial, the plan was to remotely track the energy consumption of all households and their use of the display via software installed on the HEMS. As a backup, the fitter who installed and uninstalled the HEMS was to write down the meter readings at the beginning and end of the trial.

§ 5.3.4 The challenges

Through this setup, a broad spectrum of knowledge could be gained on the use and effectiveness of HEMS. Extensive preparation was put into the trial, with high expectations. Unfortunately, numerous technical problems occurred both before and during the trial that had severe consequences for the study, the measurements and the results.

The extensive technical problems might give the impression that the case study failed. However, this was not the case. The technical problems revealed what households' frustrations were and what their underlying needs and wishes were. Despite its faults, households apparently appreciated the multifunctional HEMS. At the end of the trial, 17 of the 65 households were not willing to let the HEMS be uninstalled even after several letters from the energy provider.

Delays in the software development and additional technical problems with the hardware and software led to the first multifunctional HEMS being installed only in June 2010. However, the rollout was put on hold again in July for the development of a new operating system. There were irresolvable technical glitches in the previous version, which had a negatively impact on the gas consumption of a number of participants. In September, the go-ahead was given for the installation of the new operating system under the current households and for the resumption of the rollout for the remaining households. The final household was only installed shortly before Christmas mainly due to logistical challenges, such as weather conditions, a limited number of fitters and sickness.

§ 5.3.4.1 Redesigns

Due to the technical and organizational difficulties, redesigning the energy management interface was not deemed possible within the pilot study and its given time constraints. Therefore, a concept test (CT) was conducted in a lab setting. The 1-hour session consisted of both a usability study of the newly developed concept and a co-design exercise in which the participants compiled an interface for the HEMS based on those functionalities that were important to them. The usability test consisted of assignments to be carried out using the prototypical interface. The co-design exercise was conducted using sets of card fans visualizing the different screens of different functionalities/ applications in addition to a paper A3 home screen on which stickers of the different applications could be put. Participants in the concept testing were recruited from the same group as the usability test participants as well as among clients of the energy provider and trial participants. This was done through the call centre of the energy provider's subsidiary. The actual redesign of the HEMS, including new hardware and a complete redesign of the thermostat and energy management interface, extended beyond the trial and was therefore not implemented in the trial.

§ 5.3.4.2 Focus groups

For the same reasons, the setup of the focus groups was altered. The topics of the first and second sets of focus groups were combined into one, and the fourth set was cancelled, leaving two sets of focus groups. With respect to the content, for the first set of focus groups a cultural probe was used to initiate a discussion on households' use of the HEMS. Particular attention was paid to the feedback on electricity consumption. The technical hiccups of the HEMS and the challenges households encountered were also discussed. Afterwards, participants were requested to design their ideal HEMS. Finally, a set of 12 pictures of diverse existing and prototypical HEMS with a one-sentence explanation of their functionalities were laid on the table and participants were asked to choose two HEMS they found the most and the least appealing, respectively, and to explain why. The second set of focus groups on gas (which had initially been the third set) started with a number of questions about the participants' gas consumption, their homes and families, and past refurbishments, after which the HEMS' feedback on gas consumption was discussed and whether this was perceived as helpful in relation to the previous questions. The same co-design session used in the concept test was then integrated.

§ 5.3.4.3 Baseline and control group

Gathering the quantitative data did not work out for a number of reasons. For the smart metering group (group S), pre-trial baseline energy consumption turned out to be complex to measure. Most households in this group had switched to smart meters shortly before the trial or as a direct result of the trial, and the combination of meters turned out to be complex due to bureaucratic and legislative reasons. Therefore, historical comparison was only limitedly possible. This also strongly reduced the number of households available for the control group, which therefore did not turn out to be representative. The switch of a significant number of participants to smart meters at the start of the trial also had consequences for the trial itself. Legislation, consent forms and the different parties involved in smart metering and the HEMS trial resulted in a delay of one month after installation before households started receiving feedback. The electricity consumption of the additional peripheral devices that were needed to make the HEMS function further obscured the electricity consumption figures.

§ 5.3.4.4 Tracking data on use and energy consumption

The 7-month delay in rollout added to the seasonal influences made comparison between households unreliable. The remote tracking software was not finished until December 2010, due to the technical difficulties and the prioritization of repairing the bugs and operating system, meaning that for several months of the pilot study the use of the HEMS as well as households' energy consumption could not be measured. In January, it became apparent that of the 33 participants in group A, only six had received feedback that was perceived to be reliable by the team. This meant that the tracking data on energy consumption were also unreliable. This made it questionable whether it could be said that all households had received feedback. The remaining questionnaires were therefore cancelled. In the final protocol for the fitters for the removal of the HEMS, writing down the end meter reading was accidentally omitted so the back-up measurement was no longer possible.

The use of the feedback integrated in the home screen for group A could not be registered as a separate entity, leaving only historical feedback, the weather, thermostat and traffic apps for both groups. Because of the previously mentioned challenges, the data could only be analysed for the months of February, March and April. Added to the previously mentioned technical problems and bugs, the quantitative energy consumption and HEMS usage data was therefore deemed largely unreliable and/or unobtainable.

§ 5.3.4.5 Revised setup

To compensate for the loss of quantitative data, interviews were held amongst the participants who did receive 'reliable' feedback and were recruited via the call centre of energy provider's subsidiary. The interview utilized the same format and a largely similar set of open questions to the second case study. The interviews were held in people's homes and lasted 1–1½ hours. Upon inspection of the energy consumption figures in the HEMS during the interview, the feedback from one additional participant turned out to be unreliable.

In the end, the setup of the case study was strongly altered in comparison to the initial setup. The revised setup is shown in Figure 25.

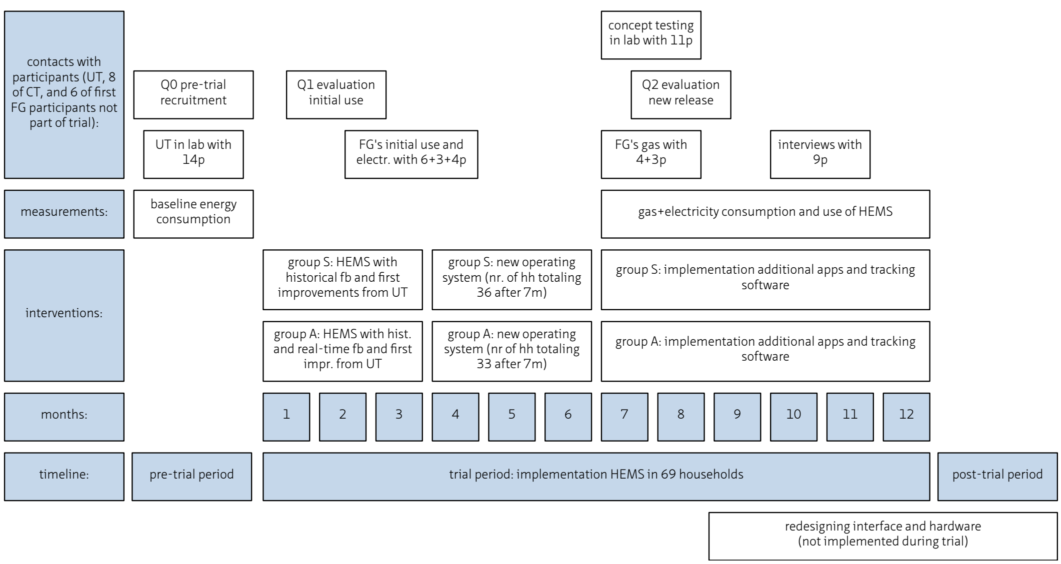
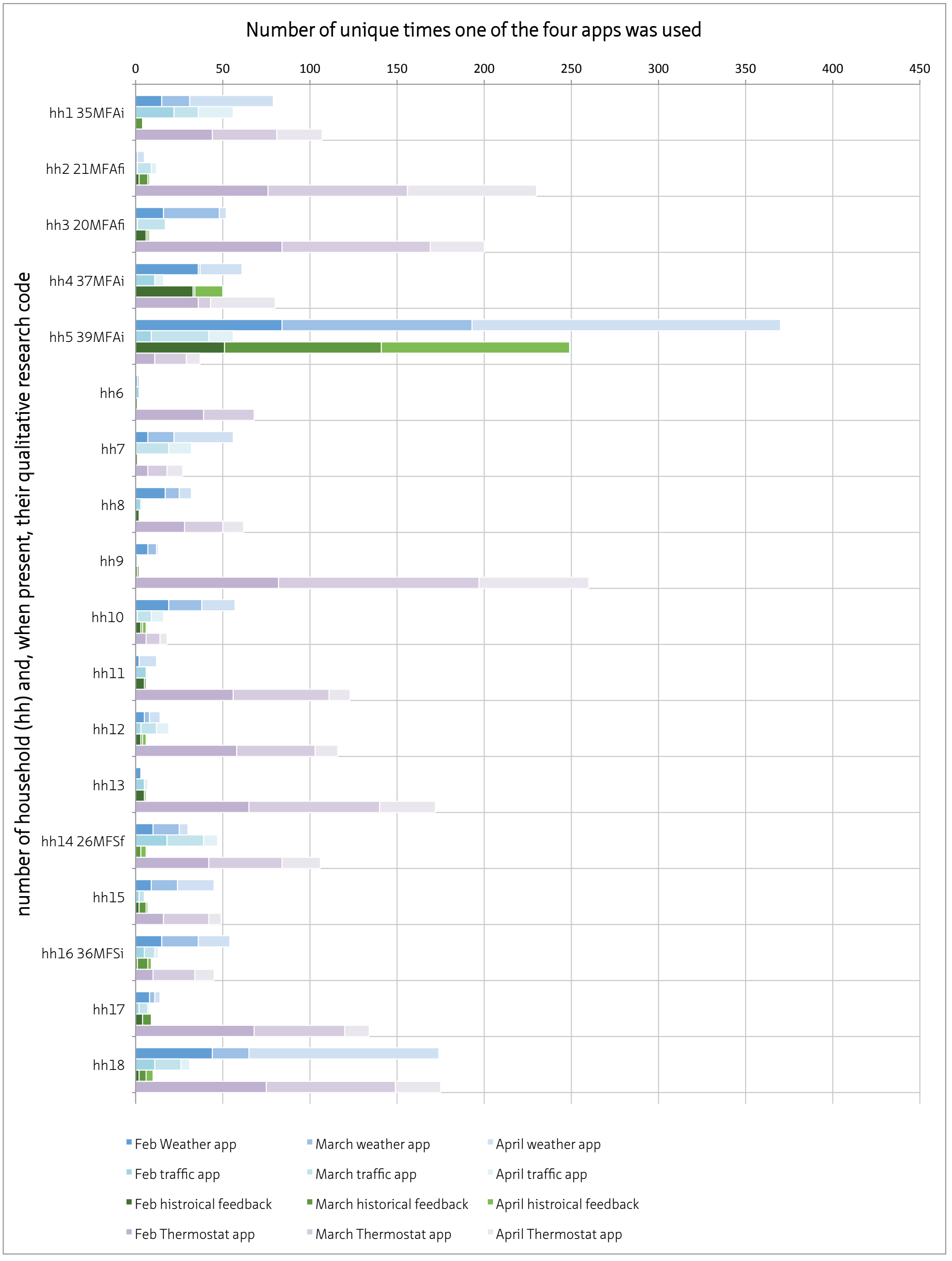


Figure 25
Revised, final setup of case study 3



Number of unique times one of the four apps was used
0
50
100
150
200
250
300
350
400
450
number of household (hh) and, when present, their qualitative research code
hh1 35MFAi
hh2 21MFAfi
hh3 20MFAfi
hh4 37MFAi
hh5 39MFAi
hh6
hh7
hh8
hh9
hh10
hh11
hh12
hh13
hh14 26MFSf
hh15
hh16 36MFSi
hh17
hh18
Feb Weather app
March weather app
April weather app
Feb traffic app
March traffic app
April traffic app
Feb histroical feedback
March historical feedback
April histroical feedback
Feb Thermostat app
March Thermostat app
April Thermostat app

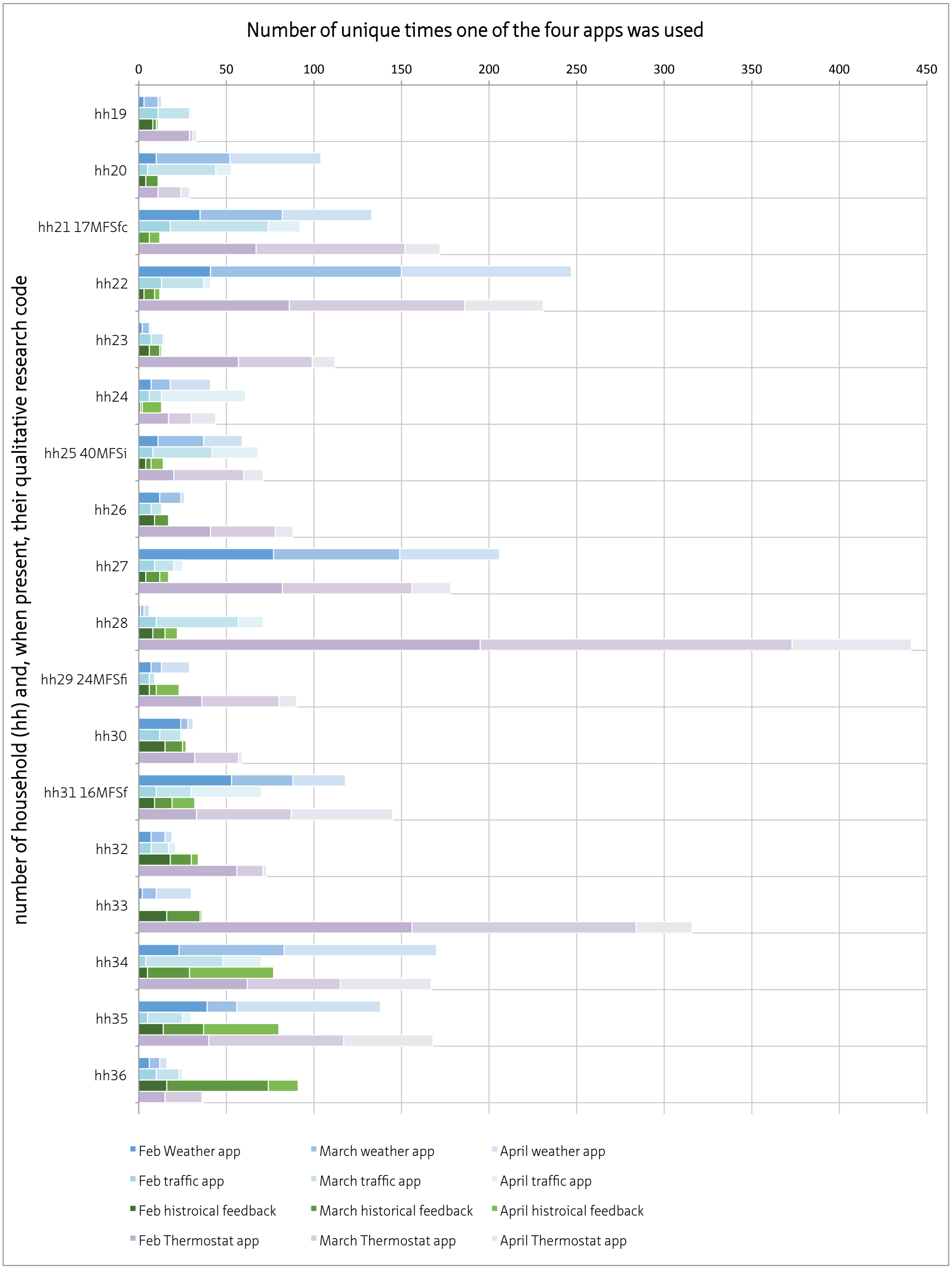


Figure 26

Tracking data of case study 3 on the use of apps.

§ 5.4 Data analysis

Through the extensive contacts with participants, and the long-term and repeated contacts with several participants, much in-depth knowledge was obtained on households' use of HEMS and their needs and wishes; this is presented in Chapter 6. Audio or audio-visual recordings were made of all qualitative contacts with participants and all focus groups and interviews were transcribed and condensed. Due to the different, more practical and industry-related aim of the usability test and concept test, these were only condensed.

An attempt was made to analyse the remaining quantitative data from the third case study, which consisted of the tracking data on the use of the HEMS during February, March and April 2011, and to link this to the qualitative data. Data on the use of the historical feedback app, thermostat app, weather app and traffic app were available for households. The tracking data from five households in the analogue group who received 'reliable' feedback were combined with the data of 31 of the 33 smart metering households, for whom the data on all three months were present. Figure 26 presents an overview of the number of times participants used the various apps. Households were kept in their respective groups (A or S) and sorted in ascending order according to the number of times they used historical feedback. Households (hh) 1 to 5 belonged to group A, and 6 to 36 to group S. Eleven of the households participated in one of the qualitative elements, which is indicated by an additional research code (for an explanation of the code, see § 6.4.2).

Large differences are visible in the amount of use of the four apps. However, the author found it inadvisable to draw conclusions from the data for a number of reasons. The most important of these were:

- Missing data on the first 2–8 months of use.
- Highly questionable comparison between households due to differences of up to 6 months in starting date, and to problems that households encountered with the software and hardware in the initial months filtering through in the use of the HEMS.
- Missing data on the use of real-time, and later per 24h, feedback in the home screen.
- Too few households for statistical analysis on whether the differences are significant.
- Insufficient qualitative data are available to explore the extreme cases.

§ 5.4.1 Shift in research questions

So while the quantitative data was very limited, a large amount of qualitative data were available. Due to the diverse nature of the data, the database was very rich. The shift in data, however, resulted in a shift in answerable research questions. Initially, the research questions were:

- How does the use of HEMS change over time?
- What is the role for HEMS (specifically: energy management devices) in helping households manage their energy consumption?
- Which elements increase the longitudinal period of use of HEMS?

The main question for both case studies became:

- What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?

Two sub-questions were also formulated:

- What can be learned from this concerning the design and implementation of HEMS?
- What are reasons for the non-use of HEMS?

§ 5.4.2 Data used in Chapter 6

To give an overview of the types of data gathered and who participated, Figure 27 visualizes how many participants participated in which elements.

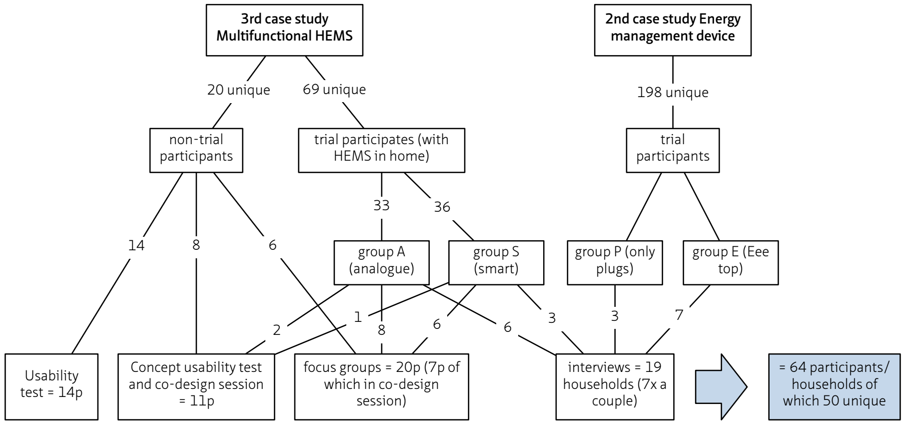


Figure 27
Number of participants in 2nd and 3rd case study and how many participated in which elements.

Twelve participants participated in more than one element; as a result, the total figure is 64 participants or households, of which 50 were unique. The age of the participants varied between 26 and 80, with diverse educational backgrounds and family situations. For a coded overview of the 50 participants, which research they participated in, their gender, age, educational level, type of job and family composition, see the table in Appendix A V. The data used in Chapter 6 mainly draws on the participants who participated in the interviews in both case studies, as well as on the four focus groups with trial participants from the third case study (thus 33 participants, of whom 28 were unique). This is because of their longitudinal use of the HEMS. To a lesser extent, the usability study and concept testing were used mainly as verification for the findings in Chapter 6 and the insights in Chapter 7. However, the qualitative data from the first case study, as reported in Chapter 4, were still available. Where possible, therefore, these data used to underpin the qualitative data from the second and third case studies.

§ 5.5 Conclusions of Chapter 5 and moving on to Chapter 6

A number of lessons can be learned from the setup and execution of these case studies. Cooperation between universities and the private sector is becoming more common. There are definite advantages to this approach through the combination of expertise of the different parties involved. However, this chapter also revealed a number of drawbacks to such cooperation, which are briefly addressed here and dealt with in more detail in Chapter 9.

One aspect is that the goals and interests of industry might differ from those of scientific researchers. Industry often sees scientific underpinning as a benefit, or they are interested in research on HEMS because of their corporate social responsibility. However, commercial, business, or market interests can lead to different priorities and the merits of scientific research can be gauged differently. Necessary compromises between the different parties involved can lead to solutions that are suboptimal from a scientific point of view, for example concerning scientific criteria and output.

Though all parties involved may find privacy important, privacy laws and the meaning of privacy may be subject to different interpretations. Especially when this coincides with a desire to be on the safe side, it can have negative effects on the available data for scientific research. Therefore, written/nonverbal agreements, particularly related to privacy issues and the sharing of data are essential. These should ideally be made in the earliest stages of setting up the case study, which might be challenging, if not impossible, when one of the parties becomes involved only later in the process, as was the case in the second case study.

However, even when all the appropriate actions have been taken and the parties involved are on common ground, 'life' can sometimes get in the way, as with the technical challenges that were encountered in the third case study. It should also be considered that finding enough participants might take more effort than expected. Limited reports of similar challenges can be found in the literature, for example with technical barriers (Nye et al., 2010) and participants (Hutton et al., 1986). Hutton et al. (ibid.) excluded one of the four sample groups from the results because: "*The Dallas study experienced the most difficulty operationalizing the experiment. A significant number of subjects could not be recruited to fill the treatment conditions according to standard recruiting techniques.*" So while cooperation with industry is currently advocated within the scientific community, there are issues that need to be given consideration in order to make this endeavour a success.

Furthermore, a number of insights can be drawn from the data. Chapter 6 analyses the data from Chapters 2 and 3 by addressing the users and their application of HEMS.

6 Exploring use patterns through a classification of users and their use and application of HEMS

This chapter explores the differences between users and their use of HEMS by studying the use of two different HEMS in their contexts. One of the main conclusions in the first case study presented in Chapter 4 was that a fuller understanding of the influence of contextual factors, design, usability, and users' characteristics and/or ecological attitudes is highly desirable. Therefore, a second and a third case study were executed with the two HEMS (the setup of these two studies was explained in Chapter 5). As was the case with the first study, the second and third were carried out in cooperation with energy companies, HEMS manufacturers and TU Delft. Focus groups, in-depth interviews and observations led to a range of insights into how people use HEMS in their daily lives.

This chapter presents the findings of these studies by answering the question: 'What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?' To do so, the qualitative data from the second and third case studies were combined. This revealed distinct differences between users and their usage of HEMS that would not have surfaced by studying only one type of HEMS. This led to the classification of the participants in the case studies into five types of users.

Within the framework used throughout this thesis, this chapter probes the influences of the dark blue elements, as visualized in Figure 28. It explores users' specific uses and applications of HEMS, and the practices that emerge along with users' attitudes towards energy consumption, and the family dynamics and context that surround consumption and the use of HEMS. In doing so, this chapter provides a better understanding and a coherent depiction of the use of HEMS, its users and the context of use, with the intent to increase the potential effectiveness of HEMS.

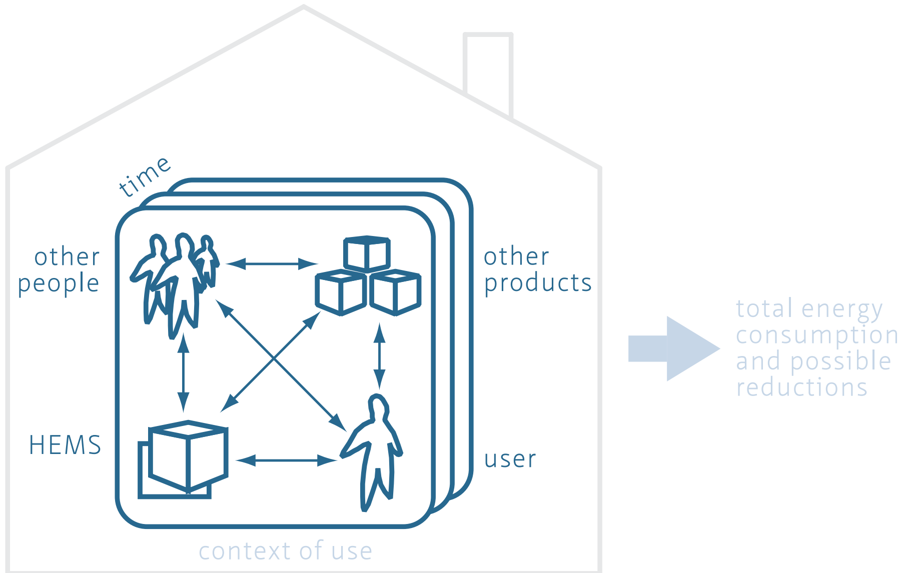


Figure 28
Aspects of the framework addressed in Chapter 6

§ 6.1 Introduction

To help households maintain significant energy savings over prolonged periods, HEMS need to be used. If a HEMS is not used (or is not used successfully), a household will not receive feedback on its energy consumption – the driving principal of most HEMS. So, the use of a HEMS is a prerequisite for a HEMS to be effective. However, this is not saying that using a HEMS guarantees savings, or that households that save energy do so only because they use a HEMS. Research suggests that more frequent use of a HEMS leads to more energy savings: Jain et al. (2012) found that people who saved energy logged on to the HEMS twice as often as those who did not save energy. It could also be the case that households that save more are more intrinsically motivated and therefore use the HEMS more (van Dam et al., 2010). The literature also shows that there are large differences between households in the amount of use of HEMS (Ueno et al., 2006a).

The successful use of a HEMS implies that its users are able to attain their desired goals and use of the HEMS, and to receive accurate and understandable feedback. The successful use of HEMS therefore ties in with its usability. Usability is defined as *"the* *extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (ISO, 2006). Applying this definition to the current discussion, the usability of HEMS concerns the use within the context of a home by one or more members of the household with the goal of giving them insight into and reducing their direct energy consumption.

Research shows that HEMS are often neither understood (Hargreaves, 2010, Strengers, 2011) nor used very successfully (Pierce, 2010, Kidd and Williams, 2008, Wallenborn et al., 2011), and are not always very effective in reducing energy consumption (Table 2 on page 39). HEMS frequently do not become embedded in the daily practices of households (Strengers, 2011), at least not in the long term (van Dam et al., 2010), and rather slowly drift out of view (Ueno et al., 2006a) or become less effective (van Dam et al., 2010, Van Houwelingen and van Raaij, 1988, Darby, 2006a).

Understanding how and why HEMS are or are not used and why they do or do not become engrained in daily life, and then adapting HEMS to alter this tendency, is essential to increasing their effectiveness. Strengers (2011) concludes her paper by advocating that "*designers of eco-feedback systems must begin by studying everyday interactions and designing devices to support them*", and saying that "*Without refocusing attention on everyday life, IHDs [in-home displays, i.e. HEMS] are likely to remain limited in their scope and potential audience, appealing only to those householders interested in saving energy and water, and achieving a diminishing return over time as new non-negotiable 'needs' emerge.*" In the same vein, Shove et al. (2012, p. 12) state that "*If new strategies and solutions in product or service development are to take hold, they have to be embedded in the details of daily life and through that the ordering of society.*" An important starting point is therefore to study the use of HEMS, their users, and the creation of routines in context, which is done in this chapter.

§ 6.2 Objective and method

This chapter provides a better understanding and a coherent depiction of the different usages of HEMS, their users and the contexts of use. In doing so, it explores the elements and interactions shown in Figure 28. The intention is that this will lead to a better assessment in future research of the effectiveness of HEMS and why this differs per household; and that designers will be able to improve the design of HEMS, adapting them to fit the desired use and context of use, and thereby striving both to increase their potential effectiveness and to make them appealing to a broader audience.
This is in line with Fulton Suri's explanation of empathic design. It "*is about using our understanding to inform and inspire the creation of more useful and enjoyable*

things for people we may never meet" (Fulton Suri, 2003a) and "*Designers need to be more broadly aware of people's goals, aspirations, rituals and values; personal, social, cultural and ecological contexts; the processes and interrelationships between different features, elements and objects within these contexts*" (Fulton Suri, 2003b).

Therefore, this chapter answers the question: 'What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?' It also answer the following two sub-questions: 'What can be learned from this concerning the design and implementation of HEMS? And what are the reasons for the non-use of HEMS?' Patterns (here, use patterns) refer to a reliable sample of traits, acts, tendencies or other observable characteristics of a person, group or institution (Merriam-Webster, 2013). This suggests that the patterns that emerge in the use and application of HEMS cannot be seen in isolation from the user who brings them about. Therefore, in order to present the findings in a manner that gives a coherent and intact description of the context of use and the significant differences between users and their use of HEMS, the findings were translated and categorized according to types of users and their use and application of HEMS.

To a certain extent, past research reported on qualitative findings from interviews and focus groups with users, narrating the use of HEMS and people's understanding of and attitudes and behaviour towards energy (Kidd and Williams, 2008, Hargreaves et al., 2010, Riche et al., 2010, Petkov et al., 2011, Liikkanen, 2009). Although these studies have provided valuable insights into the use of HEMS, they predominantly focused on short-term use, with the exception of Hargreaves (2012). Furthermore, these insights were mostly broken down with findings addressed according to subject rather than presenting a coherent description of the context of use. Liikkanen (2009) took a first step towards categorizing typical (albeit extreme) users and their use of HEMS. He classified three types of extreme users, namely the wisdom seekers, the detectives and the judges. The difference from the present research is that his classification was based on the use of an energy meter for individual devices that users borrowed for one week. This is a vastly different context of use: a fixed and strictly limited period of time. It is therefore not possible to assess whether and, if so, how HEMS are used and embedded in daily life, as this is likely to have changed since the initial use of HEMS.

The added value of the present research is that it explored not only the first-time use of HEMS, but also their longitudinal use (>4 months). Furthermore, through the categorization, it leaves largely intact the different types of users, their use of HEMS and the context of use observed in the case studies. The categories address different types of users encountered in the case studies and their use of HEMS, and new practices that emerge around HEMS in the mid to long term. Although it is not the intention to categorize the whole population according to these types, the chapter explores the possibility that they are applicable to a larger population through a comparison to literature.

Based on this characterization of users and their use of HEMS, the chapter hypothesizes on avenues for the further development of the design and manner of implementation of HEMS. It also explores the possibilities for stimulating certain desirable usages of HEMS and types of energy saving behaviours, and for inhibiting other, less desirable behaviours. While it is not possible to predict what new practices and use patterns will emerge, an attempt is made to suggest ways in which the design and implementation of HEMS can facilitate and nurture the emergence of new practices and use patterns by, for example, linking them to existing practices, habits and rituals in the home.

However, to understand the current context in which a HEMS is used, it is important first to understand the background of HEMS, the school of thought from which they originated and how they have developed. Therefore, the following section provides a short introduction to their background and intended purpose.

§ 6.3 A short history of the development of HEMS

Feedback is the core principle of most HEMS. The effect of feedback on household energy consumption has been studied for a number of decades with varying degrees of intensity and success. Feedback was introduced from a psychological perspective to influence behaviour, and the first studies commonly used written messages or bills to relay feedback or written requests to participants to self-report meter readings. This was a rather costly and time-intensive process that sometimes necessitated daily visits to households (Seligman et al., 1978). An additional drawback was that the feedback was given at fixed points in time that were often few and far between and had been unnaturally orchestrated by a researcher. The potential to apply products to relay the energy feedback to households soon became apparent. The advantage of a HEMS is that it can give real-time feedback at any moment of day, whenever the user chooses. This provides users with additional flexibility in their utilization of feedback.

In the first instance, the 'HEMS' that relayed the feedback were low-tech solutions, such as a Lucite frame in which plastic numbers could be inserted (Seligman and Darley, 1977) or a blue indicator light (Seligman et al., 1978) that flashed under certain conditions. The application of digital displays introduced a whole new range of possibilities. The Fitch electricity monitor (Funk, 1978) was a forerunner in its application within scientific research (McClelland and Cook, 1979), and the first research on a gas monitor was published in 1989 (van Houwelingen and van Raaij, 1989, based on gas monitor presented in van Beurden, 1982). Little interest was shown in HEMS in the 1990s, but in recent years their potential to reduce the energy consumption of households has drawn an increasing amount of attention. Numerous companies and start-ups are developing new HEMS and they are the subject of increased research.

However, the inclusion of a HEMS in the case study design and the flexibility a HEMS gives households in their use of the feedback, warrants the study of the specific influence of the HEMS itself and of its use by households. However, this has received limited attention. HEMS were initially implemented by the domain of social psychology, with a predominant focus on the effectiveness of the feedback. This chapter fills this gap by reporting on the findings from the second and third case studies on the use of HEMS.

§ 6.4 Setup

This section describes the setup of the interviews. The setup of the second and third case studies and the other qualitative data collection methods can be found in § 5.2.3, § 5.3.3, and Appendix A I-A IV where it was explained that during the course of the two case studies a usability study among 14 potential users, 5 focus groups, a usability test and co-design session among 11 participants for a conceptual interface, and 19 interviews were conducted. Twelve users participated in multiple elements, which gave extra richness to the data and provided a longitudinal perspective. The insights from these 64 personal interactions with 50 unique participants form the basis of this chapter. However, due to the setup and nature of the different forms of qualitative data gathered, the classification of users and their use of HEMS mainly draws on the 19 interviews with users of the two types of HEMS. This is because more in-depth knowledge and background information was gained through the semi-open interviews. Nonetheless, the other data remain essential, because they underpin the findings and give them solidity.

§ 6.4.1 Setup of the interviews

The interviews were conducted in a semi-structured manner with the help of a list of open questions. They were held at people’s homes and lasted roughly 1–1½ hours. Two interviews were conducted by telephone. The protocol can be found in Appendix A III.

The results and conclusion of the first case study in Chapter 4 as well as the literature review in Chapters 2 and 3 formed the basis for the questions. Both studies used the same set of questions; only some adjustments were made due to the differences in the type of HEMS. The aim of the interviews was to gain an overall understanding of the users, their households, and their use of the HEMS and household appliances. Questions about motivation, reasons, goals and expectations concerning the trial and the HEMS were asked. Interviewees were also asked about their use and other household members' use of the HEMS, as well as about the HEMS itself and its location. Furthermore, questions about family dynamics, household's energy consumption, whether the interviewee was aware of how much money the household spent or how much energy it used (in the past), whether the HEMS had made the interviewee aware of a certain consumption, and whether and, if so, how he or she had tried to adjust household consumption. Attention was also paid to how the interviewees used household appliances, the choices they made therein, and the contextual barriers and enablers. Finally, they were asked about their technical background, education, jobs, family size, and age.

The interviews were conducted with ten households that were using an energy management device and nine that were using a multifunctional HEMS. Two single-person households were interviewed; one was a single male, the other a single female. Three couples without children were interviewed. The majority (14 households) were couples with children. Of these households, in two cases only the mother was interviewed, in five cases only the father was interviewed, and in seven cases both the father and the mother were interviewed (although in several of these cases, the mother did not actually use the HEMS). In all cases, the main user was present and in most homes there was only one main user, that is, a person who used the feedback from the HEMS significantly more than the rest. The households using the energy management device were participants in a 5-month study and the households using the multifunctional HEMS were participants in a 6- to 12-month study. At the time of the interview, all users had had the HEMS in their homes for between 6 weeks and 10 months. A full overview of the participants is given in Appendix A V.

§ 6.4.2 Coding

A coding system was used to identify the participants. Each participant received a unique number (1–50). After the number, letters indicated which HEMS the participant had used, which research group he or she was in, and what type of qualitative research he or she had participated in.

In the case of the multifunctional HEMS, the letters that were used indicate, in order of use, the multifunctional HEMS (MF), whether they were in the smart (S) group, analogue (A) group or used the HEMS only in a lab setting (blank), and whether they participated in the usability study (u), one or two focus groups (f or ff), the concept test (c) and/or the interview (i).

Participants in the second trial using the energy management device have the letters (EM) and an additional letter indicating they were in the group with only plugs (P) or in the group that also had the Eee top (E). Interviewees are indicated by an (i). The bold letter indicates from which data the citation came. In the cases where two adults were interviewed within one household, an "(M)" or "(F)" indicates whether the comment is from the male or the female.

§ 6.4.3 Type of HEMS

The two HEMS that were used by the participants were an energy management device and a multifunctional HEMS. A full technical description is given in § 5.2.1, § 5.3.1, and § 8.3.1.

§ 6.4.4 Method of data analysis

This section details the method used to analyse the data and categorize the users and their use and application of HEMS. The recordings, transcriptions and field notes made of the direct communications with participants during the two case studies were analysed and condensed using a recursive abstraction approach. Striking and distinct comments in two areas – namely the user and the dynamics between the user and his or her energy consumption; and the dynamics between the user and his or her HEMS – were particular focal points when condensing the data. As such, special attention was paid to the user's background, upbringing, interests and attitude towards technical appliances. Knowledge of, affinity with, and handling of energy consumption and the money spent on it, the appliances related to that energy consumption, and the behaviour and choices of the household members causing the energy consumption were also distilled. Finally, reasons for wanting to participate in the trial, how they used or did not use the HEMS, and how this related to other household members, were extracted. Defining statements of participants were left intact as far as possible for use in the presentation of the results.

Although strong differences in the use of HEMS emerged from the data, similarities between participants also became apparent. To effectively convey the broad range of data gathered while retaining the rich and individual characteristics of the users, their use of HEMS and the surrounding context, the extracts from the communications with participants were categorized by grouping together similar users and their types of use. Nine characteristics formed the basis for the classification: six relate to user characteristics that have indirect effects on their use of HEMS, and three directly relate to their use of the HEMS. These nine characteristics are:

Users distinctive and key characteristics and their perceived responsibility for/ organization of energy, appliances, money and parenting-related household tasks. How mindful or aware they are of energy and their willingness and perceived capability to save.

- Whether they had a technical background (e.g. in their job or schooling).
- Whether they were or had been keeping track of their meter readings (e.g. weekly or monthly, using their memory, a note pad or an Excel spreadsheet).
- What their motivations were to participate in the case study.
- Whether they had underlying motives (e.g. altruistic, economic or fire safety motives) and, if so, how strong they were.
- Whether they were more inclined to implement technical energy saving solutions (e.g. implementing time switches, powerstrips with flip switches, energy saving or energy producing equipment) or behavioural energy saving solutions (e.g. reducing unnecessary use, using products less) to keep their consumption under control with the help of the HEMS.
- Why they use the HEMS (their goal).
- Whether their goal-related interest in the HEMS seemed short term or longitudinal.
- Whether certain specific desires surfaced related to the HEMS.

In doing so, five clusters of users and their use of HEMS surfaced. Table 10 gives a short overview of the nine characteristics and how the five types of users and their use of HEMS vary in relation to these characteristics.

