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DOI (link to publication from Publisher):
10.5278/vbn.phd.tech.00045

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Jensen, R. H. (2018). *Interaction Design for Sustainable Energy Consumption in the Smart Home*. Aalborg Universitetsforlag. https://doi.org/10.5278/vbn.phd.tech.00045

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DISSERTATION SUBMITTED 2018

AALBORG UNIVERSITY
DENMARK

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by

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Thesis submitted July 2018

Dissertation submitted: July 2018

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Department: Department of Computer Science

ISSN (online): 2446-1628
ISBN (online): 978-87-7210-240-5

Published by:
Aalborg University Press
Langagervej 2
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

Printed in Denmark by Rosendahls, 2018

ENGLISH SUMMARY

There is little doubt that human demand for electricity has environmental consequences for the climate on earth. One response to combat increasing electricity demand and CO_2 emissions is to research and develop smart home technology aiming to change how people consume electricity in their homes. This PhD project contributes with understandings of how smart home technologies can be designed to see how these are going to be sustainably beneficial for people in everyday life.

To this end, this PhD project investigates what characterises interaction design of smart home technology aiming to instigate sustainable energy consumption in the home and how such technology shapes sustainable energy consumption in everyday life. To structure this research enquiry, the PhD project explores different design imaginations of possible sustainable futures in the smart home and conducts studies of people using such technologies in concrete, everyday practices. The PhD project reports on three studies that each explore opportunities in smart home technology through different design concepts (assisted shifting, provocation and the desirable concept of *hygge*) that are manifested in concrete designs. Each design intends to change how households consume energy sustainably by intervening in everyday energy-consuming practices.

The findings of the studies show that each design concept is distinctive in its characteristics. Assisted shifting focusses on instigating sustainable energy consumption – conveniently and effortlessly – assisted by automated and intelligent technology. Provocation focusses on the disruptive and unexpected elements in the interaction design to challenge households to reflect and adapt to new routines. *Hygge* challenges existing smart home practices by proposing alternative ways to achieve desirable, enjoyable and aesthetically pleasing experiences in the smart home that also happens to be less energy-intensive.

The empirical findings of this PhD project demonstrate that the appropriation of technologies aiming to instigate sustainable energy consumption in everyday life is more complex than to develop and diffuse 'smart energy' technologies to the public. Households embed smart home technologies in everyday day practices in ways that are meaningful, enjoyable and desirable, which may actually end up undermining people's desire to live sustainably. The results of this PhD project contribute with imaginative design futures for the desirable and sustainable smart home and understandings of how such design shapes practices and energy consumption.

This PhD project is sponsored by the DICYPS research centre (http://www.dicyps.dk) funded by Innovation Fund Denmark. The aim of this research centre is to use software and data of complex cyber-physical systems to develop smarter and user-friendly solutions that benefit the individual and the society.

DANSK RESUME

Der er ingen tvivl om, at menneskets efterspørgsel efter elektricitet har miljømæssige konsekvenser for klimaet på jorden. Som svar på bekæmpelsen af den stigende efterspørgsel på elektricitet og CO2-emissioner, ser vi flere forskningsprojekter der undersøger og udvikler smart home-teknologi, der sigter mod at ændre, hvordan folk bruger elektricitet i deres hjem. Dette PhD-projekt bidrager med indsigter i, hvordan intelligente teknologier kan designes og studerer samtidig hvordan disse teknologier miljømæssigt kan gavne mennesker i hverdagen.

Med henblik herpå, undersøger dette PhD-projekt, hvad der karakteriserer interaktionsdesign af smart home-teknologi, der sigter mod at skabe et bæredygtigt energiforbrug i hjemmet, og hvordan en sådan teknologi kan udforme et bæredygtigt energiforbrug. For at strukturere denne undersøgelse udforsker PhD-projektet forskellige designs af mulige bæredygtige visioner af et smart hjem og udfører studier af husholdninger, der bruger sådanne teknologier i konkrete, dagligdags aktiviteter. PhD-projektet henviser til tre undersøgelser, der hver især udforsker mulighederne i smart home-teknologi gennem forskellige designkoncepter (assisteret fleksibilitet, provokation og det attraktive koncept af hygge), der manifesteres i konkrete designs. Hvert af disse design har til hensigt at ændre, hvordan husholdninger bruger energi bæredygtigt ved at intervenere i hverdagens energiforbrugende aktiviteter.

PhD-projektet resultater viser, at hvert designkoncept har udprægede kendetegn. Assisteret fleksibilitet fokuserer på at indføre et bæredygtigt energiforbrug, nemt og ubesværet, assisteret af automatiseret og intelligent teknologi. Provokation fokuserer på de forstyrrende og uventede elementer i interaktionsdesignet for at udfordre husholdningerne til at reflektere og derefter ændre eksisterende rutiner til nye. Hygge udfordrer nuværende smart home praksis ved at foreslå alternative måder at opnå behagelige og æstetiske oplevelser i smart hjemmet, der samtidig er energibesparende.

De empiriske resultater i dette PhD-projekt viser, at teknologier, der sigter mod at skabe et bæredygtigt energiforbrug i hverdagen, er mere komplekst end blot at udvikle og udbrede intelligente energiteknologier til offentligheden. Husholdninger integrerer og anvender intelligente teknologier i dagligdagen på måder, der er meningsfyldte, behagelige og attraktive, hvilket rent faktisk kan ende med at underminere ønsket om at leve bæredygtigt. Resultaterne af PhD-projektet bidrager med fremtidige design ideer til det attraktive og bæredygtige smart home og en forståelse for, hvordan design kan ændre praksis og energiforbrug.

Dette ph.d.-projekt er sponsoreret af DICYPS forskningscenter (http://www.dicyps.dk) finansieret af Innovation Fund Denmark. Formålet med dette forskningscenter er at bruge software og data fra komplekse cyber-fysiske systemer til at udvikle intelligente og brugervenlige løsninger, der gavner individet og samfundet.

ACKNOWLEDGEMENTS

While a PhD project can be a solitary endeavour, I would never have reached this point without help from great people around me. Many people have inspired, helped and challenged me on the way, for which, I am sincerely grateful. First, I would like to thank my supervisor Jesper Kjelskov and co-supervisor Mikael B. Skov for giving me the opportunity to pursue a PhD. You gave me the needed freedom, mentoring and support to explore exciting directions in my work and helped me to get back on track when going astray. Big thanks to Ivan Aaen for convincing me that PhD would be fun 'thing' to pursue and for asking those 'annoying' thought-provoking questions.

Second, I would like to thank all the people in both HCC group and CS with whom I worked and studied with over the past five years. A special thanks to my big research brother and friend Dimitrios Raptis for always being willing to listen, help, and engage in provoking, crazy research idea thinking and writing – particular over a G&T. Thanks to Jeni Paay for all the support across continents and for teaching me the true meaning of champagne o'clock. Also, thanks to Peter and John for the many insightful conversations and to Michael Kvist for being a great PhD brother. Anders, Tim, Lefteris, Maria K, Stine, Maria H, Nis, Jane, Rikke, Susanne, Helle S and Helle W – thanks for the all support over the years! Thanks to my fellow software nerds, Thomas, Kenneth, Jeppe and Heidi and the helpful people at Neogrid. A huge thanks to the families who participated and shared experiences with me during this project!

In 2017, I had the pleasure to spend the spring with Yolande Strengers at RMIT, Melbourne, whose insights and inspirational advice contributed greatly to this PhD project. I am truly grateful for being given the opportunity to visit the Beyond Behaviour Change group, which helped me recognise the significance of practice theory to approach energy consumption, design and intervention. Also thanks to both Yolande and Larissa Nicholls for co-authoring two of the papers and to Cecily Maller and Mahmoudi Farahani for making me feel welcome in the BBC group.

Furthermore, I would like to express my gratefulness to my dear friends, who helped me to burst out of my research bubble now and again. Thanks to my CFAA friends for providing a carefree community. A special thanks to the Nash'es for always being there, and Mariann and Nanna for enduring hours of talk about this PhD project, while making me stronger. I would also like to thank my family, especially my mom and 'dad' Ole, who gave me the belief that this endeavour was worth pursuing. Also big thanks to my wonderful sister Sisse, who has always supported me and helped me out when she possibly could. Last, but not least, thank you, my sweet Anca, for being awesome at enduring months and months of total research bubble. Without your love, support, enormous patience, and a bit of Balkan stubbornness, this endeavour would not have been this fun!

THESIS DETAILS

Thesis Name: Interaction Design for Sustainable Energy Consumption in the Smart Home

PhD Student: Rikke Hagensby Jensen, Aalborg University

Supervisors: Professor Jesper Kjeldskov, Aalborg University
Associate Professor Mikael B. Skov, Aalborg University

The main body of the thesis consists of the following papers:

1. Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16). https://doi.org/10.1145/2971485.2971525

2. Dimitrios Raptis, Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2017. Aesthetic, Functional and Conceptual Provocation in Research Through Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (DIS '17), 29–41. https://doi.org/10.1145/3064663.3064739

3. Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B Skov. 2018. Exploring Hygge as a Desirable Design Vision for the Sustainable Smart Home. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18), 355–360. https://doi.org/10.1145/3196709.3196804

4. Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18), Paper 4. https://doi.org/10.1145/3173574.3173578

5. Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2018. Assisted Shifting of Electricity Use: A Long-Term Study of Managing Residential Heating. *ACM Transactions on Computer-Human Interaction* (TOCHI), 29 pages, (Accepted April 2018).

6. Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18), 1387–1400. https://doi.org/https://doi.org/10.1145/3196709.3196779

This thesis has been submitted for assessment in partial fulfillment of the PhD degree. The thesis is based on the submitted or published scientific papers which are listed above. Parts of the papers are used directly or indirectly in the extended summary of the thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty.

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CHAPTER 1. INTRODUCTION

In 2017, global demand for electricity increased by 3.1% [63]. A demand that was met by a 72% use of fossil fuels, whilst CO_2 emissions in 2017 reached a historic high of 32.5 gigatonnes [63]. This growth in both electricity demand and CO_2 emissions is worrying. Not only do these numbers continue to rise [63], but they do so, despite happening in a time where there is little doubt, that energy consumption has devastating environmental consequences for the climate on our planet. In addition to this, research [50] documents these consequences will continue to unfold unless human intervention successfully conveys effective and rapid societal changes as to how people consume electricity.