	'techie'	'one-off user'	'manager'	'thrifty spender'	'joie de vivre'
Key characteristics	Data geek, energy conscious, technical, interested in gadgets, maintainer (and installer) of appliances and equipment	Goal-oriented, technical, interested in gadgets, maintainer (and installer) of appliances and equipment	Controlling, strict parenting, managing family members (and administration/ money), energy conscious	Frugal, sober upbringing, does administration, keeps track of money. Want to economize, though not sure how to.	Enjoys life, laid-back, relaxed parenting style, likes new designs, keeps overview of money. Unmindful of energy
Technical background	++	++	+/-	--	--
Interest in gadgets	++	++	+/-	+/-	+
Kept track of meter readings	++	+/-	+/-	+/-	--
Motivation to participate	Fun/sport, gadget appeal	Looking for saving opportunities, fun	Check on other family members	Free, find ways to save money	Gain insight, Suspicion checker
Underlying motives	Predominantly environmental, also economic	Predominantly environ-mental and fire safety	Environ-mental or economic, both strong	Economic, strong	Environ-mental or economic but not very dominant
Goals	Discovering consumption (of appliances), reducing as much as possible, keeping track of consumption	Discovering consumption preferably of individual appliances. Find (technical) reduction measures	Discover energy consumption, keep track of whether applian-ces are left on unnecessarily and who is responsible	Save money	Find phantom loads, global overview/ indication for bill at the end of the year
Short-term or longer-term (goal-related) interest in HEMS	Discovering and reducing: mainly initial use. Keeping track: longer-term (frequent)	Short term	Discovering: mainly initial use Keeping track: Longer-term (frequent)		Phantom loads: short-term overview: Longer term (infrequent)
Behavioural or technical solutions/ control	Technical	Mainly technical	Mainly behavioural	Behavioural	Neither
Desires	Raw, exportable, detailed data, prognosis, shower use data	Raw, detailed data	Control mechanism, baseline check, shower use data	Information, perso-na-lized advice, insights	Certainty, reference, overview

Table 10

Classification of users according to nine characteristics

This categorization has similarities with personas and overlapping aims to the ease with which this research can be implemented within design practice. The aim of personas is to give designers a better awareness of the user (Fulton Suri, 2003b). This is because personas are effective in helping "*understand its target audience as well as aid in design and development decisions*" and "*focus attention on aspects of design and use that other methods do not*" (Pruitt and Grudin, 2003). However, the classification in this chapter is specifically based on the observations during the case studies and therefore might not be representative of the whole population. As such, this chapter does not profess that the findings are generalizable to the whole population, in contrast to personas (Chapman and Milham, 2006). Nonetheless, it does investigate the extent to which past research has found similar results, which might give indications that the findings are applicable to a larger population. The five types of users and their use and application of HEMS from the classification are discussed in further detail in the following section.

§ 6.5 A classification of users and their use and application of HEMS

This section presents the main findings of this chapter through the presentation of five types of users and their use and application of HEMS. The aim is to keep the richness in the data alive and to present a provocative image of the different use patterns that emerge. The titles of the five categories are used to identify the user but the user cannot be seen in isolation from their use pattern. First, the key characteristics of each type of user and his or her use of energy and appliances are explained. Their use of HEMS is elaborated upon in the ensuing sections. Actual citations from the users are used to exemplify the statements about the type of user and his or her use of the HEMS. Not all interviewees fit into one of the categories and therefore a short explanation concerning of these users and why they were not placed within a category is be given.

§ 6.5.1 The 'techie'

Characteristics of the techie

Techies often have technical jobs or deal with data analysis and are therefore comfortable with numbers and tinkering with appliances. They love gadgets and feel at home with products that look technical.

Techies often keep track of the meter readings or have done so in the past. There is sometimes a direct reason to start keeping track. They commonly keep a notepad next to the meter or keep track of the readings in Excel, and sometimes also correlate the gas consumption with degree days. 41EME**i**: "*The way in which I go about it is that I now, I used to do it weekly but now monthly, write down my meter readings. The gas, water and electricity meter readings. And at the same time, the readings of the solar panels. That just continues to add up, but then at least I know what their yield is. And, well, I put that in an Excel spreadsheet where I can view the consumption over a period* *and I can make a prognosis of, say, what the consumption will be towards the end of the year. I'm accustomed to working with spreadsheets a lot at work, so it's not so difficult to set up."* Techies will often have noticed how their energy and/or water consumption increased following the birth of children, or decreased when children left the home. 43EMP**i**(M): *"The thing that does really stand out, is just that the water consumption has become so enormously more than, er…" "Than before we had children?"* his partner asked. *"More water and more gas."*

Keeping track of their energy consumption is seen as a hobby. 50EMP**i**: *"I just like watching it [the energy management device]."* When they get a new appliance or solar panels, this interest spikes: 50EMP**i**: *"Well, of course, I will, um, sit in front of the meter closet for a week to see how much the solar panels produce. And see, when I shine a torch on it, if it goes up."* They will often have done some investigation amongst neighbours or on the Internet to find out what the norm is for energy consumption. 43EMP**i** (M): *"When we compare it [our energy bill] with those of others in our neighbourhood, we often have a lower bill. And so much lower that people ask 'Gosh, how is that possible?'"* Besides knowing off the top of their heads how much gas and electricity they consume, or at least their monthly energy bill, and keeping track of their historical consumption, they are particularly interested in the details per appliance or per room. 50EMP**i**: *"But, um, then you have the total. Yes, but what I say, the particularization per room, I would… That would seem more fun to me than my total."* As such, techies sometimes prefer an electricity meter to measure the consumption of individual devices to an electricity monitor, and may already have had experience with it before participating in a HEMS study.

For some techies, keeping track of their energy consumption is their one and only goal. These techies are more data analysts. A particular risk for the data analysis techies is that they are less motivated to save energy. 39MFA**i** *"No, I'm not going to take the plugs of my TV out,"* and laughs. And they can easily play down savings as being only a couple of cents: 43EMP**i**(M): *"That is indeed something of which I thought, hey, when I saw all those graphs. Like, ohhh, it actually only costs three cents."* In contrast, other techies get a kick out of reducing their consumption as much as possible.

Techies and their use and application of HEMS

Techies are often male and the instigators and sole users of the HEMS and the feedback it gives. Other household members will regularly give the HEMS a wide berth. 41EME**i**: *"Yes, I'm the user [of the energy management device]. Yes, that is even not 99% but 100%"*, or 50EMP**i**: *"I look at it [the energy management device], yes, yes, yes. My girlfriend doesn't look at it, no, no, no. No, she doesn't look at it."* Due to the additional functionalities in the multifunctional HEMS, other household members may use these non-energy-related functionalities, although participants indicated that others use it less than they do.

A HEMS, and in particular an energy management device, is interesting because of its gadget appeal, energy saving potential, and/or energy measurement and collection capabilities. However, the schedules evoke mixed feelings. Especially with certain appliances, like PCs, they do not want to risk it shutting down while its being used, even though this may be rare. In general, techies are quite motivated to make the effort to turn appliances off themselves. However, they are also very interested in technical solutions to save energy and keep their consumption under control, such as efficient lighting, timers, hot-fills and energy-saving software. They will also sometimes browse forums for more unorthodox solutions, such as attaching the washing machine to a thermostatic (shower) mixer, and make the effort to compare the consumption of different settings (in the HEMS). But if these technical solutions do not meet expectations, they may be removed again. 50EMP**i**: "*We had put those LED lights and those dimmable CFL lamps in*" *but removed them again because of* "*ugly blue light*" (the CFLs he showed were advertised as 'warm white'). The technical solutions and gadgets can sometimes annoy other household members, because they have to follow special procedures or are hindered in their use of certain appliances. Differences in comfort levels of household member may also lead to compromises, for example jokingly saying that setting the temperature a degree lower, as 37MFA**i** would prefer, "*would cost me my marriage … non-negotiable*".

HEMS are consonant with techies' meter-reading interest and, as such, their use of HEMS has a longer-term dimension, with for example a fixed weekly use and/or as part of a going to bed ritual, as a 'baseline check' so that no 'unnecessary' appliances are left on. They are interested in real-time and historical consumption, but also in a prognosis of what their consumption will be over a given period. They also indicate that they would like to switch appliances off centrally during the baseline check: 24MFSf**i**: "*The fact that you can manage all sorts of things from one spot, where you would normally actually need to make a going-to-bed round.*" But they sometimes also indicate that their desire to be able to turn off appliances via a HEMS, for example using an app in bed, is partly due to the gadget appeal.

Design implications and a comparison to literature for validation

Techies enjoy seeing lots of information, graphs (e.g. calling it "*counting grass*"), comparisons, and disaggregated details for both gas and electricity consumption (and production) in a HEMS, and enjoy tinkering with the setup and arranging things to their liking. Both the duration of showering and the amount of gas used to heat the shower water are interesting details. They want to be able to export information to their computers for further analysis. Techies are highly motivated and willing to make the effort to conduct research and analyses, and it is likely that they would enjoy added features that support this on the HEMS. A further design opportunity could be to address those techies who are currently singularly interested in analysing the data and making prognoses. While they are actively involved with their HEMS, it is likely that HEMS are currently not very effective with this group, but giving them an interesting challenge to reduce their energy consumption as far as possible could be worth pursuing.

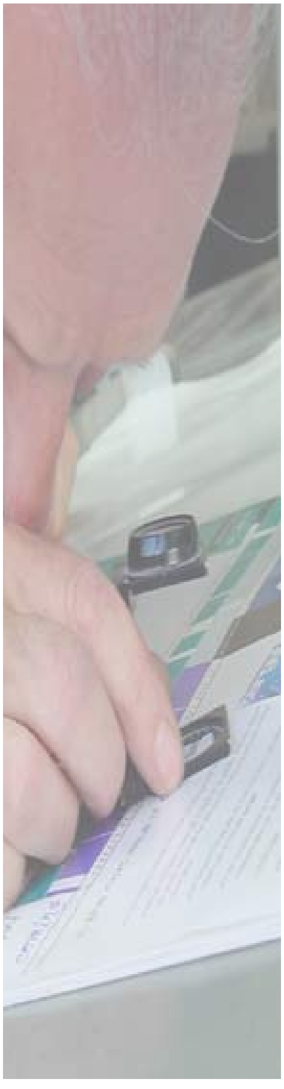
The going-to-bed ritual is sometimes inhibited by the design or location of the HEMS, and the integrating the HEMS in the thermostat can create a friction with this ritual when techies try to save energy by having the thermostat switch off ahead of time: 24MFSf**i**: "*When I go to bed, the thermostat has already been off for 30 or 40 minutes. So in fact, it is in the round, but not in the going-to-bed round.*"

The literature also mentions that the production of renewable energy can be particularly interesting to HEMS users (Strengers, 2011), and that HEMS have a gadget appeal, particularly for men (Grønhøj and Thøgersen, 2011). Similarly, it seems to suggest that HEMS are sometimes perceived as technical (Wever et al., 2008) and that certain (female) users will not use the HEMS (Strengers, 2011) because they do not view themselves as technical (Kidd and Williams, 2008). One mother who signed up for a HEMS, but then delegated it to her husband, also gave a clear indication of this. 47EME**i**(F): "*I don't understand anything about it, but then I'm not technical. Only I was, like, show me what our standby consumption is.*"

§ 6.5.2 The 'one-off user'

Characteristics of the one-off user

One-off users have many similarities with techies regarding their background, interests and use of energy. Like techies, they are technically inclined and love gadgets. They sometimes keep track of their overall energy consumption, or know the monthly costs. However, keeping track is not a goal in itself: they are more interested in the consumption of individual appliances. 46EME**i** stated as goal: "*Well, to get insight into the consumption, really. Not the overall consumption, but the consumption of an appliance or group of appliances.*" While it is likely that they have the skills to do so, figuring out the consumption of individual appliances based on total consumption can be too much effort. One-off users are mainly interested in keeping check of their energy consumption and finding ways to save, but other motives for using a HEMS may also play a role, for example burglary prevention (switching lights on) or fire safety measures (switching appliances off). 46EME**i**: "*Both [savings and fire safety] are equally important, although safety comes first.*" Like the techies, one-off users are also interested in the own production of energy.



One-off users and their use and application of HEMS

One-off users enjoy the process of discovery: 46EME**i**: "*We both though it [the energy management device] seemed like fun. So then we ran through the whole house together placing plugs in everything... Like two kids in a toy shop.*" The main difference from techies is that one-off users only use a HEMS for a short period. 44EME**i**: "*If I'm into it, in the 'vibe', then I enjoy being occupied with it, then I enjoy adjusting the settings, then I enjoy knowing 'small facts', to click on something for 'did you know that?', then I will read it all. But the rest of the time. I have other things on my mind, then I am busy with my own work, with my kids, with the home, with all sorts of other stuff.*" He said that he was "*lazy saving*" because of the single-naturedness of the schedules he set in the energy management device. One-off users are more goal-oriented in their use of HEMS. They utilize the HEMS as a very informative but short-term tool to discover where they can save energy and to be able to implement technical solutions or adapt their behaviour on the basis of that. 42EME**i**: "*I am not a gram-chaser like with backpackers, not every kWh that I don't have to use, that isn't necessary for me. But I do want to know more for myself, like where does it all go, what are easy ways of learning, like for example the TV on standby at night, which we already do. That kind of things, I would then want to train preferably, maybe a bit exaggerated, want to learn.*" Like techies, one-off users will verify the effects of an implemented solution. For example, after discovering through the energy management device that the network attached storage (NAS) consumed more energy when he started to let the HEMS switch it off at night, this one-off user searched and found software on the NAS itself and used that instead. 42EME**i**: "*Like with that NAS, I therefore learned that the program indicates that itself, a kind of on/off at fixed times, and I now use that, and it's programmed once and I'll probably never touch it again.*"

When one-off users have achieved their goal and gained the insight they were looking for, they can lose interest in the HEMS, which can be a reason to stop using it. 42EME**i**: *"Well, that's actually quite interesting, what do my appliances use then, how much energy do we consume? I know the total of every month, but where does that go to approximately… Then, you find out, then the 'awareness' has been made… Then I don't have to keep on trying endlessly."*

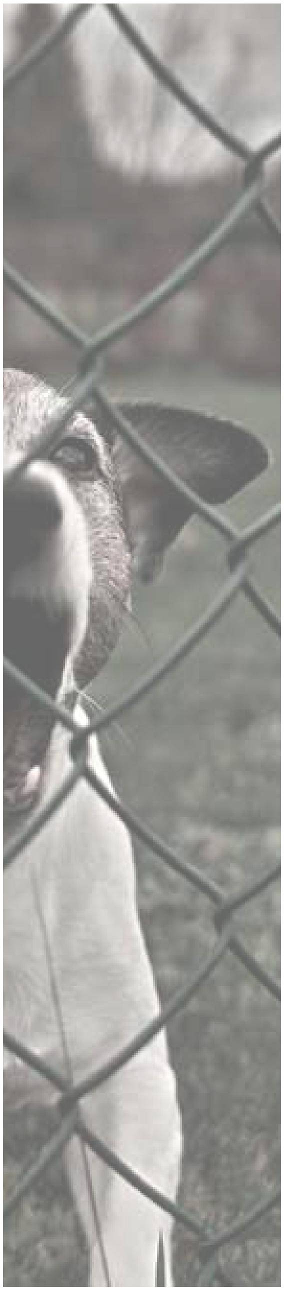
Design implications and a comparison to literature for validation

Disaggregated feedback is essential to one-off users. It is likely that the type of HEMS can contribute to people stopping using it, because they feel that it does not help them to attain their goal. 46EME**i**: *"The chapter on energy management device is closed; our savings quest isn't"*. An indication of this can also be found in the first case study where a participant using the energy monitor (giving feedback on overall electricity consumption) wrote in the online questionnaire after four months: *"Used daily in the beginning. Tried to get insight into disaggregated consumption. When that didn't succeed, stopped."* He handed the electricity monitor back, but indicated in the follow-up 11 months later that *"I bought an energy meter [to measure the consumption of individual appliances] to measure what the energy monitor could not. However, this meter is too inaccurate with low consumption."* His initial savings after 4 months were 5%; after 15 months, he was 'saving' -1.6%.

Whether users are able to achieve their goals with a HEMS may be dependent on the HEMS, but may also be dependent on the users themselves and their goals. A different participant with the same electricity monitor wrote that: *"In the beginning you don't know the consumption of each appliance and you look very frequently at the real-time consumption. After some time (months) you know it well. Added value becomes nil then."* Although both discontinued their use of the HEMS, one participant seemed satisfied whereas the other did not. This is worth exploring further. A HEMS that does not work as expected or that does not function properly, or an energy management device whose schedules are not consonant with the one-off user's lifestyle (for example, because of night shifts), can also be a reason to stop using a HEMS. In addition, the setup of the case study can contribute to a one-off-user type of use, for example in studies in which the participants are expected to return the HEMS after several months and are held responsible for any damage to it.

Other research has noted a decreased use of HEMS in households within the first months of use (Hutton et al., 1986, Ueno et al., 2006a). The one-off user's utilization of HEMS is similar to Liikkanen's (2009) description of wisdom seekers, although to a certain extent they are also judges, verifying the consumption of certain appliances.

§ 6.5.3 The 'manager'



Characteristics of the manager

Managers are often parents with school-age children. They can be either male or female. Managers do not necessarily have any affinity with technical things but take a more behaviouristic approach instead: they are on the lookout for lights and appliances that have been left on by other family members, to see if they are behaving up to scratch. There are a couple of underlying motives for managers, which they also try to bring across to other family members: they are either altruistic motives (wasting energy is seen as wasteful for the environment) or money-saving motives. Or both. 43EMP**i**(F): *"I can also just get really furious if someone forgets to turn the washing machine on during the cheap tariff."* And 47EME**i**(F): *"Well, I am environmentally conscious, and they [pointing to husband and two children] aren't."* Managers can have 'control freak' tendencies. However, there is a balance in how much effort they are willing to put into managing others. 43EMP**i**(F): *"Energy consumption, yes, but with water I have that a lot less. Well, you make a consideration as to the amount of energy it costs you to constantly run after them."*

The duration of showers, and the resulting consumption, are of particular annoyance to managers. Annoyance over showering behaviour can lead to measures such as hammering on the bathroom door, turning the water off at the mains, or deliberately causing the shower to supply cold water when someone has been showering for too long. 43EMP**i**(F): *"I always put it on cold"* and 17MFS**f**c *"then you turned the tap on downstairs, but that doesn't work anymore with those high-efficiency boiler, that is really annoying. In the past, when those girls of mine were under the shower, I just turned the warm-water tap on and then hooooooo!"* Managers can be quite expressive in voicing their opinions about their children's wasteful consumption, for example concerning excessive water use when they wash their hands. 43EMP**i**(F):*"That really irritates me completely"* and *"I find that really terrible."* The standard temperature at which the thermostat is set or pre-set can also be a source of conflict, with other family members wanting a higher temperature and, unbeknownst to the manager, adjusting it.

Managers and their use and application of HEMS

Like the previously mentioned types of users, managers too initially use the HEMS to discover and make an assessment of their energy consumption. However, they have an additional goal that makes their use of the HEMS longer term. This goal is to regularly keep a watchful eye out, by means of the HEMS, for appliances that are left on unnecessarily. A HEMS is appealing to managers because they see it as a useful tool with regard to the behaviours and activities of other household members; either to keep the behaviour of those other household members in check, in particular that of children, or with the desire that other household members will spontaneously become interested in the HEMS and start to change their behaviour of their own accord. 21MFAfi: "*See, and that was of course also a bit my intention, to make them [teenagers], um, more conscious of what is used here in electricity and gas, but I have not yet been able to achieve that completely… Well, children in puberty, it doesn't interest them that much. Other things keep them occupied.*" And in another case: "*Well, they have the exact same behaviour. My husband just pulls the plug [of the energy management device] out if the computer … So it has not achieved behaviour change with my household members.*" Sometimes a school project is a reason to participate and attempt to get their children more involved.

HEMS are seen as particularly useful for addressing showering habits: 21MFAfi: "*In particular showering, because I believe that is one of the large… That if you make your children aware, like hey, if you shower a minute shorter then you save something at least. And not so much that, of course on the one hand for the costs, but just becoming aware of the fact that everything that you do, that it costs energy. I had, before I got that HEMS, a very simple device, which was just an hourglass that I hung up in the shower. I had got it as a gift or something, I don't know. It ran for four minutes. And when you're done… After all, then those are the little things that worked for a while, I should say. Hourglass died, regrettably.*" The perceived wasteful habits of family members lead to a desired utilization of HEMS in which the manager is able to feel more in control by, for example, knowing if someone has changed the thermostat settings, being able to keep track of how long a person spent under the shower or knowing how much money a shower has cost. Some managers indicated they would like more coercive possibilities, such as being able to switch the warm water off via the HEMS. This, however, also highlights a drawback: a HEMS can lead to tensions between family members, as not all members are necessarily happy with the tactics of the manager.

Design implications and a comparison to literature for validation

One important design opportunity related to family dynamics is to try to create a positive rather than a negative dialogue with family members, because conflicts may decrease the potential effectiveness of HEMS. Hargreaves (2010) addresses the tensions that can occur and mentions a participant who indicated, albeit jokingly, that his wife wanted to move out because of the HEMS. Other literature has also made mention of the use of HEMS as a 'badgering tool' (Kidd and Williams, 2008) to control (Grønhøj and Thøgersen, 2011) or a tool to police 'excessive' householders (Strengers, 2011).

Furthermore, managers are analytical and will try to figure out cause and effect relationships, based on the total consumption figures. However, they generally do not have a specific technical background, and they may ask other more technical household members to use the HEMS and interpret the information for them (as did 47EMPi(F)), which implies that a HEMS should not be too technical. The location of the HEMS can also influence the ease with which the manager can apply the HEMS as evidence. Locating it close to the targeted activity and providing activity-based feedback might be beneficial.

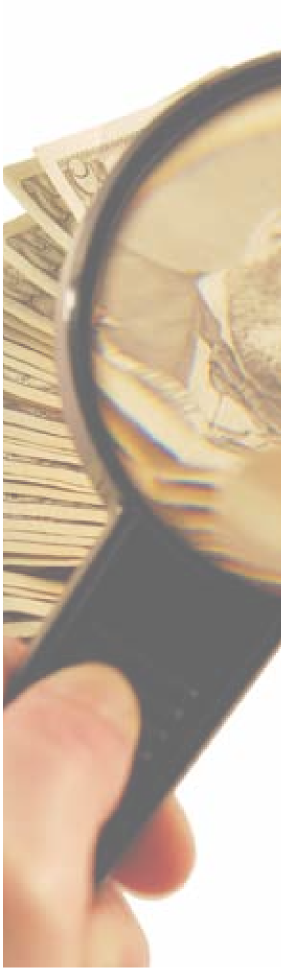
A baseline check to see if the consumption drops at night can be used to establish whether an appliance, for example a PC, has been left on in a child's room (Kidd and Williams, 2008). A participant in the first case study indicated that he was thankful that, because of the HEMS, a fire had been prevented when their daughter left the clothes iron on. He also wrote after 15 months that he thought they had saved because of "*tighter control over the kids (ADHD).*" (after 4 months they used 1.3% more energy and after 15 months 0.7% less than their baseline). The manager likes certainty and appreciates a prognosis of the energy consumption and the end of the year.

§ 6.5.4 The 'thrifty spender'

Characteristics of the thrifty spender

Thrifty spenders have some characteristics similar to those of managers, but with an important difference: they are motivated by money rather altruism. Thrifty spenders are often middle-aged or older. They have had a sober upbringing. Old lessons learned about thriftiness and turning lights and appliances off are now ingrained in their behaviour. 38MFA**i** "*It's not the case that I cannot pay for it otherwise or something, but it is just, well... That's from my childhood, also from my parents.*" So while they now often do not need to be frugal, they still maintain a sober lifestyle and do not spend money unnecessarily. 38MFA**i** "*Yes, I have friends who continually buy a new lounge suite, or continually... They have to go along with all the latest things. And not I, I will only throw something away if it is rather worn-out. My lounge suite is worn out now, and I have had it for 20 years. I do not go along with the latest fashion and change my whole home, I think that is wasteful.*" 38MFA**i** "*I try my best to keep my bill as low, to be thrifty... But I will not sit in the cold to do so*" [her temperature settings were 16°C when she was away or at night and 18 °C when she was at home]. Thrifty spenders prefer to reduce their consumption by changing their behaviour, as they are not very technically inclined. Their frugality can sometimes lead to conflicts with other members of household.

Unlike managers, thrifty spenders' idea that they are thrifty is based more on a feeling than on hard facts or their energy bills. 48EME**i** did not know her consumption or monthly payment: *"If you think 'I can be more thrifty', then you will engross yourself in it, but I think, well, actually, I can't be any more thrifty."* Thrifty spenders are not as well informed about how much appliances, transformers or lights consume. In their economizing mind-set, they will not quickly consider replacing a well-functioning appliance with a more energy-efficient one, even though this can save them money in the long term. 48EME**i** *"No, I'll just wait till it [her second-hand fridge of unknown vintage] is worn out. I'm not going to buy a new one anyways"*.



Thrifty spenders and their use and application of HEMS

A HEMS is particularly interesting if it is offered free of charge and can be used to find out how to save money. 48EME**i**: *"To see if I could be more thrifty than I already was."* Although they generally do not expect to be able to save money because they are already thrifty, the relatively small savings that the HEMS makes apparent are often still interesting. 48EME**i** *"Still I saw that, despite the small…, it is still €30 that I can cut back per year."*

Because thrifty spenders feel that they are not able to save further, a HEMS may be perceived as a failure, particularly when the control functionalities are not consonant with their families' daily lives. 48EME**i**: *"It has no merit for me because my husband works at home. It is never the case that we are away."* While they are receptive to saving energy, they can find it difficult to know how to apply the energy management device or how to save based on the feedback. 48EME**i**: *"For example, I checked my washing machine, but I can't launder more economically. Because I try to make it as full as possible, on low temperatures, then you can't be more thrifty."* When a HEMS, or an integrated thermostat, is too technical they will avoid programming it or leave it up to the installer or another household member. Thrifty spenders will also likely not program the thermostat because they find the program too ridged and not consonant with their practices and therefore causing unnecessary use. Personalized tips on how to save more money are desired, but they will not go out of their way to find this information on their own. 38MFA**i**: *"I did not pursue it to really find out. A bit slack, but not wasteful."* These aspects may mean that the longitudinal use of HEMS is limited.

Design implications and a comparison to literature for validation

Simplicity and pricing are key to thrifty spenders. Providing easily accessible and personalized information on energy saving opportunities via the HEMS is a potential opportunity for the design of the HEMS. 48EME**i**: *"Then I would have to look into that. Into how much energy an energy efficient refrigerator consumes. I don't know. That would be handy if it [the HEMS] said that. Like: 'Well lady, that refrigerator of yours uses a lot of energy'*." Thrifty spenders would appreciate a thermostat designed to facilitate not being left on unnecessarily, for example by easily being able to let the thermostat switch off automatically after a fixed amount of time, or being able to indicate, when turning a heater on, at what time is should turn itself off. Other research does not seem to make specific mention of this type of user, which might in part be due to cultural differences.

§ 6.5.5 The 'joie de vivre'

Characteristics of the joie de vivre

Joie de vivres enjoy living to the full. They are not overly interested in energy or keeping track of their meter readings. 29MF**c**: "*Of course not, that is nonsense.*" They generally do not have a technical background and, as such, they usually have little notion of what a kWh or a m^3 of gas is. They can easily mix these terms up. While they are not into budgeting, they do want to keep a global overview of how their money is spent, for example with banking software. A certain amount of mistrust towards their energy suppliers and energy bills is commonly also present and can therefore be their motivation to use a HEMS. 20MFAf**i** "*It caught my attention that my consumption increased so substantially and it was more my frustration that I did not know where it was going. Not that I couldn't pay it, but then you get these ideas, like, yes but isn't any energy leaking away? And that is because I have a renovation behind me, and that was actually the background. And actually I haven't got an insight into it, and I thought, now it's structural again, it's placid again, well, that's fine then.*"

Joie de vivres are not easily annoyed by how household member use energy or water. As parents, they do not want to be continuously reprimanding their children when they leave lights on or take long showers. Although they might want to instil care for the environment, it is not their parenting style to nag their children about it, 29MF**c**: "*No, I am not like that*".

Joie de vivres and their use and application of HEMS

Joie de vivres want to use HEMS to keep a global but intermittent overview of what they spend on consumption. However, they have a certain amount of antipathy towards being continuously confronted with their consumption. 20MFA**fi**: *"I don't like looking at it [the HEMS]. That money drives me crazy."* They therefore want to place consumption figures in a submenu to be viewed of their own accord, which entails the risk that they will overlook it. Disaggregated feedback can be seen as too detailed and too complex. Information on showering is also not interesting. 29MF**c**: *"That's not for me. No, whether someone showers for three or four minutes... I know, look, it's not wrong to keep paying attention, but I just want to shower comfortably. No, no, no, I am not that type."*

A desired application of the HEMS is as 'suspicion checker', that is, being able to discover what the cause of their energy consumption is. However, a vacillation can take place when joie de vivres are frustrated (for months) that they do not know what is causing their high consumption, but avoid looking at the feedback because they do not want to be confronted with the consumption of an appliance. An example is the high consumption of a newly acquired dryer. 20MFA**fi** said that he had not checked: *"No, not really, I don't want to know." "Ostrichism,"* he explained. *"I would not want to miss it any more, mind you. My, what a... The best buy. Away with those crazy drying racks!"* And laughs.

Joie de vivres need a frame of reference for their energy consumption. 20MFA**fi**: *"You receive information, only I can't really do anything with the information, because I don't have a reference, don't have material for comparison."* 20MFA**fi**: *"The device currently shows a consumption of 350 kWh [the display showed 350 W]. Right now that doesn't mean anything to me, because I don't know what the norm is and in situations like this that normal appliances are on, what are you allowed to use? The number doesn't mean anything to me. I can figure it out, only I don't do anything about it."* Although a high-tech look, with graphs and numbers, can easily be daunting to joie de vivres, peaks in consumption do act as visual cues. The use of colours is also more understandable to them than plain numbers

Design implications and a comparison to literature for validation

When designing for joie de vivres, a challenge is find a balance for the interface so that it is not so confronting that they drop out, but can bring saving energy to their attention in a manner that is stimulating and positive. If joie de vivres discover, through the use of a HEMS, that there is nothing 'wrong' with their bills, there is a risk that they will continue on the same foot or even start to use more energy (Pyrko, 2011). Due to this risk and the joie de vivre's desire for a referencing point, social feedback (Nolan et al., 2008) and other persuasive technology (Fogg, 2003) are worth considering to improve the design and effectiveness.

It is likely that a focus on simplicity and the provision of an aesthetic overview of total consumption would be favoured by the joie de vivres. They are interested in novel things and appreciate aesthetically pleasing products and strong visual cues in the interface, rather than plain numbers and figures. While they do want to know where their money is going, care should be taken in translating real-time consumption from watts into monetary values, because this eliminates the peaks and it can contain difficult to understand extrapolations, for example 'If you use your current consumption the whole day, it will cost you…', as also mentioned by Darby (2010).

§ 6.5.6 Reasons for users' non-use or discontinued use of the HEMS

The patterns that emerged in the above classification of five types of users and their use and application of HEMS, were visible across different interview participants and in the other qualitative research participants.] However, not all users fit entirely into this classification for two reasons: certain users and their use and application of HEMS were difficult to classify because there was little overlap with others in relation to the nine defining characteristics given in § 6.4.4, and certain main users in households had stopped using the HEMS for specific reasons. Additionally, other household members who participated in the interviews but were not using the HEMS, indicated reasons for their disinterest or non-use. The following briefly explains for these participants who did not fit into the categories their reasons for participating, their reasons for not using the HEMS or their disinterest in HEMS, and their unfulfilled desires.

Reasons for participating

- Several members of different households named the one and only reason for participating as being the gadget appeal of the HEMS. They had no particular interest in the feedback functionalities.
- One participant indicated an "*extremely high bill*", due to a defective heater in combination with her children's energy-saving school project, as the reason to participate.

Reasons for the non-use of the HEMS

- Technical problems that led to confusion amongst participants and discontinued use.
- Feedback not functioning properly.
- Errors in the software.
- Difficulties filling in historical consumption on the website, which in combination with the technical difficulties, resulting in an indication of their expected consumption (based on their historical consumption and their goal) during a given month was not available.
- Peaks in daily consumption that were largely due to the smart meter not transmitting daily consumption data on one or more consecutive days and then giving an accumulated total on the ensuing day.
- Loss of interest over time.

Reasons for disinterest in the HEMS

- The money that can be saved does not warrant the effort needed to save.
- Disinterest in numbers and figures.
- Desire for comfort and seeing energy as a necessity to achieve that.

A number of desires surfaced amongst participants who did not use or had discontinued using the feedback:

- Prognosis for the month and year (based on the previous year or the goal) to let them know how they are doing.
- Ability to use historical feedback in the same way as a detailed telephone bill: to know why it is higher in a certain month or week, and which call (respectively, appliance/room) was responsible.
- Comparison of the current week's consumption to that of the previous week.
- Comparison of how much is being consumed during a certain period (e.g. hour or day) in comparison to their usual pattern during similar periods. \
- Breakdown for individual lights and appliances

§ 6.6 Discussion

This chapter has identified five types of users and their use and application of HEMS based on the users that the author worked with and interviewed during the two case studies. This classification is valuable because it gives a rich representation of the users and suggests ways to improve the use and effectiveness of HEMS, and to interest and activate certain types of users. Nonetheless, there are a couple of areas for discussion.

While most participants had the HEMS in their homes for prolonged periods, and in several instances there were repeated contacts over the course of five months, the findings remain time-bound. The users' characteristics and their use and application of the HEMS are likely both time- and context-dependent, and it is therefore likely that the use patterns around HEMS evolve over time. Certain life stages or events may trigger or erode a certain type of use patterns. For, example, it is plausible that the tendencies of a certain 'manager' might be amplified by raising children, or slowly fade away after his or her children have left home, perhaps leading to a more 'thrifty spender'-type use. And the 'techie''s interest in keeping track of his or her energy consumption might lie dormant for years, but could be spiked by an event, such as the acquisition of solar panels.

While the diverse contacts with participants supported the classification, the participants are unlikely to be representative of the entire Dutch (let alone western) population. As such, certain users might be overrepresented. Due to the techies' love of gadgets, their technical insight, and the author's impression that the HEMS that are on the market at the moment are designed by and targeted at techies, they are likely to be the innovators and early adopters. To decrease the likelihood that the types of users are not representative, published research as well as quantitative data from the first case study was consulted to verify the results. The classification was also discussed with HEMS researchers and representatives of the HEMS industry to verify whether these were indeed types of users that they had also come across in the field; this was largely confirmed, especially for the techie and the manager. Nonetheless, further research with additional types of HEMS may provide more insight into the different types of users and their use of HEMS.

An additional consideration is that not all the participant users fit exactly into one of the categories. Everybody is unique, and as such there is never a 100% overlap of all characteristics. It is likely that there are additional types of users; for example, children were not specifically studied in this research.

The first case study seemed to indicate that there is often one main user in the home (Figure 32 on page 185). However, in the interviews with households, it emerged that in certain households other members of the household do have at least an interest in

HEMS and/or savings. Nevertheless, HEMS currently do not seem to appeal enough to these other members of households. Because household members are generally not all alike, designing HEMS to suit various desired uses and applications, such as those addressed in this chapter, might create opportunities to also interest other members of households.

§ 6.7 Conclusions

The aim of this chapter was to answer the question: 'What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?' The patterns that emerged in the use and application of HEMS cannot be seen in isolation from the users who bring about these patterns. Strong differences between users and the way they used and applied HEMS were found amongst the participants in the second and third case studies. To present the findings in a manner that gives a coherent description of the context of use and the strong differences between users and their use of HEMS, the findings were presented through a classification of types of users and their use of HEMS. Five distinct types of users and their use and application of HEMS were addressed in this chapter.

The classification highlighted a number of important differences in the use of HEMS. HEMS are not always well suited to these different types of use. In the design of HEMS, consideration should therefore be given to users' desired uses, practices and goals, and this chapter has addressed a number of implications for their design. If future HEMS are designed to suit these types of uses, a better human–machine match can be attained. However, as not all desired applications of HEMS might contribute to their effectiveness, this needs to be given careful consideration.

Within the different categories, particular attention should be paid to those aspects that seem beneficial to the effectiveness of a HEMS, for example drawing attention to baseline consumption and the reduction thereof, or giving specific feedback on shower use. Furthermore, the effectiveness of HEMS could potentially be enhanced through the application of insights from interaction design research – such as influence and persuasive strategies using social comparative feedback – to target the different types of users and their use of HEMS.

An avenue for future research would be to additionally use quantitative methods to measure which design strategies have a positive influence on effectiveness, thereby reducing energy consumption. It is also worth pursuing whether the differences between users and their use and application of HEMS influence the quantitative energy savings users achieve. This classification might also have implications for the marketing of HEMS.

Through the classification, this chapter has also presented a number of practices that have emerged and could emerge around HEMS. For example, integrating HEMS into existing products, for example thermostats, has consequences for the practices that can possibly emerge around HEMS. A baseline check before going to bed, or in retrospect in the morning, is a practice that can be facilitated by the design of HEMS. Also family dynamics play an important role in the acceptance and use of HEMS. Designers can facilitate this process and perhaps create opportunities for more positive dialogues, for instance through social games or paying attention to positive achievements. It is important to keep the emergent practices in mind, because these facilitate the embedding of HEMS in daily life.

This chapter has provided a better understanding of HEMS users and their use of the devices. Understanding users and designing HEMS with these issues in mind can be useful in the design process. However, additional techniques and sources of information are also available. Fulton Suri (2003b) suggests four methods to discover what matters to users. Ranging from objective to subjective, these are: learning from data (deduced from experimental comparisons), looking at people in context of use, asking people to participate in part of the design process, and trying things out as designers (sometimes literally putting oneself in the shoes of the user). By implementing these tools and paying attention to the different types of users and their use and application of HEMS, the design of HEMS, and hopefully therefore their effectiveness, can be greatly improved.

Overall conclusions of Part II and moving on to Part III: lessons learned from the case studies

This chapter has delved into HEMS users and the different ways in which they use their HEMS. It has fleshed out and provided an in-depth understanding of who HEMS serve and the practices that emerge around HEMS. Avenues for further research and the improvement of the design and effectiveness of HEMS have been addressed. Added to the results concerning the longitudinal effects of HEMS presented in Chapter 4, a wide range of insights can be gleaned. This following section proceeds by drawing on the results from the case studies and translating these into insights into the design, use, implementation and research of HEMS.

PART III Interpretations: lessons learned from the case studies

This part of the thesis draws on the results of the three case studies that were presented in part II. Whereas part II mainly focused on presenting the results, **Chapter 7** takes a more comprehensive approach of combining and interpreting the results from the different case studies into insights and guidelines on the design, use, and implementation of HEMS. Each of the interactions and elements within the framework of Wever et al. (2008) and van Kuijk (2010) are addressed, and the framework is thereby used to structure the insights presented in the chapter.

7 Insights into reducing household's energy consumption through HEMS

van Dam, S. S., Bakker, C. A. & van Hal, J. D. M., 2012. Insights into the design, use and implementation of home energy management systems. Journal of Design Research, 10(1),pp. 86-101.[1]

Drawing back on the results from part II, this chapter merges those results and analyses factors influencing the potential for HEMS to reducing energy consumption within the home. Based on the three case studies that were executed by the author since 2008 and knowledge from literature, this chapter presents a number of insights intent on increasing the effectiveness of HEMS. All three case studies were a joint cooperation between energy companies, HEMS manufacturers and Delft University of Technology with a different HEMS being applied in each case study. There are several issues outside the actual feedback that contribute to the potential success or failure of HEMS. To order and put the observations into perspective, the human-computer interaction framework adopted by Wever et al., (2008) was used. The different interactions visualized within the framework will be discussed in separate sections. Each topic is concluded with the consequences for the design and implementation of HEMS. To clarify the discussion, usability is defined as: "*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (ISO, 2006). Applying this definition to the current discussion, the usability of HEMS concerns the use within the context of a home by one or more members of household with the goal of giving them insight and reducing their direct energy consumption.

1 This chpater is an updated version of the article

§ 7.1 Introduction

Home energy management systems (HEMS) are defined as intermediary devices that can visualise, monitor and/or manage domestic gas and/or electricity consumption (van Dam et al., 2010). Their main purpose is to give users direct and accessible insight into their energy consumption. This makes them different from smart meters, which are predominantly intended for automatic two-way communication of energy data between the gas or electricity supplier and homes. Smart meters generally need HEMS to give users the intended insight.

HEMS are being given increasing attention both in academia and in commercial enterprises and are much advertised and promoted as 'high potentials' for domestic energy savings. Studies have indeed reported positive results (up to 10% to 20% savings), at least in the short term (Ueno et al., 2006a, Wood and Newborough, 2003), but in the mid to long-term studies it was found that HEMS are less effective (van Houwelingen and van Raaij, 1989, van Dam et al., 2010, Hutton et al., 1986).

The objective of this chapter is to explore the factors influencing the medium to long-term energy saving potential of HEMS, taking a broad perspective including the design of the device (and the way it gives feedback), the human-device interactions, and the social, physical and organizational contexts in which HEMS are used and implemented. Most literature today is predominantly focused on the effectiveness of feedback, for instance by studying the relationship between different types of feedback and energy savings, or by developing novel design approaches for giving feedback (Froehlich et al., 2010). A few authors have explored user interactions with energy monitors (Wood and Newborough, 2003) or social contexts of use (Hargreaves et al., 2010). Longitudinal field research is however rare, as is research addressing these different approaches to HEMS holistically.

This chapter will build on findings from literature, and will present additional insights from three case studies by the authors since 2008. The case studies are a joint cooperation between energy companies, HEMS manufacturers and the Delft University of Technology. In each case study a different HEMS was used. Focus groups, in-depth interviews, and observations led to a range of insights into how people use HEMS in daily life. The chapter will conclude by presenting several new factors that contribute either positively or negatively to the medium to long-term effectiveness of HEMS.

§ 7.2 Method

Three case studies were conducted with three different types of HEMS. All took place in the Netherlands. The first case study (van Dam et al., 2010) ran between 2008 and 2009 with 189 participants, for a total of 15 months. The HEMS used was an electricity monitor that gave real-time and cumulative (24 hour) feedback. The quantitative data for this study was gathered by means of self-reported meter readings and four online questionnaires.

The second study dealt with ten households who implemented an energy management device in 2010. This type of HEMS gave real-time and historical feedback on the electricity consumption of individual appliances. The system worked with a touch-screen or via the participants' personal computers and could be used to manage if and when the connected appliances consumed electricity. Two months into the five-month pilot, usage data was gathered during house visits by means of qualitative, semi-structured in-depth interviews.

In the third case study a multifunctional HEMS was used, which gave historical, and for a subgroup of participants real-time, feedback on gas and electricity consumption. The device (a touch-screen) doubled as a programmable thermostat and could also provide up-to-date weather and traffic information. In total, 69 participants used this HEMS in their homes for six to twelve months. Data collection took place by means of three online questionnaires, five focus group sessions, ten in-depth interviews with households, and two usability studies (where the device and different user interfaces were tested in a lab setting).

In total, across the three case studies we could draw experiential data from 290 participants, over a period of five to 15 months. The participants were between 26 and 80 years old and had diverse educational backgrounds and family situations. In-depth qualitative data was gathered from a total of 50 unique participants. In 14 instances, participants took part in multiple sessions, giving the data extra depth and richness. A mixed-method approach was used for data analysis, involving statistical analysis of datasets as described in Van Dam et al. (2010), and qualitative analysis. For the qualitative analysis, all interviews and focus group sessions were transcribed and the datasets were analysed using a recursive abstraction approach (which involves summarising datasets to elicit insights). The findings in this chapter are mainly drawn from the qualitative data analysis, using literature and the available quantitative data to substantiate the results.

§ 7.2.1 Conceptual framework

In order to enhance the energy saving potential of a HEMS, it is important to improve the quality of the (long-term) interactions between the user(s) and the device. This is the central tenet of this chapter. A useful framework for human-product interaction (Figure 29) was developed by Van Kuijk (2010) and previously applied in a sustainability context by Wever et al. (2008) and adopted for this chapter.

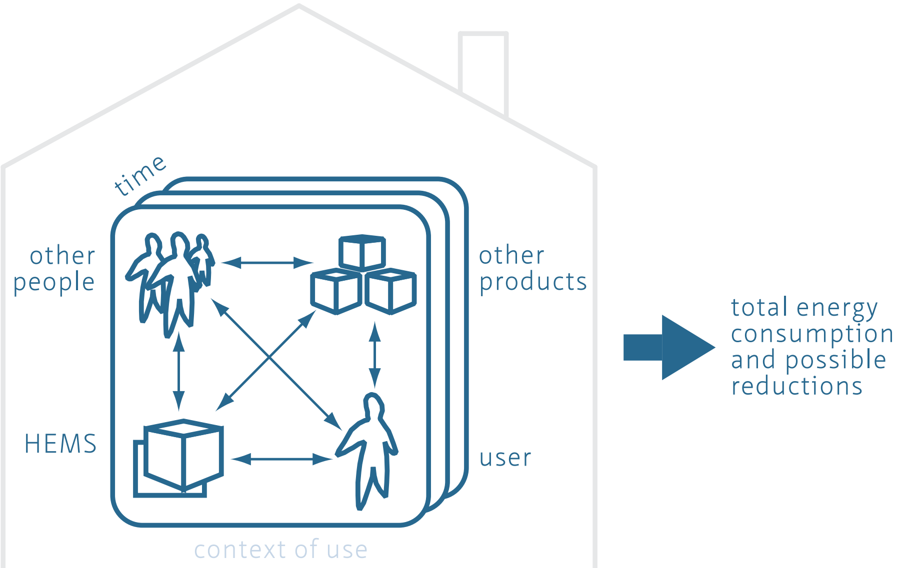


Figure 29
Aspects of framework addressed in chapter 7. Adapted from Wever et al. (2008) and van Kuijk (2010)

When applied to HEMS, this framework illustrates the interactions that take place between a user and a HEMS, and between the HEMS and other networked products. It also shows that other people can be involved in or affected by a person's HEMS use. Finally, the context of use (i.e., home context, organizational context) will be a determining factor for the overall quality of the user-device interaction. These interactions will be dealt with one by one in the following sections. Within the context surrounding the HEMS-user interaction we would like to propose the additional element of time, as this is an important factor in the use and effectiveness of HEMS.

§ 7.3 Insights based on framework

Following the framework in Figure 29, this section addresses the one-on-one interaction between users and HEMS, as visualized in Figure 30. If these devices are to fulfil their purpose, namely to help households save energy, they must be used actively, and over a longer period (several years). There are however different factors that impede this prolonged use.

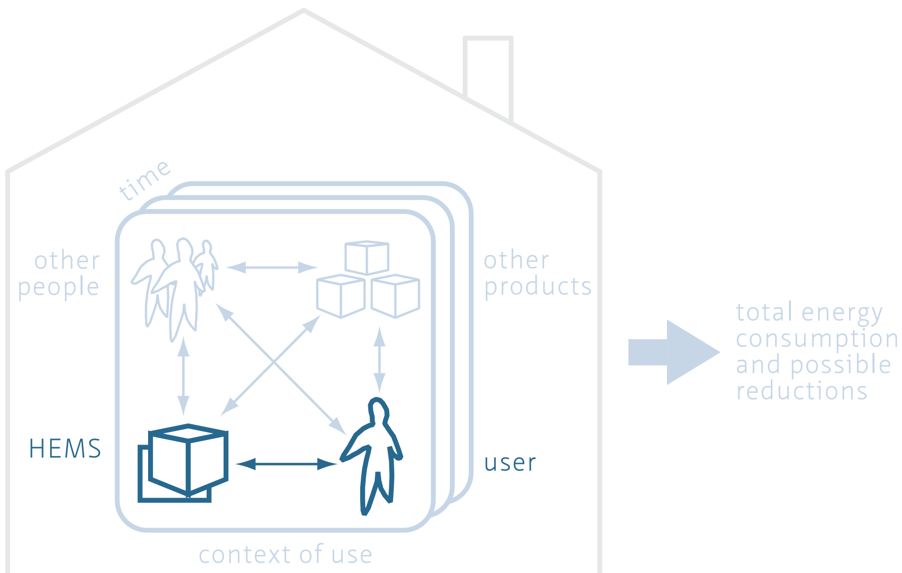


Figure 30
The interaction between a HEMS and its user

§ 7.3.1 Human-HEMS interaction (HEMS-user interaction)

§ 7.3.1.1 Malfunctioning devices

The participants' homes were the context in which the interactions with the installed HEMS took place. This section looks at an important, but often overlooked, aspect of this context of use: a reliably functioning HEMS. The systems used in the case studies malfunctioned relatively often. Even commercially available HEMS appear to malfunction regularly. Incorrect installation, poor system capabilities, faulty hardware or software, can all have a severe effect on user perception. As one participant explained: *"If you get inexplicable peaks of 180 euros for gas and 150 euros for electricity per day it is hard to believe the rest. You can't steer on it... All these numbers, measurements, they don't mean anything anymore."*

In the Netherlands, electricity suppliers and grid managers lead the implementation of HEMS, often in collaboration with commercial enterprises (that are responsible for design and production of HEMS). HEMS are increasingly offered to households via the energy suppliers, who also take care of the system's installation and maintenance. Some systems can be purchased on the market; these require consumers to self-install.

Having properly functioning HEMS is a straightforward condition that needs to be met, but this appears to be challenging for several reasons:

The wide variety of electricity and gas meters in use today, in the Netherlands. HEMS must be able to communicate with them all. Even smart meters can be very different (i.e., they utilise different communication protocols, and some are unable to transmit real-time feedback), making it very hard to develop a generic HEMS that works reliably with all possible systems.

The novelty of the technology used. Even though electricity monitors were introduced over three decades ago (Funk, 1978), and the first gas monitor in the Netherlands in 1982(van Beurden, 1982), the real technology development seems to have accelerated only in recent years with the introduction of different protocols for wireless transfer of energy data, and the possibility to give real-time data, via (interactive) displays or via users' PCs. With a rapidly developing technology landscape, new HEMS can be almost out-dated when they come on the market.

Analysis of the case study data confirmed that users with faulty HEMS stopped using the devices, even after these had been repaired. Obviously, if the data cannot be trusted, people stop trying, which in effect makes HEMS useless.

§ 7.3.1.2 User interface

The developers of HEMS have to combine technological know-how with user-centred design principles in order to make high-quality HEMS interfaces. It seems that for many HEMS technological challenges have dominated the development, resulting in devices with a rather 'technical' interface (see Figure 31). Many study participants expressed difficulties interpreting interfaces with numerical digits or mathematical graphs. In our third case study a participant remarked: *"It is all numbers; it doesn't mean anything to me"*. Likewise, Kidd and Williams (2008) reported a participant in one of their studies saying *"I certainly haven't used it…I certainly am not techno…"*

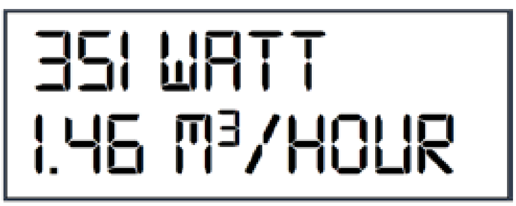


Figure 31
Example of numerical feedback ('technical interface')

Only the most tech-savvy participants, we found, had few problems with such data. The design of the interface of HEMS is a subject that needs further attention. Froehlich et al. (2010 p. 2004) noted this, asking: *"How important is it that eco-feedback be even minimally interactive? What types of information and presentation mediums are most effective (e.g., graphs versus abstract ambient representations)?"*

Based on our findings, part of the answer should be that interfaces with complex graphs and lots of numbers are unlikely to be acceptable to a large group of users. Some of our participants, for instance, felt more comfortable with abstract indicators (i.e., colours, size). A usability participant said: *"So then those numbers are sort of meaningless…I think colours more. More than numbers"*. Another participant used the 'clicking' sound of his current thermostat as an auditory prompt. He indicated:

"If I think it's too warm in the house and I hear 'click', then I know that someone has altered the settings of the thermostat. And then I say: 'who touched the thermostat?"

We conclude that users are 'wired' differently and have different needs and expectations. Successful HEMS should accommodate the significant variation in users' capacities and manners of cognitively processing information by using a combination of methods to relay energy consumption data. Consideration should be given to the other senses as well, not just visual stimuli.

§ 7.3.1.3 One size does not fit all

The characteristics of users and their needs and expectations influence their preferences for a specific type of HEMS. In our case studies, some participants had a preference for feedback at household level while others wanted data on each individual product (i.e., disaggregated feedback). In a focus group session, one female participant wanted to know 'everything': each detail as to the consumption of every appliance through time, while another female participant indicated that an indication of total consumption was quite enough for her. Some participants were interested in receiving nightly consumption figures because that is where they felt they could save, others did not want to be confronted with real-time consumption data. As one said: *"that makes me panicky, that's not healthy"*. One participant was interested in a monthly or quarterly overview of his consumption to see how it changes over time, but this was *"only to be viewed on my own initiative"*.

In Chapter 6, six different types of users and their specific use of HEMS over the course of four to twelve months were identified. Likewise, in the past, Liikkanen (2009) identifying three types of HEMS users: wisdom seekers, detectives and judges for an energy meter that was used for one week. Each 'type' looked for different kinds of feedback. These different types of users and their diverse use of HEMS show that one size does not fit all, meaning that there's probably a market for a variety of HEMS that offer different approaches towards feeding back energy data. For instance, HEMS can offer aggregated feedback (household level) or disaggregated feedback (product level). For any HEMS design, however, due consideration should be given to the most likely ways the system will be implemented and used, taking into account how people learn, and enabling HEMS to evolve with the users over time.

§ 7.3.1.4 The energy enigma

It is not a given that users have a (correct) conception of what a kWh or m^3 entails, nor that they know what to do with that information. Two of the 14 participants in our usability study had difficulties understanding m^3. One said, *"what does 'm' '3' mean?"* A second person asked: *"It says here 2 uhmm...How do you measure gas again? Cubic or something?"* In our first case study (Van Dam et al., 2010), the participants were required to self-report their meter readings, resulting in a high margin of error. It appeared that many participants had omitted digits, reversed the readings of day and night tariffs, or had reported data that was for example a factor 100 off from their previous readings. This seems to suggest that the conception of energy is low amongst households. Literature affirms this view: *"for many people, processing complex energy information presents a formidable task"* (Stern and Aronson, 1984, p.83)

Part of the challenge of HEMS is giving users a better conception of what energy entails. One possible strategy, which is often employed, is to translate energy data into monetary values. Our research findings suggest that this works for some, but (again) not for all participants. Therefore, the design of HEMS should consider the user's depth and understanding of energy. A design solution we advocate is a layered interface, which provides simple information at a quick glance and increases the depth of information in ensuing steps. For this 'first glance', simplicity is a key factor, as Fogg (2009) explains in his research on persuasive design. If it takes too much effort people will not be persuaded to act on it, or to embark on a search process.

Another approach is to see HEMS not as the ultimate solution, but as part of a system, where users are stimulated to enter a search process that leads to other media or people for further analysis and in-depth information. Stern and Aronson (1984) advocate a 'full court press', saying: *"feedback is more likely to be effective if given as part of a program in which the energy user is an active participant rather than simply being a passive recipient – even when information is offered about how to interpret the feedback"* (p.88).

§ 7.3.1.5 The baseline check

As users interact with HEMS, new behaviours develop. HEMS becomes embedded in people's lives and routines start to surface. In the first case study, it appeared that the most popular routine was to check the electricity consumption before going to bed, affirming that the house was at its baseline energy consumption. The baseline energy consumption is the amount of electricity a household consumes when none of the appliances are in active use. In most homes, electricity is consumed 24/7, for instance to keep the ventilation system and refrigerator going and to power the products that are in standby mode. This routine, which we called 'the baseline check', was also noted in Kidd and Williams (2008) who quoted a user: *"There were times sitting in bed, turned the light out and then try to get the little light (on the monitor) to come on so we could read it in the dark – 'yea, we've dropped! Night night, darling!"*

In our second case study, a participant indicated he would like a small screen in his bedroom so he could check and turn off appliances that had accidentally been left on while he was already in bed.

For HEMS to be used effectively over time, they should become embedded into people's daily routines. Understanding which daily routines emerge from the use of a certain type of HEMS can be important information for designers, as it helps them tailor the system to those preferred use situations.

§ 7.3.1.6 Obsoleteness

In our first case study, we found that a significant user group had incorporated the electricity monitor into their daily routines and checked it habitually. An even larger group however (just over half of the participants) had stopped using the electricity monitor, with the majority opting to stop using and giving back the device after the first four months of the study. We found that when people were beginning to lose interest, relatively small triggers like a (temporary) malfunction or even the need to change the battery could be the 'last straw'. One lady using the energy management device in the second study said: *"I believe my husband has pulled the plug [of the device] out again... so then I thought; I'm really giving up"*. Ueno et al. (2006a) found a significant decrease in the interactions with the energy monitor that was used in their nine month study, indicating a similar drop-off rate. There is obviously a risk that HEMS become obsolete long before their technical lifetime is over. Studying how HEMS are used (and disused) in the short and long term and implementing these findings in the design to make them fit better, might reduce those risks.

§ 7.3.1.7 It is my 'thing'

In talking to HEMS users, it surfaced that the device is often the 'pet' tool of one person in the family. As one person using the energy management device said: *"Yes I* *am the user of it, yes, not even 99% but 100%"*. Figure 32 shows that the majority of households had one main user, and Figure 33 shows that this user was generally male.

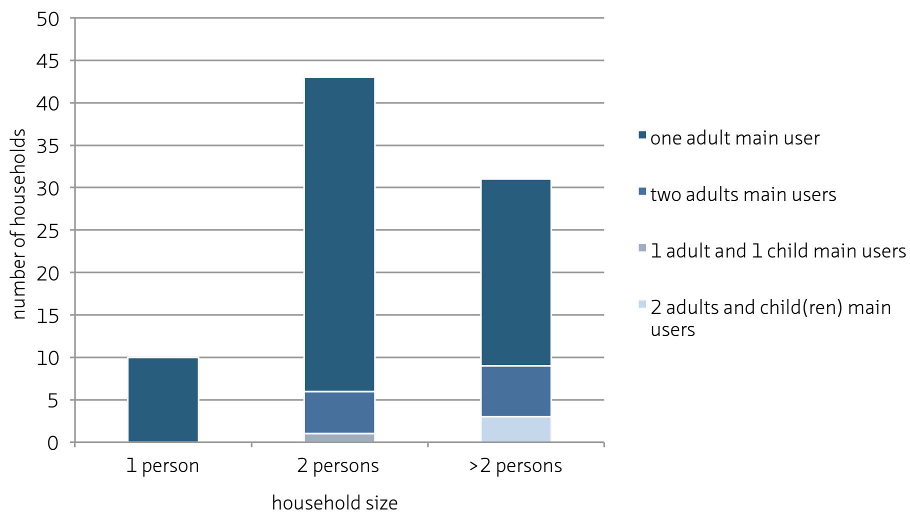


Figure 32
Number of main users per household after 15 months (N=93)

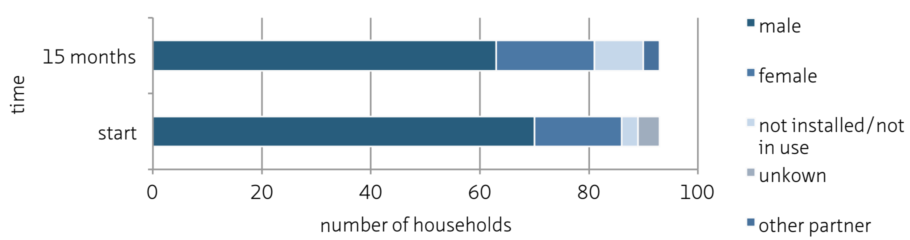


Figure 33
Gender of the main user(s) (N=93)

The findings of Hargreaves' (Hargreaves, 2010) interviews with 15 participants were in line with our one-main-male-user finding. It is however possible that different HEMS appeal to different genders and that one of the areas to be addressed is how to make HEMS more appealing to women. Because it is not always the feedback as such that is unappealing to women but sometimes the way in which it is presented or designed:

"My wife doesn't like it as much as just the old thing, which had a single big number on it, because there are too many things on here for her to look at. She doesn't understand it really. She understands a tick and a cross so that's okay." (Hargreaves, 2010)

In the second case study, a female signed up with the motivation: *"Well, I am more energy conscious, and they [points at her husband and 2 daughters] aren't…I don't understand anything at all about it [the HEMS], but I am also not technical for the rest. Only I was a bit like, let's see what our phantom loads are."* It is worth pursuing whether HEMS can be designed to appeal to more members of the household.

§ 7.3.2 Households dynamics and their influence on achievable energy reduction (interaction between users and other people)

This section will look at the way the main HEMS user relates to other members of household (see Figure 34), as this may have an important bearing on the effectiveness of HEMS usage. Also, the social context of households will be taken into account, where households compare themselves to other households.

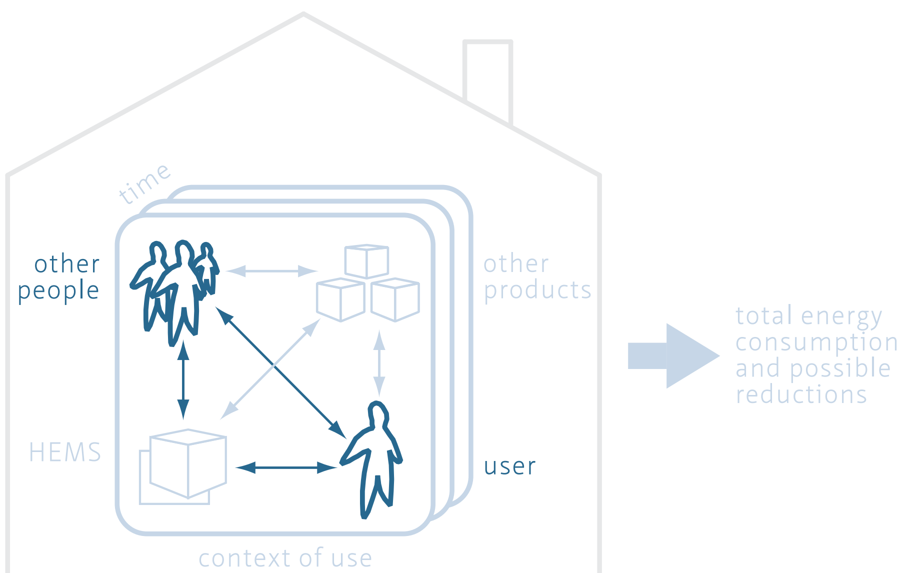


Figure 34
The interaction between the user and other people: household dynamics

§ 7.3.2.1 Sustainability and/or cost advocates

Often, one adult in a household holds sustainability dearest to his/her heart. This person is the family catalyst concerning sustainability. The tactics vary, but regularly this person will 'badger' other members of the household concerning the length of their showers, their forgetfulness in turning off lights or appliances, etc. For a number of households this is not just about sustainability but also (or only) about cost management (Figure 35).

Some of the sustainability/cost advocates who tested an energy management device indicated they now feel better equipped to this task. One participant said: "*My children used to shower every other day. But nowadays they all – except for me – shower every day. And sometimes they take long showers, and then the door is locked, so then I have to knock on the door once in a while. Like: 'hurry up a bit!'. How much that costs, I don't know exactly. But now I could quickly run down the stairs to look. And then I can also show it...*"

A female participant said she hoped her husband would use it and change his behaviour. Five months later she reported that her son and husband were starting to pay attention to not leaving lights and the computer on, but commenting that "*I still have to switch the lights off after them once in a while*". Another participant indicated that their "*consumption had become easier to discuss with the family members*". Whether the main HEMS user in households is always the same person as the sustainability or cost advocate is an interesting question for further research.

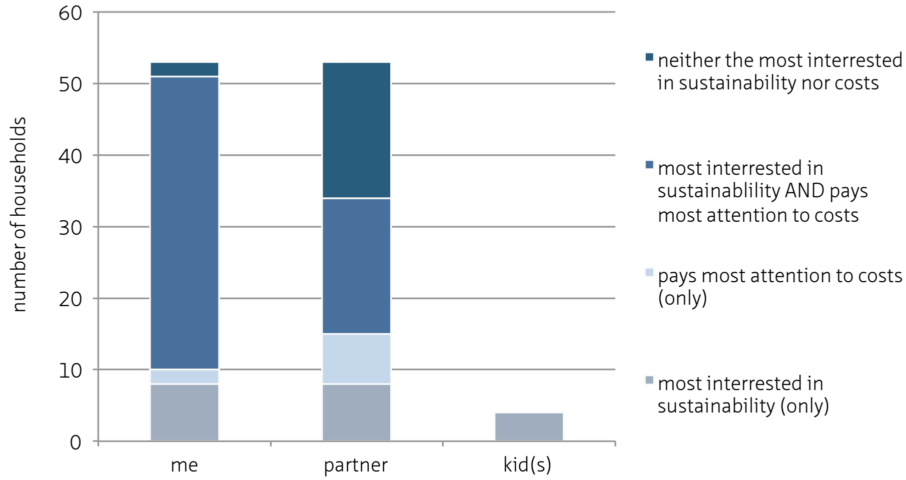


Figure 35
Which household member is most interested in sustainability and/or pays the most attention to costs (N = 53)

Outside these case studies, mention has also been made that users apply a HEMS as 'badgering tool':

"I mean some nights I can come home from work and the whole house is lit up like Blackpool Tower – the computer's on, the telly is on, the radio's on in here and there's nobody in the house! That used to drive me up the wall but they are now starting to think. I've been badgering them and I've been flashing that meter in their faces!" (Kidd and Williams, 2008)

Hargreaves (2010) approaches these 'family negotiations' as a limitation, warning for a potential increase in conflicts and stressing the need to consider the complex social context in which HEMS are implemented. Thøgersen and Grønhøj (2010) found that *"there are predictable patterns of interaction among household members that influence their electricity consumption"*. HEMS should therefore aim at opening a positive dialogue between members of households and serve as tool in helping identify, and alter specific behaviours of members of household.

§ 7.3.2.2 The boomerang effect

Moving to the broader social context surrounding households, households need a reference for their total energy consumption. But this needs to be tailored to different household types. Several participants in our case studies indicated they did not know if the energy consumption displayed on their HEMS was abnormal or not, and some jumped to (unsupported) conclusions. In the first case study one participant, with an annual consumption of 4,110 kWh (which is slightly above average) and a family of four, concluded after two months that: *"the electricity monitor confirms that we are doing well. Further savings would barely be possible in our household"*. It might therefore be useful to give households a norm to compare themselves to. However, (Schultz et al., 2007) warn of the boomerang effect: the phenomenon where households increase their energy consumption, instead of decreasing it, because they are below the norm (the norm being the average neighbourhood energy consumption). Researchers disagree on how to prevent a boomerang effect from happening. (Schultz et al., 2007) claim that giving people normative as well as injunctive feedback (approving or disapproving certain behaviour) eliminated the boomerang effect. (Ayres et al., 2009) however, did find the boomerang effect for low energy consumers in both their studies even though both descriptive as well as injunctive norms were used. The overall energy savings in these studies were however still positive. This indicates than when using comparative feedback, care should be given to preventing the boomerang effect. This could be done either by only giving high-energy consumers comparative feedback, thus creating tailored HEMS, or by setting different norms for different use groups and adjusting these through time.

§ 7.3.3 HEMS in relation to other appliances and household members (Interactions between HEMS and other products/users)

HEMS have a mediating role, they provide people with a (visual) representation of energy consumption, and help them mentally interpret the actual energy (or monetary) figures and perceive the energy consumption of other products. (Ihde, 1990) calls this relationship between users and products a hermeneutic relationship. The HEMS-user interaction cannot be seen separate from the relationship between HEMS and other symbiotic products or users and other products. This next section will centre on this part of the conceptual framework (Figure 36): the triangular interaction between HEMS, users and other products.

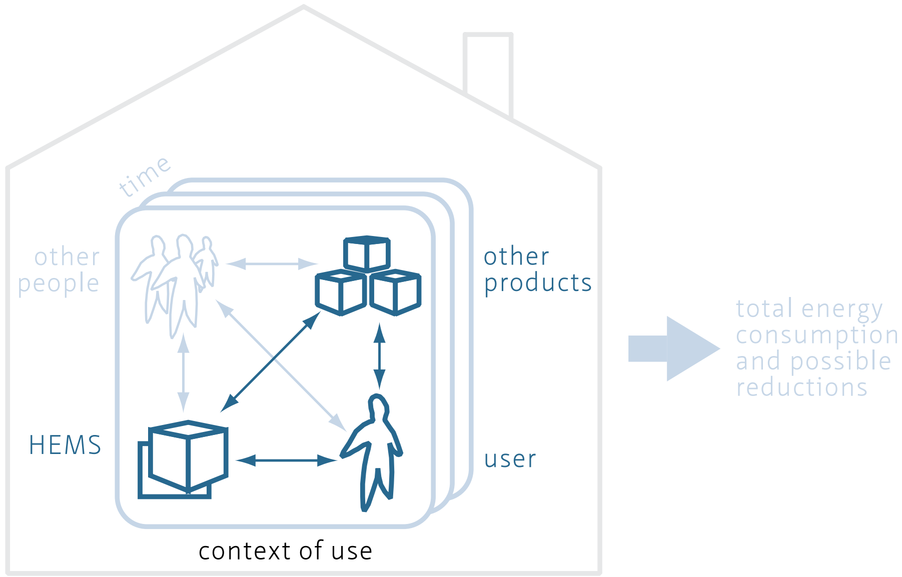


Figure 36
The interactions between HEMS, users, and other products

§ 7.3.3.1 Cause and effect

Understanding energy consumption is hard for many people. This makes it difficult to relate the feedback given by HEMS to real actions. Plain facts on energy consumption bring knowledge but not understanding. When a household knows which actions cause a large spike in energy consumption, it is far easier to act upon this. For electricity consumption disaggregated feedback can help reveal which appliances or behaviour was the cause, and for gas consumption a correlation between and outdoor temperatures could potentially reveal behavioural or poor insulation causes.

Because energy consumption varies substantially throughout the week, this makes an average daily consumption figure relatively useless. One participant in the third case study said about the cumulative total of the last 24 hours: "*it is useless for me*". As (Darby, 2010) noted, extrapolating daily or weekly consumption to expected monthly or yearly consumption can lead to highly erratic estimates, which users can find hard to trust and difficult to act upon. In their design, HEMS should strive to make the consequences of the users' actions clear, and not resort to useless statistics. Admittedly, achieving useful figures and statistics can be challenging and will require user testing.

§ 7.3.3.2 How to manage the energy management device

Certain types of HEMS (called energy management devices) can help people control if and when appliances use energy and circumvent the complexity of behaviour change, for instance through scheduled timers. Timers are however not always a good solution. For one, households' schedules fluctuate throughout the week. With increasing household size, the household dynamics and rhythms of daily life become increasingly complex. In the second case study, this led to members of households (permanently) bypassing the system when it was not in sync with their lifestyle, thereby annihilating the savings. Also, households with programmable thermostats appear to use more energy than those with a manual thermostat (Guerra-Santin and Itard, 2010)

In general, most households have little knowledge of the workings of their appliances to successfully use an energy management device. This can lead to appliances being switched off that should not be (e.g., for safety reasons) or appliances that are left 'on' unnecessarily. Two of our case study participants put a timer on their refrigerators to make them turn off during the night; several participants did not know their appliances or gadgets (e.g., game consoles) were still consuming power even though they had switched them 'off'; and one participant never shut down his modem for fear of receiving a blacklisted IP address. The difficulty for many people is not turning on their devices; the problem is turning them off (or not knowing when or how to do this correctly). Designers should be aware of this when designing household appliances and consumer electronics.

Households can find themselves 'locked-in' by their own appliances. (Jackson, 2005) describes lock-in as "*far from being able to exercise deliberative choice about what to consume and what not to consume*". Two users in the third case study stated that certain energy inefficient behaviours were not of their own choice. While they themselves did not see the necessity of heating the whole house or even preferred not to, they were 'forced' by their heater. Either their installer had prescribed the need to heat a majority of rooms for their heater to function properly or the heater had actually given an error code because it was heating too few rooms. A third user was in the process of changing his lights to energy efficient alternatives but was unable to do so as his halogen lights "*were not replaceable by an energy efficient version*".

This teaches us that even highly motivated people may find it hard to change their energy consumption behaviour, due to their (busy) lifestyles, lack of knowledge on how and when to turn off their products and choices from the past that hinder change.

§ 7.3.4 Overall effects of HEMS on net energy consumption

The human-computer interaction framework of Figure 29 offers a practical model for describing our observations regarding the daily usage of HEMS in three different case studies. This final section will address the cumulative user experience over time (as indicated in the 'time frame' in Figure 37). More precisely, we will examine the relationship between the usability of HEMS and their effectiveness. Effectiveness is defined as the extent to which users can maintain net energy savings over prolonged periods.

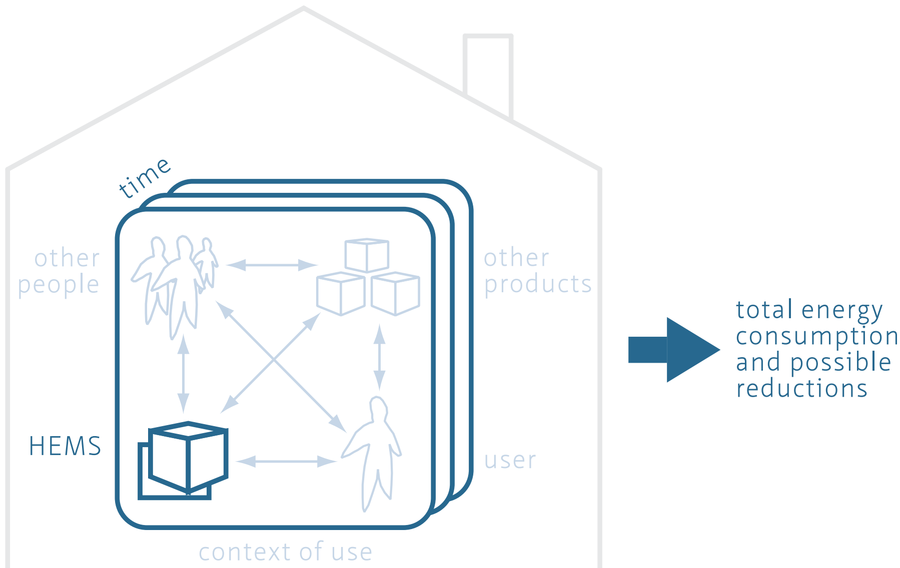


Figure 37
The element of time

§ 7.3.4.1 Short term effects

The overall effectiveness of HEMS in mid to long term case studies is indecisive (van Houwelingen and van Raaij, 1989, Mountain, 2006) or shows a negative trend (van Dam et al., 2010).To date, the effectiveness of HEMS seems mostly short lived.

We have already discussed that HEMS are not useful for all households, and not all households want to, or manage to, reduce energy consumption. It is therefore questionable whether implementing HEMS 'en masse' will contribute to overall energy efficiency. In fact, it might result in an overall decrease of the total HEMS effectiveness. Careful consideration is therefore needed as to which user groups will be targeted.

§ 7.3.4.2 Process of change

A number of participants in the case studies indicated that acquiring a HEMS was part of a longer process of change in which they were 'growing' towards sustainability. One participant in the second study explained: *"I think that in part I did become more conscious when I started working at the ASN bank [sustainable bank in the Netherlands (eds.)]. Also about all the possibilities there are [to be sustainable]. You don't realize all those options in the beginning."*

He indicated that through the energy management device he had received more insight into the standby use of appliances and turned them off at night, adding that: "*[It] was also pointed out a bit by my colleagues in the past*", and commented further on the persuasive social influence his colleagues had on him. A second participant responded in a similar way. He said: "*that I became more conscious is 4 years ago, I think approximately*". He was now implementing flip switches and timers throughout the home. When asked about the reason he explained he was inspired by an 'eco-minded' colleague. Sometimes there is a direct trigger, like a participant's bill: "*In the last electricity bill [half a year before] it turned out that we used about one and a half or two times the national average*". He continued: "*In first instance I messed around a bit with energy meters and that sort of thing*" after which he signed up for the case study. Two months into the study he purchased solar panels. Coincidentally there was a price incentive offered by his municipality that influenced his decision, which again gives an indication that HEMS should be seen as part of a larger scheme.

(Woodruff et al., 2008) found that for the 35 homes they interviewed, sustainability was often a progressive development over many years. While for some sustainability is a philosophy that permeates their whole life, certain phases in life or financial positions can assist or inhibit this process. As one focus group participant told, his electricity consumption dropped from 5,500 to 3,200 kWh when his two sons moved out. This aspect needs to be examined in more detail, in order to understand the role HEMS can play in aiding people in this change process. Measuring the exact effects of HEMS however, becomes far more complicated as it can be part of a chain reaction and permeates into other areas of life. The examples above also show that social dynamics are an important aspect to consider.

§ 7.3.4.3 Clothesline effect

It is likely that part of the initial effectiveness of HEMS is due to the newness of the HEMS and the novelty of the feedback. A strategy to counter the decreased interest of users and effectiveness over time is to regularly giving users new stimuli to create recurrent awareness of energy reduction amongst HEMS users. Designers should therefore consider not developing HEMS as a one-off design, but rather devise a longitudinal design strategy to continue stimulating their users. Woodruff (2008) poses a similar conclusion in saying that interactive technologies 'would be more effective if they evolved over time in the same path as the user'.

§ 7.3.4.4 Net impact of HEMS

Consideration should be given to the overall life cycle impact of HEMS and not only to the savings that can be achieved. In other words, a trade-off needs to be made between the energy needed for production, use and disposal of the device versus the amount of energy saved by using it. When the savings achieved through HEMS are only sustained for a short period, it is hard (or even impossible) to break even with the amount of energy invested. An assessment of the cumulative energy demand (CED) can be a useful tool here, which will be discussed in Chapter 8.

§ 7.3.4.5 Smart grid future

A smart grid system allows for two-way communication between utilities and consumers. Smart grids focus on peaking shifting, e.g., through dynamic pricing schemes. This process employs smart meters and HEMS that provide real-time pricing, which gives consumers the incentive to reduce electricity use during high-priced peak periods. Research from 1987 implementing HEMS with pricing schemes has shown that the overall consumption is not reduced but rather shifts to periods with cheaper electricity (Sexton et al., 1987), implying that smart grid systems mainly lead to different energy usage behaviour (and not necessarily to energy conservation). The environmental benefit of smart grids is the creation of more evenly distributed grid-loads, but such societal benefits are relatively abstract for individual households and difficult to communicate. In a smart grid system, HEMS will be indispensible for giving users insight in the energy pricing schemes. They may also offer some level of control over smart appliances. However, the amount of user control and the influence this has on energy consumption needs further study.

§ 7.4 Conclusions

As stated in the introduction, the aim of this chapter was to present a number of insights useful to the design and implementation of HEMS. By using the conceptual framework on human-product interaction, a number of important areas have been highlighted that have received little attention in literature reporting on the effectiveness of HEMS feedback. It has been shown that studying the HEMS-user interaction and how this changes over time can give a wealth of knowledge that can contribute to better design and implementation. Additionally, family dynamics and the social context are a notable factor in the acceptance of HEMS and the achievable savings. The chapter has also looked at the triangular interaction between HEMS and its user and other symbiotic products showing that these intertwine with the achievable effects of HEMS.

Finally, the chapter concluded that the 'effects' of HEMS should be placed in a wider context. Effects are far more complex and harder to define than the just direct outcome on energy consumption. It is important to consider the entire life cycle and the embedded energy. Effects also need to include a time factor and the scale of implementation: how long HEMS are used, which (kinds of) households manage to save energy and what the 'durability' of the achieved savings is.

Some of the insights need to be further substantiated by means of quantitative data. How often do HEMS become obsolete prematurely, at what point in time does this happen and what are the causes and effects? How can feedback be made more understandable and appealing to (other) members of household and how can HEMS positively involve all members in reducing energy consumption? How detrimental are defective functioning and technical interfaces to energy savings?

In answering these questions, longitudinal research with an interdisciplinary character through close collaboration between social sciences, the human-computer interaction (HCI) community, energy suppliers, designers and developers, as well as HEMS users, is essential. One possible case study could be to test a number of different HEMS (interfaces) simultaneously using a mixed method approach. Another is to study the effects of implementing HEMS as part of a range of interventions and incentives to reduce consumption (a 'full court press' approach). Thirdly, experience sampling (a technique to make participants record temporal things like feelings in the moment) could prove to be a relevant approach to come to a better understanding of which household member(s) is/are using the HEMS and how, when and for what reason, so that HEMS can be better tailored to these situations.

There is still significant progress to be made in the development and implementation of HEMS. But by taking the areas shown in this chapter into consideration and studying them further, the effectiveness of HEMS will improve.

PART IV Reflections on HEMS

The previous part of this thesis extracted insights into the design use and implementation of HEMS from the findings of the case studies. This, the fourth and final part of the thesis reflects upon HEMS in general.