One response to combat climate changes is to look for ways to reduce CO_2 emissions and our dependency on fossil fuels. A step in this direction is to make people consume less electricity and from renewable resources like wind and sun. While this might seem like a straightforward approach, electricity is a resource people consume in everyday life because it powers most technologies people surround themselves with. This includes the home, where energy-consuming technology is embedded in many domestic activities e.g. washing, heating, lighting, entertainment, cooking and cleaning. To make these activities comfortable, convenient and pleasurable, households appropriate energy-consuming technologies in ways that reflect a modern lifestyle. Changing how households consume electricity is therefore highly complex because it is interwoven with how people expect everyday life to be carried out [120].

Today we see many ‘smart’ digital technologies e.g. home automation, smart grid infrastructures and energy management systems, envisioned to encourage households to consume energy more sustainably [51,66,106]. Households are often conceptualised as smart homes in such envisioned futures [92], where interconnected, automated and intelligent technology is anticipated to assist households to manage their energy consumption. However, if smart home technology is going to make a sustainable difference in the future, it matters how households embed these in everyday life.

To contribute with understandings of how such technology can instigate sustainable change in the future, this PhD project sets out to investigate what characterises the interaction design of smart home technologies and study how they are embedded in everyday mundane, energy-consuming activities. To this end, the PhD project engages in three studies that explore different design concepts to imagine possible sustainable futures in the smart home and study these in concrete, everyday practices.

The following sections introduce the context of sustainable energy consumption in Denmark, along with perspectives on how interaction design and the smart home fits into this context. The chapter concludes with the two research questions guiding the work in this PhD project.

1.1. SUSTAINABLE ENERGY CONSUMPTION

To combat growing CO_2 emissions, the Danish government has responded with multiple initiatives aiming to reduce the use of fossil fuels in energy production. The goal of these initiatives is to produce 50% of electricity from wind energy alone by 2020 and convert to a 100% renewable energy production by 2050 [28,29,36].

To reach these ambitious goals, wind turbines and solar panels are increasingly being used in the Danish energy production, generating electricity when the wind blows and the sun shines. Since the availability of renewable sources fluctuates along with unpredictable weather conditions, renewable energy is produced independently from when people consume energy. This gives rise to a misalliance in energy production and consumption, which has the risk of destabilising the energy grid. An unstable energy grid can be problematic in a modern Danish society because it depends heavily on energy consuming technology in most facets of everyday life.

In response to finding solutions that will ensure a stabilised renewable energy grid in the future, multiple Danish stakeholders have formed partnerships in large-scale research projects addressing various problems related to sustainability and energy [20]. Most of these projects approach sustainable energy problems as scientific problems that need solving through development of technology. This perspective is tended towards a technology-centred design approach, where solving sustainability problems are driven by the ambition to understand our world by science and change it by technology alone [90]. What is emerging from the technology-centred projects are novel digital technologies showcasing the opportunities in trending concepts like smart energy grids, smart homes and smart devices making it possible to monitor and control energy consumption in people's home [41,59,91]. The devices, infrastructures, systems and services such novel digital technologies offer households, will in this rest of this thesis be referred to as smart home technology.

Interestingly, a majority of the technology-centred research projects envision households to welcome smart home technologies as empowering tools that assist them to use energy sustainably [20,29]. Although many projects can make claims that such technologies can be useful and efficient tools for assisting households to be more sustainable [41,91], relatively little research is conducted with actual people [20,66]. Therefore, we need more insight into studying the effect of smart home technologies that are embedded in everyday life, before claiming these technologies are going to change how people consume electricity.

One step to this end, could be to conduct more investigations into how smart home technologies can be designed, and ensure their use is going to be sustainable beneficial for people in everyday life before becoming part of shaping normality. To structure such investigations Silberman et al. [124] suggest to; 1) prototype, build and support future scenarios, which explore the possibilities of novel smart home technology, and 2) do studies of people using these in their everyday practices to inform future designs.

1.2. INTERACTION DESIGN RESEARCH AND SUSTAINABILITY

As a response to digital technology penetrating our everyday life, the interaction design discipline has emerged to scope research and the practice of *"designing interactive products to support the way people communicate and interact in their everyday and working lives"* [102]. This means that interaction design projects often encompass a design or a redesign of digital technology e.g. a product, service, application, infrastructure or a system [56]. To capture the different aspects of what and how to design interactive digital technology, interaction design is gradually used as an all-encompassing term, e.g. user interface design, web design, experience design, user-centred design, software design and product design [88,102].

Recently, we have seen a growing interest in the interaction design community to understand how to instigate societal change through interaction design [110] in domain-specific areas, including sustainability and energy consumption. Motivations to engage in sustainability research endeavours are two-fold. Firstly, it has been recognised that as a design community we are also responsible for the sustainability implications the use of our designs may lead to [9,10]. Secondly, there is a belief that interaction design can provide valuable insights on how to design solutions with digital technologies, and study their use to better understand how we in the future can tackle sustainability problems [59,72,124].

As the interaction design research discipline draws on multiple design practices and academic disciplines including HCI (human-computer interaction), it is diversified in its use of methods and frameworks to understand, research and practice design [74]. In interaction design research looking to understand how design can instigate sustainable change, we see mainly two types of research contributions. *Design contributions* where interactive artefacts are created from explorative design-driven activities (intervention), and *empirical contributions* providing understandings of relations between designed artefacts and people (empirical studies of use and people) [141].

Design contributions are usually represented as prototypes exploring different visions, which are manifested in concrete designs to reveal new possible futures [82]. Stolterman and Wiberg [126] argue that we can distinguish between situation-driven and concept-driven interaction design research contributions in the field. Situation-driven design research has a strong focus on understanding a specific problem domain, where the design solution is derived through a detailed exploration of users' needs and desires to get a profound understanding of the situation and problem at hand.

The starting point for concept-driven design research is conceptual, which is explored through the development and design of artefacts (prototypes and probes) that manifests theoretical ideas to portray future designs [126]. Concept-driven research explores new ideas, are futuristic and seen as probes used to get a sense of how people will respond to characteristics of future designs. Concept-design research is therefore also a way to explore new technology in ways that are not asked for by any user [126].

In sustainable HCI and interaction design research endeavours, it is common to see design research contributions that present designs of prototyped artefacts exploring interactive possibilities to change how households consume energy. Mainly two approaches drive these design endeavours. Firstly, we see endeavours that approach design by exploring automated and intelligent technology to prototype artefacts that effortlessly and efficiently support households to consume energy sustainably [2,59,73]. These artefacts are often designed with the intent to make change happen with as little human interaction as possible. Secondly, we see endeavours that approach design by exploring how digital technology can change human behaviour towards sustainable energy consumption. These artefacts are often designed to persuade households to change attitudes and behaviour by intervening in decision-making choices through rewards and motivations [116]. This design approach translates theories from pro−environmental behavioural psychology using Fogg's framework of persuasive technology [39,40,43]. Further related sustainable interaction design research contributions are presented in Chapter 2.

Empirical contributions of studying how people use and embed interactive artefacts into everyday life, convey energy consumption is shaped by more complex social structures [19,31,131]. Often in such contributions, we see a growing critique of approaching sustainable change as rational decision-making made up of attitudes, behaviours and choices [121]. Brynjarsdóttir et al. [19], for instance, develop a critique that persuasive technology tends to be limiting in framing sustainability and human behaviour. In addition, Strengers [127,131] and Pierce and Paulos [97] argue that household energy consumption is deeply embedded in mundane routines, where expectations and social norms, rather than individual behaviour and choices, shape consumption. These empirical contributions often draw on social science theories to provide a more holistic perspective on how people appropriate and embed technology in everyday life.

This stance to account for more subjective qualities in interaction design has previously been captured in 'the third wave' HCI by Bødker [11]. Sengers et al. [119] draw on the third wave HCI, suggesting four new themes for sustainable HCI including encouraging deeper reflection by designers to not just create solutions at an individual or technological level, but to also engage in bigger cultural aspects of sustainable problems. Based on prior studies, Hazas et al. [59] recognise that novel intelligent technologies has the potential to change how households use energy, but highlight a need to re-imagine how such technologies can be designed to better account for how everyday practices are carried out. An outcome of the empirical insights is a recent call to 'turn to practice' in HCI [79]. This includes sustainable HCI [100], where it is argued a practice perspective can be used to broaden our understandings of how cultural and social aspects of sustainability can be critically understood and captured in sustainability design research contributions.

In conclusion, the two types of contributions explore possible futures afforded by novel interactive design opportunities and provide critical empirical understandings of people's use of interactive artefacts. Because of the duality of exploring future opportunities in design and critically reflecting on its use, I believe, interaction design research can contribute with further understandings of instigating sustainable change in the smart home. One step in this direction could be to explore possible design imaginations of how smart home technology can be designed to better instigate sustainable change in everyday practices. However, sustainability is only part of the vision of novel digital technology starting to penetrate people's domestic space. The design and use of such technologies more broadly fall under the all-encompassing concept of the smart home.

1.3. THE SMART HOME

The smart home is about imaginative possible futures of a home where digital technology naturally partakes in everyday life. Such envisions of a future home have been with us for decades [54]. Efforts to understand and design this possible future home can roughly be condensed down to three lines of enquiry. One line that focusses on constructing interconnected and interactive technology for people's homes, one that focusses on enhancing the kind of experiences the use of such technologies may bring into the home and lastly one that sees the smart home as an enabler to overcome sustainability and energy problems.

Smart Home Technology

The smart home is often understood in technical terms, where interconnected sensors, actuators, along with digital computational devices, infrastructures and services are seen embedded into people's physical world. In this line of enquiry, the smart home is often defined by *"the interactive technologies it contains"* [54]. Research in this direction tends to focus on the complex design problems of working with ubiquitous [27,34,35,136], pervasive [18,61], interconnected [55], home automated [17,142] technologies that move into people's homes. Lately, we have seen the design of such interactive technologies conceptualised as smart home technology [30,85,86,92,139].