Chapter 8 goes back to Chapter 1 and the starting points and goals for this research by reassessing the effectiveness of HEMS. This is done through a reflection on whether HEMS actually make sense when taking into account their achievable long-term savings, life expectancy and embedded energy. Effectiveness was defined in Chapter 1 as the extent to which users can maintain significant savings on energy consumption over a prolonged period. For the purposes of this chapter, the definition of effectiveness is narrowed to mean positive net energy savings where $e_{saved} > e_{invested}$. This leads to a different perspective on the value and effectiveness of HEMS

Chapter 9 reflects on the different case studies and the underlying experiences with regard to the context and conditions in which the HEMS were implemented and the challenges in setting up case studies and executing them. It discusses the insights gained through the process of conducting scientific research with HEMS, as much can be learned from the story behind the energy savings results of HEMS. It addresses how these contextual factors and the manner of setup and execution of the case can influence the use and effectiveness of HEMS and the measurable results in case studies.

8 Do HEMS make sense? Assessing the overall lifecycle impact of HEMS.

van Dam, S. S., Buiter, J. C. & Bakker, C. A., submitted as journal article, May 2013[1].

This chapter revaluates the effectiveness of HEMS. In recent years several studies have reported on the energy savings that HEMS can achieve. The figures seem impressive, often ranging from 5 to 15% reductions in electricity or gas consumption. However, researchers tend to focus on the resulting direct energy reductions within the home and often over a limited period of time. They do not take the overall lifecycle impact of the HEMS itself into account. As Chapter 4 presented evidence that the achieved savings decrease over time and that HEMS become obsolete before their technical lifespan has ended, a more holistic approach is necessary to assess whether HEMS can effectively contribute to household energy savings. This chapter therefore evaluates the overall effectiveness of HEMS by addressing the HEMS themselves and their effectiveness over time within the framework in Figure 38.

1 This article is a revised version of the paper VAN DAM, S. S., BUITER, J. C. & BAKKER, C. A., 2012. Assessing the Overall Life Cycle Impact of Home Energy Management Systems. In: proceedings of CIB W115 Green Design Conference. Sarajevo, 27-30 September 2012, Rotterdam CIB

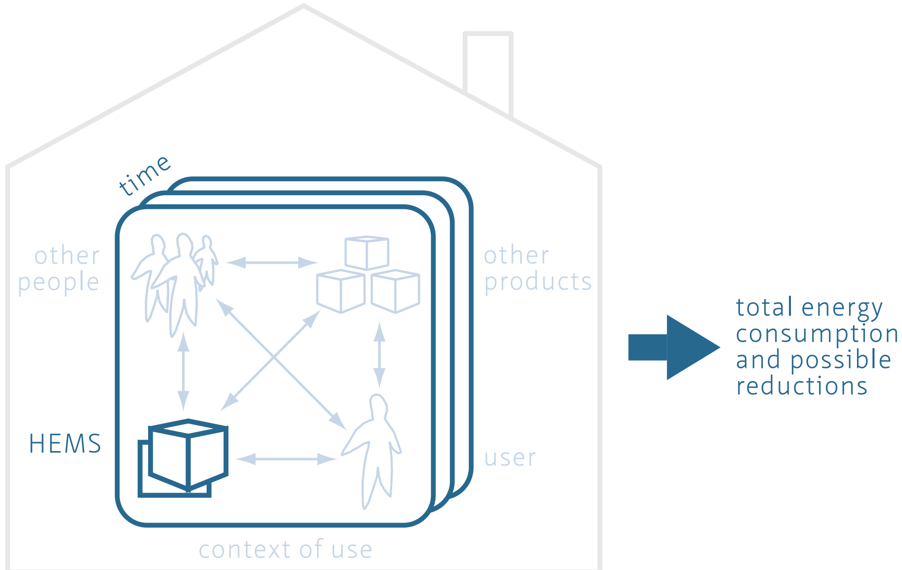


Figure 38
Aspects of the framework discussed in Chapter 8. Adapted from Wever et al. (2008) and van Kuijk (2010)

A trade-off needs to be made between the energy needed for the production, use and disposal of the device versus the amount of energy saved by using it. Therefore, a lifecycle assessment and a cumulative energy demand (CED) method were used to analyse three distinct types of HEMS. Based on the literature, several scenarios were developed in order to find the break-even point, where $e_{invested} = e_{saved}$. The results show that the overall impact is dependent on the type of HEMS, and that if the duration of use is short or the achieved savings are small, the benefits do not always outweigh the environmental costs.

In the light of the uncertain long-term effects of HEMS, it can be argued that these devices should not be developed as stand-alone products, but should be integrated into existing products. Care should be taken not to develop HEMS with unnecessarily elaborate parts or functionalities and that their own electricity consumption is minimized.

§ 8.1 Introduction

HEMS are defined as intermediary devices that can visualize, monitor and/or manage domestic gas and/or electricity consumption (van Dam et al., 2010). Their main purpose is to give users direct and accessible insight into their energy consumption. This makes them different from smart meters, which are predominantly intended for automatic two-way communication of energy data between the gas or electricity supplier and homes. Smart meters generally need HEMS to give users the intended feedback and insight (van Dam et al., 2012, Klopfert and Wallenborn, 2011).

HEMS are receiving increasing attention both in academia and in commercial enterprises, and they are advertised and promoted as having a 'high potential' for domestic energy savings. Studies have reported positive results of up to 10% or even 20% savings for individual households, at least in the short term (Ueno et al., 2006, Wood and Newborough, 2003); in the mid- to long-term studies, it was found that HEMS are less effective (van Houwelingen and van Raaij, 1989, van Dam et al., 2010, Hutton et al., 1986).

While savings of 5 –15% (Darby, 2006) in electricity or gas consumption might sound impressive, this is not a complete picture for a number of reasons. Savings are regularly not achieved on the total energy consumption of a home but on only a part of it. For example, savings were only achieved for the gas or electricity consumption of one appliance (Wood and Newborough, 2003, McCalley and Midden, 2002), or for overall electricity consumption but not for heating or gas (van Dam et al., 2010), or vice versa (van Houwelingen and van Raaij, 1989). There is currently little evidence that these same savings can be achieved for other appliances and little research on spill-over effects to other types of energy.

A second reason why the stated savings present an incomplete picture is that studies tend to report on the resulting straightforward, direct energy reductions within the home. In such studies, the savings are usually calculated in the following manner: a number of households are selected, pre-trial baseline consumption measurements are made and/or control group(s) are selected, the HEMS are installed and the meters are read (or the consumption data are tracked) and, after a specified period of time, the meters are read again and the HEMS uninstalled. The two (or more) readings are subtracted from each other, possibly corrected for seasonal influences and compared to the pre-trial baseline or control group measurement. This is an important assessment. However, it should not be the last or the only assessment. In the strictest sense of the word, not all these 'savings' are savings. Energy is needed to produce, use and dispose of the HEMS. HEMS need hardware to measure the consumption of appliances and/or energy types. More hardware will probably mean that more energy is needed to produce and/or run the HEMS. When this energy is subtracted, the net energy savings become apparent. This is a more accurate depiction of the effectiveness of HEMS.

A third reason is that the savings are calculated over a limited period of time. However, the period after an intervention has ended presents a number of uncertainties. Care should be taken when extrapolating the savings to the period after the intervention. There is evidence that the achieved savings decrease over time (van Dam et al., 2010, van Houwelingen and van Raaij, 1989), and that not everyone manages to save with a HEMS (van Dam et al., 2010). There is also a risk that HEMS will become obsolete before their technical lifespan has ended (Ueno et al., 2006). Taking these factors into consideration, a holistic approach becomes essential. Only then can it be assessed whether the benefits outweigh the costs. Therefore, a holistic view is advocated by taking the overall lifecycle impact of the HEMS itself into account. This is currently not a standard approach. Only one study could be found where the overall lifecycle impact was analysed and reported. This was for a HEMS intended to conserve water (Willis et al., 2010).

§ 8.2 Objective

This article provides a more complete picture of the overall effectiveness of HEMS. Consideration should be given to the overall lifecycle impact of HEMS and not only to the direct energy savings that can be achieved. In other words, a trade-off needs to be made between the energy needed for the production, use and disposal of the device versus the amount of energy saved within the home by using it. When the savings achieved through HEMS are sustained for only a short period, it is hard to break even with the amount of energy invested.

Effectiveness was defined by van Dam et al. (2010) as the extent to which users can maintain significant energy savings over prolonged periods (>4 months). This definition is not sufficient for this article, as the meaning of 'energy savings' needs to be more specifically defined. A distinction must be made between net, direct and indirect energy savings. In the literature on implementing HEMS, 'energy savings' usually refer to direct energy savings on gas and/or electricity, depending on the type of energy the HEMS targets. Spill-over effects to other forms of energy or savings on indirect energy consumption (i.e. energy embedded in the production, transport and disposal of consumer goods such as fruit, ready-made meals, etc.) are difficult to measure and attribute to a particular intervention. As such, they are less studied, with a few exceptions (Abrahamse et al., 2007). In this article, the focus is on positive net energy savings where $e_{saved} > e_{invested}$ So, within the stated definition of effectiveness, the words ‘energy savings’ refer to a positive outcome of the equation: direct energy savings through use of the HEMS minus the energy invested in the HEMS itself.

The primary objective of this research was to assess whether the environmental benefits of HEMS outweigh the environmental costs, and in doing so effectively contribute to household energy savings. As this is time dependent, an additional objective was to determine after what time a break-even point can be achieved where $e_{invested}=e_{saved}$ and whether it is realistic that this will be achieved during the economic and technical lifespan of a HEMS. The final objective was to evaluate whether the HEMS are economically viable for households and what the payback is.

Based on previously conducted lifecycle assessments (LCAs) and on HEMS usage tests from previous studies, we had certain expectations. Because ‘simple’ HEMS (e.g. HEMS with few parts or with small displays rather than LCD touchscreens) are relatively low-tech products, we thought that these would have a positive net energy balance. In contrast, as our experience from running trials with HEMS showed that the energy consumption of more complex HEMS was not optimal and that duplicate peripheral devices were sometimes implemented as part of the setup of the HEMS, we thought it highly questionable that the net energy savings would be positive in these cases.

§ 8.3 Setup and methodology

To assess the impact of the production, use and disposal of HEMS on the overall effectiveness of HEMS, three HEMS were analysed using cumulative energy demand (CED) and eco-costs indicators. For the use phase of the HEMS, a number of scenarios were developed for the potential energy savings. The three HEMS were chosen due to their diverse nature and as a representation of the different types of HEMS available on the market.

§ 8.3.1 Description of the three HEMS

The HEMS were an energy monitor, a multifunctional HEMS and an energy management device and this section will give a description of all three HEMS.

§ 8.3.1.1 The energy monitor

The energy monitor is a small, straightforward, dedicated device that gives real-time feedback on overall electricity consumption within the home. Figure 39 gives a schematic visualization of the setup of the energy monitor and Figure 40 depicts the hardware of the energy monitor.

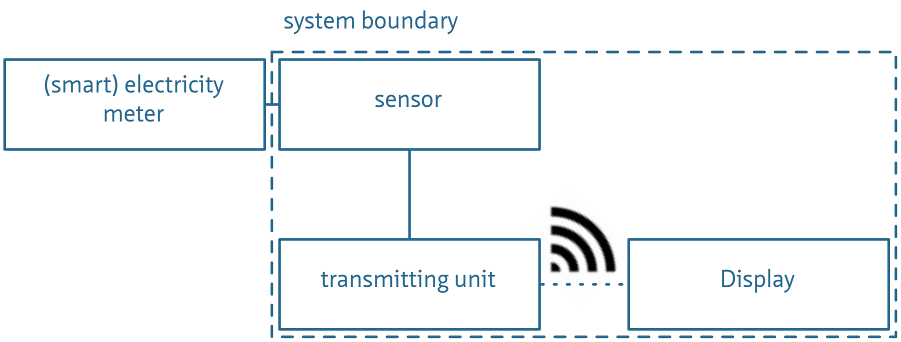


Figure 39
Schematic visualization of the setup of the energy monitor

Figure 40
The hardware of the energy monitor

The energy monitor consists of a sensor, a transmitting unit and a display. The sensor and transmitting unit are connected to the electricity meter and are powered by two AA batteries. The transmitting unit sends a radio signal to the display, which is plugged into a socket. The display contains (seven-segment) display components and a flashing green light. The display unit uses 1 W and the batteries in the transmitting unit last six to twelve months depending on the frequency with which the signal is transmitted. There is an accompanying website with a step-by-step plan and advice for saving energy.

§ 8.3.1.2 The multifunctional HEMS

The multifunctional HEMS gives historical, and in certain configurations real-time, feedback on overall gas and electricity consumption. The device – a touchscreen – doubles as a programmable thermostat and can also provide up-to-date weather and traffic information. Figure 41 gives a schematic visualization of the setup of the multifunctional HEMS and Figure 42 gives a portrayal of the hardware.

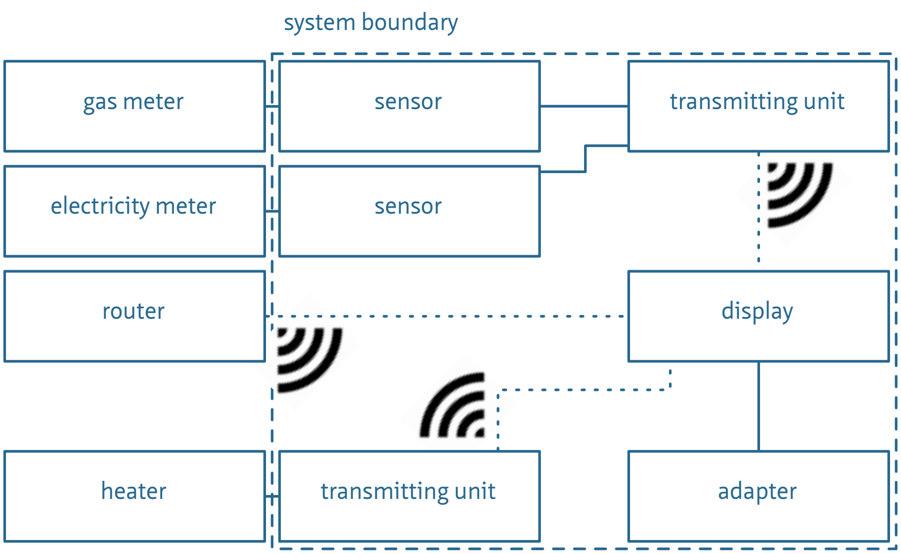


Figure 41
Schematic visualization of the setup of the multifunctional HEMS

1 2 3 4

Figure 42
Hardware of the old multifunctional HEMS (Picture 1: display and transmitting units, Picture 2: adapter display, Picture 3: sensor, Picture 4: repeater)

The system consists of an 8" LCD touchscreen, two sensors for, respectively, the gas and electricity meter, two transmitting units for, respectively, the meters and the heater (i.e. furnace for the central heating system), a switching adapter and, depending on the house, 0–3 repeaters (to increase the signal strength of the wireless communication between transmitting unit(s) and the display). Communication between the various parts happens by means of z-wave, but a wireless router also needs to be present in the home for two-way communications outside the home. An accompanying website is also present where more information on the energy bill and energy savings advice can be found. It is estimated by the manufacturer that the display and adapter use almost 38 kWh per year, equivalent to using the display 14 minutes per day. The two transmitting units and repeater were not included in this energy consumption calculation. Because working units were no longer present at the time this paper was written, the values were estimated on the basis of the idle load of four transformers (not switching adapters) of small household appliances that were tested by the author. These are similar to the type used in the units. The transformers used between 1.6 W and 2.2 W when idle, and on the basis thereof, the assumption was made that the two units and repeater use 2 W each continuously, or in total 53 kWh per year, which is probably a conservative estimate due to the 'no-load' measurement. This means that the total consumption of the multifunctional HEMS is 90 kWh per year.

In a later, improved version of this multifunctional HEMS, the energy consumption was optimized by replacing the transformers present in most units with switching adapters, reducing the size of the 8" display to a 7" display, wiring the display to the heater which strongly decreased the need for one or more repeater(s), and omitting the need for an additional Wi-Fi router (besides the one assumed to be present within the home). The new multifunctional HEMS is portrayed in Figure 43. The new configuration uses an average of 44 kWh per year under normal use of the display, as measured by the manufacturer. Switching adapters are currently becoming the norm in almost all appliances and therefore the new configuration is more comparable to the HEMS currently coming to the market. Based on what was known of the new configuration, the eco-costs and CED of the new multifunctional HEMS were calculated and presented next to the results of the old configuration.

Figure 43
Hardware of the new multifunctional HEMS

§ 8.3.1.3 The energy management device

The third HEMS – the energy management device – gives real-time and historical feedback on the electricity consumption of individual appliances. Figure 44 gives a schematic visualisation of the hardware of the energy management device depicted in Figure 45. The provided software can be used to manage whether and, if so, when the connected appliances consume electricity.

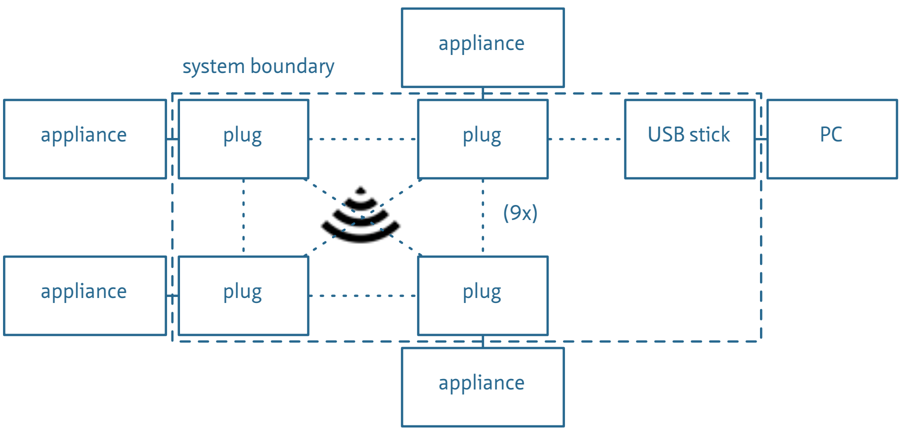


Figure 44
Schematic visualization of the setup of the energy management device.

Figure 45
Hardware and software of the energy management device.

The system consists of individual plugs in a Zigbee mesh network. The plugs of the appliances are inserted into the plugs of the energy management device, which are inserted into the wall sockets. One plug is wired to transmit the data from all plugs to a USB flash drive inserted in the participant's personal computer. For this study a set of nine plugs were sampled (only four are visualized in Figure 44). Together, they use 3.6 W when all connected appliances are switched off via the software and 9.9 W when all are 'on' according to the software. The manufacturer estimates that the nominal consumption is 43 kWh per year, equivalent to all connected appliances being switched off 19 hours a day. If the energy management device is only used to monitor consumption, without powering off appliances, it would use 87 kWh per year.

§ 8.3.2 Description of the savings scenarios

This section presents a calculation for the net energy savings. For the energy consumption of households, the rounded off Dutch averages of 3500 kWh and 1600 m^3 of gas (EnergieNed, 2008) were used, which equals 12,600 MJe plus 52,800 MJth of energy per year. An increase in electricity consumption of 1.5% per year was included. To estimate the electricity and gas prices, a number of Dutch energy comparison websites for consumers were consulted and an average distilled at €0.22/kWh and €0.65/m^3, including taxes. Rises in the price of energy were not taken into consideration.

Based on the literature, scenarios were developed for the potential savings. As the savings given in the literature vary for different studies (Darby, 2006, Abrahamse et al., 2005), it was decided to create six savings scenarios (Figure 46). The duration of use (i.e. the use phase) was set to five years, as it was assumed that this was within the technical lifespan of these HEMS.

§ 8.3.2.1 Level-savings scenarios

In five of these scenarios, respectively 2, 4, 6, 8 or 10% savings were hypothetically achieved, in comparison to the pre-intervention baseline consumption, by introducing a HEMS. These savings on baseline consumption were maintained in the following five years. So no fall-back or additional savings in the consecutive years were assumed. For reference, reducing the thermostat setting by 1 °C is can result in savings in gas consumption of 7% (Milieu Centraal, 2012) or even op to 12% (Tommerup et al., 2007). 10% savings in electricity is equivalent to replacing four or five 60W incandescent light bulbs with CFL bulbs, or reducing 62.5% or all of the standby consumption of appliances (Zimmermann et al., 2012, p. 395-397). So technically the mentioned savings scenarios are attainable for households.

§ 8.3.2.2 Fall-back scenario

In actuality, however, it is more likely that households will to a certain extent return to their old consumption patterns (van Houwelingen and van Raaij, 1989, van Dam et al., 2010). Therefore a 'fall-back' scenario was also developed in which for the first half year gas and electricity savings of 8% were achieved, and that in the consecutive year savings dropped to 4%, after which consumption increased to the original levels for half a year. In the remaining three years, the gas consumption remained constant at 0%, while the electricity use resumed to follow the national trend by increasing by 1.5% per year (EnergieNed, 2008).

§ 8.3.2.3 Type of energy

As all three HEMS gave feedback on electricity consumption, but only the multifunctional HEMS gave feedback on gas consumption, the hypothetical savings were calculated only for the type of energy households received feedback on. This was done because there is currently little evidence on which to base a calculation of a potential spill-over effect to other forms of energy consumption.

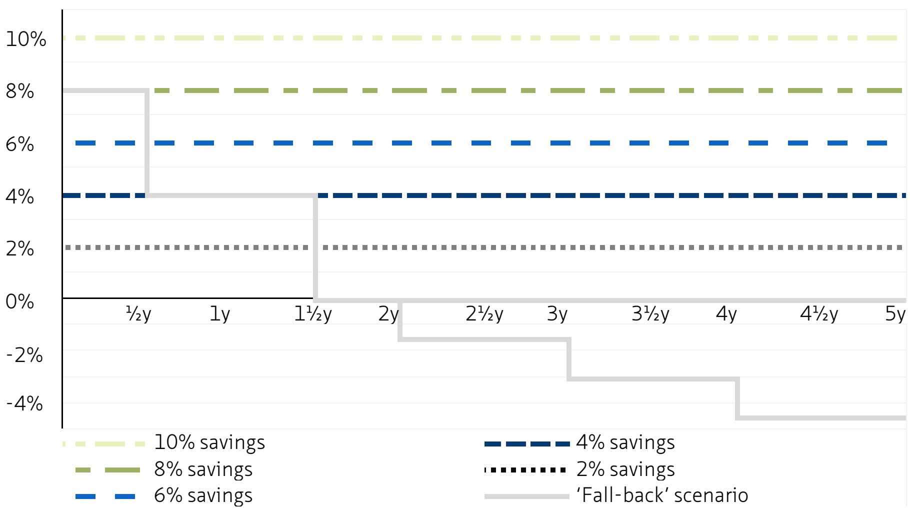


Figure 46
Six savings scenarios over a 5-year period in comparison to pre-intervention baseline consumption

§ 8.3.2.4 Specificalities concerning the scenario of the energy management device

For the energy management device, the situation is complex as the potential savings are achieved with a set of individual plugs. Energy consumption for a single appliance is a fraction of the total energy consumption of a home. Western household own between 28 and 65 appliances (IEA, 2009), with Dutch households owning an average of 51 appliances (excluding lighting), either working or defective (GfK Panel Service Benelux, 2007) and British households owning an average of 34 light sources and 41 appliances (Owen, 2012). Savings with a HEMS intended for one appliance would therefore make only a small dent in the total energy consumption of a home. However, disaggregated feedback is believed to be more effective than aggregated (Fischer, 2008), but currently more hardware is needed to deliver the feedback from a number of individual appliances.

These facts make the development of the savings scenarios more complicated. Extrapolating the savings to a percentage of the total electricity consumption is difficult because this is dependent on many variables. The energy consumption of individual appliances can vary widely and the possibilities to save are dependent on the type of appliance. The influence of an inhabitant's behaviour on the consumption of individual appliances can also vary strongly, due to the autonomous functioning of certain energy using products. The calculation would therefore become too hypothetical. As such, the savings scenarios were left the same as with the other two HEMS and were calculated on the basis of the overall electricity consumption. However, consideration should be given to these issues when viewing the results.

§ 8.3.3 Assessing the lifecycle using Ecoinvent

The Ecoinvent database (Ecoinvent, 2012) was used to calculate the eco-costs, cumulative energy demand (CED) and economic payback time for each HEMS. These two single indicators were chosen because the CED gives an accurate depiction of the energy invested versus the energy saved, which is the main objective of this article. However, the drawback of this indicator is that it focuses too singularly on energy, and such aspects as toxicity and disposal are not accurately depicted. Therefore, the eco-costs indicator was also chosen to assess the environmental burden.

All three HEMS were disassembled and weighed or measured. The printed circuit boards (PCBs) were weighed after removal of the connectors and copper transformers. The type of PCB was compared to the PCBs in Ecoinvent and the PCB that seemed most similar was selected, in this case the printed wiring board for a laptop mainboard.

§ 8.3.3.1 Specificalities concerning the multifunctional HEMS

Calculating the CED and eco-costs of the display of the multifunctional HEMS was more complex. Ecoinvent contains a standard 17" LCD display. One option was to use this value and scale it down to compensate for the smaller area of the 8" and 7" displays. An inspection of the background information on the 17" display in Ecoinvent revealed that the weight to size ratio of the 17" display was larger than those of the 8" and 7" displays. The 8" display was 22% of the area but only 9% of the weight of the 17" display, while the 7" display was 17% of the area but only 5% of the weight. This meant that a margin of error was present. The second option was to calculate the CED and eco-costs for the separate components of the display, in other words, the PCB, LCD subassembly, screws, and the plastic shell. This decreased the CED and eco-costs of the old multifunctional HEMS by 1% and 4%, respectively, and for the new multifunctional HEMS by 5% and 12%, respectively. Due to the margin of error that is always present in LCAs, the relatively small difference between the calculations, and the possibility that the value for the complete 17" display was more comprehensive than the separate components, the first option was chosen.

Furthermore, the repeater, meter sensors, and display adapter of the old multifunctional HEMS were not available for research and therefore the hardware of the new multifunctional HEMS was used instead and a couple of estimations were made based on other components. These missing parts were relatively small in comparison to the other parts and had a relatively low impact due to the limited amount of PCB's present.

§ 8.3.3.2 Assumptions

Finally, a number of assumptions were made. It was assumed that all PCBs were lead free. Additionally, it was assumed that all parts were produced in China and that assembly took place in Europe, since the effects of this transport on the CED and eco-costs was minimal. The lifespan of the battery used in the energy monitor was set to one year.

§ 8.4 Results

This section presents the results from the eco-cost and CED calculations. First the eco-costs and CED of the HEMS are presented (Table 11), after which the CED is used in the scenarios to calculate at which point in time the energy saved exceeds the energy invested.

§ 8.4.1 Eco-costs and CED of the HEMS

Table 11 shows that when calculating the CED over a 5-year period, the use phase is more energy intensive than the production phase. The disposal phase is by far the least important. However, the eco-cost indicator gives more weight to the production and disposal phase.

	Energy monitor	Multif. HEMS (old)	Multif. HEMS (new)	Energy management device
CED prod+disp	231 MJ	1535 MJ	1176 MJ	1285 MJ
CED use phase	534 MJ	5493 MJ	2676 MJ	2639 MJ
Total CED	765 MJ	7028 MJ	3852 MJ	3924 MJ
Eco-costs prod+disp	€4	€34	€26	€25
Eco-costs use phase	€5	€48	€23	€23
Total eco-costs	€9	€82	€49	€48

Table 11
CED and eco-cost calculations for production, use and disposal, calculated over 5 years

The results show that the overall impact is dependent on the type of HEMS. It also shows that the improvements to the multifunctional HEMS have a significant impact on the use phase as well as on the production and disposal phases. The eco-costs and CED are reduced by around 40–45%, with the reduction in energy consumption being the most significant contributor, followed by the size of the display.

§ 8.4.2 Net energy savings

Using the six scenarios from Figure 46, Table 12 shows the break-even point for each scenario and HEMS, respectively. The energy needed for production and disposal was used as negative starting point. Then for each consecutive half year, the CED was calculated based on the total electricity (and gas) consumed in the home (including the electricity needed to run the HEMS) with, dependent on the scenario, a subtraction for the energy saved through the use of the HEMS. This was then compared to the CED for 'business as usual', namely no HEMS was installed, no energy was saved and the electricity consumption followed the national trend. When the CED in the scenarios was less than 'business as usual', the net energy savings were considered positive and a '+' was noted. When the CED was more than 'business as usual', due to the energy needed for production use, or disposal of the HEMS, a '-' was noted.

	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%
0y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
½y	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	-	-	+	+
1y	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+
1½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+
2y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Energy monitor						Multifunctional HEMS (old)						Multifunctional HEMS (new)						Energy management device					

Table 12
Break-even point for the CED of the three HEMS calculated for the six scenarios

The results show that all HEMS break even within two years for all scenarios. The simplest HEMS, in this case the energy monitor, quickly reaches a break-even point even with small savings. These are positive outcomes.

Table 12, however, also shows that as soon as the HEMS is more technically complex, the duration of use is short and the achieved savings are small, the benefits do not always outweigh the environmental costs. The more elaborate HEMS (i.e. large displays, multiple plugs or components) take longer to attain a break-even point.

To visualize the potential amount of net energy savings that can be achieved, Figure 47 gives a graphic visualization of Table 12 with the inclusion of the old and the new version of the multifunctional HEMS and a variation in the consumption of the energy management device.

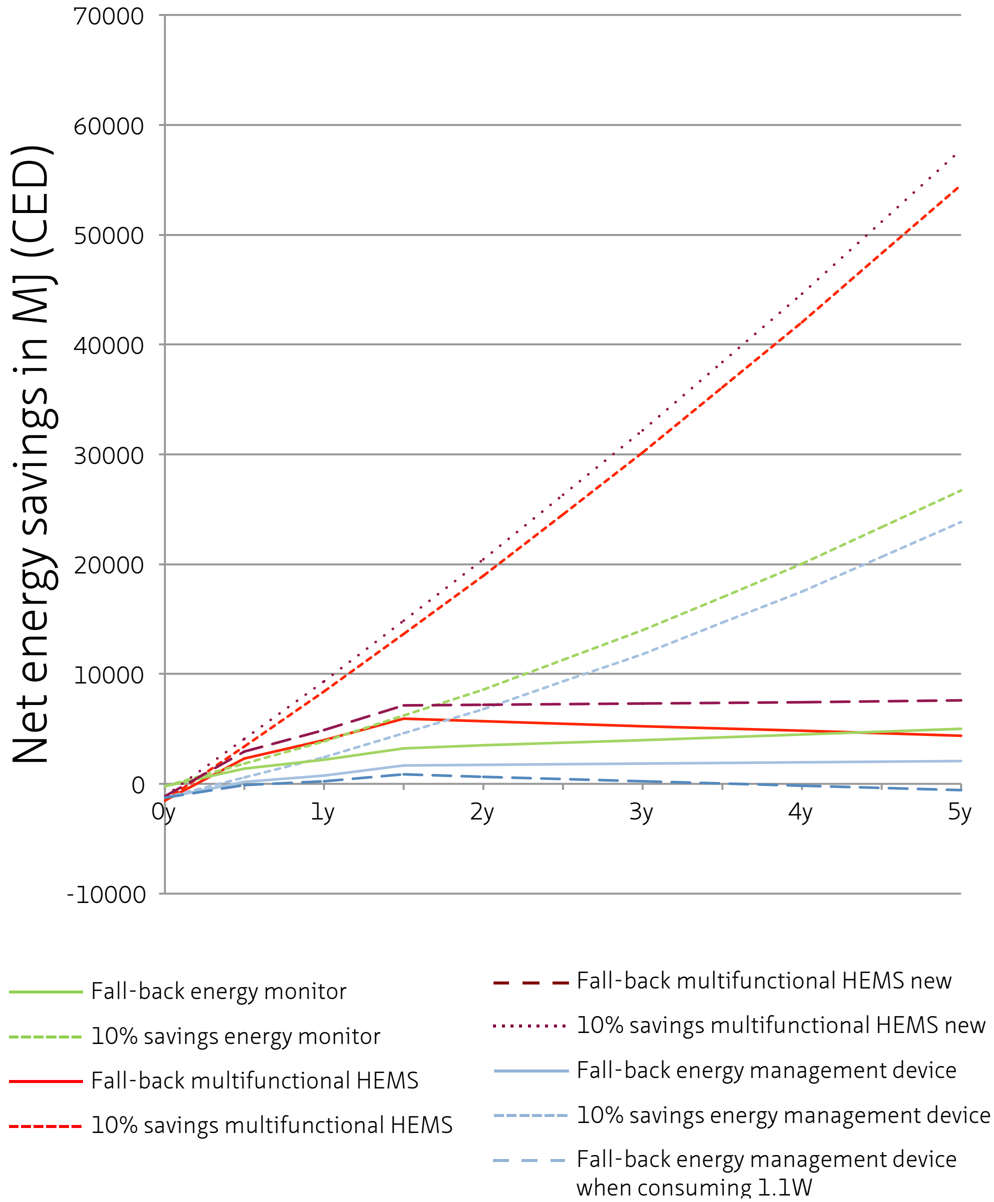


Figure 47

Net Energy savings in MJ for 3 (+1) HEMS for the 'fall-back' and 10% scenario over 5 years

Only two of the six scenarios are displayed for each of the three HEMS to visualize the difference: the best-case scenario with 10% savings and the fall-back scenario. On paper, the multifunctional HEMS (both the old and the new version) has the potential to achieve the greatest net energy savings in the 10% scenario because it targets both gas and electricity. The energy monitor and energy manager only target electricity and as such their potential is less than half. In comparison, the potential net energy savings in the fall-back scenario are marginal.

The flattening in the curves of the fall-back scenario is caused by the fall-back in savings and the electricity consumption of the HEMS themselves. A difference between the curve of the old and that of the new multifunctional HEMS can be seen. The curve of the new version flattens, while the curve of the old version bends and starts to head towards the horizontal line again due to the higher energy consumption of the HEMS itself. A similar but more extreme example of this can be seen with the energy management device, which highlights the significance of the energy used by the HEMS itself: Figure 47 displays an additional fall-back line for the energy management device in which each of the plugs consume 1.1 W continuously, that is, 87 kWh per year rather than 43 kWh. This is a real possibility in the case that households only use the HEMS to monitor the energy consumption of appliances, and do not switch them off via the software of the energy management device. Here, the line dips back under 0 after 3½ years, meaning that the energy management device no longer breaks even.

§ 8.4.3 Economic costs

The previous results focused on the environmental costs. This section briefly discusses the economic costs as visualized in Table 13.

	'Fall-back'	2%	4%	6%	8%	10%
Energy monitor	-€5	€81	€158	€235	€312	€389
Multifunctional HEMS	-€237	-€131	€50	€231	€412	€593
Multifunctional HEMS new	-€186	-€80	€101	€282	€463	€644
Energy management device	-€239	-€153	-€76	€1	€78	€155

Table 13
Economic profit in euros after 5 years for the 3 (+1) HEMS for the six scenarios

While Table 12 showed that there were environmental benefits for all HEMS within two years at the most, the economic benefits are not positive even after five years for a number of scenarios. Notably, no HEMS are profitable in the fall-back scenario, and only the energy monitor is profitable in the 2% scenario. The HEMS that is least likely to achieve a positive return on investment (ROI) is the energy management device, due to its high price tag and the fact that it only targets the electricity consumption of appliances. While a negative ROI might defeat the purpose for which households buy a HEMS, from an environmental perspective this is not necessarily a negative outcome: it can prevent a rebound effect whereby households invest the saved money in other energy-intensive products or services (Berkhout et al., 2000, Druckman et al., 2011).

§ 8.5 Discussion

A lifecycle assessment always contains a number of assumptions and as such there is always a relatively large margin of error. The comparison of the three HEMS was hindered because they are in effect three distinctly different products that have, from an LCA point of view, distinctly different components. Particularly the differences in PCBs and displays made them more difficult to compare, and possibly increased the margin of error.

There is a reasonable risk that the HEMS will become obsolete before their technical lifespan has been reached. The scenarios have the basic assumption that the HEMS are used by their owners for five years, or at least consume energy during that period. However, it is possible that at a given point in time, owners consciously or unconsciously discontinue the use of the HEMS, and that they then cut the power to the HEMS or let the battery die (Hargreaves et al., 2012). If households were to sustain their savings without receiving any more feedback, the lines in Figure 47 would be steeper. However, there are strong indications (van Houwelingen and van Raaij, 1989, van Dam et al., 2010) that a certain amount of fall-back will occur, resulting in a flattening or even negative bend of the lines.

It is not known whether a spill-over effect can be achieved where savings in a different type of direct or indirect energy consumption, other than the one that is targeted, can be achieved. There is little evidence available on spill-over effects, but it is possible that this will occur. In such a scenario, a HEMS can be more profitable.

The calculations in this article are based only on the physical HEMS itself within the system boundaries as shown in Figure 39, Figure 41 and Figure 44. However, there are two issues concerning these system boundaries that should be taken into consideration when viewing the results. First of all, the peripheral devices outside the system boundaries are essential for the functioning of the HEMS mentioned in this article and need to be present. The HEMS will not work without a meter or smart meter, a router or PC. These peripheral devices also have embedded energy and use electricity to function. While it can be argued that in some cases the energy would be consumed anyway, this will not hold true in all cases.

Second, it is now commonly advocated or, in certain countries, legislated to implement a smart meter and with it a HEMS (Darby, 2010). The calculations in this article exclude the LCA of a smart meter. For the discussion on net energy savings within the home and simply on the basis of the technical complexity of a smart meter in comparison to a HEMS, a strong note of warning should be given as to whether implementing smart meters is environmentally beneficial and will achieve savings. Many HEMS do not necessarily need a smart meter per se and can function with current 'dumb' meters.

However, there is another side to this coin. There is a wider discussion taking place concerning the implementation of smart metering, and savings within the home is but one of reasons for which smart meters are being advocated. Smart meters are often regarded as part of smart grid developments. Smart grids focus on peak shifting through, for example, dynamic pricing schemes. This process employs smart meters together with HEMS that provide real-time pricing, with the aim of giving consumers an incentive to reduce electricity use during high-priced peak periods. The calculations within this article were based on net energy savings within the home that can be achieved by means of a HEMS. In contrast, the environmental benefit of a smart grid is in the creation of more evenly distributed grid-loads. Research from 1987 implementing HEMS with pricing schemes showed that the overall consumption is not reduced, but shifts to periods with cheaper electricity (Sexton et al., 1987), implying that smart grid systems mainly lead to different energy-usage behaviour (and not necessarily to energy conservation). This makes the calculations of the environmental benefits far more complex and outside the scope of this article.

§ 8.6 Conclusion

All three HEMS can theoretically achieve net energy savings and a positive ROI within their technical lifespans. However, particularly for the energy management device, substantial energy reductions need to be achieved before the HEMS becomes economically (and environmentally) viable. The chances that net savings will actually be achieved are dependent on a number of factors into which there is currently too little insight. It is unclear how many of these HEMS will still be in use after five years. It is also unknown how the savings of households will progress in the course of five years, as so far this has not been documented in research. Savings over such a period are difficult to calculate and to trace back to a particular intervention. In future research reported savings by means of a HEMS should be rectified to account for the embedded energy in the HEMS itself and the resources needed to produce a HEMS.

The reservations that were voiced in § 8.2 concerning whether more complex HEMS would have a positive impact, were not confirmed. The more complex HEMS also have positive environmental results after five years. However, the results from the multifunctional HEMS and energy management device still show that care should be taken not to develop HEMS that have unnecessarily elaborate parts or functionalities and that their own electricity consumption is minimized. Design strategies towards reducing the amount and size of parts and the HEMS' energy consumption have positive effects on the CED and eco-costs

There are a number of conclusions that can be drawn for the individual HEMS based on the schematic visualization of the three HEMS and the results in Figure 39 - Figure 47 and Table 11 - Table 13. These are:

- The energy monitor is technically the simplest HEMS and is dependent on the least number of peripheral devices. Figure 47 shows that the potential net energy savings that can be achieved are relatively high. However, the potential to use persuasive technology (Fogg, 2003) or other behaviour change strategies, for example those suggested Lockton (2009) or Nolan et al. (2008), is limited due to the type of display. Therefore, while the small display is positive for the CED, it could limit the actual potential to achieve net energy savings through behaviour change.
- The results in Table 11 for the old and new version of the multifunctional HEMS show that reducing the number and size of parts and the device's energy consumption has effects on the CED and eco-costs, which were reduced by 40-45%. This HEMS has the most potential on paper for net energy savings due to the inclusion of gas consumption. Gas (39%), in particular for heating (comprising 73% of gas consumption, (Milieu Centraal, 2008)), is a larger energy source than electricity (25%) for households in Europe (European Environment Agency, 2012), with similar tendencies in other countries that also have colder climates, yet few

HEMS bring this across. However, it is unknown whether the multifunctional HEMS also has the most potential to effectuate behaviour change and thereby create actual savings. This is likely to be dependent on the visualization of the feedback on the display and the use of persuasive strategies.

- A number of paths could be taken to increase the positive net energy savings of the energy management device. It is a modular system and can be extended at will. Therefore, one option could be to only implement plugs on 'high potential' appliances, namely those with high energy consumption and large feasible savings, such as the pump for under-floor heating and close-in boilers. Another option would be to use a different marketing model, for example by leasing or renting them to households for a short period, after which this can be repeated with a next household. This option could harness the effectiveness of disaggregated feedback (Fischer, 2008) without the drawback of the extended energy consumption during the use phase. However, a more innovative approach would be the use of electromagnetic interference for disaggregation algorithms or non-intrusive load monitoring. This gives the benefit of disaggregated feedback without the need for extra hardware due to the plugs (Gupta et al., 2010, Zoha et al., 2012), though it does not have the benefit of a control mechanism. A final option would be to combine a very modest number of plugs from the energy management device with an energy monitor. This could be used for the incidental testing of the consumption of different devices and then for the permanent management of the 'high potential' appliances while keeping tabs on the overall consumption.

Finally, in the light of the uncertain long-term effects of HEMS it can be argued that these devices should not be developed as stand-alone, dedicated products, but should be integrated into existing products. However, care should be taken that the simplicity and accessibility (Fogg, 2009) of the feedback is maintained. This is an important yet controversial issue. Integrating a HEMS into an app, TV page or thermostat can arguably contribute to its functionalities being snowed under or forgotten amongst the rest of the functionalities or apps. In conclusion, it is important to weigh the different issues and find a balance that does justice to the odds that are at stake.

§ 8.6.1 Acknowledgments

We extend our sincere thanks to Joost Vögtlander and the companies involved for the data (and hardware) they provided and their input regarding the calculations.

Overall conclusion Chapter 8 and moving on to Chapter 9

This chapter has reflected on the overall effectiveness of HEMS, revealing both their potential as well as their shortcomings in reducing the direct energy consumption of households. It has shown that HEMS do indeed have the potential to achieve net energy savings in households, but that their effectiveness is constrained. Attention needs to be given to the energy consumption of HEMS, their embedded energy, their design, and their potential to influence behaviour and the energy consumption of households. The next chapter will also give a reflection. It will reflect on the process of implementing HEMS in existing houses and conducting research with them.

9 Reflections on implementing HEMS in existing houses and conducting research with HEMS

This chapter focuses on the contextual factors that influence the use and effectiveness of HEMS and impede the implementation of HEMS, and addresses lessons that can be learned for the benefit of researchers and the HEMS industry. Conducting field studies with HEMS and implementing them in existing houses can be a strenuous and drawn-out affair. Most articles on case studies with HEMS tend to focus on the results achieved on energy consumption, and will perhaps in the discussion mention some noteworthy fact, shortcoming or pitfall in the setup or execution of the case study and the implementation of HEMS. However, much can be learned from the story behind the energy savings results of HEMS, as contextual factors can influence the use and effectiveness of HEMS. This chapter presents these findings. It also provides insights into reducing the energy consumption of households, implementing HEMS or executing field studies with them that will be of use to such practitioners as HEMS designers, energy providers, HEMS installers and housing industry and housing associations.

§ 9.1 Introduction

The setup of case studies, the manner, implementation and installation of HEMS, and the potential challenges that occur during this process can strongly influence whether a HEMS can be used successfully. If a HEMS cannot be used successfully, this can negatively influence its effectiveness. Therefore, the goal of achieving savings and the ability to measure these savings can be jeopardized. If these boundary conditions and contextual factors are poor or lacking, the system as a whole fails. This chapter looks more at these contextual factors in more depth.

The framework of Wever et al., (2008) was introduced in Chapter 2 to visualize the factors that influence the use and effectiveness of HEMS. It is presented again in Figure 48. In this framework, 'context' forms the perimeter around household energy consumption and the use of HEMS therein. The previous chapters of this thesis focused on the internal aspects of the framework: the HEMS, the users, the relation to other household members and appliances, and the influences these aspects can have on the use and effectiveness of HEMS, with the context of use mainly discussed as a sideline. This chapter looks in more detail at the perimeter of this framework and the effects this context can have.

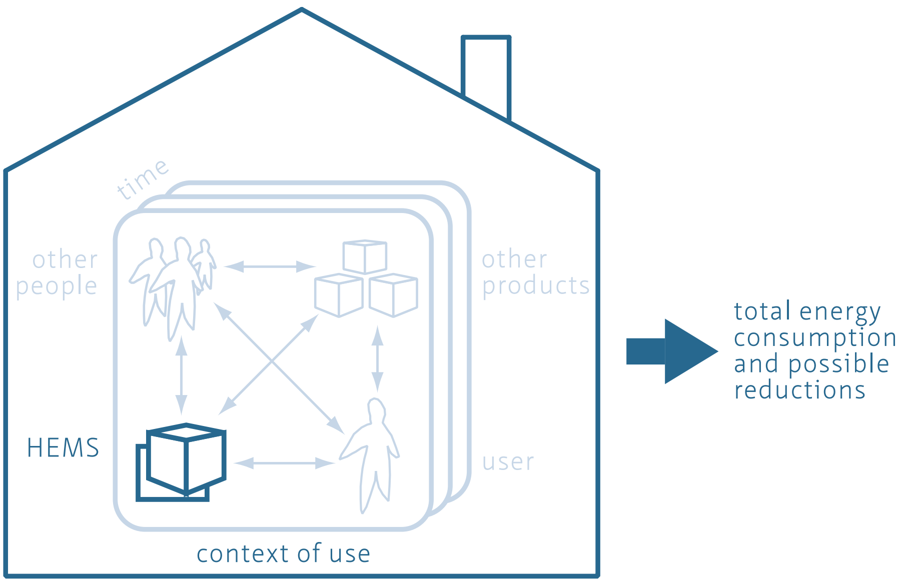


Figure 48
Aspects of the framework discussed in Chapter 9. Adapted from Wever et al. (2008) and van Kuijk (2010)

For the purposes of this thesis, the context is defined as the architecture of the house, the energy structures embedded within it and the technical prerequisites. In essence, this chapter deals with the technical, physical and structural barriers and challenges that impede the implementation of HEMS and their ability to achieve savings. As van Vliet et al. (2005) and Shove (2005, 2010) explain, our consumption patterns are configured by the infrastructure and architecture of the house surround us. Shove (ibid., p. 1278) writes: "*Critically, certain forms of demand are unavoidably inscribed, for example, in the design and operation of electricity and water infrastructures and in the architecture of the home itself.*" The context influences the habits and energy patterns of households and, as such, tie into the potential success of HEMS, as is discussed in this chapter.

§ 9.2 Objective

This chapter has three goals. The first is to explore the direct and indirect effects that contextual factors surrounding the implementation of HEMS in existing housing, can have on the use and effectiveness of HEMS, and on the outcome and results of case studies on HEMS. This addresses the specific contextual factors arising from the third research question: "What factors might influence the use and effectiveness of HEMS?"

The second goal is to assess what lessons can be learned for the benefit of the built environment and the HEMS industry from these contextual factors and the influence they can have on the effectiveness of HEMS. The third goal is to assess what lessons can be learned for the future setup and execution of case studies on HEMS. These two goals are addressed by answering the fifth research question: "What can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing houses?" To do answer this question, the setbacks that occurred in the case studies in which the author directly and indirectly participated were analysed. This chapter is by no means intended to deter research on HEMS or the implementation of HEMS. However, it does aim to give a realistic picture of the complexities involved and to make better preparations and thereby more successful implementations possible.

§ 9.3 Method

The insights in this chapter were gathered in a number of ways. The foremost source of knowledge was the personal experience of the author in conducting research with HEMS. During the course of my PhD research, various commercial parties instigated trials with HEMS and gave me the opportunity to participate in them. However, a number of the HEMS trials were delayed, cancelled, discontinued or had severe setbacks, and thus could not be used in this research. In the end, the results from three case studies were implemented in this thesis. Communications concerning the issues that arose during the setup and, when followed through, the execution of the various initiatives were recorded throughout this process. A personal and informal log was also kept, in particular of one case study. The communications and log form the basis of this chapter. Due to the sensitivity of the information, mention of the specificities of the HEMS trials and the companies involved in them is avoided in this thesis, and no sensitive details are revealed. Furthermore, representatives of the HEMS industry and other researchers were consulted to verify and expand the mentioned issues. To further validate the issues, they were addressed in two special sessions with both commercial parties and researchers (Appendix A VII).

The insights are addressed from the viewpoints of the different stakeholders involved: households, the HEMS industry, HEMS implementers, the construction industry and HEMS researchers. As a setup for the following chapter, first the implementation in existing houses is discussed, along with the obstacles to such implementation. Then the specific challenges of conducting research with HEMS are highlighted. Tying in with this, ethical and privacy issues are discussed. In closing, the conclusions for housing and the construction and installation industry, the HEMS industry and HEMS designers, and HEMS researchers are individually addressed.

§ 9.4 Implementing HEMS in existing houses: the challenges

A HEMS is an intermediary product. As such, it cannot function on its own. It needs to be connected to a meter/smart meter or other appliances for the transmission of information. It also needs to function within the structure of a house. As these aspects can impede the successful implementation of HEMS, they are addressed in the following section. Figure 49 presents a visualization of the contextual factors addressed. Using a top-down approach, first the issues tying in with the location of the house and the structure of the house are addressed along with the peripheral devices. Next, the location of the meter and of the HEMS are discussed. Finally, the meters and the communication with different types of HEMS are elaborated upon in more detail using the flowchart in Figure 51 on page 239. While much can be said about the design of the HEMS, the aim of this section is to highlight only those aspects that are relevant to their implementation in existing housing. Those aspects related to the core of Figure 48 – such as the design of the interface, and the interactions with the user and other household members – were discussed in Chapter 7.

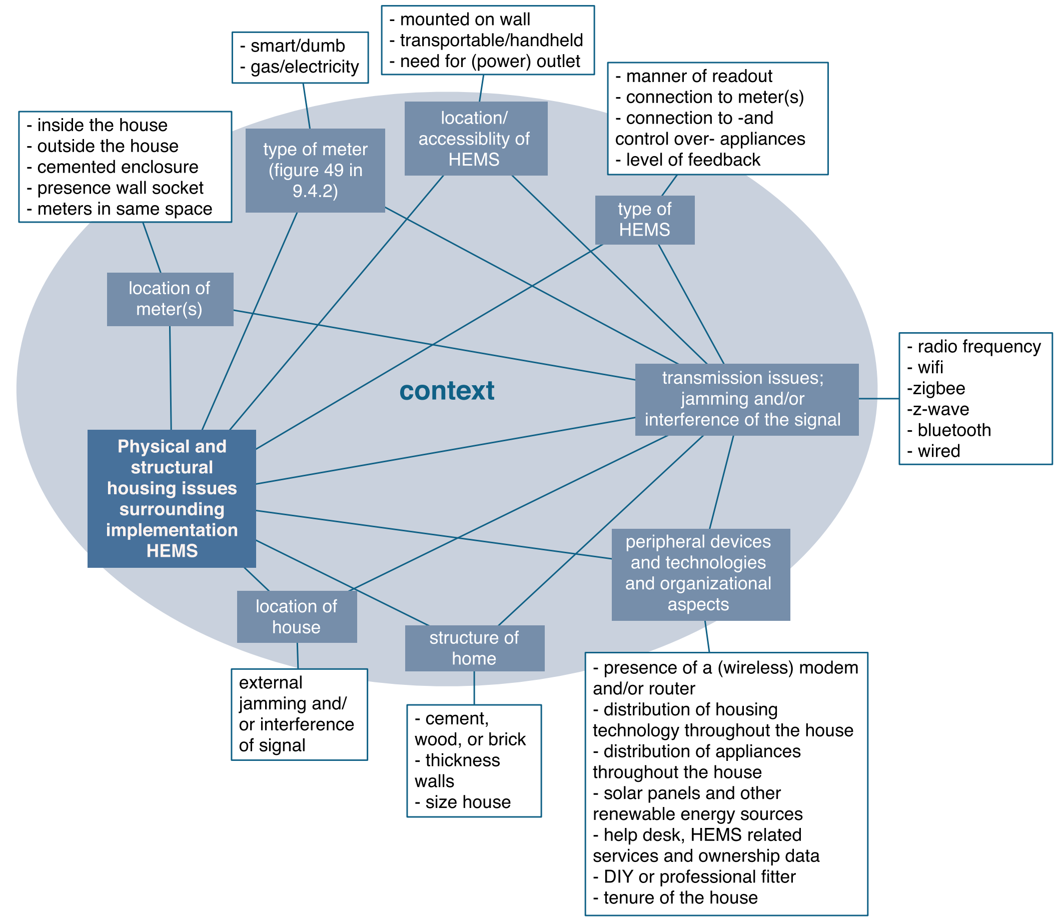


Figure 49
Contextual factors influencing the use and effectiveness of HEMS and their implementation in existing housing

Before using the top-down approach to assess the influence of the various physical and structural aspects, the transmission of energy consumption data is briefly explained. In Figure 49, the textbox 'transmission issues' is linked to all the other textboxes. This is because all the physical and structural elements influence or tie in with this issue in one way or another. Most HEMS relay some kind of energy consumption information to household members in one form or another. This data has to be transported to the HEMS. To minimize the amount of retrofitting that is necessary to install the HEMS in existing houses, the preference is often given to transmitting the data via wireless networks rather than cables or wiring. Radio frequencies, Wi-Fi networks, Zigbees or z-waves are commonly used. Although western society is awash with this type of technology and it surrounds us everywhere, there are numerous problems that can occur and impede the transmission of the data. Therefore, the contribution of the various physical and structural elements to the transmission of the data is addressed in the following section, starting at the top of the hierarchy with the location and structure of existing housing.

§ 9.4.1 Location and Structure of existing housing and its housing technology in relation to HEMS

§ 9.4.1.1 Location of existing housing

Starting at the highest level, the spatial positioning of a house can influence the feasibility of implementing a HEMS. An obvious, and these days a usually uncomplicated prerequisite for several types of HEMS is access to the Internet. In most urban areas, this is not a problem. It does, however, mean that a wireless router needs to be present within the house. Besides this, there are installations outside the house that can intentionally or unintentionally hinder the transmission of HEMS data in the house. In most cases this is unintentional, but finding the cause can be difficult. One HEMS company found that twelve households in one neighbourhood were experiencing interference. The cause turned out to be the x-ray machine of a local dentist. Gauging transmission problems and making the right assessments and connections can be both energy- and time-intensive. Realizing that a car alarm interferes with the Wi-Fi network only when the car is parked in the driveway, and not in the garage, as happened in one case, illustrates this.

§ 9.4.1.2 Structure of the home

While participants in the think-tank indicated that interferences from outside the house is perhaps not likely to occur, the physical architecture and structure of the house can pose more common challenges. 'Existing housing' is a very general term for an array of different housing types, structures and sizes. The type of building material – for example, reinforced concrete, wood or brick – can influence how far the signal can carry. Enclosing the meters in a reinforced concrete structure is a common hindrance (though the wall thickness only needs to be 18 mm in the Netherlands according to the norm (NEN 2768)), and thick, reinforced walls or large houses can be an additional challenge.

§ 9.4.1.3 Housing technology

The structure of the home is of particularly significance when the housing technology or appliances that the HEMS needs to be in connection with are spread throughout the house. An example is having the converter of the solar panels or the heater for the central heating system in the attic, while the meters are in the hallway on the ground floor and the HEMS is in the living room. This can make the transmission of data particularly challenging.

§ 9.4.1.4 The influence of the structure on the transmission of data to the HEMS

HEMS designers try to circumvent these transmission problems in different ways. Some HEMS implement repeaters to amplify the signal. While this workaround solves the transmission issues for some households, having to ensure that the signal is strong enough increases the average installation time.

HEMS that give feedback at appliance level commonly use a Zigbee or z-wave mesh network. Mesh networks are intended to be less dependent on one device emitting the signal. However, in some instances, households have to position plugs strategically throughout the house for the plugs to be in communication with each other. This is not always easy to achieve, because an appliance or socket is not always present at a necessary location and/or the energy consumption of an appliance in a certain location is not interesting to householders. Even then, HEMS users found that the signal from the plugs attached to certain appliances cannot always be found even though the appliances were well within the stated range. A relatively new approach in the design of HEMS that prevents the need for a mesh network of plugs uses disaggregation algorithms and probability theory to distil the electricity consumption of individual appliances from the overall electricity consumption as registered by the digital meter/ smart meter or a single point sensor (Gupta et al., 2010, Greeniant, 2013).

§ 9.4.1.5 Organisational aspects

An area that emerged from the think-tank is that a number of organizational aspects may influence the use and effectiveness of HEMS, though they may not all fit completely into the context as defined by this thesis. Whether the house is rented or bought, can influence household's willingness but also ability to implement changes necessary for the installment of the HEMS. Furthermore, the presence of services such as informational websites and a helpdesk can influence households ability and success and installing the HEMS and achieving savings. Likewise, whether the installation is DIY or executed by a certified fitter, may also influence the successful installation.

§ 9.4.1.6 Renewable energy technology

Renewable energy is another housing technology that is an obstacle to the implementation of HEMS. An increasing number of households are installing solar panels or other forms of renewable energy. HEMS often cannot deal well with the production of energy, partly because production is not always registered as a separate entity, for example in the case of solar boilers and heat pumps. There are sometimes no straightforward solutions for measuring production, like with solar boilers, but at other times there are possibilities. The second important reason why HEMS cannot deal well with production is due to the way in which the meters keep track of energy consumption and production.

The issues HEMS have with renewable energy are briefly exemplified for the case of solar panels, the most commonly implemented renewable energy source. Part of the problem is that keeping track of production and reading this data out (from e.g. the converter) is not always considered during the installation of solar panels. Another part of the problem is that a HEMS usually requires an additional sensor either on the meter itself or on the converter or the wiring to it. Most HEMS do not have an additional sensor to keep track of consumption through the meter. Even when production can be measured, this does not guarantee that the HEMS is able to 'read' this, or that the software is designed to visualize production alongside consumption. In Section § 9.4.2, the challenges with meters in general are discussed, and the issues different electricity meters have with renewables are visualized in Figure 51. It is likely that renewable energy will become more important in the future. In fact, some households in the case studies indicated that solar panels were the reason to start to keep track of energy consumption.

§ 9.4.1.7 Locations of (smart) meter(s)

The location of the meter was touched upon in the previous sections. This section highlights a number of additional considerations concerning the location of meters. The majority of HEMS rely on the presence of a meter that keeps track of how much gas and/or electricity is consumed. Most houses have one or more meters, although their location and presence differs per country and per house type.

The application of HEMS in households is in part a result of both the location of meters and the manner in which they give information. A meter theoretically already gives feedback: it displays the historical consumption of households, usually by means of digital 7-segment displays, dials or mechanical counters. However, most meters are not designed to display real-time energy consumption. Real-time feedback can only be derived from, for example, the frequency with which the infrared light flashes or the disk rotates. In Italy, smart meters do display current and historical energy consumption, but a button needs to be pressed as many as 16 times to reveal this information (Kerrigan et al., 2011), which is neither insightful nor intuitive.

Additionally, in existing housing meters are often positioned where they are hard to reach and they display information that is often not specifically designed to be understood by the average householder. Meters can be located outside the house, on the perimeter of the property or on the façade, in a cupboard next to the front door, or in the basement, where the display is far below or far above eye-level (Kerrigan et al., 2011). In the Netherlands, most meters are located inside the house (Figure 50); in newly built houses, the meters must be within three metres of the front door (NEN 2768). However, the considerations of household members usually do not seem to be at the top of the priority list regarding the location of meters, as the following example from the GWL water company in Amsterdam illustrates. *"Apart from the inappropriate (from a consumer's point of view) language, in which water consumption is expressed, accessibility is also a problem for consumers. The traditional place for water meters in Dutch homes, for example, is under the floor just inside the front door. In most cases it takes some effort just to have a look at the meter, let alone to do this regularly. Even the new water metering project in Amsterdam [during which meters were installed for the first time at the request of customers] aims to install meters at the most appropriate place in terms of costs and existing infrastructure, which in many cases will be an inconvenient spot for regular household meter reading (GWL interview, 1999)."* (Chappells et al., 2000).

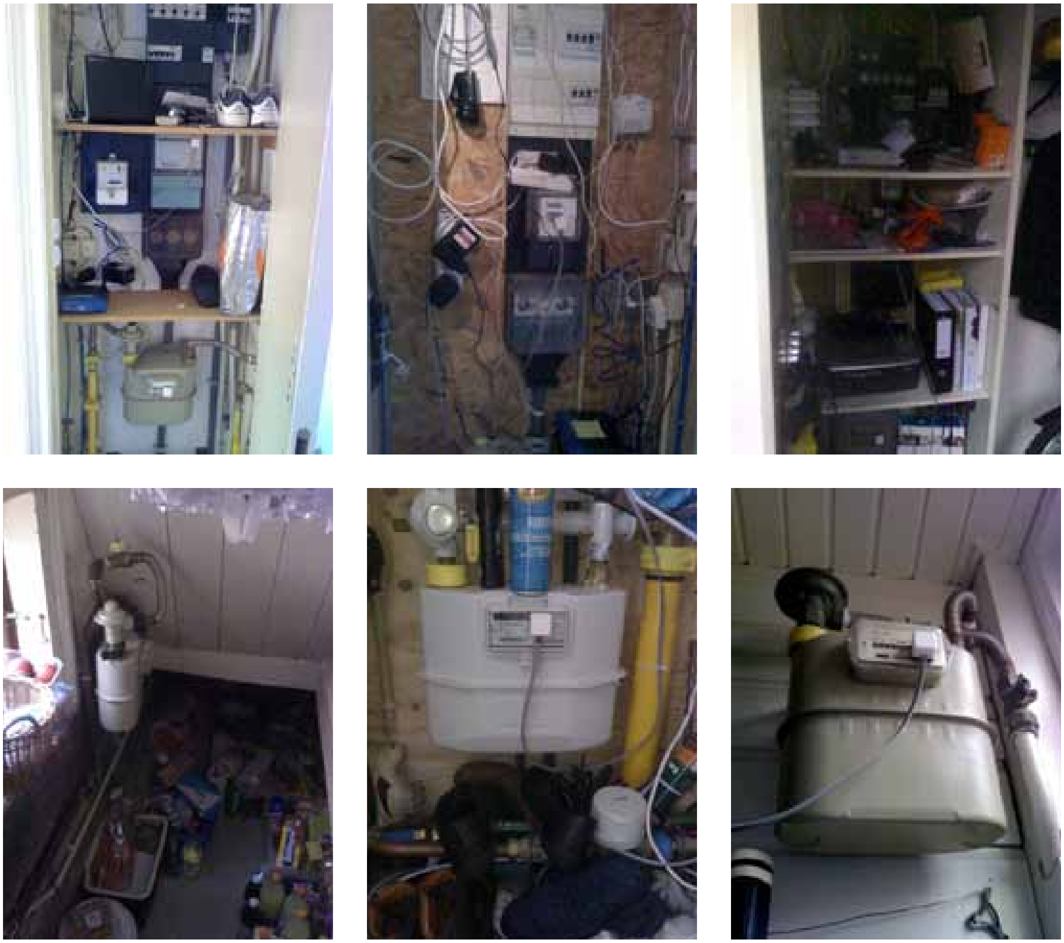


Figure 50
location of meters

While HEMS have been introduced to solve these issues and provide understandable and accessible information, the location of the meter can still hinder this aim for a number of reasons. As mentioned, a cement structure can obstruct the transmission of data; in addition, placement outside the house can mean that the signal is out of range. Not having gas and electricity meters in the same physical location can also complicate matters. Additionally, a very important prerequisite is the presence of a socket near the meters to power the HEMS. This is a legal requirement for new housing, but is usually not the case in existing housing. New smart meters have an integrated power supply which can solve the issue. A battery operated transmission unit is another alternative, but the drawback is that the battery has to be replaced every so often, with the risk that when the battery dies, it is not replaced. These small details can increase the complexity of implementing HEMS to the extent that it can be unsuccessful.

§ 9.4.1.8 Location of HEMS

Even though HEMS are intended to resolve the issue of accessibility, in some cases the location and the accessibility of the HEMS itself are also an issue. The location where the feedback is given within the house is an essential component in the success or failure of achieving energy reduction. Certain HEMS require a power supply from the mains or input from a heater or other device. If a socket is needed for energy supply, then the location of the HEMS is dependent on the presence of a socket. A socket cannot be easily adapted and some householders have a strong distaste for extension cords because they find them visually unappealing. Sockets are a particular problem for HEMS that give feedback at appliance level, because the appliances have to be plugged into the HEMS. This can be problematic in the case of, for example, built-in kitchen appliances, where the plugs and sockets can be inaccessible. With certain HEMS, for example those integrated with a thermostat, additional necessary wiring can limit the location. In existing housing with central heating, wiring to the heater is usually already present, limiting the location of the HEMS to the outlet of the wiring in the wall.

In both cases, it is not only the house but also the physical design of HEMS that can aid or hinder the accessibility of the feedback. A fixed HEMS that is mounted on a wall can hinder certain uses because it might not be in proximity to the gas or electricity consuming activity of the user. One participant of a usability study conducted by the author indicated that he did not intend to walk up and down a flight of stairs just to check how the electricity consumption changed when someone turned on the washing machine. Another said that she liked the 'speedo' on the display but wondered how useful it would be, because it was fixed in place at a location that was useful to the thermostat functionality but not particularly handy when it came to using the feedback functionality. She even called it useless because of this, saying *"If you're busy in the kitchen, you can't see it."* It is therefore advisable to weigh the various interests.

A HEMS is intended to be visibly on display in a house. Yet it is also subject to people's personal taste. A couple of test users wanted to cover it up or hide it in a cupboard. In one case study, half the users had a large display. Two of the ten users that were visited by the author had placed their display on the floor behind the couch, and two others had it in the study. Some, however, were proud of the display and liked to show it off to visitors.

§ 9.4.2 Type of meters and HEMS and the transmission of feedback to the HEMS

This section goes one step further and discusses energy meters and the manner of transmission of data to the HEMS. Meters are an essential component in the quest to give households feedback. A majority of HEMS need a meter to give households feedback and/or an overview of their overall energy consumption. Only a limited number of HEMS exclusively give feedback at appliance level. Because meters are such an essential component and much goes wrong in practice with their readout, they are discussed in detail. The type of meter and the way in which the consumption data is transmitted can influence the possibility to receive feedback and the way in which users can or want to use the feedback.

There are four main issues: the frequency or intervals with which cumulative (e.g. in kWh or m^3) feedback is given, whether real-time feedback (e.g. in watts) can be given, the possible delays in transmission, and the accuracy of the [feedback on amount of energy currently being consumed by the household. There are a number of reasons why these issues can cause problems or lead to confusion. As they are closely intertwined with the type of meter the HEMS transmits the data from, each issue is discussed according to the type of meter involved. Figure 51 provides a schematic overview of the types of meters and the issues that can occur with them.

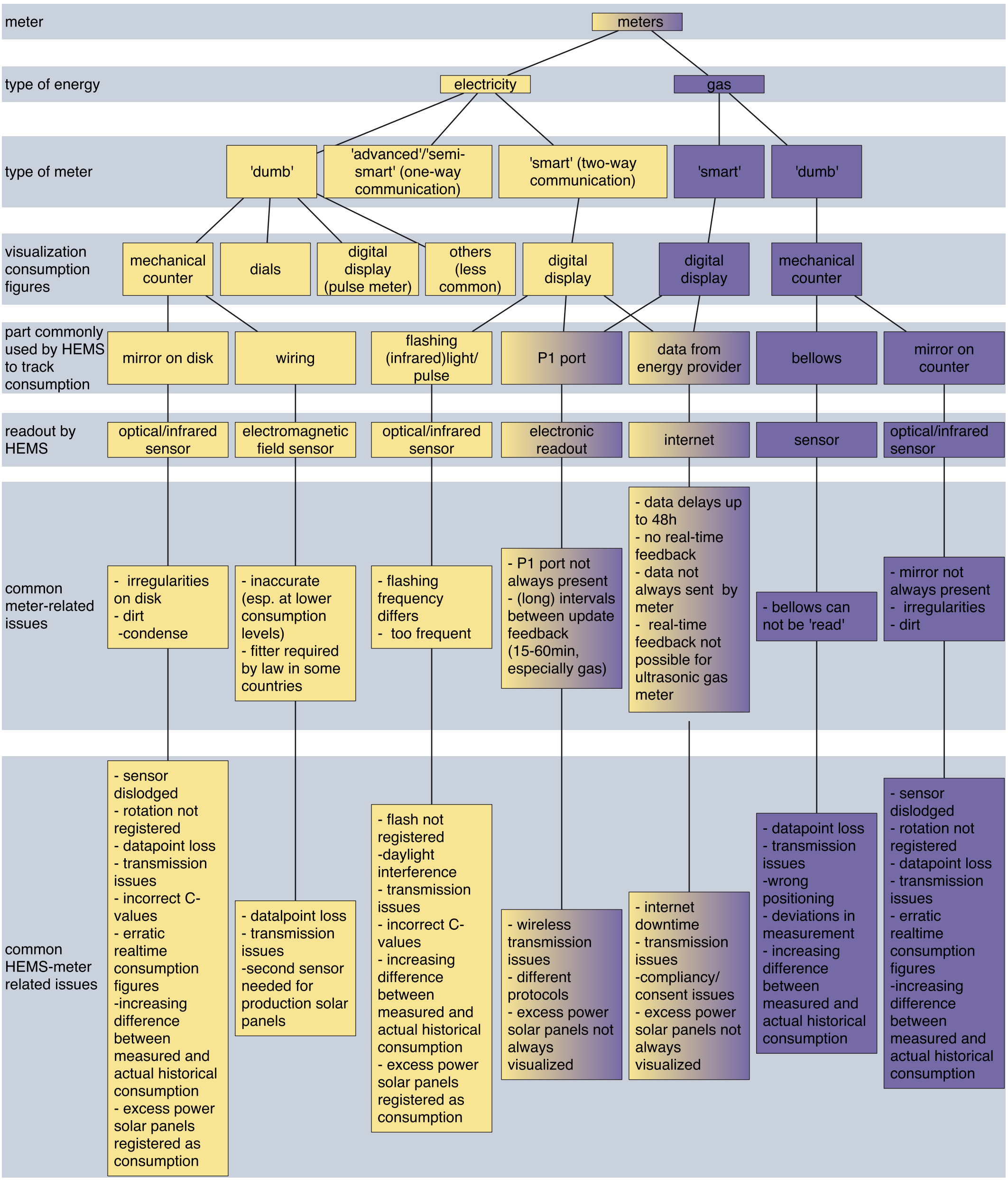


Figure 51

Types of meters and common issues that occurred with the readout by HEMS

Figure 51 goes a step further than Figure 49 by focussing on the textbox 'type of meter'. Meters are seen as a housing technology and, as such, are part of the context in which HEMS are implemented, as shown in Figure 49. Figure 51 presents a schematic overview of the different types of meters, the way in which they display the energy consumption they keep track of, which part of the meter HEMS usually use to read out how much energy is being consumed or has been consumed, the meter-dependent issues that commonly occur with the different types of meters that hinder their readout, and the issues that occur due to the interplay between the meter and the HEMS. It is not a comprehensive overview, but does present the most common types of meters and the ways in which HEMS track the data from these meters. In doing so, it shows the complexity of designing a HEMS that will work with all the meters installed in existing houses. Each type of meter is discussed in the following section, starting with smart meters.

§ 9.4.2.1 Smart electricity meters

The first problem to be discussed is that of the frequency with which feedback is given. Here, a distinction needs to be made between HEMS operating with advanced, semi-smart or smart meters, and those operating with traditional 'dumb' meters. As (Darby, 2012) explains, 'advanced' or 'semi-smart' meters can only transmit information (e.g. to an authorized party outside the property), while smart meters are equipped for two-way communication (both transmitting and receiving).

HEMS that work together with these smart/smarter meters can give very accurate energy consumption data, although this is sometimes rounded off to whole units. However, the possibilities as to the frequency of transmission and whether real-time the data is available depend on the type of smart meter and, to a certain extent, the type of HEMS. Certain smart meters are designed to only relay information to an authorized party outside the property, who can then relay the information back to the customer. In the USA, this is usually referred to as automated meter reading (AMR). In the Netherlands, this was the (cheaper) type of smart meter commonly installed up until 2011. The transmission of data to the external party happens at fixed intervals, usually daily, but newer meters transmit more frequently, usually every 15 minutes but sometimes as often as every 10 seconds. The protocol of these older smart meters prevents the automated local readout of the data, although certain HEMS can circumvent this. The workaround is to read the meter with a sensor in the same manner as a 'dumb' meter. Other smart meters with different (P1, Dutch) protocols can be read out locally by a HEMS (KEMA Consulting, 2008, see Appendix A VI). Depending on the frequency with which the data are transmitted, they can give cumulative and possibly also real-time feedback. When the meter only transmits (cumulative) data at quarterly or hourly intervals, this is, strictly speaking, not 'real-time' feedback.

Infrequent feedback on cumulative consumption, be it at quarterly, hourly, daily or monthly intervals, has the drawback that it is harder to track energy consumption back to a particular appliance (Kidd and Williams, 2008). In one case study, data from older smart gas meters and older smart electricity meters were transmitted to an external party once a day for processing, and there was a delay of 48 hours before the customers received the feedback. As a result, they did not receive real-time feedback but a cumulative total of the day before yesterday, and then only changes in whole cubic metres or kilowatt-hours. The problem with this is that people have to try to remember what was using power, which can be difficult enough after 15 minutes, let alone two days. Additionally, changes in whole cubic metres or kilowatt-hours can be too inaccurate to guide users, particularly regarding gas usage in the summer. As a result, it can be difficult to verify whether an attempted behaviour change has had an effect. Adding to these issues was the fact that the smart meter failed to transmit data every day, leading to no feedback for one or more days, followed by a cumulated peak of two or more days' worth of energy.

When installing smart meters, the interests of the households involved, particularly concerning the type of feedback they can receive, are not always considered enough. Additionally, current protocols for smart meters are still under development and are commonly regulated on a national level, with little international cooperation. In future, attention for universal standards and the interests of the consumer should be given more priority. Sometimes, the more classical system using 'dumb' meters is currently more effective at providing certain types of feedback and thus more useful for households although there can also be issues with these meters, as the following section illustrates.

§ 9.4.2.2 'Dumb' meters

The more classical system uses a sensor to register the energy consumption on a dumb meter – for example, an electromechanical induction meter (rotating meter) or a digital pulse electric meter – and then transmits this to the HEMS. Although this thesis uses the term 'dumb' meter because it covers the generality of non-smart meters, from the householder's perspective they can be smarter than some of the 'smart' meters discussed in the previous section.

HEMS that track these dumb meters usually use one of two working principles. Some HEMS use a clip to measure the electromagnetic field, while others use an infrared sensor to track rotations of the disk or the number of pulses. In this scenario, it is not the meter that is the limiting factor for the frequency with which feedback is given, but the HEMS transmitter that is attached to it. The transmission interval can often be adjusted, for example from every five seconds to every minute. Both working principles are predominantly aimed at giving real-time feedback on current consumption, but they can also keep track of cumulative energy consumption over a given period, depending on the HEMS involved.

Figure 52
type of (smart) electricity meters

However, dumb meters also pose a number of challenges in being able to give feedback to households. The first is that the margin of error for cumulative energy demand can be quite large due to the dependence on a large number of data points and the loss of a certain amount of data. Second, in the Netherlands alone there are currently thousands of different gas meters and hundreds of different electricity meters installed in houses (Figure 52). A HEMS has to be able to read all the different meters involved, and as a pulse meter is very dissimilar to a rotating meter, this can be challenging. Every different manufacturer, type and production year can lead to variations to which the HEMS needs to be adaptable. The third challenge is that the C-value varies per meter. As it is not always clearly stated on the meter, at least not from an average householder's perspective, errors can occur when entering this into the HEMS, leading to erratic energy consumption figures. Fourth, the sensor has to be attached to the meter and in certain cases, in particular for gas meters, this blocks the view of the reading that is necessary for the energy bill. A fifth issue is that the sensor can easily be dislodged. This happens often in the Netherlands, due to the meter being placed in a meter cupboard next to the front door, where it is used to store all manner of items.

§ 9.4.2.3 Delays and accurateness of HEMS working with dumb meters

Besides the issues related to the meter, there are also some issues with the HEMS that is attached to a dumb meter. To start with the more common systems worldwide, these work with a clip that measures the electromagnetic field. The clip is attached to one of the mains electricity cables leading from the electricity meter to the fuse box. This system has the advantage that it can be installed relatively easily and is less affected by the differences between meters. In that sense, it is quite a simple solution – except that certain meters work with two- or three-phase rather than one-phase systems. Additionally, in certain countries only a qualified fitter is allowed to install them. There is, however, one major drawback in that these clips can be quite inaccurate, especially when it comes to measuring constant low loads. The difference in accuracy can be illustrated by two basic energy monitors: the Energy Detective (TED) and the PowerCost Monitor. The former can detect loads of 10 watts, while the second has difficulty with anything below 300 watts (interview Parker (2008) as cited in Carroll et al., 2009). It can therefore be hard for users to find a baseline (night-time) use for their household or to understand what is causing a certain peak in energy use. When real-time feedback is given with a delay, peaks in energy consumption can be inexplicable to users. (Kidd and Williams, 2008)

In addition to the energy monitors that work with clips that measure the electromagnetic field, there are also those that work with a more accurate, albeit not fool-proof, infrared sensor that measures how often the disk of the meter turns round or how often the light pulses. Reading the disk itself is a more accurate measurement of real-time feedback, but still poses a problem for cumulative/historical feedback, as mentioned in the previous section. Additionally, due to the variety of meters that one sensor needs to cater for, there can be a risk of the sensors falling off or of incorrect feedback, as happened in two of the case studies. With these infrared sensors, data delay is usually not a problem, unless the current consumption is very low. As the pulses are very infrequent/the rotations are very slow with low consumption, changes take longer to detect.

§ 9.4.2.4 Gas meters

Several of the abovementioned issues with dumb and smart meters also apply to gas meters, and are therefore not addressed again. However, in some respects, gas meters pose a greater challenge than electricity meters in the Netherlands due to the large number of different meters and the difficulties in developing one HEMS that can read all meters (Figure 53). While there are two basic working principles for gas, the readout poses problems. Most gas meters have bellows, but in recent years ultrasonic gas meters have been introduced. With dumb gas meters, most HEMS use the mirror on the mechanical counters to track consumption, which is, however, not always present. A sensor for directly reading the bellow is also available and is currently being tested, and in the UK some HEMS resort to webcams (with OCR text recognition) for readout. With smart meters, the bellow can sometimes also be read, but most HEMS use either the P1 port (when available) or the data from the energy provider sent via the Internet. For ultrasonic meters, these last two are the options currently being used.

Figure 53
type of (smart) gas meters

An additional challenge for gas consumption is that its patterns differ significantly from electricity consumption. First, there is no straightforward equivalent for 'watt'. As such, it can be difficult to bring real-time consumption of gas across to households. Second, there are fewer technical installations and appliances in the house that use gas rather than (or in addition to) electricity. However, 60% of the average Dutch energy bill is due to gas consumption, and 70% of gas consumption is caused by heating (Milieu Centraal, 2008). Besides modulating heaters/furnaces, heaters are usually 'on' or 'off', leading to very high peaks followed by periods with practically no consumption (only the pilot light is on). Cooking behaviour is far less energy intensive but gives a starkly different consumption pattern that can be hard for householders to distil from the energy consumption of the heater. In communications with households using HEMS and during the concept testing, a number of households indicated that information on showering use and showering patterns was very interesting to them. As with cooking, this can also be hard for households to distil from the consumption data. This is particularly the case with older smart meters that only relay feedback on a daily basis in whole cubic metres, as was discussed in the previous section on smart meters. But showering behaviour is also difficult to distil from smart gas meters with a P1 protocol, as they usually only give feedback at 15- or 60-minute intervals. Disaggregated feedback is an important tool for households, and there is evidence that this is more effective than cumulative feedback (Fischer, 2008). One study showed that HEMS were less effective in all-electric houses, where the electricity consumption for heating was indistinguishable from other consumption (Mountain, 2006).