Earlier, most of the work in this area has focused on building the underlying hardware and software technology enabling designers to showcase the functionality, utility and usefulness of such technology to prospective users [35]. In this line of work, the design of smart home technology often follows Weiser and Brown's vision of calm computing [137]. Here, smart home technology is envisioned as functional, useful and unobtrusive tools [5] that proactively act when conditions in the environment change, but otherwise quietly operate in the background of everyday life.

The Smart Home

The smart home is also understood in terms of a place, where households live with smart home technologies in the messiness of everyday life [34,92]. In this line of enquiry, the smart home is often defined by how well the design of smart home technology manage to enhances the kinds of experiences people expect of modern lifestyle [85]. Aldrich's smart home definition [3] is widely used to connote these expectations to be; *"a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond"* [3].

The kinds of experiences people expect to have in the smart home, changes along with people starting to adopt these technologies in everyday life [85]. For example, Woodruff et al. [142], show that smart home technologies used for religious purposes shape routines, expected behaviours and social relations of family life. This indicates that visions of the smart home continue to evolve as people are getting experiences of living along these in everyday life. Strengers and Nicholls recent insights [133] observe that the smart home industry, designs and markets smart home technologies to enhance aesthetic experiences within the smart home in a vision they coin 'pleasance'. Here, the smart home is envisioned as a home where the imaginative creation of pleasance upholds desired expectations that the smart home is a place of luxury and relaxation that enhances *"any activity, from parties, intimacy and playing tennis through to working from home and vacuuming the floor"* [134].

Sustainability and the Smart Home

The idea of sustainable home life is a significant part of how the HCI community envision the smart home [54,81]. In this context, smart home technology is often understood as an enabler to instigate sustainable change afforded by the technical possibilities of the interconnected technologies and the infrastructures and services they provide [66,81,92,106,140]. Through the realisation of novel digital technologies, like smart devices and smart grid infrastructures, interested actors [92] anticipate householders to be able to control and monitor energy consuming devices from anywhere inside or outside the boundaries of their home [81,140]. This narrative of the sustainable smart home has lately been criticised, as it does not account for the messiness of everyday life [51,66,129,139].

This vision of the smart home has also been researched beyond the HCI community. Nyborg and Røpke, for instance, observe [92] that the smart home vision is a 'melting pot' of trends entailing home automation, smart grid and energy management, home security and entertainment, which impact sustainable outcomes differently. Gram-Hanssen and Darby's study [48] observe that while public actors anticipate the smart home to help combat challenges related to energy management, research contributions into the field are more diversified. Instead, most endeavours explore different ideas of what home life means to people and how these ideas may clash in a smart home context.

It is not only designers, public actors and researchers of the latest technology who anticipate sustainability problems can be solved through the integration of smart home technology. Households seem to expect the same outcomes of bringing these technologies into their homes. This, for example, is observed in Wilson et al.'s [140] recent survey study of prospective smart home users. According to their study, prospective users of smart home technology, list sustainable energy consumption as the primary benefit of smart home technology. Intriguingly for HCI and interaction design, these prospective users also perceive the primary design intent of smart home technology to enable users to control and manage their energy consumption.

Despite sustainability being part of the smart home vision, the design of smart home technology is also about supporting the everyday experiences people expect to have in a modern home, as noted above [85,134]. As smart home technologies are starting to move into people's everyday life, they provide a myriad of new ways to use these technologies that go beyond energy control and monitoring, which may actually undermine sustainability outcomes [53,92,129,139,140]. Thus, we see the design of smart home technologies influencing different expectations of how smart home living could be carried out. These kinds of expectations, as argued by Shove [120], also shape how everyday designs become embedded in everyday practices [122,123], as they stir the normality of which people aspire towards. Therefore, it matters how households embed smart home technology into everyday practices and how they expect smart home life to be experienced as it consequently contributes to or undermines sustainability outcomes.

Based on these prior observations, I argue in this PhD project that if smart home technology is going to change how households consume energy sustainably in the future, the design of these technologies needs to be approached broader, rather than just perceived as an enabler that effectively and efficiently controls and monitors energy consumption. Therefore, I see a need to explore different design imaginations of a future sustainable smart home life, to better afford sustainable energy consumption in everyday life.

1.4. RESEARCH QUESTIONS

This PhD project contributes with understandings of exploring different design imaginations of possible sustainable futures in the smart home as well as understandings of people using such technologies in concrete, everyday practices. Inspired by suggestions of Silberman et al. [124], the PhD project structures this research enquiry by 1) prototyping imaginative possible futures to instigate sustainable energy consumption in the smart home 2) conducting studies of people using such technologies in concrete, everyday practices with the purpose to inform future designs.

Following Stolterman and Wiberg's [126] concept-driven design research approach, I set out to; 1) explore opportunities afforded by novel smart home technology, 2) investigate different concepts to instigate sustainable energy consumption manifested in concrete designs (prototypes and probes), and 3) study their use and characteristics in everyday life. The following two research questions will guide this research enquiry:

Research Question 1: What characterises interaction design of smart home technology aiming to instigate sustainable energy consumption?

This enquiry will be conducted by exploring different concepts for possible smart home futures manifested in concrete designs of interactive artefacts. Paper contributions 1, 2 and 3 of this PhD project deal with the first research question. The papers present three different approaches to design artefacts aiming to instigate sustainable change in different routinised energy-consuming activities namely; heating, washing clothes and smart lighting.

Paper contribution 1 explores the concept of assisted shifting in household heating. The paper presents a prototype that investigates how to utilise automatic and intelligent technology to manage decisions of shifting energy consumption to when it is sustainable favourably. Paper contribution 2 explores the concept of provocation. The paper presents a designed artefact aiming to disrupt existing washing practices through provocation to challenge households to reflect upon their interactions with their washing machine. Paper contribution 3 explores the desirable concept of *hygge*. The paper presents a designed probe, which aims to challenge existing smart lighting practices by suggesting alternative ways to achieve desirable, enjoyable and aesthetically pleasing experiences in the smart home that also happens to be less energy-intensive.

Research Question 2: How does smart home technology shape sustainable energy consumption in everyday life?

The last three paper contributions of this thesis deal with the second research question. These three papers present empirical insights into how smart home technologies shape energy consumption in concrete, everyday practices. Paper contribution 4 presents three smart home personas representing households' desires for smart home technology, reflected in everyday practices and impacting energy consumption in different ways. Paper contribution 5 presents a long-term study of households adapting to automatic and intelligent technology that makes decisions surrounding their heating practices and sustainable energy consumption. Paper contribution 6 presents a study of households adapting, reflecting and forming new washing routines and expectations after living with a provocative design intervention.

1.5. THESIS OUTLINE

The next chapter presents related work on sustainability and HCI and outlines three design-driven HCI perspectives to understand and instigate sustainable change through design. Chapter 3 summarises each of the paper contributions. In chapter 4, I discuss the broader implications of the findings of this PhD project, while chapter 5 concludes the work done in this project, along with presenting research limitations and implications for the future of sustainable interaction design. In this last chapter, the six paper contributions are presented in details.

CHAPTER 2. RELATED WORK

The previous chapter briefly introduced various research directions looking to instigate sustainable change for combating the growing energy consumption and CO_2 emissions through the design and use of smart home technology. Grounded in these observations, the previous chapter also presented two research questions. To guide and inspire the research enquiry in this PhD project, this chapter will outline current HCI research directions investigating how digital technology can be designed to support sustainable energy consumption in the home.

2.1. SUSTAINABILITY IN HCI

Investigations into how digital technology can be designed to instigate sustainable change is a quest the HCI research community has engaged with for about a decade. Since Blevis first introduced the term sustainable interaction design at CHI in 2007 [9], the community has conducted enquiries in various sustainable directions. This includes water conservation [44,94], heating and cooling optimisation [1,21,23,25,145,146], transport [13,16,42,58,135], food [12,22,45,147], consumer production [10] and the support of sustainable energy consumption. These latter endeavours have either investigated how to reduce [69,71,93,103] or shift electricity consumption to align with renewable production [68,97,114,125].

Since the HCI and interaction design research community is relatively young and draws on multiple scientific fields, this has resulted in the use of interdisciplinary methods and frameworks to understand the relationship between digital technology, design, people and changes in society [74,80,102,110]. According to DiSalvo et al. [31], this interdisciplinary approach also exists within sustainable HCI research endeavours. The authors argue that different perspectives on how to frame design problems and solutions of sustainability tend to cluster research contributions in the community and its measures for success.

The rest of this chapter will outline three design-driven HCI perspectives to understand and instigate sustainable change through design. Each of these perspectives uses different approaches to frame design interventions aiming to support households to consume energy sustainable. One perspective that sees unsustainable user behaviours as an energy management problem, one that solves behaviour problems through technological interventions, and one that sees the whole energy consuming practice as the unit of intervention.

2.2. ENERGY MANAGEMENT AS FEEDBACK IN HCI

The prevalent perspective to frame sustainable energy problems within HCI is to look towards users and focus on their problematic unsustainable behaviours. This perspective sees change of behaviour as an energy management problem that can be solved by providing individuals with the right kind of information to enable positive behaviour. This is often approached by gathering various types of energy information and design feedback systems to raise awareness about consumption patterns.

This approach is commonly known in HCI as eco-feedback design [43]. Eco-feedback design is inspired by Fogg's framework of persuasive technology [39,40] that draws on theories of pro-environmental behaviour psychology. It is a framework, which assumes that people can be motivated and persuaded to change behaviour by using technology to reward people with positive feedback [39]. This means eco-feedback design studies often investigate solutions that visualise different kinds of energy information to support people in managing energy consumption.

Motivations to engage in such design efforts are varied through. Pierce and Paulos, for instance, engage in such endeavours because visualising an invisible and intangible resource like electricity to users is a design problem in itself [96]. Hasselqvist et al. [57] and Fischer et al. [38] examine how to use energy information to tailor information to professional energy advisors [38] and amateur cooperatives [57] to support them in making more informed energy decisions about a building's energy usage. Others examine how to use physical forms [15,138], light [64], ambience and art [49,107], and wearables [114] as designerly feedback techniques.

The general framing of eco-feedback designs, though, is about informing households about their energy consumption patterns to raise awareness about 'good' and 'bad' behaviour. Such studies outline various accounts of how to visualise past and forecasted energy information on different interactive displays, e.g. mobile phones [42,69], situated home displays [68,104,125], or public displays [6,25]. Other studies have explored various information and feedback techniques to support households to move energy consumption in time to align consumption with the production of renewable energy. This is a concept, which Pierce et al. have coined as shifting in HCI [99]. Pierce and Paulos [98] also argue the eco-feedback design can play an important role in facilitating shifting behaviour. Among HCI design studies exploring shifting through eco-feedback are; Schwartz et al.'s HEMS [116], Pierce and Paulos' Local Energy Indicator [97], Kjeldskov et al.'s eForecast [68], Rasmussen et al.'s ClockCast [104], Simm et al.'s Tiree Energy Pulse [125] and Schrammel et al.'s FORE-Watch [114]. Together these design efforts attempt to rationalise and facilitate some of the decision-making surrounding energy management, assuming householders are empowered by such designs as Strengers' Resource Man [130].

Most of these studies are accompanied by empirical studies reporting success in raising awareness of unsustainable consumption patterns [68,69,104] and demonstrate that such information can be valuable to people who are already motivated to act sustainably [125,147]. Yet, many also report a limited success of eco-feedback leading to profound behaviour change long-term [68,71]. This echoes Dourish's argument

[33] that a focus on a personal moral choice can end up being a demotivating factor as it operates on guilt to instigate sustainable change. Such results are backed up by empirical studies contributing with understandings of how people embed such designs into their everyday life and how they shape energy consumption. Examples are Hargreaves [52] and Strengers' [131] studies of eco-feedback in everyday life, which observe that more complex social structures shape electricity consumption.

Together these results have led to a growing critique in HCI of framing designs as an energy management problem that can be solved by motivating people to change behaviour through persuasive technology [19,31,131].

2.3. AUTOMATING SUSTAINABLE ACTIONS IN HCI

A parallel research stream has explored how pervasive, automated and intelligent technology can instigate sustainable change in households. This perspective sees the replacement of human actions with automated and intelligent technology silently operating in the background, as a solution to users' problematic unsustainable behaviour. Therefore, this design perspective often explores advances in smart home technology to increase the efficiency of sustainable energy consumption and aims to make sustainable changes happen as effortless and convenient as possible.

In HCI, this design perspective is commonly used to investigate how to automate the decision-making of when and how households should consume energy. Examples of such studies are Alan et al.'s Tariff Agent [2], Scott et al.'s PreHeat [117], and Koehler et al.'s TherML [73]. The objective of these studies is to instigate sustainable change by involving households as little as possible. Therefore, the common design problem in these studies is finding a balance between what users control and what the system controls. These studies do report a high potential of automating decision-making surrounding energy efficiency. However, their evaluation efforts tend to focus on the efficiency of usability and the functional and algorithmic features of the system, rather than how people experience and adapt to these technologies long-term. What is common in these design efforts is that they tend to follow Weiser and Brown's vision of *calm* computing [137], where technology is supposed to be designed to fade quietly into the periphery of everyday life.

A few HCI empirical studies do provide understandings on how smart home technology that is purposely designed to support sustainable energy consumption is experienced in households. One is Yang et al.'s extensive user study of the NEST [143,144,145]. The NEST is a commercial smart thermostat designed to intelligently deduce and schedule households' heating and cooling based on how people interact with the artefact. In their study, they report that people interact less and less with the artefact as time goes by, resulting in missed opportunities to save energy. Based on a user study exploring how pervasive, automated and intelligent technology can support sustainable heating consumption, Clear et al. [24] suggest to challenge households more in our design efforts. The authors argue this can, for instance, be accomplished by advocating new comfort strategies. This line of enquiry follows Rogers' vision of engaging Ubicomp experiences [108] suggesting that design efforts with smart technology should focus more on empowering people, by provoking people to learn, understand and reflect when interacting with smart technology in everyday practices.

Following this line, other studies have focused on prototyping future scenarios envisioning dynamic price schemes and smart grid technologies in specific energy-consuming activities. Costanza et al. [26], for example, studied a prototyped 'smart agent' that implements a shifting scenario for washing. The aim of the study was to investigate how to enable users to run the washing machine effectively when renewable energy was available. Bourgeois et al. [14] studied a similar scenario, where they developed four different technological interventions mixing feedback, proactive suggestions and an intelligent 'agent' able to run the washing machine when it was sustainably favourable. Both studies report that HCI is well situated to prototype future scenarios to get more profound insights into how peoples experience and adapt future technology.

Other empirical studies account on how prospective users perceive future smart grid and smart home technologies. Rodden et al.'s [106] user study investigate prospective users' attitudes towards smart energy infrastructures and home automation. They report that prospective users lack trust in envisioned future smart energy technologies resulting in them being disengaged in energy issues [106]. Wilson et al.'s recent survey study of smart home technology [140] highlights that prospective users point to energy savings, energy management, and control of their home as the primary benefits of smart home technologies. However, they also argue that while these technologies may support energy management, they also enable energy consumption by providing new or intensifying existing services. They conclude that how these technologies ultimately end up shaping households energy consumption depend on how they are designed and embedded in everyday practices [140].

2.4. EVERYDAY PRACTICES IN HCI

Recently, we have seen a 'turn to practice' in HCI [79] and suggestions to use practice-oriented methods when aiming to instigate sustainable change [100]. The practice perspective sees the whole energy consuming practice as the unit of intervention where everything related and interwoven in the practice is potentially changeable [79]. This perspective has primarily been used to critically describe and understand how sustainable energy consumption is shaped in everyday life, but rarely used as a design framework in sustainable HCI.

Kuutti and Bannon [79] argues that a practice perspective have started to emerge in HCI in recent years. They see the practice perspective as an alternative, complementary theoretical lens to understand the relation between humans, computers and interactions, as to what they label the interaction perspective. The authors argue the interaction perspective focuses on individual human-computer interactions in ahistorical situations, where the practice perspective instead moves away from framing interactions as the centre of the investigation and approaches it as one aspect among many. While elements of a practice perspective are seen in HCI e.g. Rogers' call for 'in the wild' studies [109,111] and Dourish's framing of embodied interaction [32], we recently seen it explicitly mentioned in a call to use practice-oriented methods within sustainability studies [37,66,75,131,132]. The latter has most notably been advocated in the 2013 TOCHI special issue of *"Practice-oriented Approaches to Sustainable HCI"* [100].

The practice perspective in sustainable HCI draws inspiration from recent social science research pointing out that by studying practices of everyday life, rather than everyday behaviours, may provide new insights into how energy consumption is shaped and changes [46,47,83,120,132]. The practice perspective recognises that energy consumption is not a practice in itself, but interwoven in the mundane activities people do at home like e.g. cleaning, heating, washing, and cooking. This means that what people do, how they use 'things' and the activities they engage in, takes a centre stage in a practice perspective. To conceptualise this perspective, Reckwitz's definition is widely used:

> *"A 'practice' (Pratik) is a routinized type of behaviour which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge"* [105].

In their seminal book [122] from 2012, Shove and her colleagues rework prior fuzzy definitions of the elements of practice. In doing so, the authors provide a concise framework of practice, which they conceptualise as configurations of three elements; competences, materials, and meanings [122]. The competences element includes skills, know-how and techniques, providing a shared understanding of what is an appropriate performance of the practice. The materials element includes technologies, infrastructures, designed artefacts and the human body used when performing the practice. The meanings element describes symbolic meanings, ideas, aspirations that provide rationales for engaging in the practice.

Using this theoretical framework also means that practices can be understood as socially shared ways of doing and thinking that are meaningful and desirable. To understand the sustainable implications, Shove argues [120] that socially shared desirable expectations, such as comfort, cleanliness and convenience, play a critical role in shaping normality, and that such expectations also have significant energy consumption implications. A practice perspective is therefore often used as an analytic lens to describe and understand the dynamics of everyday practices and interwoven consumption. Moreover, a practice perspective can also be used to get a broader understanding on how people appropriate designed artefacts [123] and technology [46] in everyday life and how they influence consumption patterns [47,120]. Many sustainable HCI studies using a practice perspective provide insights into how resource consumption is shaped by describing the status quo and pointing to design implications [45,58,66,97,128,131]. Hasselqvist et al. [58], for example, use a practice perspective to study different families' experiences of living car-free (intervention) for a year and point to opportunities for design to support change of more sustainable transport practices. Ganglbauer et al. [45] also use a practice perspective to study food practices through a technology probe to suggest design strategies for integrating related practices that influence food waste, rather than focusing on waste itself.

Shove et al. [122] practice framework also describes how practices change over time. The authors argue that new elements (materials, competences, and meanings) or new configurations of existing elements change practices. Therefore, if one is to follow a practice perspective to instigate change through design means to realise that not only the material element can be changed but all elements are potentially changeable and can be targeted for intervention. Shove et al. [122] also distinguish between practices as performance and practices as entities. A practice as a performance refers to when people carry out a practice in a specific space and time. A practice as an entity refers to practice as a socially shared and recognisable way of engaging in the practice that persist over time and space. A practice entity changes when new elements and new configurations are integrated in the practice through regularly performance [122]. This means that practice becomes embodied in people's mind and body when they actively perform the practice. Therefore, people are considered as carriers, performers or practitioners of practices.

Recently, we have seen HCI method contributions suggesting a practice perspective as an alternative way to frame behaviour change when designing for sustainability. Entwistle et al. [37] present the "Contextual Wheel of Practice" framework, which the authors argue can be used by researchers and designers to better understand practices, design effective design intervention and facilitate collaboration in teams with different background. Kuijer and Bakker [76] suggest to use a practice perspective to *"envision change beyond the status quo to achieve a higher effectiveness with designed interventions",* while Pettersen presents key principles and approaches from different design fields including HCI, and discuss these in the light of a practice approach to sustainable design [95].