§ 9.4.3 Conclusions on implementing HEMS: complexity is detrimental

This chapter has shown that the successful implementation of HEMS is dependent on a large number of factors. The location, the structure of the house and the embedded housing technology – especially the type of gas and electricity meters – can have a negative impact on the successful implementation of HEMS. These elements might also lead to HEMS not functioning properly or to households receiving intermittent, erratically fluctuating or incorrect feedback. This is a likely contributor to the fallout rates of households in case studies, because technical boundary conditions are not met.

While HEMS have been developed to be implemented in existing houses, a certain amount of retrofitting is often necessary. Not all meters are suitable and therefore need to be replaced. New wiring or extension cables need to be implemented, repeaters need to be installed, heaters need additions or replacements, or households simply have to make do with a sub-optimally functioning HEMS. As a result, the potential to help households to achieve energy savings is restricted.

The more elaborate the product, the more chances of technical difficulty. This is an exponential growth: as the number of variables increases, the chances that the whole system will be jeopardized because one element in the system does not work, increase dramatically. A simple electricity monitor has to be able to read the electricity meter, of which there are hundreds of varieties in the Netherlands alone. Increase the complexity of HEMS by also giving feedback on the gas meter, of which there are thousands available, and the chances that the HEMS is suitable for both meters decreases exponentially. Add the heater/boiler to the equation, and the number of households for which all three variables are in place falls dramatically. If one adds this to a network of plugs and/or communication with radiators for temperature control, the chances that one functionality or part does not work as expected are considerable. Careful deliberation should therefore be given before increasing the complexity, and parties should always accept that during the implementation of HEMS far more will go wrong than expected.

Smart meters will be able to remove a majority of the complexity if a universal protocol becomes available, and this will make the challenge of meters less pressing. International, rather than national, standards would be beneficial, and this should be given priority. However, from a household's perspective, smart meters currently sometimes give less useful information than dumb meters, and this therefore should also be given attention in the design of smart meters.

§ 9.5 Conducting research on HEMS: insights into gathering and analysing data

The previous section focused on the challenges faced in implementing HEMS in existing houses. These were to a large extent discovered by conducting research with HEMS in houses. The knowledge that was gained by conducting research is not, however, limited to insights into the implementation of HEMS in existing houses and the influence of the context on the use and effectiveness of HEMS. The setup and execution of case studies with HEMS also provided abundant insights and considerations for future research on HEMS. These are discussed in this section, which explains the disparities that can occur between theory and practice. This applies particularly to joint ventures between industry and academia, where a balance must be found between the interests of the parties involved.

When reading publications on the effectiveness of feedback, which is usually given by means of a HEMS, the execution of the study seems rather a straightforward affair. Households were selected, the HEMS were installed, one or more questionnaires were sometimes filled in, and after a specified period of time the achieved savings were calculated. The more rigorous studies mention that extra preparation time was allowed for the pre-trial baseline consumption measurement and/or the setting up of control groups. In the scientific community, negative energy-saving results might sometimes be published, but articles on failure (or the reasons for failure) to even measure results are rarely found. Extensive information is therefore rarely available on setbacks and other misfortunes that commonly occurred during the setup and execution of a study, apart from a couple of sentences either in the case study setup or discussion section. When the setbacks are too severe, the study will most likely not be deemed worthy of publication and therefore little becomes known of the difficulties that were encountered. Mentions of setbacks are even less common in rollouts of HEMS outside the scientific community, most likely due to the fear of releasing company-sensitive information.

Nonetheless, this knowledge on setback is very valuable. Implementing HEMS is a complex task, and in practice the implementation often does not go according to plan despite careful planning. Therefore, the potential pitfalls need to become known, in part so as not to reinvent the wheel but especially because the manner of setup, implementation and installation of HEMS and the problems that occur can strongly influence whether a HEMS can be used successfully. Therefore, the following section first discusses considerations for gathering energy consumption data and the analysis of this data. The choices concerning the installations of HEMS are then elaborated on. After this, considerations for setting up pilot studies, the need for taking into account the possibility that setbacks, including technical ones, will occur and how to deal with these setbacks through good communication and cooperation are discussed. Finally, privacy and security concerns are addressed.

§ 9.5.1 Setting up case studies or pilot studies with HEMS

There are a number of aspects that are addressed concerning the setup. First, considerations for the selection of households and the timing of the start of the pilot study are discussed. Then different ways of gathering energy consumption data and the pros and cons of each way are delved into.

§ 9.5.1.1 Selection of households

From a scientific point of view, it is desirable that the households are representative of the population in order to make possible a better comparison with other studies and to validate the results. One implication is that the participants are preferably not biased or overly knowledgeable about energy matters, for example because they are employees of an energy company. However, this is not always completely unavoidable, especially when signup is on a voluntary basis. Another implication is that the energy consumption of the households has a normal distribution. This means that it is desirable to know beforehand what the energy consumption of the participants is, which might make working together with energy companies beneficial. This has the additional benefit that a comparison of any energy savings that are achieved during the trial can be compared to the pre-trial baseline consumption.

However, the abovementioned restrictions imply that a high fallout rate is likely to occur. Because not all households will be suitable, historical data will not always be present, changes in family circumstances can render the consumption data unusable, etc., far fewer households than initially intended will commence the trial and even fewer will finish it. During every HEMS trial, a certain number of participants decide to quit prematurely. When the issues addressed in § 9.4 are also taken into consideration, the fallout rate will be even higher. This can jeopardize the intended number of participants for trials. As having too few households can make it challenging to conduct statistical analysis, it is advisable to take these aspects into consideration in the recruitment of participants.

In addition, too many prerequisites for households can result in too few of them being eligible, making it impossible to draw conclusions from the results. This was the case in one HEMS trial that was not included in this thesis, because of the 1300+ people approached for participation only 4 ended up having a HEMS installed, rather than the around 150 that were initially expected.

§ 9.5.1.2 Delays in rollout

In practice, HEMS trials rarely start on time. Besides the participants, prototypical HEMS can be a major issue. Because many HEMS are still under development, the software often contains bugs, and testing and eradicating these bugs can take much longer than expected. It is important that these issues are resolved as far as possible beforehand through extensive testing. If they are not, the simultaneous commencement of the study can be jeopardized. This is the subject of the following three paragraphs.

§ 9.5.1.3 Simultaneous commencement of the case study

An additional consideration is that all households need to start at roughly the same time, especially when seasonal differences need to be taken into account. When there is a large spread in the starting date of participants, the consumption data may become unreliable and therefore objectionable to use. Setbacks during the implementation of HEMS can jeopardize the intent to start at the same time, which happened in several studies the author had dealings with as well as in other research (Hargreaves, 2010, Nye et al., 2010).

Chapter 5 explained the challenges that were encountered in two case studies and prevented simultaneous commencement. For example, sickness among and the number of qualified fitters (who needed to be qualified to install meters, skilled in repairing central heating systems and knowledgeable on issues affecting the display) led to delays. Another challenge was the discovery of compatibility issues with certain heaters or meters, as discussed in § 9.4.2. This led to the need to find last-minute replacements for certain households, or to replace meters with smart meters – which in turn led to a four-week delay between the installation of a smart meter and the household receiving feedback. Technical hiccoughs and bugs delayed further rollouts in one case study and/or delayed the point at which households started to receive feedback in two case studies.

In part, extensive testing of the HEMS beforehand in a natural setting can prevent this. As a general guideline, the introduction of HEMS in houses cannot be done without an extensive amount of preparation concerning both the design of the HEMS and in the way in which they are introduced. Soliciting advice from other companies and researchers with experience is therefore beneficial.

§ 9.5.1.4 Installation of HEMS

The choice whether to let households self-install the HEMS or have a fitter do it is dependent on a number of factors and should be carefully considered. One aspect is the tenure of the house, as permissions for retrofits to personal property do not require the consent of a third party.

Self-installation is more cost-efficient than installation by a fitter. However, it can delay the simultaneous commencement (because some households need more time to install the HEMS) and/or increase the dropout rate (because some households give up after encountering problems installing the HEMS). Additionally, in one trial, the helpdesk's work overload led to further delays. Another consideration is that self-installation is not always legally allowed, depending on the type of HEMS and the country.

Installation by a qualified fitter can obviate some of these problems. It can make HEMS accessible to a larger group of households that are not technically gifted. However, problems can still occur. Some participants like to tinker with the setup and installation, as they want to use the wireless router for other purposes or to find a backdoor in the software so that the settings can be adjusted better to fit their wishes. During the trials, this occasionally led to problems that had to be fixed by a fitter, but other problems were caused by inherent weaknesses is the system, such as sensors that can easily become dislodged.

§ 9.5.2 Gathering data

Three methods are commonly used to gather energy consumption data, HEMS usage data, and other information: 1) questionnaires with self-reported readings/meter readings by participants, 2) readings/meter readings by the gas man or electrician, and 3) remotely tracking energy consumption data and HEMS usage data. Each method has its advantages and disadvantages, which can also differ for different countries. All three methods were used in the case studies conducted for this thesis. The following are some of the advantages and disadvantages of the methods.

§ 9.5.2.1 Self-reported meter readings

Self-reported meter readings are usually acquired by means of questionnaires. Relying on self-reported meter readings during the course of a pilot study introduces a high margin of error and large numbers of missing data points. In the first case study, which was discussed in Chapter 3, only 18% of the data were usable because of this. A number of issues contributed to this. Many reported meter readings were inconsistent with previously reported meter readings, especially when there was a day and a night tariff. People had difficulty reading meters. Not all participants filled in all the questionnaires, meaning that one or more data points were missing. In addition, participants were not always in the vicinity of their meter (for example, due to using their email address from work) and either did not realize that the questionnaire could be reopened at a later time or could not be bothered. Explicitly stating alongside the request to fill in the meter readings (rather than at the start of the questionnaire) that it can be filled in later, may reduce the number of people who do not fill it in.

§ 9.5.2.2 Meter reading conducted by experts

Although meter reading conducted by experts is used more often in research (Nolan et al., 2008), it too is subject to human error (Petersen et al., 2007). In one of the HEMS trials, oversight led to the final version of the checklist for de-installation not instructing the fitter to record the meter readings. As a result, the acquisition of energy consumption data failed. The meter readings were actually intended as a backup dataset for the remote tracking of consumption data, but due to technical problems these were also not usable in the end. The problems that can occur with remote tracking is discussed next.

§ 9.5.2.3 Remote tracking of data

The remote tracking of data can give the richest type and amount of data on both energy consumption and the use of HEMS. However, it is vulnerable to a number of problems. Remote tracking is usually achieved by letting the HEMS send data via the Internet to a server. However, in one HEMS trial, wrong settings on the server lead to the loss of the data. This mistake basically boiled down to the omission of a checkmark, but the trial was well underway before it was discovered. In another HEMS trial, individual households could not be distinguished in the data, making certain important comparisons impossible.

An additional problem is that most HEMS keep track not of the actual meter readings but of changes in the readings, for example the number of rotations. There are two main problems that can occur as a result. One is that no hard data are available on the actual energy consumption. In practice, a certain number of data points will always be lost and other factors (e.g. those discussed in § 9.4.2) can lead to the data being polluted. This leads to the second problem: that the data is unreliable. Bugs in software, incorrect installations and hardware issues led to erratic peaks in energy consumption in one HEMS trial using remote tracking. Some companies use workarounds to ensure that they can calculate savings from the remote tracking data. One company asks its participants to fill in the actual meter readings in the HEMS every six months in order to calculate the margin of error. In England, webcams and optical character recognition software are sometimes used to read gas meters. It is also important to make clear agreements beforehand regarding the properties of the data that will be tracked, and especially to test whether the tracked data fulfils the requirements. When the correct data have been gathered, the analysis can begin.

§ 9.5.3 Analysing data

There are two common ways to analyse data: one can compare a household's consumption during a trial with its historical pre-trial/baseline consumption, or compare a household's consumption to that of a control group. Ideally, both comparisons are done in order to take into account external factors that could have caused the changes in energy consumption. Care should be taken that the pre-trial baseline consumption is over a representative period in comparison to the length of the trial, and that seasonal influences are taken into consideration. Trials are usually conducted over a relatively short period, but there is a risk that savings will decrease over time (van Houwelingen and van Raaij, 1989, van Dam et al., 2010). As such, considerations should be made as to the length of the trial and the achieved savings should be viewed in light of the length of the trial.

However, issues within the case study setup like those mentioned in the previous sections can sometimes also cause the data to become unreliable. If households do not receive feedback or the feedback is inaccurate for a prolonged period during the trial (e.g. due to software bugs or hardware problems), it can become dubious whether one can speak about the effects of receiving feedback. Additionally, relying on this incorrect feedback on energy consumption to calculate savings through the remote tracking of data, can give an incorrect representation. Another issue that made the gas consumption data in one HEMS trial unreliable was that crashes in the software of the HEMS caused the heater to stay in the position it was in at the time of the crash. In other words, the heater stayed 'on' or 'off'. This had significant influences on the gas consumption of a number of households because it happened repeatedly or was not noticed due to a holiday. Some participants indicated that the integrated thermostat in the HEMS had a different temperature calibration or responded differently to the warmth of sunlight than their old thermostat. This resulted in perceived differences in room temperatures despite similar settings, which logically influenced the gas consumption, though it was not possible to quantify or measure this. Furthermore, the electricity consumption in one HEMS trial was also polluted due to the high electricity consumption of the HEMS itself. These types of issues severely hampered the analysis of data in two HEMS trials. Added to the issues mentioned in § 5.3, the quantitative energy consumption data from these studies became unusable.

Thus, numerous things can go wrong during the execution of a HEMS trial. This cannot be completely prevented, and because of this communication between cooperating parties and especially with participants becomes essential. This following section deals with this.

§ 9.5.4 Cooperation

The HEMS studies that are currently being conducted were often initiated by commercial parties. There are several interesting benefits of a cooperation between researchers and commercial parties when studying the effectiveness of HEMS. Cooperation between researchers, energy companies and HEMS manufactures can greatly benefit the setup and execution of a study. Excluding one of these parties can have drawbacks. But there are also a number of pitfalls to cooperation. A number of these benefits and challenges are presented below.

Energy companies
Energy companies can benefit from scientific backing of the HEMS they market. Without the aid of an energy company, gathering energy consumption data becomes more complex. Baseline energy consumption data need to be gathered. Cooperation with energy companies can shorten the start-up time and reduce the number of initial participants that need to be contacted, since energy companies have accurate and up-to-date consumption data on the majority of their customers. This can also simplify the possibility of a follow-up after completion of the trial.

§ 9.5.4.1 Manufacturers

Manufacturers can directly benefit from insights gained through the research (e.g. insights into the use and the design of the HEMS) and benefit from the scientific backing of their claims. Furthermore, involving the manufacturer in the study can greatly simplify the installation of HEMS and the execution of the study due to their knowledge of the product. This can shorten the lines of communication in the case of unexpected technical hiccoughs in the implementation of the HEMS.

§ 9.5.4.2 Scientific researchers

The different perspectives of the scientific and commercial parties can be beneficial for the data analysis. Both cooperation during the analysis and making the data available to all parties can be advantageous to the type of insights that can be extracted. A researcher can ensure that certain boundary conditions are met, thus ensuring that the study leads to usable outcomes. Because a researcher is an external party, it can sometimes be easier to maintain a more objective view on the achieved results.

§ 9.5.4.3 Users

Working together with users can greatly benefit the design of HEMS. Poor interfaces or technical functioning can lead to decreased use and even non-use of the product, which can in turn effect the results of HEMS trials. By working together with users in the design process, a product can be developed that is usable by laypeople who are not involved in energy in their day-to-day lives. All case studies had a high fallout rate and several people indicated that they did not understand the interface or the energy consumption figures that were displayed. The usability study conducted before one of the HEMS trials revealed a number of key areas that greatly influenced the usability. If these problems had not been solved (as far as was possible) beforehand, they would have seriously influenced the use of the HEMS during the pilot study.

§ 9.5.4.4 Prerequisites for cooperation

Cooperation requires trust between the different parties involved, especially concerning the sharing of data. While there are strong advantages to cooperation, too large a consortium may not always be beneficial. Additionally, different parties have different interests. Having a good project manager can minimize the challenges. When working together with different parties, good communication strategies between the different parties are critical. The communication with participants is a point that should receive particular attention.

§ 9.5.5 Communication with participants

Good communication with users is essential. No matter how well a case study has been set up and how technically perfect a product is, during roll-out it is inevitable that new problems will be unearthed. As one participant said: *"That [it] doesn't work, doesn't matter, because it is a test thing. But look, I was going to be called back; I was going to be called back. It is just the communication. That is just really, really, really too crazy for words."* It is advisable to prepare a communication strategy and equip helpdesks for these scenarios. Cherish the frequent callers who report bugs. They are an essential help in perfecting the product.

Communication with regard to the setup of case studies, contracts and liability also needs to be given thought, because these matters can impact on the use of HEMS.

Trials are often expensive and companies understandably try to keep the costs as low as possible and to manage the financial investment and risks involved. However, conclusions on the incorporation of HEMS into people's daily lives can be obscured by the setup of the case study. If it is overtly known that the product is only being lent to a household – or statements are made in contracts that returning a product too late will result in a fine and that they will have to pay if they damage the product – the household will not regard the product as its own. Several participants in one HEMS trial voiced their concerns about their contract. One participant, who was wary of the clause that damage to the HEMS would be at their own expense, purposefully kept the sticker on that was only intended to protected the screen and keypad during transport. This can influence the natural use of HEMS and hinder using the HEMS to its full extent. Therefore, in communications with participants, care should be taken that the manner of communication does not unintentionally obstruct the natural use of the HEMS by participants.

§ 9.5.6 Privacy issues and power balance with smart metering and HEMS

The final issue to be addressed in this chapter is privacy and power balance with smart metering and HEMS. There are a number of facets to privacy, depending on the perspective of the specific party. For example, some users have concerns regarding the erosion of their privacy and security due to HEMS or smart meters. As one participant commented: *"The possibilities that energy companies have to gather information through 'HEMS-like' appliances disturbs me."* Households are afraid that their private information concerning when they use energy will fall into the wrong hands. The fact that this information can be gained through other means, such as having a mobile phone and that much other data of users are tracked does not make this less troublesome to users. However, this concern is not shared by all HEMS users, as others communicated a desire for a smart meter. In addition, others saw advantages in coupling energy information to addresses because of their interest in gaining a comparison between households. Sharing their own information, however, may be a sensitive issue.

The privacy concerns are not completely unfounded. Rouf et al. (2012) found that automated meter reading posed real security and privacy risks to households in the United States. With "*modest technical effort*" the automated meter readings could be picked up by unauthorized third parties. The data that was gleaned revealed the occupancy of houses and the daily rituals of households.

Privacy issues need to be an important consideration for the HEMS industry, especially when consumption data are tracked in real time or when a comparison between households is being given. The length of time during which both the HEMS usage and the energy consumption data are gathered, how these data are gathered and who has access to the data should be considered. In the cooperation with companies, it was evident that different companies had very different attitudes towards the collection of data and who had access to these data, which also had an effect on the data that were available for research. Companies should ensure that security measures are in place, take extra effort to reassure households that they are not abusing their position (and indeed not do so!), and be honest about what information is being gathered and what is being done with it.

Attention should also be paid to the power balance of smart meter data. Chappells et al. (2000) warn that in some cases, it is mainly the energy providers – rather than households – that are empowered. They add: "*What in fact happens in many cases of monitoring is that consumers are not so much 'empowered' as made co-responsible for the consequences of their own consumption, in particular its economic and societal costs. Individual metering makes it easier for providers to transfer liability for the environmental damage caused by water extraction or coal fired electricity generation to individual consumers, at least in a rhetorical sense. Although consumers are of course responsible for their own consumption, their powers to influence the strategic decisions of providers are not normally increased by getting a meter installed.*"

§ 9.6 Conclusions

A large number of insights have been presented in this chapter. The following conclusions reflect on the goals as stated in the introduction. The implications for each of the stakeholders – namely the construction industry, the HEMS industry and HEMS implementers, and HEMS researchers – are discussed individually.

To recap, the three goals were 1) to explore the direct and indirect effects that contextual factors can have on the use and effectiveness of HEMS, and on the outcome and results of case studies on HEMS, 2) to assess what lessons can be learned for the benefit of the built environment and the HEMS industry from these contextual factors and the influence they can have on the effectiveness of HEMS; and 3) to assess what lessons can be learned for the future setup and execution of case studies on HEMS.

§ 9.6.1 Conclusions for the housing and the construction industry

§ 9.4 showed that the contextual factors concerning the location, the structure of the house and the embedded housing technology (including meters) all influence how successful HEMS can be implemented and, as a result, their potential to achieve energy savings. While HEMS are intended to be implemented in existing housing, a certain amount of retrofitting is often necessary. There do not seem to be any quick fixes to this situation. Reducing the energy consumption of existing houses and achieving behaviour change will remain challenging. Relying on technology alone will not solve the problem. The increasing strictness of the energy performance index of buildings in the Netherlands (the EPC norm) does not necessarily lead to a decrease in building-related energy consumption (Guerra Santin, 2010). However, there are certain configurations that seem more effective than others.

In addition, it is essential to focus on the inhabitants – the end users of every house – during the design or retrofitting of a house. In particular, attention to details is of decisive importance and cannot be neglected. Details that are sometimes perceived as minor, can have an unexpectedly large impact on the successful implementation of HEMS and the achievable savings. Details such as the positioning of heaters and sockets, the wiring to the heater, and thick walls can strongly hinder the implementation HEMS and their successful use.

It is important to be aware that the implementation of energy reduction measures in houses does not automatically lead to their inhabitants making energy savings. The design of houses can have unforeseen consequences for households' ability to achieve low energy consumption. Taking the inhabitants into consideration during the development process is therefore a fruitful and essential approach to understanding household energy consumption and developing strategies to reduce household energy consumption. The simplicity and usability of the embedded technology needs to be considered.

There is still a tendency to design around the user, or remove the user from the equation, as was voiced during the think-tank. However, it is highly questionable whether this will indeed bring about the desired effect. Midden (2006) states that: *"These constraints caused by users have made engineers long for full automation, assuming that by excluding the user from the operational process, the efficiency, for example of a washing machine, can be optimized. One might wonder if such a setup would really lead to energy reductions."*

§ 9.6.1.1 Implications for new housing

This section briefly addresses what the implications are for the design of new housing by elaborating on the question: What would a house designed for transparent energy management and visible energy flows look like? This question leads to a number of directions that are worth pursuing.

- It would be designed to retain and visualize energy, rather than waste, hide, and bury energy-consuming technology.
- It would be a wireless-transmission-friendly structure in particular concerning the position of the energy meters.
- It would have meters that are visible, easily accessible and understandable to a lay person, and that can locally transmit current real-time and historical energy consumption data (or that at least allows those data to read out, reliably and fault free).
- It would provide an aesthetically pleasing visualization of the energy flows, so that the household can easily understand where energy consumption is going to and which products are truly 'on' and 'off'.
- It would have user-friendly technical installations and make having devices turned off or turning devices off a simple option.
- It would have low energy consumption as the default setting.
- It would have flexible wall sockets that can be easily moved (rather than replaced).

§ 9.6.2 Conclusions for the HEMS industry: designers, developers, energy companies and installers

It was stated in § 9.4.3 that complexity is detrimental to the successful implementation of HEMS. As a new technology, HEMS have a long way to go. Donald Norman's definition of technology is: *"Tech•nol•o•gy (noun): New stuff that doesn't work very well or that works in mysterious, unknown ways"* (Norman, 2011). Unfortunately, this is how households usually perceive HEMS. The issues that were mentioned in this chapter are not going to disappear overnight. The current housing stock could easily last another 100 years (MvBZK 2010). It is therefore important to test HEMS, to use them in pilot studies and to iterate their design even more extensively in a natural and realistic setting and in close collaboration with users. But it is also important to find a balance between the interests that are at stake. Of course, it is financially impossible to test and iterate unendingly, and because something will always go wrong in practice, communication with participants becomes essential. Keeping the communication lines open and appreciating those users who continuously call and address problems with the installation or HEMS itself, is critical to the eventual success of HEMS. On a positive note, even though a large majority of households had issues with the HEMS in one case, 25% of the participants did not want to return the HEMS at the end of the trial despite repeated requests. This seems to indicate that some had grown to appreciate the HEMS, despite its faults.

Due to the interest of HEMS users in locally produced energy, such as solar power, and to the increase in the amount of energy that is locally produced, energy production should be given more attention in the design of HEMS. This interest was found both in this research and in other studies (Strengers, 2011). Finally, the HEMS and its users need to be given more consideration in the design and choice of smart meters.

§ 9.6.3 Conclusions for researchers

The following conclusions can be drawn for researchers, with either a scientific or industry related interest in HEMS research, from the case study setup discussed in this chapter and in Chapter 5.

It is likely that case studies will take longer than expected due to the challenges that are likely to be encountered along the way. It is therefore advisable to take this into consideration in the research setup. Having a 'plan B' and a 'plan C' for gathering energy consumption and HEMS usage data is prudent. Due to drop-out and technical complications, it is tactical to include many more households than strictly necessary. Additionally, the development of a communication strategy towards participants beforehand can ease the process and prevent frictions in the case that challenges do occur during the implementation.

Joint cooperation between commercial parties, such as HEMS manufacturers and energy providers, and the academic community has decisive advantages. However, good project management and clear agreements with the various parties involved that are made early in the process are essential. Additionally it is important to find a balance between the various interests of the different parties involved.

Overall conclusions of Part IV and moving on to Chapter 10

This chapter concludes part IV, which gave a comprehensive reflection on the overall effectiveness of HEMS, the implementation of HEMS and the process of conducting research with HEMS. In all, this part was not intended to deter the implementation of and research on HEMS. Rather, it aimed to give a realistic picture of the current situation and to voice some concerns about the current situation, so that the implementation of HEMS and the research on HEMS can be made more successful.

The insights in this part are based on the current situation and portray the issues that currently arise in relation to HEMS. Between 2008 and 2012, numerous parties became interested in HEMS and the number of concepts, pilot studies, start-ups and stakeholders has exploded. Illustrative examples are the entrance (and exit) of two multinationals, Google and Microsoft, and their respective products, the PowerMeter and Holms. In this rapidly growing market, there are numerous new initiatives taking place, but the technological developments are also growing exponentially. We are therefore in a period of transition. Large changes to the electricity grid are being planned and implemented. Investments in smart grids and related technologies are booming. The balance in types of energy sources, such as fossil fuels and renewable energy, are shifting, as are the countries of origin. Until now, the role for HEMS has predominantly been to save energy within the home, but this is quickly changing to include peak shifting. Additionally, the local production of renewable energy is becoming more important to the use of HEMS. Therefore, a shift and an expansion in the usage of HEMS are taking place. While there is a risk that some of the issues mentioned in this chapter are therefore out-dated, they do provide a large number of aspects for both researchers and practitioners to consider, whether they are HEMS designers, implementers or installers, or housing experts.

10 Conclusions and recommendations

The aim of the research presented in this thesis was to infer design-related insights and guidelines to improve the use and effectiveness of home energy management systems (HEMS). This was done through an empirical evaluation of the longitudinal effectiveness of these devices and an exploration of factors that influence their use and effectiveness.

This chapter concludes the thesis by summarizing the main findings related to each of the research questions. It also provides a reflection on this research as a whole and on its setup, as well as on current industry developments. Recommendations for the domains merged within this research – namely housing, the building industry and the HEMS industry – as well as for future research are also presented. First, though, a brief recap of the topic of this research and its suppositions is given.

Reducing the energy consumption of existing households formed the starting point for this research. There are many facets to energy consumption, including the size, quality and age of the home, its appliances and technical installations (which increasingly run autonomously or in the background), and its inhabitants, including their demographic characteristics, practices and behaviours.

HEMS were chosen as the intervention to address the various elements that contribute to household energy consumption, thereby functioning as a pivot. This was done because HEMS can be implemented in existing households with existing appliances and technical installations. By giving feedback and/or helping households to manage their energy consumption they can, in theory, assist them in changing their behaviours and practices and thus reduce their energy consumption. The capability of HEMS to visualize background energy consumption was also seen as an essential component.

The human-computer interaction framework of Wever et al. (2008) and van Kuijk (2010) was adapted to visualize the interdependence of the various elements that influence the energy consumption of households and to structure the findings of the research. HEMS were positioned within the framework (Figure 54), postulating the pivotal role of HEMS: how they influence and relate to the other elements in the diagram and household energy consumption, thereby implying that these elements in turn influence the use and effectiveness of HEMS.

In past research, the specific influence of the various relational lines and elements was given limited or no attention, and therefore their influence remained unapparent. To explore these factors, three case studies, each with a distinctly different type of HEMS, were conducted. The three HEMS were an electricity monitor, an energy management device and a multifunctional HEMS. The following section presents the conclusions related to the research questions answered within the case studies.

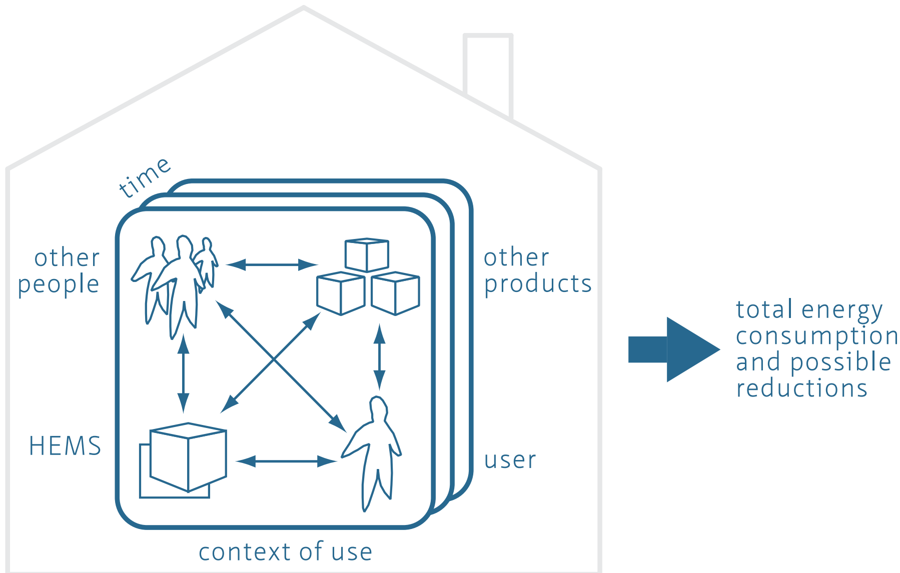


Figure 54
Factors influencing the use and effectiveness of HEMS. Adapted from Wever et al. (2008) and van Kuijk (2010)

§ 10.1 Answering the research questions

Five sub-questions were formulated in order to answer the main research question, namely: what design-related insights and guidelines can be inferred that influence the use and effectiveness of HEMS? This section presents the answers to each of the five sub-questions. After answering each sub-question, the design-related guidelines that can be inferred from the answer are formulated in order to answer the main research question. The findings are structured according to the framework in Figure 54. Finally, a closing remark on the overall research question is given.

§ 10.1.1 What are the medium- to long-term results of HEMS on energy savings?

§ 10.1.1.1 Conclusions on the element of time in Figure 54

The first case study, of 189 households that used an electricity monitor for 4–15 months, addressed this question. The conclusion was that the effectiveness of HEMS tends to decrease over time. The initial savings in electricity consumption of, on average, 7.8% after four months were not sustained over a period of 15 months.

- The participants were divided into three groups. The group that had developed a daily habit after 15 months of checking the monitor at a fixed time, achieved the largest initial savings in comparison to the groups that did not have a daily habit after 15 months or that returned the monitor after four months. Both the savings and the development of the habit were likely caused by the household's predisposition (Ch. 4).
- All three groups had the same rate of fall-back (Ch. 4).
- Households' responses to the interventions were divergent, with large differences between households in positive and negative energy savings (Ch. 4).
- An electricity monitor might not be an effective strategy in the long run if it is implemented as a standalone measure (Ch. 4).
- Interviews during the second and third case studies revealed that HEMS do sometimes facilitate engagement in a process of change, helping users to reduce their energy consumption. (Ch. 7)

Design-related guidelines and insights inferred from the answer to this research question

- HEMS should not be developed as standalone interventions but should be incorporated as part of a broader, overarching change strategy.
- Interventions that utilize current energy monitors are mainly successful if they are targeted at a specific niche of users who are highly motivated to incorporate the use of the monitor into their daily lives. Therefore the 'en masse' implementation and target audience of HEMS should be given careful consideration.
- To increase savings across the board, and to counter the difference in measured effectiveness between different users, interventions should be tailored to individual households.

§ 10.1.2 What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?

Strong differences between users and the way they used and applied HEMS were found amongst the participants in the second and third case studies. The patterns that emerged in the use and application of HEMS cannot be seen in isolation from the user who brought them about. To be able to present the findings in a manner that gives a coherent description of the context of use and the strong differences between users and their use of HEMS, the findings were translated into a classification of types of users and their use of HEMS:

- The 'techies' used HEMS to analyse and keep track of their energy consumption and production over time, which was seen as a hobby. For some techies, it was also a challenge to reduce their (baseline) consumption as far as possible, mainly through technical solutions. They had kept track of energy consumption in the past and they enjoyed the gadget appeal of HEMS and having a variety of types of feedback.
- The 'one-off users' had characteristics that overlapped those of the 'techies'. However, they used a HEMS as an informative but short-term tool to discover which appliances they could reduce energy consumption on and, where possible, to be able to implement technical solutions or, to a lesser extent, adapt their behaviour on the basis thereof. The one-off user's motivation to switch off appliances when not in use may be as much (or more) for fire prevention as for energy savings.
- The 'managers' used the HEMS to keep tabs on the consumption of appliances and other household members, using it as a 'badgering tool' or 'evidence' to address their behaviour. Showering habits and unnecessary consumption (e.g. with regard to their baseline) were a particular focal point. Family dynamics played a key role in this type of use.
- The 'thrifty spenders' were characterized by their thriftiness. A HEMS was appealing because of its money saving attributes, but also because it was supplied free of charge. Their perceived thriftiness is based more on their perceived attitude and upbringing than on hard facts or knowledge. While even small potential savings are interesting to them and they are keen on receiving advice, they tended to have difficulty applying the HEMS to achieve savings.
- The 'joie de vivres' used HEMS as means of keeping a global but intermittent overview of how their money was being spent, and possibly to verify whether their bills were correct. They disliked being confronted too often with their consumption, disliked details and tended to have difficulty understanding energy data and HEMS in general. They are dissimilar in their characteristics to the 'managers', being more relaxed and not striving for control. Comfort and convenience are valued.

Commonly, not all household members used the HEMS, and in particular the feedback it gave. Reasons that were stated were, for instance, disinterest in energy consumption, the feeling that saving is too much effort or has too little benefit, the HEMS is too technical, or that there were technical problems with the feedback.

Design-related guidelines and insights inferred from the answer of this research question

- In the design of HEMS, consideration should be given to users' desired use, practices and goals. Particular attention should be paid to those aspects that seem beneficial to a HEMS' effectiveness, for example drawing attention to baseline consumption and the reduction thereof, or giving specific feedback on shower use.
- The effectiveness of HEMS could potentially be enhanced through the application of insights from interaction design research – such as influence and persuasive strategies using social comparative feedback – to target the different types of users and their use of HEMS.
- Designers should strive to support the creation of positive dialogues between household members through the HEMS, for instance, through social games or paying attention to positive achievements.

§ 10.1.3 What factors may influence the use and effectiveness of HEMS?

Chapter 7 addressed the ways in which the HEMS, the user, other household members, and existing technical installations and appliances interplay and potentially influence whether and, if so, how households use HEMS, which can have a domino effect on their effectiveness. The factors are discussed below by systematically addressing each of the interactions in Figure 54, drawing from the findings of the three case studies.

§ 10.1.3.1 **Regarding the interaction between a HEMS and its user(s) in Figure 54, the following factors may influence the use and effectiveness of HEMS**

- Number of persons using a HEMS in a household: there was often one main user of the feedback given through HEMS, and this user was often male. This means that there was usually only one person in a household who received feedback and could potentially act on it (Chs 6 and 7).
- Mismatch between HEMS and user: users have distinctly different needs, desires and usage related to HEMS, for which HEMS are not always appropriate. Different types of feedback (e.g. real-time, disaggregated, historical comparative) fit different desires and applications (e.g. tracking, oversight, badgering tool) (Chs 6 and 7).
- (In)ability, (dis)interest or (un)willingness: not all users want or are able to save energy with a HEMS (Chs 4 and 7).
  - Users had difficulty understanding what energy figures such as kWh's and m^3 mean and indicated a need for a point of reference in order to be able to act on the information.
  - Managing the energy management device was challenging for some participants.
- User's goals and energy saving approaches differ. This influences the duration and intensity of the use of a HEMS (ch. 6).
- The quality of the technique: current HEMS that are on the market and/or are being researched are still an emerging technology, and as such they quite often still have start-up problems (Chs 6 and 7).
- A HEMS integration in a household's everyday life and practices:
  - Energy management devices do not always fit well with the rhythms and practices of everyday life (Chs 6 and 7).
  - For some users, a HEMS becomes engrained in daily life with a daily habit of checking the HEMS, which was reported by over 25% of participants in the first study. To put things into perspective, however, over half opted to return the HEMS after four months (Ch. 4).
  - A common ritual that occurs around HEMS is a baseline check, whereby households check to see whether their consumption drops at night (Chs 6 and 7).

§ 10.1.3.2 **Regarding the interaction between user and other people, and HEMS and other people in Figure 54, the following factors may influence the use and effectiveness of HEMS**

- Unappealing design or nature of HEMS: current HEMS do not appeal to the majority of members of households, although non-energy related HEMS functionalities might interest other household members more than feedback or control (Chs 6 and 7).
- Family dynamics (Chs 6 and 7):
  - HEMS may help open lines of communication between household members to reflect on behaviours.
  - HEMS are sometimes used as 'evidence' or a 'badgering tool' to try to influence the behaviour of other household members, which may be beneficial for energy savings but can lead to conflicts.
- The capability of, success at, or inclination to influencing the behaviour of other household members: HEMS users indicated that they were not always capable of or successful at influencing others, or were not inclined to do so (Ch. 6).

§ 10.1.3.3 **Regarding the interaction between HEMS and other products in Figure 54, the following factors may influence the use and effectiveness of HEMS**

- Cause-effect relationship: one application of HEMS is to trace overall consumption back to individual appliances. However, the cause–effect relationship between overall consumption and individual appliances based on aggregated feedback may be easy, challenging or frustrating, depending on the characteristics of the user. HEMS that give disaggregated feedback on individual appliances were preferred by certain users but disliked by others (Chs 6 and 7).
- Match and compatibility with appliances and users knowledge of appliances: current energy management devices are not always an optimal solution to reducing the standby energy consumption of appliances (Chs 6 and 7):
  - Some appliances – such as HD recorders, NAS, digital set-top boxes and other appliances with clocks – are ill adapted to being switched off externally (manually unplugging or with an energy management device).
  - User knowledge of the workings of their appliances and the most efficient energy settings was regularly inadequate.
  - This resulted in the suboptimal use of the energy management device and energy.
- Both technical installations and HEMS are currently poorly equipped to measure the production of renewable energy (e.g. via solar panels), while interactions with participants indicate that HEMS are particularly appealing for households that produce their own energy (Chs 6 and 9).

§ 10.1.3.4 Regarding the interaction between users and other products, and other people and other products in Figure 54, the following factors may influence the use and effectiveness of HEMS

- Energy savings approaches and motives differ: certain types of users prefer either a behavioural or technical approach to energy reduction, while others do not strive for reductions (Ch. 6). Users may have an additional or alternative motive for turning appliances off, for example to reduce the risk of fire.
  - Users who favour technical solutions to energy reduction prefer to implement technical solutions, change products or adjust their energy settings.
  - Users who favour a behavioural approach are predominantly geared towards reducing unnecessary consumption and the duration of use of, for example, lights, showers and appliances, by paying attention to the behaviour of different household members.
  - Some users or household members just won't change.
- Lock-in: Busy lifestyles, lack of knowledge of how and when to turn off their products, and choices from the past can hinder changes in energy consumption behaviour. Certain participants indicated that they found themselves 'locked-in' by past choices. Even highly motivated people may find it hard to change (Ch. 7).