However, only few contributions in sustainable HCI have used a practice perspective to frame design interventions. In such endeavours prototypes or probes are often used to envision possible future practices, which are manifested in concrete designs. Katzeff et al. [67] present a study of a designed artefact intervention that suggests non-electricity consuming activities without focusing on energy-consumption directly, in an attempt to give a different meaning on how to shift energy consuming activities in time. Pink et al. [101] explores sensory ethnography to understand heating practices as an approach to inform a future sustainable design. Using these insights, they prototype ideas of giving *"heating practices a new form"* in a concrete designed artefact called the Acclimatiser.

Prototyping and a practice perspective has previously been brought together by Mogensen [87]. By drawing on both prototyping and practice perspective (activity theory) Mogensen proposes the notion of provotyping [87] as way to qualitative inform the design on new artefacts and ensure their usefulness in a given practice. However, the design intent in a provotype is not to imagine possible future designs, but to provoke current practice. Thus, the designer is not there to outline possible futures in concrete designs that aim to support people in their everyday life. Instead the designers' role is to be *as provocateur* that provoke concrete, everyday practices, by exposing problems in the current situation by calling *"call fourth what is usually taken for granted"* [87].

Kuijer et al. [78] use a similar approach of making practices the unit of sustainable design. In their study, they are more explicit in their use of Shove's practice framework to approach their design efforts. The authors demonstrate that by making practice the unit of design, provide fruitful ways to generate reconfigurations of practice elements. The aim of their study was to investigate if 'splashing' can work as design concept to change Dutch showering practices towards a less resource-intensive practice. In their study, prototypes were purposely used to refine future designs by letting future practitioners improvise new routines of splashing with these prototypes. By observing how new 'splashing' routines were performed, the authors were able to refine the splashing concept keeping in mind that all three elements of practice *"become part of what is designed"*.

CHAPTER 3. CONTRIBUTIONS

This PhD project sets out to contribute with understandings of possible design imaginations of a sustainable smart home and provide understandings of how such designs may shape energy consumption in everyday life. Hence, the overall research approach is "*explorative in nature, aiming at manifesting visionary theoretical ideas in concrete designs.*" [126] that study *"an overall activity, involving people, artefacts, routines and daily practices"* [79]. This means that the research enquiry is developmental and future-oriented aiming to explore different concepts manifested in concrete designed artefacts (prototypes and probe), following a concept-driven interaction design research approach [126]. As the designed artefacts aim to instigate sustainable change by intervening in different routinised energy-consuming activities also suggest a practice-oriented approach following Kuutti and Bannon [79]. Hence the research enquiry is also qualitative, in situ, observational, and extended over time [79].

To guide this research enquiry, the PhD project engaged in three different studies. In each of the studies, the purpose was to imagine possible futures by exploring different design concepts (assisted shifting, provocation and the desirable concept of *hygge*) with smart home technology while intervening in mundane and routinised activities. The interventions were studied in the field with households that used them in everyday concrete practices to provide understandings of how such designed interventions shape energy consumption in the home. The specific methods used to provide such understandings is elaborated in each of the papers in Chapter 7.

The following briefly describes each of the three studies and their contributions, which is followed by a more detailed summary of each of the paper contributions.

The HeatDial study (papers 1 and 5): The aim of this study was to investigate the concept of assisted shifting. Shifting, as proposed by Pierce et al. [99], refers to shifting energy consumption in time or place to align consumption with the production of renewable energy. Prior to the HeatDial study, most research endeavours had explored this concept by aiming to proactively change households routines to align with the production of renewable energy. In this study, the aim was to explore and experiment with new smart home technology to intervene in existing heating practices with the aim to assist households to shift running times of their heat pump Paper 1 presents a concrete design formed as a prototype called HeatDial that manifests the concept of assisted shifting. Paper 5 presents empirical understandings on how households experienced living with the designed intervention long-term.

Paper 1: Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16).

Paper 5: Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2018. Assisted Shifting of Electricity Use: A Long-Term Study of Managing Residential Heating. *ACM Transactions on Computer-Human Interaction* (TOCHI) (Accepted April 2018).

The Box study (papers 2 and 6): The aim of this study was to investigate the concept of provocation in a shifting scenario. Drawing on Bardzell et al.'s [4] framework of provocation, the study explored this concept on three levels (aesthetically, functionally and conceptually). The aim was to intervene and challenge existing washing practices towards sustainability through disruption and reflection. Paper 2 presents a concrete provocative design in the form of a technology probe [62] called the Box. Paper 6 reports on empirical understandings into how households improvised, reflected and adapted to new routines influencing sustainability in different ways.

Paper 2: Dimitrios Raptis, Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2017. Aesthetic, Functional and Conceptual Provocation in Research Through Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (DIS '17).

Paper 6: Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18).

The *hygge* study (papers 3 and 4): The aim of this study was to explore the concept of *hygge* in a smart lighting scenario. The study started by empirically investigating the status quo of smart home life. By drawing on Nelson and Stolterman's framework of desiderata [89,90] and Shove et al.'s [120,122,123] interpretation of how desires shape expectations and practices, three smart home personas were developed named the helper, the optimiser and the hedonist. These results are presented in paper 4. Using these insights, the study set out to investigate if *hygge* could work as a desirable concept to reconfigure smart lighting practices to be less energy-intensive. Paper 3 presents a concrete design formed as probe pack exploring the *hygge* concept. Paper 3 also presents empirical insights into how the *hygge* concept may reconfigure everyday practices towards a sustainable energy usage.

Paper 3: Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B Skov. 2018. Exploring Hygge as a Desirable Design Vision for the Sustainable Smart Home. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18).

Paper 4: Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI 18)

3.1. HEATDIAL: A DESIGN FOR ASSISTED HEATING

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16).

This paper presents a design of an artefact intervention named HeatDial, which explores the design concept of assisted shifting to instigate sustainable change in household heating. The design intent was to assist households in consuming electricity produced from renewable resources by intelligently shifting running times of their heat pump. To this end, we engaged in design activities resulting in a new design convention - a temperature tolerance range - presented to households as a different way to understand and control their heating more sustainably.

The design intent was to automate most of the decision-making of finding and shifting running times of a heat pump, while still letting households have control of the heating in their homes. To support both purposes, we explored how automatic technology and intelligent infrastructures could be designed for assisted shifting. The result of the design activities was the HeatDial prototype, a three-part system, consisting of temperature sensors located at each household, an intelligent system capable of controlling individual heat pumps from the outside and an interactive application.

In the interaction design itself, the design intent was to hide the complexity of the intelligent system automating shifting on behalf of householders. The primary design challenge we engaged in, was to conceptualise shifting in an interaction design that also suited the mechanics of intelligently running a heat pump. Earlier design approaches have designed shifting through concepts of energy control measures or specific running times. Instead, we explored the design of assisted shifting as boundaries of temperatures. The result was a new design convention where households can specify boundaries of their comfort in temperatures, in which, they allow the intelligent system to operate within. With this design, the responsibility of adapting to sustainable actions and conforming to household heating expectations are primarily transferred to the technology. Because most of the interaction in the HeatDial system fades into the periphery, this approach to instigate sustainable change resembles Weiser and Brown's vision of calm computing [137].

The HeatDial design demonstrates how it is possible to draw on automatic and intelligent technology to assist households in some of the decision-making surrounding sustainable energy consumption for heating. The design concept of assisted shifting is an example of how the design of technology can make some of the mundane decision-making surrounding sustainable energy consumption more convenient and effortless for households to engage in.

3.2. THE BOX: A PROVOCATIVE DESIGN FOR WASHING

Dimitrios Raptis, Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2017. Aesthetic, Functional and Conceptual Provocation in Research Through Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (DIS '17)

This paper presents a provocative design of an artefact intervention named the Box. The objective of the study was to explore the design concept of provocation to purposely challenge and provoke the idea that renewable electricity is an always available resource for households to consume when washing clothes. The design intent was to use energy information in a provocative design to disrupt mundane washing routines by making these more challenging to carry out to make households reflect upon their washing practices.

To design for provocation, we explored functional, conceptual and aesthetic aspects of both digital and physical interactive forms, inspired by Bardzell et al.'s framework of provocative design [4].

In the Box design, the *functional* aspect was facilitated by challenging the norm of interacting with a washing machine. The Box design facilitated this aspect by purposely cutting off the washing machine's power supply when there was no supply of renewable energy. The Box design also adopted an emergency button metaphor, which allowed households to start the washing machine if there was no supply of renewable energy. This design metaphor was used to provoke a sense of reluctance, as it signals that the button should not be pressed without consideration. The *conceptual* aspect of provocation was facilitated by challenging the expectation that electricity is always available and cheap, and the idea that there is no need to reveal the origin of the energy production. To facilitate this aspect, the Box was designed with a colour-coded clock representing different types of electricity. The Box design also introduced a price-schema, which made washing using renewable energy free and fossil-fuel energy twice as expensive as the normal price of electricity. The *aesthetic* aspect of provocation was facilitated by purposely designing the form of the Box as far away from the mainstream visual design of simplicity, minimalistic and beauty. Instead, the Box was crafted with an old, industrial case for electric equipment to materialise a bulky, retro style look, which was supported by old-school, numerical LED screens.

The Box design demonstrates how it is possible to draw on the concept of provocation in design as a means to disrupt, provoke and challenge current household washing routines. The design concept of provocation is an example of stepping away from designing for effortlessness and convenience towards designing for more human proactivity in the form of reflection and improvisation as a way to instigate sustainable change.

3.3. *HYGGE*: A DESIRABLE DESIGN FOR SMART LIGHTING

Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B Skov. 2018. Exploring *Hygge* as a Desirable Design Vision for the Sustainable Smart Home. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18)

This paper presents a design and study of an intervention exploring an alternative low-energy vision inspired by the Danish concept of *hygge*. The objective of the study was to explore a desirable concept for smart lighting that also happens to be low-energy consuming, without promoting sustainability directly. The design intent was to challenge existing smart lighting practices, by proposing alternative ways to achieve aesthetically pleasing experiences that are less energy-intensive. For this purpose, we turned to *hygge*, a Danish concept promoting a desirable lifestyle full of cosiness and companionship. It is also a concept, which is gaining hype as being cool and hip in countries like the U.K. and Australia.

Hygge was fascinating to explore in a sustainable smart lighting setting, because it embodies ideas of low-level and natural lighting, without encouraging sustainability directly. To explore if *hygge* could challenge existing smart lighting practices, we designed a probe pack containing a *hygge* book, quiz, diary and a playful lighting app designed for this study. The design intent was to explore if a desirable but a presuming low-energy concept of *hygge* could reconfigure household practices by mixing elements (materials, meanings, competencies) of practice. An approach inspired by Shove et al. [122] theory of social practice that argues that reconfigurations of these elements can lead to practice change. Therefore, the design intent was to challenge meanings of aesthetically pleasing experiences of smart lighting by circulating new ideas as to how to achieve these through different materials.

To obtain empirical insights into if *hygge* as concept would shape household practices and influence energy consumption, the paper also presents a field study with two Australian households. As lighting infuses a range of household practices, the study showed that new meanings, competences and materials started to become embedded not only in smart lighting practices but in other practices too, potentially leading to both less or more energy consumption.

The *hygge* design demonstrates how it is possible to draw on a desirable concept to introduce new meanings, materials and competencies, which may reconfigure everyday practices towards sustainable energy usage. The study shows, it is possible to challenge expectations of what is desirable, by proposing alternative ways to achieve desirable, enjoyable and aesthetically pleasing experiences in the smart home, without proactively promoting sustainable change. Therefore, the study is an example of how to reorient expectations of desirability and sustainability in the smart home.

3.4. UNDERSTANDING THE DESIRABLE SMART HOME

Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B. Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18)

This paper presents empirical insights and understandings into how desires and expectations for the smart home shape energy consumption. As most sustainable HCI research endeavours tend to overlook desirability when evaluating the sustainable benefits of smart home technologies, we wanted to investigate how desires embedded in smart home designs shape and enhance everyday experiences and energy consumption. Moreover, as many smart home technologies are starting to move into people's homes and being embedded into everyday practices, we wanted to further our understandings on the kinds of desires that do not directly involve sustainability but have sustainability outcomes.

The contribution of the paper is three-fold. Firstly, the paper investigates different desires embedded into the design of smart home technologies and how these are reflected in everyday practices. Secondly, the paper identifies the key implications, desires have on energy consumption. Lastly, the paper discusses how desirability can be used to steer the design of smart home technology towards sustainability.

The empirical investigation was conducted as a qualitative study, through interviews and home tours, where 23 Australian households reflected on their experiences of living with smart home technologies. We drew on two frameworks as an analytical lens to understand how desires and expectations shape people's use of a design. To understand desires we drew on Nelson and Stolterman's framework of desiderata [89,90]. This framework understands desirability of designs through reason, ethics and aesthetics. To understand how desires become embedded in everyday practices we turned to Shove and her colleagues' [120,122,123] interpretation of how desires shape expectations and in turn become embedded (or rejected) in everyday practices. The result of the analysis is a typology of householders' desires structured into three overall smart home personas; the helper, the optimiser and the hedonist that impact energy consumption in the smart home in various ways. The helper captures desires related to the functional purpose of the smart home. The optimiser captures desires related to desired outcomes for the smart home. The hedonist captures aesthetically pleasing desires in the smart home.

The results of the study demonstrate how householders' desires for the smart home shape expectations, everyday practices and associated energy consumption. Furthermore, the results show that different desires both compliment and contrast each other, highlighting an energy paradox in smart home design. While smart home technologies afford different uses that reflect a modern lifestyle, they may actually undermine the desire to live sustainably.

3.5. UNDERSTANDING ASSISTED HEATING LONG-TERM

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. Assisted Shifting of Electricity Use: A Long-Term Study of Managing Residential Heating. *ACM Transactions on Computer-Human Interaction* (TOCHI), accepted April 2018.

This paper presents a long-term empirical study with eight Danish households experiencing an artefact intervention – HeatDial - designed to automate and manage household heating sustainably. The objective of the study was to gain insights into how households adapted to the HeatDial system assisting them with shifting energy consumption on their behalf.

The contribution of the paper is three-fold. Firstly, the paper investigates expectations and experiences of living long-term with automated heating intervention and how its presence influenced household heating practices. Secondly, the paper identifies how efficiently HeatDial shifted energy consumption and how assisted shifting affected the comfort in the home. Lastly, the paper discusses the opportunities and challenges of automating mundane sustainable decision-making in routinised activities.

The empirical study was conducted with eight households over a period of 6-18 months. In the study, both qualitative and quantitative datasets were collected and analysed. The qualitative analysis resulted in the three overall themes; convenience, control and complexity. The threes themes describe various aspects of living long-term with the HeatDial intervention. The paper also presents a quantitative analysis illustrating how well HeatDial managed to conform to households' comfort expectations, while scheduling the heat pump to run on sustainable energy. The themes show that automatic, intelligent technology can reduce complex sustainable energy concepts like shifting. Furthermore, the results show that automating sustainable decision-making can be an effective way to instigate sustainable change because households experience this as an effortless and convenient way to consume electricity sustainably. However, the results also highlight that rational design conventions do not always capture 'irrational' human actions, which can undermine the sustainable design intent.

The empirical results of the HeatDial study demonstrate the opportunities of letting an automatic, intelligent artefact instigate sustainable change, by exploring the possibilities of new smart home technology. The study also highlights the challenges of automating sustainable decision-making and transferring responsibility of adapting to sustainable actions to the technology. Because when sustainable decision-making is designed to be achieved effortlessly and conveniently, it fades into the periphery of everyday life. This means such interventions do not necessarily manage to engage people or raise questions about sustainable energy consumption.

3.6. UNDERSTANDING PROVOKING WASHING PRACTICES

Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18)

This paper presents an empirical study of four Danish households experiencing a provocative artefact intervention - the Box - when washing clothes. The Box was designed to purposely provoke mundane and routinised interactions with a washing machine with the intent to support a more sustainable energy usage. The objective was to empirically study how washing practices were disrupted, reflected upon, adapted and improvised after experiencing a provoking design aiming to intervene in household routines by making washing more challenging to carry out.

The contribution of the paper is three-fold. Firstly, the paper investigates households' experiences of living with a provocative artefact intervention. Secondly, the paper identifies how households adapted, reflected and formed new routines and expectations related to washing practices. Lastly, the paper discusses design opportunities of provocation to disrupt everyday practices and challenge expectations.

The empirical study was conducted as a qualitative study, through interviews and home tours, with four households that lived with the Box for four weeks. The data analysis resulted in the five overall themes each describing various aspects of living with the Box. The themes demonstrate how established household routines of interacting with energy-consuming technology can be provoked and disrupted through design, leading to higher engagement in households to instigate sustainable change. Furthermore, the results show how provocation can lead to reflections that challenge current household expectations of washing, which have other sustainability implications. While washing routines may be adapted to support sustainable energy consumption, not all end up following the design intent. It shows that designers may inscribe sustainable intent into designs that can shape use, but design intent itself cannot determine how such designs are embedded in everyday practices.

The empirical results of the Box study design demonstrate that provocation can be used as a designerly means to disrupt and challenge existing washing routines and expectations to instigate sustainable change. By provoking the status quo, it is possible to observe how households reflect, adapt and improvise new routines. Most notably, the study demonstrates that changes to household routines were triggered by adding complexity to the interaction, rather than designing for effortlessness and convenience. Lastly, the study shows that engaging in a provocative design investigation can be a highly reflexive process, where not only participants get provoked but where a designer's assumptions and intentions get challenged too.

CHAPTER 4. DISCUSSION

The aim of this PhD project has been to explore the design of smart home technologies to instigate sustainable change that contributes to households consuming energy more sustainably. The previous chapter presented the six paper contributions that constitute this PhD thesis. The first three papers presented three designed artefact interventions that explored different design concepts to instigate sustainable change. The latter three papers presented empirical understandings of how households embed smart home technology into their everyday practices and how it shapes energy consumption. In this chapter, I will discuss the broader implications of the results of my studies. Three main sections constitute this chapter. The first section discusses an energy paradox of the sustainable and the desirable smart home. The next section discusses implications of bringing a practice perspective to sustainable interaction design. The last section discusses the role of interaction designers as provocateurs.

4.1. THE SUSTAINABLE AND DESIRABLE SMART HOME

There is little doubt that novel digital technologies and the services and infrastructures they provide, will form future solutions like smart energy grids and smart homes with the aim to support households to consume energy more sustainably. The EU, for example, explicitly states sustainability as one of the core measurements of success for smart technology research initiatives [84]. Despite many prospective smart energy technologies being under development, e.g. smart grid facilitation in Denmark [70], we see more and more smart home technologies already moving into peoples' home and become embedded in their everyday practices. While prospective smart home users [140] and other interested actors [29,92] may see energy management as the main benefit of smart home technology, householders' use of these technologies seems to be more multifaceted as such.

The findings in paper 4 contribute to understandings of how households' desires for the smart home technologies impact energy consumption that goes beyond energy management and control. As desires are reflected in everyday practices and impact energy consumption in different ways, the findings in paper 4 highlight an energy paradox in the smart home. While householders might desire smart home technology to assist with consuming energy more efficiently, they also desire to aesthetically enhance experiences in that smart home, which may actually undermine their desire to live sustainably. This paradox of the desirable and sustainable smart home echoes other empirical studies, which argue that there is little evidence that smart home technologies will lead to energy savings when households embed such technologies in everyday life, and they might even intensify energy consumption [53,92]. So why does the desire to use energy sustainably not shape householders' appropriation of smart home technologies alone?

If we are to follow Nelson and Stolterman's framework of desiderata [90] to understand why people desire to use a designed artefact, means to go beyond the rationality and moral codes of acting, for example, sustainable. As paper 4 highlights, it is a more inclusive whole of the desirable – or desiderata – that shapes householders' desires and expectations for the smart home, and thus contributes to or undermines sustainability outcomes.