§ 10.1.3.5 Regarding the element of context in Figure 54, the following factors may influence the use and effectiveness of HEMS

- Organisational aspects such as tenure, type of installation (e,.g. DIY), accompanying services, and data transmission with external parties can hinder the successful implementation of HEMS (Ch. 9).
- The location, the structure of the home and the embedded housing technology – especially the type of gas and electricity meters – can have a negative impact on data transmission and the implementation of HEMS (Ch. 9).
- These elements may furthermore lead to the HEMS not functioning properly or to households receiving intermittent, erratically fluctuating or incorrect feedback (Chs 7 and 9).

§ 10.1.3.6 Main factors

In summary, the main factors that can be derived from the above-mentioned bullets are:

- The characteristics of the user and other household members (their knowledge, capabilities, motivations, interests and desires).
- The design of the HEMS (its specifications and functionalities, the type of feedback, the quality of the technique, its usability, applicability and relevance, and its integration and implementability in household daily life and practices).
- The design and functioning of appliances.
- The design of the dwelling.
- The match/mismatch or compatibility/incompatibility between HEMS, users, appliances and the dwelling, and the adoption of the HEMS by household members.
- Family dynamics.
- The complexity of reducing energy consumption and users' preferred type of reduction approach.

Design-related guidelines and insights inferred from the answer of this research question on factors that may influence the use and effectiveness of HEMS

- One size does not fit all. To increase the audience of HEMS, they should be diversified using a user-centred design approach, for example with different types of feedback and persuasion techniques.
- Consideration should be given to users' different (and possibly shifting) capabilities, manners of cognitively processing information, interests, levels of energy- and appliances-related knowledge, and technical know-how, for example by creating a layered design in the interface, by using a combination of methods to relay energy consumption data, and making comparisons, e.g. between different time periods, energy sources, and households, easy.
- HEMS should strive to make energy reduction opportunities easy and apparent
- In order to create recurrent awareness of energy reduction amongst HEMS users, designers should consider not developing HEMS as a one-off design, but rather devise a longitudinal design strategy to continue stimulating their users over time.
- HEMS should stimulate users to begin a search process that leads to other media or people for further analysis and in-depth information, e.g. for (interactive) graphs, correlations between energy consumption data and weather, or energy reduction opportunities, because only a limited number of functionalities and amount of information can fit on the HEMS platform.
- HEMS should support users who have limited knowledge of energy and of the functioning of their homes, technical installations and appliances. This is particularly relevant for removing the confusion as to what current 'best practices' for energy reduction of energy-using products are.
- Attention should be paid to the possibility to develop daily habits around HEMS, particularly the baseline-check or night-time ritual of checking the HEMS.
- Attention should be paid to the ability of HEMS, particularly energy management devices, to function according to households' daily practices, for instance by evaluating their architecture and location with regard to the vicinity to a given activity and integration in other products.
- Ways of making HEMS more appealing to other household members who do not use the HEMS should be explored.
- The proper function and usability of HEMS should be given the highest priority.
- Feedback on the production of energy, such as PV cells, should be considered and promoted.

§ 10.1.4 What is the overall effectiveness of HEMS when taking their lifecycle and embedded energy into account?

The positive result of the lifecycle assessment conducted in Chapter 8 is that all three types of HEMS studied can theoretically achieve net energy savings (where $e_{invested}$ > e_{saved}) over the course of five years. To reach this conclusion, the cumulative energy demand (CED), eco-costs and economic payback were calculated for the three HEMS used in the case studies. The net energy savings were calculated using the CED indicator and six energy savings scenarios. In five scenarios, the savings were fixed and ranged between 2% and 10%, with an additional 'fall-back scenario' based on the first case study.

However, there are a number of significant nuances:

- The electricity monitor is the simplest HEMS and, on paper, it becomes effective sooner than the other HEMS: it achieves positive net energy savings within 6 months in all scenarios.
- On paper, the multifunctional HEMS has the greatest potential because it addresses the household's total energy consumption (i.e. both its gas and its electricity consumption).
- Within the given scenarios, it can take up to 18 months for the multifunctional HEMS and up to 24 months for the energy management device to achieve net energy savings, as they have more hardware and higher electricity consumption than the energy monitor.
- If the electricity consumption of the HEMS itself is too high, the net energy savings may become negative again within the course of five years. This was illustrated in the fall-back scenario with the energy management device.
- For all three HEMS, the economic payback time was more than five years in between one and three of the scenarios.

Design-related guidelines and insights inferred from the answer of this research question

- Reported savings by means of a HEMS should be rectified to account for the embedded energy in the HEMS itself and the resources needed to produce the HEMS.
- Overall, it may be argued that HEMS should not be developed as standalone, dedicated products, but should be integrated into existing products. However, care should be taken to maintain the simplicity and accessibility of the feedback.
- Design strategies towards reducing the number and size of parts and the HEMS' energy consumption have positive effects on the CED and eco-costs, as was shown by the comparison between the old and the new hardware of the multifunctional HEMS.
- Careful trade-offs needs to be made with regard to the architecture of the HEMS. While the small size of the display of the electricity monitor is positive for the cumulative energy demand (CED), it could limit the potential to achieve net energy savings through behaviour change, due to the limited interface design opportunities.
- It is recommended that energy management devices should be implemented only into 'high potential' appliances – that is, those that have the highest potential for large energy reductions – or by combining a very modest number of plugs from the energy management device with an energy monitor.
- Openness to innovations. One example is the use of electromagnetic interference for disaggregation algorithms or non-intrusive load monitoring, which gives the benefit of disaggregated feedback without the need for extra hardware due to the plugs.
- Different marketing models should be explored to take the effectiveness of HEMS and their embedded energy into consideration, for example by leasing or renting them to households for a short period.

§ 10.1.5 What can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing households?

Two of the case studies reported in this thesis encountered challenges during the setup and execution (Chapter 5). Chapter 9 reflected on these challenges, which gave an unexpected dimension and a different layer of insights on helping households manage their energy consumption. The conclusions are briefly listed for the housing sector, the HEMS industry and researchers, and are more extensively detailed in § 10.3.

§ 10.1.5.1 For housing and the building industry:

§ 9.6.1 and § 9.6.2 reflected on the implication for housing and the building industry. The main conclusions were:

- It is important to be aware that the implementation of energy reduction measures in dwellings does not automatically lead to their inhabitants making energy savings. Taking the inhabitants into consideration is therefore a fruitful and essential approach to understanding household energy consumption and developing strategies to reduce their energy consumption.
- The design of dwellings can have unforeseen consequences for households' ability to achieve low energy consumption. In the case of the HEMS, contextual factors concerning the location, the structure of the home and the embedded housing technology (including meters), all influence a household's ability to use and save energy with the help of a HEMS.
- Details, which are sometimes perceived as nitty-gritty, can have an unexpectedly large impact and should not be neglected. Details, such as the location of sockets and technical installations, can strongly hinder the implementation HEMS and their successful use; therefore, the choice of HEMS and other energy saving technologies should be given careful consideration.
- To implement HEMS, a certain amount of retrofitting is currently often necessary, yet it is undesirable.

§ 10.1.5.2 For the HEMS industry:

From the case study setup (Ch. 5) and the reflection in Chapter 9 the HEMS industry can glean the following knowledge with regard to the implementation of HEMS.

- Complexity is detrimental to the functioning of HEMS. When the complexity of a HEMS is increased by adding functionalities, the likelihood that the whole system fails increases exponentially. Extensive testing, piloting and iterating the design of HEMS in close collaboration with users is essential.
- Keep the communication with users open and appreciate those who provide either positive or negative feedback.
- Due to the interest of HEMS users in locally produced energy, and to the increase in the amount of energy that is locally produced, energy production should be given more attention in the design of HEMS.
- The HEMS and its user need to be given more consideration in the design and choice of smart meters.

§ 10.1.5.3 For researchers:

From the case study setup (Ch. 5) and the reflection (§ 9.6.3), the following conclusions can be drawn for HEMS researchers.

- Be prepared for setbacks in the research setup: it is likely that case studies will take longer than expected.
- Having a 'plan B' and a 'plan C' for gathering energy consumption and HEMS usage data is prudent.
- Due to drop-out and technical complications, it is tactical to include many more households than strictly necessary.
- Develop a communication strategy towards participants beforehand to able to manage expectations and communicate challenges that may be encountered.
- Try to make clear agreements with the various parties involved in the process as early as possible, for example with regard to the division of tasks and the sharing and analysing of data.

§ 10.1.6 Conclusions on what design-related strategies may influence the use and effectiveness of HEMS

Household energy consumption is a complex issue. This research found that the role of HEMS in reducing the energy consumption of households is constrained. The assumption that feedback is an effective strategy to reduce the energy consumption of households in general is problematic, at least when feedback is studied or implemented in isolation. It should not be expected that implementing HEMS in households, without any consideration for, amongst others, their design, their usability, the context, accompanying interventions, and family dynamics, will achieve substantial and lasting energy savings for households. The design-related insights and guidelines that where inferred can be found in the blue text boxes in § 10.1.1–§ 10.1.4. HEMS should be seen as part of a range of energy conservation strategies, and their implementation should be given careful consideration and extensive planning.

This thesis has presented a wide range of knowledge for the HEMS industry, the building industry and HEMS researchers, and aspires to benefit these three domains:

- It has provided guidelines for the HEMS industry be able to design HEMS that are capable of influencing users, that are effective in reducing energy consumption, and that are easy to use and implement in everyday life.

- It has shown the building industry the need for and benefit of considering the behaviour of inhabitants in achieving sustainable housing transformation. It has also presented lessons in how the building industry can contribute to increasing the ease of implementation of HEMS.
- It has provided HEMS researchers with findings that they may use in future research to deepen our knowledge on the effectiveness of HEMS and to make the devices as effective as possible.

§ 10.2 Reflections

Here, three issues are addressed. The first is the choice of framework and the positioning of this research using the domain of psychology, and whether this was the best approach. The second concerns the current shifts in the marketing and development of HEMS, and the time-bound nature of this research. The third relates to the design guidelines and whether solutions for increasing the effectiveness of HEMS or reducing the energy of households should be sought in the design of HEMS or in the design of energy-using products.

§ 10.2.1 Reflections on the framework and positioning the research using the domain of psychology

§ 10.2.1.1 Relevance of the various elements and relational lines within the framework

This thesis provides empirical evidence that the relational lines and elements within the framework postulated in Chapter 1 and visualized in Figure 54, influence the use of HEMS. With regard to the influence of the relational lines and elements on the effectiveness of HEMS in reducing energy consumption, the influence of the element of time was confirmed.

That the other relational lines and elements have an impact on the effectiveness was deduced based on the use/non-use of HEMS and the challenges that were encountered, but could not be measured or quantified in energy consumption figures due to technical challenges during the second and third case studies. The need to consider the relational lines and elements within the framework when studying the use and effectiveness of HEMS has nonetheless been validated.

However, the significance of the relational lines may be dependent on circumstances, particularly for the relational lines 'HEMS <-> other products' and 'HEMS <-> other people'. These lines are dependent on the HEMS and the household involved and are not always apparent or visible. As this was an exploratory research, the relational lines and elements warrant further investigation in future research.

§ 10.2.1.2 Reflection on the framework itself and the positioning of this research

This research was initiated with the idea that human–product interaction mattered for the potential of that product to save energy. It soon became apparent that the verbatim definition of human-product interaction was insufficient and that a more encapsulated definition needed to be used. This led to an exploration of HEMS and the choice of the framework of Wever et al. and van Kuijk. Because of the time dependency of the use of HEMS, the additional element of time was added. Furthermore, in this framework HEMS were positioned as an intervention, which is based on a psychological school of thought on behaviour change. However, it may have been interesting to also explore the potential of practice theory because it transcends individual's behaviours and rather looks at practices as the unit of analysis.

A drawback of practice theory is that knowledge of specific strategies to change a certain practice is limited. Shove et al. (2012) even argue that while practices definitely change over time, wilfully influencing this change process, and in particular knowing the outcome, is challenging. This approach is still very new and it is at the forefront of design research. It is mainly geared towards policy and therefore current application in the design field is limited. As a result, it fell outside the scope of this research.

§ 10.2.2 Reflection on the development and marketing of HEMS

§ 10.2.2.1 Development of HEMS

This thesis reflects the current situation of HEMS, thereby binding the results to this era, current technology, and the Netherlands. The HEMS studied in this research were all new products that had recently entered the market; in fact, the third HEMS was introduced only as this thesis was being finalized. The technology is rapidly developing and therefore some of the mentioned issues could be passé within a couple of years. We are therefore in a period of transition. Large changes to the electricity grid are being planned and implemented. Investments in smart grids and related technologies are booming. The balance of types of energy sources, such as fossil fuels and renewable energy, are shifting, as are countries of origin. Until now, the role for HEMS has predominantly been to save energy within the home, but this is quickly changing to include peak shifting. Additionally, the local production of renewable energy is becoming more important to the use of HEMS. Therefore, a shift and an expansion in the usage of HEMS is taking place.

§ 10.2.2.2 Marketing of HEMS

HEMS were created with the goal of helping households reduce their energy consumption or shift their energy consumption to a different point in time. Yet as time progresses, and perhaps in part due to setbacks in achieving this goal, certain HEMS companies have stopped developing HEMS that are specifically intended to save energy. Rather, some have started to focus on giving a central information point or insight. In some cases, the energy saving goal simply became snowed under, but the marketing and positioning of HEMS seems to be a larger contributing factor. Although this research did not focus on the marketing and positioning of HEMS, the close cooperation and diverse contacts with industry seem to indicate that the marketing and positioning is not always straightforward. Two major global players – Google and Microsoft – discontinued this line of business while the present research was being conducted. As customers may be wary of paying for a device that is only intended to reduce their energy bill, different marketing strategies are being devised. However, there seems to be a risk inherent to certain marketing strategies. What may start as merely a marketing strategy to position a HEMS as a product to provide customers with insight, may soon metamorphose into developing a product capable of only doing that. While marketing a product need not focus on its energy saving intent, developing a product to save energy requires focusing on that goal throughout the development, including further development throughout the use phase of the product.

There is a real danger that the erosion of this goal will result in a situation whereby we have merely added yet another piece of technology to our already tech-filled homes. This could lead to an increase in total energy consumption rather than energy reductions, as was calculated in Chapter 8. This leaves us with an unsettling question: in the long run, will HEMS actually contribute to an overall decrease in energy consumption on a global scale?

§ 10.2.3 Reflection on the design of energy-using products

This thesis has been geared towards improving the use and effectiveness of HEMS. As such, the insights and guidelines are aimed at the design of HEMS. However only so much can be achieved in the design of HEMS, and in certain cases a more straightforward and less cumbersome solution is at hand in, for example, the design of appliances and technical installations. This is especially the case concerning the baseline consumption of households and the reduction thereof. Feedback can make households aware of this consumption, but it is up to the user to act on this, which regularly does not happen. An energy management device can potentially assist in automatically powering appliances off when not in use, but a more straightforward and transparent solution lies with the appliance or technical installation itself.

Examples of guidelines that can be formulated concerning energy-using products are:

- Designers should strive to decrease the consumption of energy-using products and, in particular, their standby consumption as far a possible,
- Designers should enable the complete powering off of appliances, prevent malfunction, and reduce the need to adjust or reset (time) settings when appliances are turned on again. Malfunction, for example, may occur with digital set-top boxes after a long holiday.
- Energy-efficient power setting of energy-using products should be simplified and easily accessible or made the norm.

§ 10.3 Recommendations

This has largely been an exploratory research on HEMS and therefore recommendations for the future are in place. This thesis therefore concludes by making recommendations for the various disciplines involved in this research, namely housing, the HEMS industry and researchers.

§ 10.3.1 For housing and the building industry

This thesis has highlighted the importance of understanding and collaborating with inhabitants in order to gain insight into the energy consumption of households, factors influencing that consumption and ways of attaining energy reductions. However, during the workshop and in communications with the buildings industry, it surfaced that there still seems to be a tendency to design around the user, or remove the user from the equation. Additionally, expectations were voiced that technique will solve the energy reduction challenge. However, the challenges documented in this thesis seem to indicate that this is too optimistic.

Attention to inhabitants, their behaviours, and their use of their homes and technical installations needs to become more ingrained in the field of housing and the building industry. While a user-centred design approach and usability testing is relatively common in the field of industrial design engineering, post-occupancy evaluation is not the norm in the housing industry and instead is mainly practiced on the margins. The application of user-centred design approaches and post-occupancy evaluations and the knowledge that is gleaned through this process need to be disseminated within this industry to achieve more effective designs and greater energy reduction.

§ 10.3.2 For the HEMS industry

The extensive contacts with HEMS users during this research resulted in insights into improving the design and potentially the effectiveness of HEMS, but it also drew attention to the need to take a user-centred approach and collaborate with users in the design of HEMS. The gap between current HEMS and users' needs and desired utilization of HEMS needs to be bridged, for which collaboration with users is an essential strategy. The avenues for increasing the effectiveness of HEMS suggested in this thesis need to be explored. It is important to test, pilot and iterate the design of HEMS even more extensively in a natural and realistic setting, to prevent malfunction in the field. However, it is also important to find a balance between the interests that are at stake.

Furthermore, a number of challenges need to be overcome in order to increase the use and effectiveness in homes. The technical look and feel that is common to HEMS needs to be adjusted to make HEMS appealing to more households. Even more so, the technical challenges that are common to HEMS need to be overcome. Complexity is detrimental to the functioning of HEMS. When dealing with existing housing and multiple types of energy and linked appliances or technical installations, the chances that one element in the system does not function properly increase exponentially, thereby jeopardizing the whole system. Because of the likelihood of encountering challenges during the implementation of HEMS, keeping the communication lines with users open and also appreciating those users who complain are essential to improving the design of HEMS. Smart meters are a crux, and in designing them more consideration should be given to the needs of households in relation to energy management, especially with the emergence of local renewable energy sources. Interest in self-sufficiency or the local production of energy and HEMS, seems to be a natural combination to which HEMS should be better suited.

§ 10.3.3 For researchers

Longitudinal qualitative and quantitative research is of essence to make a correct assessment of the effectiveness of HEMS. Consideration needs to be given to the aspects within the framework of this research (Figure 54). Future research needs to measure, quantify and compare the influence of the various factors to assess which factors are most significant to the use and effectiveness of HEMS and thus need to receive the highest priority. Due to the challenges encountered during the second and third case studies, quantified measurements on the extent to which the factors contribute to the use and effectiveness of HEMS were limited to the first case study. Lastly, in the study of HEMS, joint cooperation with industry has decisive benefits. However, considerations need to be given to the potential pitfalls that were addressed in this thesis and the necessary precautions need to be taken.

Curriculum vitae

Sonja van Dam was born on December 20th 1981 in Ware, England. She grew up in the Philippines and returned to the Netherlands when she was 14 years old to finish her secondary schooling at the Dhr F.H. De Bruijne Lyceum in Utrecht, graduating in 2000. She obtained both her bachelor's degree in Industrial Design Engineering as well as her master's degree in Design for Interaction at the Delft University of Technology, graduating in 2006 on "the cycling experience" at Koga. After having worked at Exact Software and the Cartesius institute, she commenced her PhD research in 2008 on the topic of smart energy management for households. In particular, she has studied the effectiveness of home energy management systems, their usability and how they are incorporated into people's daily lives. She is currently a guest researcher at the Delft University of Technology, living and working in Laos.

List of publications

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A I Opzet gebruiksonderzoek case studie 3

Eneco heeft in samenwerking met Home Automation Europe een display ontwikkeld die drie basisfunctionaliteiten heeft: Programmeerbare thermostaat, CV beheer en energie beheer. Per 1 april zal de prototype live onder 100 huishoudens getest worden voor 1 jaar. Om echter tot bruikbare uitkomsten van de veldtest te komen is een usability studie geadviseerd. Doel ervan is om mogelijke usability problemen met de display boven water te krijgen en op te lossen voordat het display in het veld wordt uitgezet. De display heeft de volgende mogelijkheden welke grotendeels getest zullen worden tijdens de gebruiksonderzoek.

Protocol

Welkom!
Wilt u een kopje koffie of thee?
U krijgt zo meteen een display met een thermostaat functie en energieverbruik te zien.
Ook vind u een aantal huishoudelijke apparaten in de kamer hiernaast. Het doel is het testen van de display
Wij gaan u vragen om een aantal opdrachten met de display en de apparaten uit te voeren.
Vind u het goed dat wij de opname materiaal (vertrouwelijk) gebruiken voor wetenschappelijk onderzoek en intern presentaties? U zal hierbij niet herkenbaar in beeld gebracht worden. Zou u dan dit formulier willen tekenen?
Zou u willen proberen om te volgende taken zelfstandig uit te voeren? Mocht het echt niet lukken dan kunt u mij om hulp vragen.
Het is niet erg als er wat fout gaat!
Zou u bij de volgende vragen hardop na willen denken?
Taak van facilitator toelichten: Aantekeningen maken van wat er gebeurt
Staat zijn of haar telefoon uit?
Nog vragen alvorens we starten?
Onderzoeker loopt samen met gebruiker naar de andere ruimte en stopt voor het display.
Dit is het display dat we vandaag gaan onderzoeken.
Onderzoeker legt de algemene opdracht uit..

Opdrachten

Algemene opdracht

Zou u het scherm aan willen raken en kort uit proberen? Wilt verwoorden wat u op het scherm ziet?
Stelt u zich voor: U gaat even een paar uur weg en wilt de verwarming even lager zetten. Zou u dit uit willen voeren?

Aanvullende opdrachten

Voor het geval dat sommige functionaliteiten niet ontdekt of gebruikt zijn tijdens de algemene opdracht worden eventueel een of meerdere van de volgende opdrachten uitgevoerd

Temperatuurschema instellen
U wilt de temperatuur voor een aantal dagen programmeren. Zou U in de display het programma willen instellen zoals op de volgende bladzijdes staat aangegeven?
Zondag:
vóór 9:00 de verwarming op 17°C
van 9:00-22:30 uur op 20°C
daarna op 17°C.
Maandag en dinsdag:
vóór 7:00 op 17°C,
van 7:00-8:30 op 20°C,
van 8:30-16:45 op 15°C,
van 16:45-22:00 uur op 20°C
daarna op 17°C.
Woensdag:
U bent vrij en wilt u hetzelfde programma als zondag.
Kunt u controleren of u de temperaturen op de dagen correct heeft ingesteld?

Temperatuur
U komt vandaag vroeger thuis dan normaal. U vindt het koud. Hoeveel graden is het momenteel volgens de display?
Zou U vervolgens de temperatuur 1 graad kunnen verhogen?

Gas

Stel U hoort de ketel aanslaan en U bent benieuwd hoeveel uw gasverbruik is op het moment dat de ketel aanslaat. Zou u dit op willen zoeken?
Na het bekijken van je momentaan gebruik raakt U geïnteresseerd wat het verbruik van de afgelopen week was. Zou u dit op willen zoeken in de display?

Elektriciteit
Iemand is net met vieze schoenen binnen gelopen en u wilt het even stofzuigen. Zou u dit willen doen?
Na het stofzuigen heeft U zin in en kopje thee en U zet de waterkoker aan.
U vraagt zich daarbij af hoeveel elektriciteit U op dit moment verbruikt. Kunt dit opzoeken in de display?
Kunt u opzoeken wat u de afgelopen dag in totaal heeft verbruikt? Kunt U uitleggen wat u ziet?

Vakantieschema instellen
U bedenkt zich dat U volgende week zondag een week op wintersport gaat.
Wilt u alvast in stellen op het display dat de temperatuur tijdens U vakantie op 6 graden staat?

vragen achteraf over observaties

invullen vragenlijst

- einde -

A II Opzet Focusgroepen case studie 3

Het doel van de focusgroepen is het ontdekken van de behoeftes van huishoudens zijn betreffende het gebruik van energie in huis en het besparen daarop. In lijn hiermee is de intentie om diepgaande, kwalitatieve kennis op te doen over de ervaringen van huishoudens met het implementeren van de HEMS en hoe het geïntegreerd wordt in hun dagelijkse leefpatronen. Dit heeft een tweeledige uitwerking. Ten eerste kunnen nieuwe ideeën voor een HEMS ontwikkeld worden. Ten tweede kan ook inzicht verkregen worden over hoe dit type nieuwe technologie in huishoudens worden geaccepteerd en wat de uitwerking daarvan is op het verduurzamen van huishoudens (en de conclusies die daaruit getrokken kunnen worden).

Algemene opzet focusgroepen

In elke focusgroep ronde zullen 2 focusgroepen plaatsvinden, en voor elke focusgroep zullen 7-8 participanten uitgenodigd worden. De focusgroepen zullen 's avonds plaats vinden om de werkschema's van deelnemers te respecteren en zo een verhoogde response-rate tot stand te brengen. Ze zullen plaats vinden in een van de Labs op IO zodat video opnames gemakkelijk en unobtrusive gemaakt kunnen worden. Er zal echter wel bij aanvang van de focusgroep aan de participanten verteld worden dat er opnames plaats zullen vinden met de vraag of ze een contract willen ondertekenen waarin staat dat ze hier geen bezwaar tegen hebben.

Om de focusgroepen in goede banen te leiden zullen er twee mensen aanwezig zijn gedurende de avond: een facilitator en een observator. Daarnaast zal iemand in de regiekamer aanwezig zijn om de video opnames in de gaten te houden en koffie te serveren tijdens de pauze. De focusgroep zelf zal twee uur voor uitgetrokken worden: van 19 tot 21 uur (incl koffiepauze)

Opzet: eerst een 'ice breaker' om mensen op hun gemak te stellen (kort spelletje)

dan 2-3 opdrachten (afhankelijk van de lengte) waarbij deelnemers worden gevraagd om iets te maken (of uit te kiezen) en aansluitend te vertellen waarom ze dat zo hebben gemaakt/gedaan. Het voorwerp dat ze maken/kiezen is van ondergeschikt belang op wat ze erbij vertellen en het gesprek die daarbij op gang komt. De intentie is om daaruit juist dieper liggende motivaties, behoeftes, en waardes te ontdekken.

Opzet focusgroep 1 over elektriciteit en eerste gebruik HEMS

Het doel van de eerste focusgroep is om inzicht te krijgen de eerste fase van gebruiken van de display en het gebruik van elektriciteit

Sensitizing tool (vooraf toegestuurd aan deelnemers) (16 stuks)

Een week voor de eerste focusgroep ronde zullen deelnemers een pakket thuisgestuurd krijgen door Eneco met een setje van 7 opdrachtkaarten om ze alvast over het onderwerp na te laten denken ('sensitizing'). Op elke kaart staat een korte op opdrachten waarvan ze er een per dag in mogen vullen. Naast de kaarten ontvangen ze een korte uitleg en een aantal stickervellen, die ze kunnen benutten bij het invullen. Er wordt gevraagd of ze de kaarten mee willen nemen naar de focusgroep. Inhoud

- Begeleidende brief
- Transparant A5 envelop met 7 opdracht kaarten en een profielkaart erin.
- stickervellen met plaatjes
- Stickervel met emoticons
- Stickervellen met rondjes
- Routebeschrijving en plattegrond

Protocol

Kopje koffie/koekje aanbieden
Welkom en uitleg avond en rol onderzoekers
Om de avond achteraf te kunnen analyseren zou zij jullie toestemming willen vragen om video opnames van de avond te maken. Als jullie hiermee akkoord zijn, zouden jullie dan dit formulier willen ondertekenen? Jullie komen hiermee niet op televisie o.i.d.! Het vergemakkelijkt alleen de analyse achteraf.
Het doel van vanavond is om inzicht te krijgen in jullie ervaringen met de display en hoe jullie het gebruiken. Daarom heeft u van te voren een pakketje ontvangen met een aantal opdrachtkaarten.
Klopt dit? Is het gelukt om ze in te vullen? Heeft iedereen ze bij zich? OK dat is mooi (afhankelijk van het antwoord!).
Wij zouden graag vanavond verder op de opdrachtkaarten in willen gaan. Zoals ook in de brief stond: Jullie kunnen vanavond niks verkeerd doen of zeggen! Er zijn dan ook geen verkeerde antwoorden mogelijk! Jullie zijn de experts vanavond: Jullie hebben namelijk het product gebruikt en ervaren, en daar zijn wij benieuwd naar!

Maar om even eerste te beginnen met iets ontspannend: Op jullie profielkaart mochten jullie je favoriete product opschrijven.
Icebreaker: Wat ben ik?
Opdrachten

Opdracht 1

- Wat vinden jullie van de Display?
- Twee weken geleden hebben jullie een nieuwe software installatie gekregen. hoe bevalt de nieuwe update/release?
- De informatie die de gas- en elektriciteitsiconen (widgets) op de startscherm vertonen is verandert. Is dit jullie opgevallen? Hoe bevalt dit?
- Terugkomend op de opdrachtkaarten: Als we die er nu bij halen: Welke opdracht viel u het meest op?
- In de opdrachtkaarten die u afgelopen week heeft ingevuld heeft u aangegeven op welke momenten van de week u naar de display keek.
- Kunt u laten zien op welke momenten u hem gebruikte en waar u hem voor gebruikte? (waar keek u naar) (korte discussie)
- Wie gebruikt de display bij jullie in huis?

- Pauze -

Opdracht 2

- Net hebben wij gevraagd hoe u de display gebruikt van dag tot dag bij u thuis. Nu willen we een stap verder gaan: Gelet op jullie gezins situatie: Wat zou voor jullie de ideale manier zijn om u energiegebruik onder controle te houden en energie te besparen? Kunnen jullie hiervoor 10 minuten nemen om jullie gedachten op papier te zetten? Voor de creatievelingen: wel hebben allerlei materialen tot jullie beschikking die jullie kunnen helpen om jullie gedachten op papier te zetten.
- Bedenk wat voor u de 3 belangrijkste elementen zouden zijn
- Daarnaast kunnen de volgende vijf vragen u helpen (deze liggen op tafel)
  - Hoe zou u willen besparen in huis?
  - Op wat voor manier zou u inzicht willen krijgen in uw energie verbruik?
  - Welke rol speelt uw gezinssituatie of leefpatroon?
  - Wat voor product zou in uw situatie kunnen helpen?
  - Hoe zou het product het beste passen in uw situatie?

- Op tafel ligt een opzetje die u mag gebruiken. Als u wilt kunt u ook een blanco vel gebruiken of met de andere materialen aan de slag.(er zullen een diverse samenstelling aan materialen aangeleverd worden om de collage mee te maken variërend van lampjes, slingers, touw tot plaatjes van onderdelen). Als u klaar bent mag u dit ook kort presenteren. (zelfde wijze als opdracht 1)

Opdracht 3:

Als u de volgende voorbeelden van bestaande Energie management/besparings producten ziet:

- welke zou u uitkiezen? Kunt u uitleggen waarom? (geef 3 redenen)
- Welke zou u juist niet uitkiezen? Kunt u uitleggen waarom?

Iedereen zal bedankt worden en een tegoedbon overhandigd worden. Ook zullen ze gevraagd worden of ze mee zouden willen doen aan het vervolg.

- Einde -

Opzet focusgroep 2 over gas

Protocol

Introductie (5 minuten)
Welkom, uitleg onderzoeksdoel
De eerste focusgroep ging over hoe u het gebruik van de display ervaarde.
Vanavond willen we het de eerste gedeelte van de avond specifieker hebben over uw gas verbruik en factoren die daarop van invloed zijn.
Daarna willen wij gedurende de tweede helft van de avond een nieuw concept aan u presenteren. Het doel is om te ontdekken of het concept aansluit op uw wensen en hoe wij het verder kunnen verbeteren
Uitleg onderzoekssituatie (rapportage, anonimiteit) en verzoek om vrijuit te spreken (er zijn geen foute antwoorden) en eigen, ongezouten, mening te geven
contract
Voorstellen: leeftijd, gezinssituatie, dagelijkse werkzaamheden, hobby's etc.
Icebreaker
Opdrachten

Deel 1: Vragen uurtje

We zouden willen beginnen met een aantal vragen:

- Weet u wat uw gasverbruik was in het afgelopen jaar?
- Heeft u enig idee of dit hoog of laag is?
- Heeft u een huurhuis of koophuis?
- Heeft u in het verleden maatregelen in uw huis genomen om uw energielasten te verlagen?
- Zo ja, wat voor maatregelen waren dit en wat was de uitwerking?
- Wat was de aanleiding om de maatregelen te nemen?
- Heeft u nog plannen om maatregelen te nemen? Wat voor plannen?
- Is er iets dat u hindert om u plannen uit te voeren?
- Hebben de statistieken in de display over uw gasverbruik in het verleden u inzicht gegeven? Zo ja, wat voor inzicht?
- Zou de display een rol kunnen spelen in het verlagen van uw energielasten?
- Zou de display verandert kunnen worden om u beter op weg te helpen om uw huis te verbeteren/lasten te verlagen?

Deel 2: Presenteren concepten

- Uitleg nieuwe concept
- Alle waaiers tonen van het concept
- Ook de waaiers van de huidige dislpay tonen ter referentie
- Mensen 15 minuten de tijd geven om de waaiers door te kijken en te bediscussieren
- Mensen vragen om met stickervellen een startscherm te maken
- Ze mogen ook met lege stickervellen een alternatief voorstellen

Terugkomen op vragen voor de pauze

- Denkt u dat de nieuwe concept u beter zou kunnen helpen in het inzicht krijgen in uw gasverbruik?
- Zijn er nog aspecten die verbeterd zouden kunnen worden?

- Einde -

A III Opzet interviews case studie 2 en 3

Protocol

Hallo, Ik ben Sonja van Dam.

Ik werk bij de TU en ben bezig met een 4 jarig onderzoek naar producten die mensen inzicht geven in hun energieverbruik. Ik ben vooral benieuwd naar hoe mensen dit soort producten gebruiken (of juist niet gebruiken!) in hun dagelijks leven en wat ze ervan vinden.

Dit interview is bedoeld als een open interview. Ik ben benieuwd naar jullie ervaringen en zou het leuk vinden als jullie mij daar wat meer over kunnen vertellen. Je mag wat mij betreft open en eerlijk zijn: Ik hoor graag de positieve en negatieve verhalen. Het zal ongeveer 1 uur in beslag nemen.

Ik heb eventueel een aantal vragen maar die zijn vooral bedoeld om eventueel het gesprek op gang te houden. Ik wil jullie ook de gelegenheid geven om zelf vragen te stellen maar zouden jullie die tot het einde kunnen bewaren?

De informatie die jullie mij vandaag vertellen zal geanonimiseerd worden. Jullie zullen niet met naam en toenaam genoemd worden! De resultaten van de interviews zal ik intern presenteren bij … maar het kan zijn dat ik de resultaten en bepaalde citaten gebruik in wetenschappelijk presentaties en publicaties. Zouden jullie daarom dit contract willen ondertekenen dat jullie geen bezwaar hebben voor het gebruik van de resultaten? Vinden jullie het ook goed als er geluidsopnames worden gemaakt van de interview? Mochten jullie later nog vragen hebben dan kunnen jullie contact met mij zoeken via dit adres (overhandig business card)

Zijn er nog vragen van jullie kant?

Vragen interview 2e case study

Algemene vragen (afhankelijk van of deelnemers wel of geen eee-top hebben)

- Wat was u motivatie om deel te nemen?
- Wat waren uw verwachtingen toen u aan de test mee ging doen?
- Wat vindt u van Energy management device in het algemeen?
- Kunt u mij laten zien waar het scherm nu hangtwaar P.C. staat?
- Waarom heeft u hem daar opgehangen?
- Nu u hem daar een aantal weken heeft hangen, bent u tevreden met de locatie? (Vindt u het de meest geschikte locatie?)
- Hoe ervaart u de aanwezigheid van het scherm/Energy management device in uw huis?
- Hoe vaak gebruikt u het Scherm/ Energy management device?
- Op welke momenten gebruikt u het scherm/Energy management device?
- Wat is de reden dat u het op die momenten gebruikt?
- Is uw gebruik van het scherm verandert in de afgelopen weken? Op wat voor manier is dit veranderd?
- Wat vindt u van de interface?
- Wat vindt u van het gebruiksgemak? (Kunt u dit verder uitleggen?) (kunt u dit op het scherm laten zien?)

Functionaliteiten en gebruik

- Welke apparaten heeft u momenteel aangesloten op de pluggen? (kijk ook op het scherm)
- Waarom heeft u ervoor gekozen om juist die apparaten aan te sluit? (in een interview willen mensen weleens hier meer over uitweiden)
- Heeft u verschillende apparaten aangesloten of uitgeprobeerd op de pluggen?
- Wat was de reden dat u wel/niet verschillende apparaten uitprobeerde?
- Kunt u mij vertellen wat u het meest opviel aan het energieverbruik van de aangesloten apparaten?
- Zou u kunnen vertellen hoe u Energy management device voor het eerst gebruikte? Wat deed u ermee?
- Hoe lang duurde het voordat u Energy management device aansloot en hoe kwam dit?
- Na twee weken mocht u gaan schakelen. Hoe ging dit?
- Hoe bevalt de schakelschema functionaliteit?
- Als we naar het huisenergie systeem kijken en de schema's die zij ingesteld: kunt u uitleggen waarom u ze zo heeft ingesteld?
- Heeft u de schakelschema's aangepast of verwijderd nadat u ze ingesteld heeft?
- Denkt u dat de schakelschema's invloed hebben (verschil uitmaken) op uw energieverbruik? Wat voor invloed?

- Maakt u gebruik van de mogelijkheid om via het scherm een of meerdere apparaten tegelijkertijd aan of uit te zetten? Hoe bevalt dit?
- Denkt u dat deze aan/uit functie invloed heeft op uw energie verbruik?
- Wat vindt u de meest nuttige functionaliteit? Waarom?
- Wat vindt u de minst nuttige functionaliteit? Waar ligt dit aan? Kunt u een situatie voorstellen waarbij u die functionaliteit wel nuttig vindt?
- U zou zich kunnen voorstellen dat de huis energie systeem ook toegankelijk is op andere wijzen dan via het scherm. Als u kijkt naar hoe u het huis energie systeem gebruikt en de tijdstippen waarop u dat doet, vindt u de scherm de meest toegankelijke of logische plek?
- Mist u iets? Wat mist u dan?

Energie verbruik

- Hoe bewust zou u uzelf noemen als het gaat om energie verbruik en besparing?
- Was u bewust bezig met energie voor u Energy managment device kreeg
- Wist u uw stroomrekening of stroomverbruik?
- Geeft Energy managment device u inzicht in uw elektriciteitsverbruik? Wat voor inzicht?
- Bent u een gedrag of gewoonte aan gaan passen naar aanleiding van dit inzicht?
- Wie gebruikt Energy managment device het meest in uw gezin?
- Hoe komt dat/Is daar een bepaalde reden voor?
- Heeft u het gevoel dat u iets kunt met de informatie die Energy managment device aanlevert?
- Heeft u voor u gevoel dat u genoeg controle heeft over uw energieverbruik? Is dit meer dan voordat uw energy managment device gerbuikte?

Netbeheerder

- Hoe ziet u de rol van de netbeheerder in dit verhaal?
- Vindt u energy managment device bij de rol van netbeheerder passen?
- Denkt u dat een andere partij geschikter is om dit product aan te beiden?

Achtergrond

- Ik had nog een paar achtergrond vragen:
- Wat voor een achtergrond of opleiding hebben jullie?
- Wat voor werk doet u/doen jullie?
- Mag ik nog zo bot zijn om te vragen naar uw beider leeftijden?
- Wat is uw gezinssamenstelling?
- Type huis/oppervlakte?
- Dank u wel voor uw tijd? Wat was u indruk van de interview?

Vragen interview 3e case studie

- Wat was u motivatie om deel te nemen?
- Was er een specifieke aanleiding?
- Wat waren uw verwachtingen toen u aan de test mee ging doen?
- Wat vindt u van de display in het algemeen?
- Kunt u mij laten zien waar de Display nu hangt?
- Waarom heeft u hem daar opgehangen?
- Bent u tevreden met de locatie? (Vindt u het de meest geschikte locatie?)
- Hoe vaak gebruikt u de Display?
- Op welke momenten gebruikt u het Display?
- Wat is de reden dat u het op die momenten gebruikt?
- Is uw gebruik van het Display verandert in de afgelopen periode? Op wat voor manier is dit veranderd?
- Is er verschil in hoe verschillende hoe uw familieleden de display gebruiken?
- Wie gebruikt De Display het meest in uw gezin?
- Wat vindt u van de interface?
- Wat vindt u van het gebruiksgemak? (Kunt u dit verder uitleggen?)