According to Shove et al. designers have an '*indirect but potentially decisive hand in the constitution of what people do*' [123] and essentially also on how they consume energy. Therefore, one cause for a misalignment between the sustainable and desirable smart home may be found in the development and design of the technology. As Strengers and Nicholls [133] observe, the smart home industry designs and markets these technologies as a means for enhanced aesthetically pleasing experiences suitable for a modern lifestyle. But such purpose often undermines the sustainability outcomes of the technology. Additionally, the misalignment may transpire, because designers are not imaginative enough when exploring possible futures for the sustainable smart home. Sengers [118], for example, argued in her DIS '18 keynote that imaginative possible futures of technologies are often designed by technology-centred engineers and thus shaped *"by the worlds they themselves know and value, which are only a small slice of global ways of being"*, narrowing the possibilities of diversified design imaginations [118].

Such narrowed design imaginations seem to be apparent in technology-centred research projects that develop prospective smart energy solutions intending to instigate sustainable change through the diffusion of technology alone. The majority of such research projects are able to showcase the functional and utilitarian potential to support household to reduce fossil fuel use [41,73,91]. However, householders' involvement in realising the potential of the technology is often envisioned to be a matter of activating the consumer potential [29,36]. Hence, such projects tends to not explore the sustainable smart home beyond the vision of a space where smart home technology enables effective and efficient energy management and control [20,139].

The results of this PhD project contribute with imaginative possible futures for the desirable and sustainable smart home that attempt to go beyond the technology-centred vision of smart home technologies. The studies in this PhD project show how it is possible to draw on different concepts [126] to explore and imagine possible desirable and sustainable futures such a *hygge* presented in paper 3. Additionally, as desires are reproduced through practices [122], the contributions suggest that by 1) considering concepts that speculate or provoke households about sustainable futures through concrete designs and 2) studying the designs in concrete everyday practices – interaction design researchers and practitioners are better equipped to evaluate if these design concepts are also meaningful and aligned with desires of the sustainable, desirable smart home.

4.2. SUSTAINABLE INTERACTION DESIGN AND PRACTICE

Interaction design is a discipline that strives to research and practice *"designing interactive products to support the way people communicate and interact in their everyday and working lives"* [102]. Hence, designing or redesigning digital technology (products, services, applications, infrastructures and systems) to support people in what they are doing, is one the of the core activities interaction design practitioners and researchers engage in. This framing of interaction design suggests a user-centred approach where users' needs are carefully derived in order to improve or and enhance the kind of experiences people aspire towards [56].

If we put a practice perspective on the corpus of sustainable interaction design research, the majority of design contributions aim to change how households consume energy by focussing on changing or improving the materials that are already part of everyday life. Although eco-feedback designs framed as persuasive technology [43] can be limited in instigating desired behaviour change [19,131], we can also view these design efforts as practical attempts to design or redesign energy products and services, e.g. smart meters and utility bills, that already exist in many households. Therefore, it is not surprising to see this focus in interaction design to improve the design of these materials, because they are core the elements designers work with when designing interactive artefacts.

But interaction design is also about imagining future scenarios that designers prototype through materials to let people get concrete experiences with these imagined futures [82]. To imagine possible futures of a sustainable life in the smart home also means to work with complex digital technology, infrastructures, and services (materials) because they make up most of the materials interaction designers work with [65]. The HeatDial study presented in paper 1 and paper 5 is an example of working with such complex design materials. The HeatDial study demonstrates the difficulties of capturing 'irrational' human actions in design conventions, which have to be translated to a 'rationalistic' system architecture that again has to operate within an already complicated and messy everyday life [34].

Other studies also account on difficulties of working with such design complexity in sustainable interaction design [2,26]. Nonetheless, the long-term HeatDial study highlights the opportunities of letting automated and intelligent technology take over some of the more tedious tasks of shifting. Particular if these tasks have already been semi-automated by technology like heating. As the HeatDial system operates quietly in the background of everyday life, the technology effortlessly and conveniently becomes part of conventional everyday practices as time goes by. Additionally, the HeatDial study also demonstrates that smart home technology can assist to reduce complex energy concepts like shifting. Thus, there are opportunities to be found in exploring how to 'better' the design of such complex materials, to more effortless instigate sustainable energy consumption in the smart home.

In prior work, we have seen a practice perspective providing a theoretical framing for critically describing and understanding the potential and pitfalls of current technology shaping everyday practices and energy consumption [53,131]. But can a practice perspective (material, competences, meanings) [122] be used to inform sustainable interaction design beyond 'bettering' the material element?

The findings of this PhD project provide multiple answers to this. A practice perspective can be used to understand the status quo (paper 4) to inform future interventions, like the redesign described in paper 3. The value of using a practice perspective to study the status quo and point to future directions for the design of sustainable interventions has also been conveyed in others studies [45,58,101,131]. Paper 6 demonstrates that a practice perspective can also be useful for evaluating designed interventions to get a broader understanding of the sustainable (and unsustainable) implications of the design efforts. A few other HCI studies use a similar approach to evaluate the sustainable design contributions in order to get a broader understanding of the sustainable implications of designed intervention [58,67,104]. Others in HCI have also suggested practices-oriented design methods for framing sustainable design interventions beyond user-centred methods [37,77,100].

Nevertheless, there are seems to be limited studies in sustainable interaction design that explore design concepts in concrete designs that explicit target reconfigurations of practice elements beyond bettering the materials to instigate sustainable change. Kuijer et al.'s 'splashing' study [78] is one example demonstrating that it is possible to target all three elements of practice to become part of what is designed. By making practice the unit of design, the authors show how it is possible to explore design concepts that reconfigure practice elements towards less resource-intensive practices.

The *hygge* study presented in paper 3 is also an attempt to explore possible sustainable futures that look beyond bettering the material in a practice. The *hygge* concept was explored in the designed probe to see if such a desirable concept would work as a concept to reconfigure practices by mixing elements (materials, meanings, competencies) of practices. Together these studies show that designers can get inspirations from practice theory to understand the dynamics of everyday practices to explore possible sustainable futures. Thus, a practice perspective can be used as a complementary perspective to design sustainable interventions that go beyond bettering the material element of these practices [77].

4.3. THE INTERACTION DESIGNER AS PROVOCATEUR

Interaction design can be described as a reflective design practice where designers explore and experiment with the materials at hand (software and hardware), using their competences (skills, know-how, techniques) to construct meanings (ideas, visions, aspirations), which are manifested and externalised in prototypes or probes (designed artefact). Drawing on Schön's interpretation on reflective design practice [112,113], Lim et al. [82], for example, have brought this perspective into HCI to describe prototyping as design process of exploring design alternatives and judging their rationales through a reflective design practice. We see endeavours in HCI and interaction design community that explore how designers can reflectively explore design materials to better support the creative design practice. Biskjaer and colleagues [7,8], for example, suggest to introduce deliberate constraints in the design process to trigger creativity. This designerly perspective, however, puts creativity in the hands of the designer.

The findings of the PhD project suggest another complementary perspective of the 'creative' interaction designer. The studies of this PhD project demonstrate that creative inputs also can be obtained by observing everyday practitioners performing alternative ways of doing. To create such situations also means to disrupt and challenge the status quo through design. Thus, the role of interaction designer becomes to provoke and challenge current practice – a *provocateur*.

This role has previously been proposed by Morgensen [87] who suggests: *"the notion of the [interaction designer] as provocateur provoking discrepancies in the concrete, everyday practices to call fourth what is usually taken for granted"*. Morgensen's suggested approach of provotyping [87] is not about 'guessing' a possible solution (prototyping), but suggest instead to focuses on understanding possible change by provoking concrete, everyday practice. This way, it is possible to take onset in current practice and let everyday practitioners get experiences of doing in alternative ways to inform future designs. This approach resembles Kuijer [75,78] approach of making practices the unit of design to further a practice-oriented approach in sustainable HCI. In Kuijer et al.'s [78] lab study, the concept of splashing was refined through design, by destabilising the current practice and observing a variety of improvised performances. Rogers has a similar vision of engaging Ubicomp experiences [108]. Rogers envision smart technology to provoke people to reflect and improvise upon interactions with technology and thereby engage people to be smarter and more proactive in discovering meaningful and engaging experiences in everyday practices.

The role as the interaction designer as a provocateur is particular intriguing for sustainable interaction design. The aim in most sustainable interaction design projects is to instigate sustainable change in, for example, energy-consuming practices. Most interaction design projects approach this design challenge with the assumed expectation that sustainable change is something that must be supported and not challenged. What the findings of this PhD project demonstrate and others suggest [78,87,108], this might not be the only perspective to approach change through design. In the Box and *hygge* studies, current practice was purposely provoked through design. Both studies demonstrate how provocation can be used to trigger reconfigurations of practices, by disrupting or suggesting alternative ways of doing. In the HeatDial study participating households also appropriated the design in surprising and creative ways. By seeing how participating households reflect, improvise and adapt new routines, new insights of how possible sustainable futures can be practised also emerge. Thus, everyday practitioners' improvised alternatives ways of doing, become a creative input to the design process.

Lastly, unlike Kuijer et al.'s [78] study, the three designed artefacts in this PhD project were studied in everyday concrete practices with households in real life over time. By studying how these interventions play out in everyday life, we were able to see how unsustainable routines also started to emerge. These 'seeings' [112] challenged our own design assumptions and forced us to reflect on our choices as designers and researchers. This suggests that an interaction design provocateur should have a split identity – a needed reflexivity – since we are engaged both in crafting designs as well as constructively critiquing them.

CHAPTER 5. CONCLUSION

In this PhD project, I have argued the need for more insights into how smart home technologies aiming to instigate sustainable change can be designed, in order to see how these are going to beneficial for people in everyday life. To provide such insights, this PhD project presents three studies investigating different design imaginations of sustainable futures in the smart home, explored through different designs and studied in everyday life. Each study explores different concepts manifested in concrete designs intending to change how households consume energy sustainably. Those designs are presented in the papers 1, 2 and 3. The PhD project also presents empirical studies providing understandings of how people embed such technologies in everyday mundane, routinised, energy-consuming activities and how the use of such technologies shapes energy consumption. These are primarily presented in the papers 4, 5 and 6. The rest of the chapter summarises the conclusions of this PhD project and points to future implications and limitations.