Functionaliteiten en gebruik

- Kunt u mij vertellen of een bepaalde energieverbruik opviel?
- Wat vindt u de meest nuttige functionaliteit? Waarom?
- Wat vindt u de minst nuttige functionaliteit? Waar ligt dit aan?
- U zou zich kunnen voorstellen dat de huis energie systeem ook toegankelijk is op andere wijzen dan via de Display. Als u kijkt naar hoe u het huis energie systeem gebruikt en de tijdstippen waarop u dat doet, vindt u de Display de meest toegankelijke of logische plek?
- Mist u iets? Wat mist u dan?
- Energie verbruik
- Hoe bewust zou u uzelf noemen als het gaat om energie verbruik en besparing?
- Was u bewust bezig met energie voor u De Display kreeg?
- Wist u uw stroomrekening of stroomverbruik?
- Geeft de Display u inzicht in uw elektriciteitsverbruik? Wat voor inzicht?
- Bent u een gedrag of gewoonte aan gaan passen naar aanleiding van dit inzicht?
- Hoe ervaart u het proberen aan te passen van uw energieverbruik?

Gezinsdynamieken en energieverbruik?

- Hoe komt dat/Is daar een bepaalde reden voor?
- Heeft u het gevoel dat u iets kunt met de informatie die De Display aanlevert?
- Heeft u voor u gevoel dat u genoeg controle heeft over uw energieverbruik? Is dit meer dan voordat uw de Display gerbuikte?

Achtergrond

- Wat voor een achtergrond of opleiding hebben jullie?
- Wat voor werk doet u/doen jullie?
- Wat is uw gezinssamenstelling?
- Dank u wel voor uw tijd? Wat was u indruk van de interview?

A IV Opzet concept test case studie 3

Opzet:

Tussen 6 en 9 december vond in een observatie ruimte op de faculteit IO in Delft het gebruikersonderzoek plaats. Om het inlevingsvermogen van gebruikers te bevorderen waren een aantal huishoudelijke voorwerpen in de ruimte geplaatst worden (bvb bank, stoelen een tafeltje, r).

De usability test maakte gebruik maken van wizard of oz technieken. De interface was opgebouwd uit screenshots en bepaalde situaties waren gesimuleerd.

In de ruimte waren twee camera's geïnstalleerd in het plafond. De eerste camera was op het display/papieren mock-up gericht zijn om handelingen op het scherm/mock-up te kunnen volgen. De tweede camera was op de gezicht van de gebruiker om gezichtsexpressies op te kunnen vangen. Tevens was een onderzoeker aanwezig die, samen met de gebruiker aan tafel zat of achter de gebruiker zat tijdens de interactie met de display. Zij observeerde de gebruiker en noteerde tijdstippen van relevante gebeurtenissen.

Bij aankomst werden gebruikers buiten de testruimte door een tweede onderzoeker ontvangen. Gebruikers werden direct de testruimte binnengeleid en werden daar een kopje koffie/thee aangeboden.

Gebruikers kregen een vergoeding van €20 euro voor het deelnemen aan het onderzoek en het reizen naar de testlocatie. Voor de aanvang werd uitleg gegeven over het onderzoek, hun rechten en werden ze gevraagd of ze er akkoord me gingen dat er opnames plaats vonden. Gebruiker werden tevens gevraagd om bij de taken hardop na te willen denken. Voor elke observatie was een uur voor uitgetrokken.

Gedurende de eigenlijke observatie onderzoek werden direct tijdstippen genoteerd worden waarop interessante interacties plaats vinden. Gebruikers werden aan het einde een aantal vragen gesteld en kregen de mogelijkheid om aanvullende opmerkingen te plaatsen.

Om de verschillende vragen te beantwoorden bestond het usability onderzoek uit 2 delen. Deel 1 had als doel te achterhalen hoe de gebruiksvriendelijkheid van de interface werd ervaren. In dit onderdeel voerden de deelnemers en aantal handelingen uit met de display.

Deel 2 behandelde welke iconen mensen begrepen, prefereerden en als functionaliteit in de display zouden willen hebben. Hierbij zat de gebruiker aan tafel een met papieren mock-ups voor zich.

Deel 1

Voor deel 1 werden deelnemers gevraagd worden om de display uit te proberen. Hierbij werd verteld dat de display op dit moment niet geheel werkend was maar dat we ze al vast een eerste indruk wilden geven. Mensen kregen de gelegenheid krijgen om de verschillende functionaliteiten op het startscherm te ontdekken. Vervolgens kregen ze 6 opdrachten op A5 vellen naast het display. Hierin werd een fictieve dag (4 december) in de leven van de gebruiker omschreven met de vraag om een aantal functionaliteiten van de display te ontdekken. De opdrachten waren als volgt.

Opstaan

Het is zaterdag 4 december. U heeft vandaag vrij. De rest van de familie is op stap en u heeft het huis voor uzelf. Heerlijk! Maar er staan nog wel een aantal dingen op de agenda. U staat om 9 uur op, doucht en maakt uw ontbijt klaar.

Als u voorbij u zoons kamer loopt ziet u dat zijn computer aan staat terwijl hij al vroeg vertrokken is. U vraagt zich af of deze de hele nacht heeft aangestaan en kijkt op de display wat u verbruik het afgelopen nacht was. Kunt u dit vinden?

Koffietijd

U heeft zin in en kopje koffie en u zet de Senseo aan. U vraagt zich daarbij af hoeveel elektriciteit u op dit moment verbruikt. Kunt dit opzoeken in de display?

Even weg

U gaat om 2 uur weg om de laatste sinterklaas boodschappen te doen en u kijkt even hoe laat het is op de display.

U vindt dat de verwarming laag mag terwijl u weg bent. Hoeveel graden is het momenteel volgens de display? En wat is de ingestelde temperatuur? Kunt u instellen dat u weg gaat en de verwarming op 15 mag?

Thuiskomst

Bij thuiskomst zet u de verwarming weer aan.

U bent benieuwd hoe uw totale verbruik zich verhoud tot die van uw buren. Kunt u dit opzoeken? Is uw verbruik hoog of laag in vergelijking met anderen? Hoe is dit de afgelopen dagen geweest?

Douchen

S 'avonds eet u met het hele gezin. Na het eten gaat u alleen sporten en u komt om 21 uur thuis. U hoort dat uw dochter van 16 onder de douch staat. Zij maakt er een gewoonte van om lange douches te nemen en u bent benieuwd hoe lang zij er al onder staat. Kunt u dit vinden?

Dag afsluiting

Om 23 uur gaat u naar bed. U kijkt nog even op de display of u elektriciteitsverbruik gezakt is en dat er niks onnodig aan staat. Kunt u vinden wat u huidig verbruik is?

U vraagt zich af hoe lang de verwarming aan heeft gestaan gedurende de dag. Kunt u dit opzoeken? Ziet u een effect van het uitzetten van de verwarming toen u 's middags tussen 2 en 5 uur weg was? Hoeveel heeft u verbruikt gedurende die tijd?

Deel 2a

De mock-ups bestonden uit een x-aantal 'waaiers' (zie figuur 2): een voor elke mogelijke widget op het startscherm. Elke waaiers bestond uit een aantal kaarten die in een hoek aan elkaar vast zaten met behulp van een pin. De bovenste 3 kaarten van de waaiers met een elk formaat van c.a. 6x6 cm (= 4x zo groot als normaal: bijna 3x3 cm) verbeelde 3 verschillende standen van een knop op het startscherm. Daaronder zat een blanco vel van 12x16 cm. Onder de blanco vel bevond zich de onderliggende scherm(en) waar de gebruiker in terecht zou komen als hij op de desbetreffende widget zou drukken (formaat 12x16 cm). De oude widgets waren ook vertegenwoordigd. Alle waaiers werden op willekeurige volgorde voor de deelnemers neergelegd.

Figure 55
Waaiers gebruikt voor opdracht 2 tijdens concept testing.

Deelnemers kregen de vraag om de verschillende waaiers te bekijken en diegenen uit te kiezen die ze op de display zouden willen hebben. Door de waaiers dicht te klappen konden ze een overzicht creëren van de iconen die dan op het startscherm zouden verschijnen. Niet alle schermen achter alle knoppen waren uitgewerkt. De thermostaat en file informatie waren bvb niet geheel uitontwikkeld, maar gaven een impressie van de mogelijkheden. Na afloop van elke observatie werden de waaiers gerandomiseerd.

Deel2b

Deelnemers ontvingen daarna een stickervel waarop stickers van alle knoppen stonden. Hier konden ze hun gekozen functionaliteiten afhalen en ze vervolgens in de gewenste volgorde op een papieren display op A3 formaat plakken.

Vragenlijst

Kunt u voor de volgende stellingen aangeven in hoeverre u het met deze stellingen eens bent?

1= Geheel mee eens tot 5= geheel mee oneens

- Ik ben voortdurend actief op zoek naar nieuwe technieken en technologieën
- Als er wat nieuws op de markt komt kijk ik altijd of het wat voor mij is
- Ik houd de ontwikkelingen in de gaten en sta open voor nieuwe technieken en technologieën waar door anderen al goede ervaringen mee zijn opgedaan
- Pas als het min of meer noodzakelijk is om een nieuwe techniek of technologie te gaan gebruiken, zal ik het product aanschaffen
- Ik maak nauwelijks gebruik van nieuwe technieken of technologieën
- Ik vind mijzelf technisch aangelegd
- Ik houd mijn energieverbruik schriftelijk bij of heb dit in het verleden wei eens gedaan
- Ik vind het analyseren van data leuk om te doen
- Ik ben het meest geïnteresseerd in duurzaamheid in mijn huishouden
- Van alle mensen in mijn huishouden let ik het meest op de kosten in mijn huishouden.
- Ik attendeer andere mensen in mijn huishouden regelmatig op hun energie verbruik
- Ik erger mij eraan als andere mensen in mijn huishouden lichten/apparaten aan laten staan
- Ik erger mij eraan als andere mensen in mijn huishouden te lang onder de douch staan

- Ik vergeet regelmatig lichten en apparaten uit te doen
- Mijn Energieverbruik interesseert mij niet
- Ik heb moeite om wetenschappelijke termen zoals kWh, m3, C02, etc. te begrijpen
- Ik ben gemakzuchtig als het op energie kosten aan komt
- Ik vind de vormgeving van het display en de interface erg belangrijk
- Ik ben erg van de details
- Ik vind het prettig om overzicht te houden

- Wat is uw leeftijd:...
- Wat is uw Geslacht:...
- Wat is uw beroep:...
- Wat is uw hoogst genoten opleiding:...
- gezinssamenstelling...
- Kinderen?...
- Analoog/slim of geen pilotdeelnemer...

A V Details participants case study 2&3

Partici-pant code	Degree and job	age	gender	Kids?	Partici-pant code	Degree and job	age	gender	Kids?
1MFufc	MSc/marine technology SAH mom	44	F	Y	26MFSf	BA	45	sM	Y
2MFu	MSc/industrial designer	28	F	N	27MFc	BA/telecommunication technician	60	M	Y?
3MFu	MSc/lecturer		M	Y	28MFAc	BA/staff member	26	M	N?
4MFuf	BA/trainer	36	M	N	29MFc	BA/content and online manager	39	M	Y
5MFu	BA/SAH mom	41	F	Y	30MFc	VET/manufacturing engineer	60	M	Y
6MFu	BA/pharmacist's assistant	44	F	Y	31MFc	BA/nurse	78	F	Y
7MFufc	High school/SAH mom	40	F	Y	32MFAc	lower general secondary education / finance specialist	44	M	N?
8MFu	VET/insurer	50	M	Y	33MFc	MSc/student	29	F	N
9MFuf	BA student/social work	32	M	N	34MFc	BA/student	27	M	N
10MFuf	VET/horticulture	41	F	Y	35MFAi	MBO/child care centre	36	F	Y
11MFu	MA/English teacher	48	F	Y	36MFSi	Girls'grammar/bookkeeper		F	Y
12MFu	MTS/SAH mom mom	36	F	Y	37MFAi	HBO/nurse + reintegration consulter		M (+F)	Y
13MFu	MTS/electrician	54	M	N	38MFAi	VET/secondment	54	sF	N
14MFuf	BA/ICT consultant	39	M	N	39MFAi	Operator oil refinery	40	M	Y
15MFSf			F	Y	40MFSi	BA/informatics ICT (both)	32+…	M+F	N
16MFSf	lower general secondary education	52	M	Y	41EMEi	banker		M	Y
17MFSfc	BA/volunteer	59	F	Y	42EMEi	crew chief + English teacher	37+32	M+F	N
18MFAff		63	M	Y	43EMPi	(energy) project manager CMG logica + MSc/engineering agency	39+38	M+F	Y
19MFAff	VET	62	M	Y	44EMEi	Kleding/bouwbedrijf		M+(F)	Y
20MFAfi	BA/immigration services	57	sM	N	45EMPi	Chemical technician at engineering agency + health researcher	39+38	M+F	Y
21MFAfi	BA/police	51	M	Y	46EMEi	Data analyst+Facility management/applied home economics?	43+38	M+(F)	Y
22MFAf	VET	34	M	Y	47EMEi	VET/ICT project management + secretary	51+50	M+F	Y
23MFAf	BA	40	M	Y	48EMEi	Elderly care	54	F	Y
24MFSfi	VET/computer specialist	58	M	Y	49EMEi	Marketing communication manager (energy) + schoolteacher	45+40	M+F	Y
25MFSf	lower general secondary education	80	M	Y	50EMPi	project manager ICT	39	M	N

Explanation participant code
MF= user multifunctional HEMS
A = in group A, analogue
S = in group S, smart
u = usability test participant
f = focus group participant (one or two)

c = concept test participant
i = interview participant
EM=user Energy management device
P = in group P, plugs
E = in group E, Eee top
i = interview participant

Explanation of other letters:
gender = s (single) M (male), and/or s (single) F (female). (F in parentheses means female present part of the time during interview) / kids = Y (yes) kids are present, N (no) kids are not present

A VI Smart meter information (P1 port)

The following information can be found in the KEMA (2008) report on smart metering:

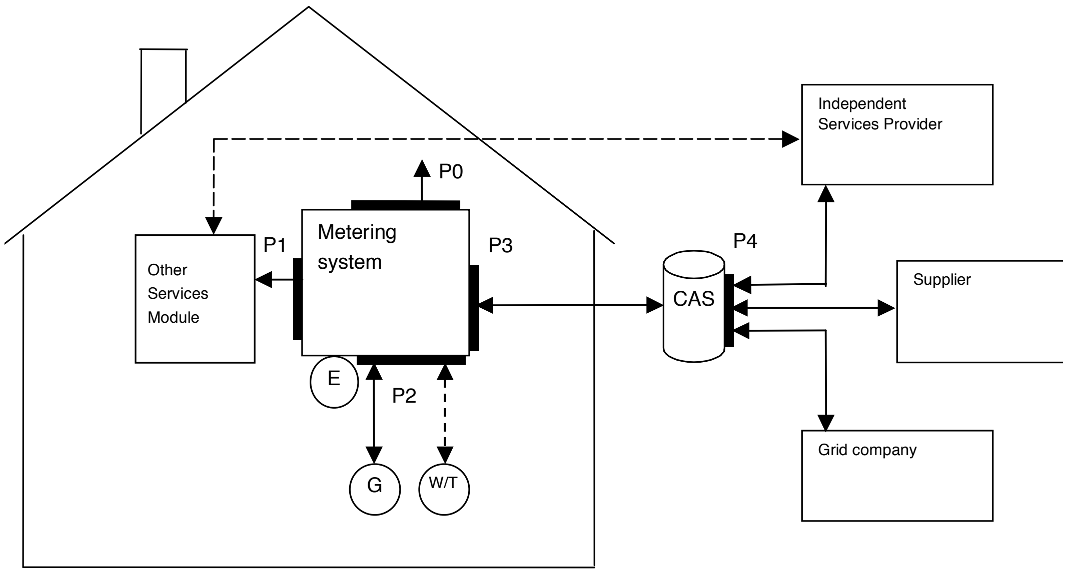

Figure 56
Communication ports belonging to the metering installation according to Dutch smart meter requirements (DSMR) source: KEMA Consulting, (2008)

"As well as the displays on various parts of equipment, the metering installation has the following communication ports:

Port P0 for communication with external devices (e.g. hand-held terminal) during installation and on-site maintenance of the metering installation. This is a local port used for installation and maintenance purposes by personnel that is on-site. A typical implementation of this port is an optical connector for laptops or hand-held terminals. The local port is an integrated part of the E meter and gateway.

Port P1 for the communication between the metering installation and auxiliary equipment (a maximum of 5 appliances can be connected). P1 is a read-only interface, i.e. it cannot be used for sending data to the metering system. The specification of P1 is included in Appendix A. Port used for the communication between the metering installation and one or more other service modules. This port is a read-only port and can therefore not be used for sending data to the metering installation

Port P2 for the communication between the metering system and one to four metering instruments and/or grid company equipments. The specification of P2 is included in Appendix B. Port used for the communication between the E meter and other M&S equipment installed at the same connection.

Port P3 for the communication between the metering installation and the Central Access Server (CAS). The specification of P3 is included in Appendix C. In version 2.0 of this document this appendix was not yet finished. Important to note is that the P3 interface will be based on the international DLMS/COSEM standard. Port used for the communication between the metering installation and gateway on the one hand and the CAS on the other.

Port P4 is the port on the CAS with which independent service providers, suppliers and grid companies gain access to the CAS. Note that P4 is outside the scope of this document."

A VII Notulen denktank over hoofdstuk 9

Opzet denktank:

9:15 inloop met koffie/thee
9:30 welkomst door Anke van Hal
9:35 introductie ronde deelnemers
9:45 presentatie Sonja van Dam
10:05 tijd voor vragen
10:15 Koffie pauze
10:30 interactieve workshop aan de hand van de volgende vragen

- Wat zijn volgens u de grootste uitdagingen voor de bouw en installatie om huishoudens helpen energie te besparen?
- Liggen de prioriteiten momenteel op de juiste plek?
- Welke verbeteringen zijn er te maken op figuur 2 en 3 uit hoofdstuk 8?
- Welke punten uit figuur 2 en 3 zijn volgens u de grootste uitdagingen voor het implementeren van HEMS in bestaande woningen? (stikkers plakken)

12:00 lunch en napraten
12:30 afsluiting

Vragen en opmerkingen vanuit deelnemers n.a.v. presentatie

- Hoe zit het met multiculturele huishoudens? Hoe gebruiken die HEMS. Is dat niet juist een extra uitdaging?
- Hoe pakt een HEMS uit in huishoudens die minder te besteden hebben?
- Zijn prepaid systemen voor energie rekening niet effectief?
- Heb je nagedacht over het koppelen van de archetypische gebruikers aan marketing onderzoeken op het gebied van energie?
- Jan Willem had ervaring met 12 verschillende HEMS in huis. Er waren er 2 die ook door zijn huisgenoten prettig werden gevonden. De e-cost en de wattson.
- Zie ik reduceren energieverbruik als belangrijkste aspect HEMS?
- In de VS is de HEMS markt verder opgesplitst. Bvb data acquisitie door een aparte bedrijf. Het ene bedrijf houd zich bezig met (uitlezen) (slimme) meter en de andere met het vertalen van deze data naar gebruikers. Hierdoor kunnen technische problemen beter opgelost worden.
- Vraag waarom mensen eigenlijk geen lichtsensoren kopen voor in huis
- In de overzicht mist watermeter en warmtemeter.

- Indien een HEMS als applicatie wordt ontwikkeld is het goed om te realiseren mensen gemiddeld 42 apps op een telefoon hebben en dat 90% geen 2e keer wort gebruikt.
- Kan merken dat sommige HEMS die nu op de markt zijn bepaalde type gebruikers aanspreken en andere HEMS andere gebruikers aanspreken.
- Komt er nog iets met praktische handvaten/lijst met aanbevelingen voor ontwerpers en ontwikkelaars? Liefst geïllustreerd en met anekdotes.
- Zijn er nog tips over hoe beter te testen en gebruiksonderzoeken uit te voeren?

Algemene discussie

- Er zijn zes hobbels voor bestuurders woning coöperaties om energie te kunnen besparen in hun woningvooraad. Zij missen:
  - organisatorische vermogen
  - financiën
  - geen helder aanbod van de markt
  - ambitie is niet verankert in governance
  - weten niet hoe ze klant zover moeten krijgen/de klant vraag mist.
  - Juridische kader en regelgeving
- woning coöperaties zijn op zoek naar een aantal zaken:
  - differentiatie
  - klant tevredenheid
  - strategie ontwikkelen
- Hoe zouden HEMS hieop in kunnen spelen?
- Is e-neutrale woning een interessante business case? Business case moet dus opnieuw uitgevonden worden. 2.4 miljoen woningen – 0.6% wordt structureel gerenoveerd. Er gebeurt niks op dit moment. 0.5% van de woningen komt leeg per jaar.
- Er is geen product dat kant en klaar is om een nieuw huis mee in te richten
- voor mensen die een (al bestaand) huis kopen en daarin willen gaan verbouwen. Dat is het moment waarop je ze een ‘pakket’ aan passende energiebesparende maatregelen kunt aanbieden. Niet allemaal losse dingen maar een samenhangend pakket, zoals IKEA bezig schijnt te zijn met een IKEA-huis.
- Product markt combinatie – wie is de klant - voor wie zijn de producten. Mens centered – wat komt daarbij kijken
- Gefragmenteerde oplossingen/geen totaalpakket – velux is interresant echter vanuit product geredeneerd
- 6-12 concepten geïntegreerd:
  - concept voor woningen – woning die geheel door zon verwarmd wordt (autarkisch)
  - toegespitst op levensstijlen
- Waarom is de vraag er niet?

  - We hebben grootste social sector – bestuurdersmodel,
  - "de staat zorgt er wel voor"/huursubsidie
  - Nederlandse cultuur – paternalisme
  - Vraag naar energie besparing is er wel degelijk!
- Betalingsachterstanden van klanten bij energiebedrijven lopen gigantisch op - Eneco in Rotterdam zuid 10% betalingsachterstand
- Besparingsuitdagingen:
  - hoe past het bij welke doelgroep?
  - Differentiatie nodig
  - Co-creatie
  - Product-markt combinaties
  - Energieverbruik – verwarming
- NEN1010 richtlijn is 60 jaar oud (Veiligheidsbepalingen voor laagspanningsinstallaties gebruikt door de elektrotechnische installatiebranche)
- Welke problemen wil je met HEMS oplossen?
- Renovaties van bestaande woningen kosten gemiddeld 30,000-100,000 euro. Als je daarbij een HEMS implementeert a €500.- dan is dat verhoudingsgewijs een kleine investering. Mocht je bovendien met de HEMS een besparing van 5% weet te behalen dan is dat ongelooflijk efficiënt.
- HEMS is misschien een prettige quick fix in vergelijking tot renovatie voor het behalen van besparing?
- Bewonersgedrag >30% bepalend voor energieverbruik
- Verbouwing OTB TUD – EPC verlaagt maar verbruik per m2 niet verminderd
- Onderzoek Duitsland – spreiding verbruik per m2 warmte verschilt factor 3-5 factor, spreiding verbruik per m2 electra verschilt factor 8-10 in vergelijkbare straten/woningen
- Comfort voor mensen belangrijkste issue, daarna geluid daarna tocht en warmte.
- Woning renovaties worden nu verkeerd ingestoken. Wordt niet voor de Nederlandse context gedaan. Alles isoleren en wtw installeren heeft geen zin als mensen willen blijven slapen met raam open.
- Grote verschillen in functionaliteiten en wensen per vertrek mbt verwarming en comfort. Woonkamer vraagt andere verwarmingssysteem dan slaapkamer. Vloerverwarming prima voor woonkamer maar slaapkamer moet warm zijn tijdens studeren maar koud tijdens slapen. Als je het raam open gooit om de warmte te laten ontsnappen is niet erg efficiënt.
- Het is beter om zones te creëren met decentrale verwarming. Dit zou betekenen dat individuele kamers of verdiepingen geïsoleerd zouden moeten worden. Alleen handmatig instellen thermostaat werkt niet.
- De genoemde implementatie uitdagingen met HEMS zijn lastig op te lossen. Mensen zijn niet geïnteresseerd om een grote verbouwing te moeten doorstaan alleen om een HEMS te installeren.
- Zijn HEMS wel marktrijp genoeg?
- Vraag vanuit gebruiker: what's in it for me?

- Het is moeilijk om mensen zover te krijgen dat ze een HEMS willen. Dit zie je ook bij andere producten. Woonbron had 130 (?) huishoudens een gratis zonneboiler aangeboden maar uiteindelijk zeiden er maar 35 ja.
- Of mensen besparen met een HEMS is een eigen keus maar iedereen moet wel de mogelijkheid gegeven worden om te kunnen besparen.
- Een probleem is dat energie te goedkoop is. Door de belastingstelstel op energie wordt besparen niet beloond.
- Hebben mensen een incentive om te besparen? Bvb wedstrijd? Lastige daarmee is dat discipline ontbreekt op de lange termijn of als het toch duidelijk wordt dat je niet gaat winnen.
- Het benchmarken van energieverbruik is belangrijk – bij auto's werkt het ook – benchmark die zichzelf corrigeert over tijd.
- Benchmark is ook belangrijk voor imago van huishoudens.
- HEMS eigenlijk soort accountant van energieverbruik
- Mensen moeten prosumer worden en zelf energie opwekken ipv consumer
- Mensen moeten eerst controle over hun energieverbruik krijgen en pas daarna kunnen ze gaan managen. Eindelijk zouden HEMS dus HECS moeten heten.
- Zijn monofunctionele, standalone HEMS niet eigenlijk een tijdelijke oplossing? Zouden ze niet geïntegreerd moeten worden in andere apparaten en dat apparaten individueel feedback moeten geven? Risico is wel dat je informatie krijgt zoals 'dit scheelt je €0.03
- Wat is de beste locatie voor HEMS? Gang is voor zakelijke activiteiten dus ok voor HEMS? Mbt huis afsluitritueel of woonkamer of gang?

Bespreking figuur 2: contextuele factoren en figuur 3: meter issues uit hoofdstuk 9

- Moet je inzetten op besparen of moet je inzetten op zelfvoorzienendheid en doet het er dan niet toe hoeveel je gebruikt. Er is genoeg energie maar we gebruiken momenteel de verkeerde energie. Tot die tijd zo efficiënt mogelijk fossiele energie gebruiken.
- Geef mensen beloning voor besparen. Belast hoeveelheid gebruikte energie ipv het merendeel gebruiksonafhankelijke vastrecht te moeten betalen. Of maak een soort energielasten verzekering met een no claim op je energie rekening. Als je minder gebuikt dan verwacht wordt je beloond als je meer gebruikt dan verwacht wordt je beboet. Als je dit samen met een slimme meter doet kan je ook een waarschuwing van tevoren geven
- Werden ook vragen gesteld bij 'zendingsdrang' op te besparen. Moet je wel mensen die niet willen besparen toch proberen te laten besparen? Je moet je rol als coöperatie hierin niet overschatten. Iedereen wordt geacht om zichzelf te verzekeren maar mensen worden daarover heel anders benaderd dan over besparing.

- Is er niet een grotere rol voor HEMS weggelegd? Afstappen van de jaarafrekening en per maand factuur betalen via de HEMS. Met tanken zie je ook elke keer de prijs staan.
- Figuur 2 geeft vooral aan dat er "idiot proof" ontworpen moet worden. Als je figuur 2 vanuit systeem theorie bekijkt dan is duidelijk dat het te complex is. Is het mogelijk om een low-tech back-up te hebben voor als het systeem faalt (zodat je niet in de kou zit). Kan je om de gebruiker heen ontwerpen? Of terwijl 'remove the idiot out of the equation'
- Woonbron gaat ervan uit dat er 45 minuten nodig is voor de installatie van HEMS en 45 minuten voor de uitleg aan gebruikers. Maar verwacht dat dit te optimistisch is in de praktijk. Hoe laat je installateurs zo'n complex product uit leggen aan klanten? Nagedacht om gebruikers als ambassadeurs op te laten treden en het product aan anderen te laten uitleggen. Van de 35 mensen die uiteindelijk een gratis zonneboiler wilde (bij opdracht 1 genoemd), hadden zich 15 aangemeld door de buren.
- sluipverbruik is ongeveer 500W
- ventilatie is ongeveer 300 euro extra per jaar
- Travo van oude deurbel vraagt veel energie?
- energie besparing is afgeleid nut van HEMS. Voornaamste nut is:
  - bewustwording van energie
  - hoort bij kwaliteit van de woning
  - primair: leerproces en bewustwording
- De aanwezigen vonden dat in de marketing niet de nadruk moest komen te liggen op energiebesparing. Voor de meeste mensen (werd gezegd) gaat het eerder om inzicht. Het hebben van een HEMS hoort bij een 'kwalitatief hoogwaardige woonbeleving'. Dat je er ook energie mee kunt besparen is mooi meegenomen.
- HEMS hoeft niet altijd informatie aan de gebruiker te geven - kan ook managen (domotica/intelligentie)
- Eindgebruiker hoeft geen onderdeel te zijn van wat HEMS doet
- Voor 50% van bewoners is feedback nuttig Andere helft zal er niks mee doen.
- Voor deze laatste groep is een super smart HEMS nuttig (domotica), NEDAP smart router
- Technologie is echt een probleem nu (bvb stopcontacten naast gas meter).
- Er zijn geen volwassen producten op de markt.
- Je moet een HEMS hebben waar de gebruiker om gaat vragen
- Binnen energie labels levert HEMS 0 punten op.
- Maar tegen 2030 zijn nieuwbouw woning geheel elektrisch. Over 20 jaar is nieuwe woning met gasaansluiting een risico.
- HEMS in totaalpakket zien en inzetten voor andere functies, zoals detectie van problemen (oude mevrouw die niet meer beweegt).
- Wat kost ijskast
- HEMS niet alleen in de markt zetten om energie te besparen –ook signalering richting installateur ivm ketel uitrol om montage behoefte.

- Niet alleen op aspect energie besparing inzetten
- 2 arrangementen die met wonen te maken hebben
- 1 argument die met energie besparen te maken hebben
- aansluitend op geplande renovaties en investeringen
- warmte regelen op kamer niveau

- Vermoeden dat in de toekomst collectieve opwekking (bvb Windvogel) een grote vlucht gaat maken. Kan een HEMS hierop inspelen? Informatie over collectieve opwekking
- Huishoudens veranderen en daarmee grote verschuivingen in hun elektriciteitsverbruik. – er komen nu de eerste elektrische autos. Hierdoor vallen andere verbruiken in het niets - mensen gaan dit verbruik zoals stand-by verbruik daardoor misschien bagatelliseren. Zinnige terugkoppeling over elektrische auto en productie zonnepanelen is lastig!
- Esco's (energy service companies) zijn steeds meer in opkomst (bedrijf isoleert woning en betaalt winst uit)
- De energie prijs is ook van belang om een aantal redenen:
- Door vastrecht wordt energie besparen niet beloond.
- Nederland kent in principe alleen 2 tarieven voor elektriciteit maar de tijdstip waarop de verschillende tarieven ingaan varieert per regio. Er zijn dus eigenlijk 3 –regio afhankelijke- dag/nacht piek/dal, hoog/laag systemen. Dit is ingebouwd in de meter maar de meeste HEMS kunnen dit niet "uitlezen" omdat de sensor niet leest welke stand de meter in staat. Alleen de P1 poort van slimme meter geeft wel aan welke tarief op dat moment geldt
- Communicatie tussen HEMS en energie bedrijven is van belang om de juiste tarief door te kunnen geven. Alleen juridisch gezien is de lokaal uitgelezen meterstand nooit rechtsgeldig, ook niet met P1 poort
- De prijsverschil tussen dag/nacht tarief is niet groot meer omdat er dag en nacht 30% overcapaciteit op het net zit. Gas centrales worden weggedrukt/uitgezet door een overcapaciteit aan kolencentrales. Kolencentrales zijn duurder om te bouwen maar goedkoper om te runnen. Er word gemiddeld 10% bijgemengd. Dit kan variëren van slachtafval tot kippenmest tot hondenbrokken.
- Veel van de genoemde problemen moet je incalculeren, Het zij zo. Bestaande woningen zijn nu eenmaal bestaande woningen.
- Het HEMS verhaal/technische problemen lost zich op termijn wel op. Op data poorten komen specialistische bedrijven. Idem voor interfaces
- Het belangrijkste is klanten. AL deze dingen kun je wel oplossen.
- HEMS zitten op dit moment niet in de EPC. Gedrag ook niet. Er is wel een discussie gaande of dit niet zou moeten maar het is lastig in te voeren.
- EPC norm voor 2016 staat al vast (0.4). De ambinitie voor 2050 is 80% reductie in de bestaande bouw.
- Vanaf 2020 zijn er geen gasaansluitingen meer in nieuwbouw. In bestaande bouw zal het langzaam ook uit gefaseerd worden.

- Gas is volgens sommigen minder relevant om realtime feedback op te geven. Dit houd echter geen rekening met de behoefte van mensen om bij te houden hoe lang er gedoucht wordt. Maar hier is andere data voor nodig dan hetgeen er uit de meter te verkrijgen is. Apparatuur Pascal van Putten kan dit. Het is alleen duur.
- Het besef van huishoudens over de % waar gas voor gebruikt wordt in huis en waar er energie op bespaard kan worden ontbreekt. Dan zou douchen wellicht minder aandacht krijgen van huishoudens.
- Een deelnemer (Electro techneut) geeft aan dat als je hoofdstroom leiding vrijmaakt dat je hier nauwkeurig en eenvoudig het electriciteitsverbruik van het huis kan meten met multimeter van €20.- Anderen geven aan dat dit lang niet altijd makkelijk is of mag.
- De (Dutch Smart Meter Requirements) P1 poort kan nog steeds verbeterd worden.
- Gas data moet beter uitgewerkt worden (meer) realtime.
- Eenduidige/standaard protocol. Voorkomen dat er verschillende firmware versies in de omloop zijn die lastig te achterhalen is.
- P1 is nog erg een Nederlands feestje. Zorg dat er internationale afspraken/ standaarden gemaakt worden

Belangrijkste aspecten in Figuur 2: contextuele factoren

- HEMS moeten "idiot proof" zijn (5 stippen)
- "zendingsdrang" – in hoeverre moten we proberen huishoudens te laten besparen?
- Locatie meters
- De klant/mens ontbreekt in figuur 2
- De regelgeving en juridische context ontbreekt in figuur 2.
- Storingen binnenshuis zijn lastig. Het is niet wenselijk om repeaters te moeten gebruiken. Worden over het algemeen niet gewaardeerd door huishoudens. (1 stip)
- HEMS moet een HIS zijn (home information systeem met waterverbruik, weer info etc) (2 stippen)
- Wapening beton. Is belangrijke belemmering (1 stip)
- De user interface (5 stippen)

Aanbevelingen Figuur 2, contextuele factoren:

- Diensten onderdeel van HEMS: Gebruiker weet niet wat C-waarde is of wat voor CV ketel ze hebben. Er is een website opgezet door een energieleverancier om geschiktheid voor hun HEMS aan te geven. Sommige huishoudens vullen vragenlijst net zo lang opnieuw in totdat er uit komt dat hun huis geschikt is.
- Koppeling met energieleverancier voor huidige tarief en prognose van rekening aan het einde van het jaar. HEMS kunnen dat op dit moment niet goed.
- Mist invloed prijs energie

- Bij type HEMS mist als variabele: Hoeveelheid controle en op welk niveu (apparaat, huishoud of woonblok)
- type woning (huur/koop) mist
- type installatie mist (DIY vs monteur) Missen een aantal organisatorische aspecten zoals
  - Afsluiten van abonnement ism HEMS en de kosten die hierbij komen kijken
  - Koppelverkoop
  - Koppeling tussen bepaalde HEMS fabrikanten en energie leveranciers
  - Product service systemen – bvb bijbehorende wedstrijd of leensystemen (uitlenen via een bibliotheek voor bepaalde periode)
  - Data uitwisselingsproblemen en vertragingen tussen verschillende betrokken partijen (leveranciers, producenten fabrikanten)
  - Eigenaarschap van de data
  - Wie mag het online zetten, delen etc
  - Fraude
  - Bereikbaarheid helpdesk voor vragen en problemen
- risico's van schadelijke (?) Straling vanuit meterkast
- Draadloze transmissie is in zijn algemeenheid een issue: ontwikkelingen zijn zo snel gegaan dat het even gaat duren voordat we alle verwikkelingen en interferenties opgelost hebben. Staat in gebruiksaanwijzing automatische verlichting dat deze het beste 50cm uit elkaar geplaatst kan worden. Router werkt bvb beter als hij verder van stopcontact af staat.
- Wi-Fi in huis geeft problemen als cabrio buiten in de oprijlaan staat ivm alarm op cabrio. Als de cabrio in de garage staat is er geen probleem. Daarnaast gaf een persoon aan dat hij in zijn lichaam kan voelen als zijn ipad op schoot ligt en kan voelen dat zijn telefoon over zal gaan voordat hij daadwekelijk gebeld word door de straling.

Non-issue in Figuur 2: contextuele factoren

- Meters - Dit lost zichzelf op (met de komst van slimme meters – die gaat er komen). Is een klein probleem tov de rest. (2 stippen)
- Structuur van het huis – dit is een basis situatie/uitgangspunt waar je niks aan kan doen. Daar moet je omheen ontwerpen. (2 stippen)
- Stopcontacten bij meters. Met de nieuwste P1 poorten is er een geïntegreerde voeding. Dus noodzaak zal langzamerhand minder belangrijk worden (1 stip)
- Externe storingen: geschat wordt dat dit alleen voorkomt in 1% van de gevallen. (2 stippen)
- Structuur van de woning: je moet het er mee doen (1 stip)
- Transmissie issues – gaat zichzelf wel oplossen door gespecialiseerde bedrijven (1 stip)
- Type HEMS (1 stip)

Belangrijkste aspecten 3: meter issues

- Niet relevante en "foute" informatie is dodelijker dan geen informatie.
- Belangrijk dat HEMS zich gaan richten op het inzichtelijk maken van energie productie (bvb zonnepanelen) in huis. Is wel lastig! Productie is voor sommige huishoudens juist reden om HEMS aan te schaffen. (4 stippen)
- Verhouding vastrecht variabel deel energie rekening (1 stip)
- Type meter – vooral dat energie leverancier weet wat voor meter er hangt
- Goede en accurate data zonder vertragingen is noodzakelijk. Poort voor lokale uitlezing gas en Electra (P1) moet altijd aanwezig zijn. Eenduidige (P1 en P4) protocol. (3 stippen)
- Onderdeel van goede energie data is dat de organisatorische issues omtrent de data moeten worden opgelost. Lange vertragingen door de lange omweg die data af moet leggen buitenshuis moet verkleind worden. Ook vragen omtrent wie is de eigenaar, security (ongewenste uitlezing), toestemming voor benchmarking en hoe publiek zijn benchmark gegevens. (3 stippen)

Aanbevelingen voor figuur 3: meter issues

- Aangeven hoe catastrofaal de verschillende issues met meters zijn/hoe zwaar wegen ze. Kan een HEMS niet dmv codes richting energiemaatschappij aangeven wat er aan de hand is/welke fout er op treed?
- Toevoegen Water meters in figuur 3
- Toevoegen Warmte meters (4% NL) in figuur 3

Non issues Figuur 3: meter issues

- Type meters en issue met domme meters wordt een non-issue. Slimme meter komt eraan. En uiteindelijk zullen de protocollen zich uitkristalliseren. (met versie 38 of zo) (4 stippen)
- Geert Jan geeft aan dat realtime feedback op huishoud niveau niet effectiever is. De meningen verschillen hierover. Een deelnemer verwijst naar rapport Karen Ehrhardt-Martinez. Het rapport geeft aan dat realtime feedback dat uitgesplitst naar herkomst het meest effectief is. Alleen realtime feedback op huishoud niveau is nauwelijks beter dan per dag of week.
- Techniek is oplosbaar – is wel een kostenpost