5.1. 1ST RESEARCH QUESTION

Research question one in the PhD project asks; *"what characterises interaction design of smart home technology aiming to instigate sustainable energy consumption?"* This research question was pursued by exploring three different design concepts; assisted shifting, provocation and the desirable concept of *hygge*. Each concept was manifested in designed artefacts intending to intervene in existing energy-consuming practices. Papers 1, 2 and 3 present the results of the design contributions. As each of these differs in exploring imaginative futures for the sustainable smart home, they are also distinctive in their characteristics. These characteristics are summarised in *Table 1.*

Assisted shifting	Provocation	Desirable *hygge*
• Supporting tools	• Disrupting	• Aesthetically pleasing
• Making it conventional	• Making it difficult	• Making it meaningful
• Making it convenient and effortless	• Making it improvisational	• Making it nourishing, fun, joyful and cosy
• Designing for calmness	• Designing for reflection	• Designing for alternative, desirable ways of doing

Table 1: Characteristics of interaction design contributing to instigate sustainable change in the smart home.

What is common in the three design contributions is that they all imagine a possible sustainable future where intelligent and interactive technology partake. But what role the designed artefacts plays in shaping energy consumption in everyday life differs among them.

The HeatDial design presented in paper 1 explores smart home technologies that aim to assist households to shift energy consumption in time. The HeatDial design is characterised by its ability to fade into the periphery of everyday life. This means most of the responsibility of deciding and acting sustainable is transferred to technology. This characteristic resembles Weiser and Brown's vision of *calm* computing [137]. Here, designs of pervasive technology are envisioned as functional, useful and unobtrusive tools [5] that proactively act when conditions in the environment change but otherwise quietly operate in the background of everyday life. Using this design characteristic to instigate sustainable energy consumption relies on the efficiency of the digital material and the use of this to design functional, useful and assistive tools. Together this means that the HeatDial design can be characterised by its ability to instigating sustainable change effortless and convenient by conforming to existing expectations and routines.

The Box design presented in paper 2 explores how energy information can be used in a provocative design to disrupt mundane energy-consuming routines to instigate sustainable change. What characterises the Box design is that interactions with the technology are designed to *provoke* the status quo by making mundane routines more difficult to carry out. This characteristic resembles Morgensen's provotyping approach [87], Kuijer et al.'s approach of making practices the unit of design [78] and Rogers's vision of engaging experiences [108]. They envision design to provoke people to reflect and improvise upon interactions with the designed artefact in their everyday practices. Using this design characteristic to instigate sustainable energy consumption means to focus on the disruptive, unexpected and provoking elements in the interaction design. Hence, the Box design can be characterised by its ability to instigating sustainable change by provoking existing expectations and norms aiming to engage people to reflect, challenge, adapt and improvise new routines towards sustainability.

The *hygge* design presented in paper 3 explores how a desirable concept can be used to challenge ideas about desirability and sustainability in the smart home. What characterises the *hygge* design is that it challenges existing smart home practices, by proposing alternative ways to achieve aesthetically pleasing experiences that are less energy-intensive. This characteristic resembles Strengers and Nicholls' high energy-intensive industry vision of pleasance [134], and the hedonist persona depicted in paper 4. Both embody desirable expectations of nourishment, coolness, joyfulness, cosiness and aesthetically pleasing experiences of the smart home. Similar to Kuijer et al.'s 'splashing' study [78], the *hygge* design proposes alternatives ways to achieve enjoyable and aesthetically pleasing experiences that are less energy-intensive without promoting sustainability directly. This means that *hygge* design can be characterised by its ability to reorient expectations of desirability and sustainability in the smart home, by challenging how aesthetically pleasing life in the smart home can be achieved.

In conclusion, the distinctive characteristics of the three designed artefacts contribute to an understanding of proposing alternative ways of designing smart home technology to instigate sustainable change. The designs contributions demonstrate that by drawing on different concepts and perspectives (e.g. provocation [4] and practice theory [122]) to imagine possible sustainable futures, designers are able to design interactive artefacts that go beyond seeing these technologies as enablers that effectively and efficiently control and monitor energy consumption. Furthermore, as suggested by Silberman et al. [124] and Hazas et al. [59], the findings of this PhD project demonstrate that the interaction design community is well situated to imagine possible sustainable futures in the home, by externalising these imaginative futures in concrete designs that can be studied in everyday practices.

5.2. 2ND RESEARCH QUESTION

Research question two of the PhD project asks; *"how does smart home technology shape sustainable energy consumption in everyday life"*. This research question was pursued by empirically studying how households embed smart home technologies in everyday practices and how they shape energy consumption. The results of the research efforts are two-folded. Paper 4 presents a status quo of the smart home providing understandings of how householders' desires for smart home technology are reflecting in everyday practices and impacting energy consumption. Papers 3, 5 and 6 provide insights into how households experience living with artefact inventions that purposely were designed to instigate sustainable energy consumption.

The empirical findings of the three studies of this PhD project demonstrate that the appropriation of technologies aiming to instigate sustainable energy consumption in everyday life is more complex than to develop and diffuse 'smart energy' technologies to the public. The smart home personas presented in paper 4 reflect this complexity. They demonstrate that householders' different desires for smart home technology impact energy consumption in different ways. This finding echoes previous research work arguing that smart home technology also enables energy consumption by providing new or intensifying existing services and expectations [48,60,129,134,140].

The empirical findings also demonstrate that artefact interventions purposely designed to instigate sustainable change are experienced in several ways, summarised as;

- The HeatDial long-term study shows intelligent and automated technology is experienced as an effortless and convenient way to instigate change – leading to an expectation of *conformity*.
- Box study demonstrates that by provoking and disrupting the status quo, households' reflections can challenge current expectations and practices – leading to *improvisation.*
- The *hygge* shows that challenging what is aesthetically desirable, it is possible to reorient expectations of desirability and sustainability in the smart home – leading to *meaningful, enjoyable and desirable* ways of using less.

The HeatDial long-term study presented in paper 5 demonstrates that automating sustainable decision-making can be an effective way to instigate sustainable change because households experience this as an effortless and convenient way to consume electricity sustainably. The study shows this is a particularly effective design characteristic in practices were some tasks have already been semi-automated by technology like heating. However, this characteristic also means such interventions do not necessarily manage to engage people or raise questions about sustainable energy consumption leading to an expectation of conformity of experiencing sustainable change. Lastly, the HeatDial study demonstrates that by studying designed interventions long-term, researchers are able to better account for how they become embedded in practices over time, as everyday life is messy and unexpected [34,123].

Both the Box and *hygge* studies demonstrate that it is possible to disrupt or challenge the status quo in everyday life through design, by letting designers act as provocateurs and make households reflect on what is usually taken for granted. The Box study presented in paper 6 shows that by experiencing a disruptive, provoking designed intervention like the Box, households reflect, adapt, and improvise new routines that also challenge expectations embedded in the practice. The *hygge* study presented in paper 3 shows that by proposing alternative ways of doing can introduce new configurations of meanings, materials and competencies about meaningful, enjoyable and desirable experiences in the smart home. In addition, the findings in the studies show that householders experience and embed designed interventions, which may be different and independent from the intentions and assumptions of the designer. Therefore, by studying designed interventions in concrete, everyday practices, it is possible to see if the designed interventions lead to new configurations of practice that undermine or contribute to the sustainability outcomes intended by the designer.

In conclusion, the empirical contributions in this PhD project give insights into how possible sustainable futures can be practised, by studying designed interventions in concrete, everyday practices. Moreover, the empirical findings demonstrate that households embed smart home technologies in everyday day practices in ways that are meaningful, enjoyable and desirable, which may actually end up both undermining the sustainable intent of the designer and people's desire to live sustainably. More importantly, the studies show that by studying design concepts in concrete, everyday practices, researchers and designers are better equipped to evaluate if these design concepts also are meaningful and aligned with desires of the sustainable, desirable smart home. Furthermore, the empirical contributions show that studying sustainability through artefact interventions is a highly reflexive process, where not only people's expectations and mundane everyday routines get challenged, disrupted and provoked, but where a researcher's or designer's assumptions likewise get challenged and provoked. This suggests that sustainable interaction design can be a reflexive process, where householders' expectations and designers' assumptions are there to be judged, provoked and challenged.

5.3. IMPLICATIONS

The contributions of this PhD project do not point to a universal answer as to how interaction design can solve sustainability problems. Although, I do not believe such a universal answer exists, the PhD project does provide concrete alternative design examples of how interaction design can instigate sustainable energy consumption in a future smart home practices. Furthermore, the findings point to areas that are ripe for further investigations for both practitioners and researchers in sustainable interaction design. I summarise these as follow:

1) Interaction design practitioners should be more proactive in exploring desirable, imaginative futures for the sustainable smart home that are deliberately different from what has previously been seen. This could, for example, be done by focusing on alternative ways of understanding meaningful, enjoyable and desirable practices that also happens to less energy-intensive. 2) Interaction design practitioners should be more proactive in studying what can challenge and disrupt the status quo instead of the more predominant interaction design approach of designing artefacts that are functional, useful and supportive and aiming to fulfil users' needs. 3) Interaction design practitioners should embrace the duality of exploring opportunities in design and critically reflecting on their use. 4) Lastly, interaction design practitioners should be better at involving everyday practitioners through the role of the *provocateur,* to get inspirations of how future practices could be performed.

5) HCI and interaction design researcher should be better at utilising frameworks, e.g. desiderata [90] provocation [4,87] and social practice change [120,122,123], to explore more diversified design imaginations of sustainable futures for the smart home. 6) HCI researchers should use more diversified perspectives when designing sustainable smart home technologies and study their use in concrete, everyday practices before they become integrated into commercial products and infrastructures and partake in shaping normality. 7) HCI researchers should increase focus on studying the long-term implications of design interventions, to better understand what shapes the use of these technologies in everyday life.

I believe more focus in these areas will make us better equipped to understand how to design future sustainability interventions, so they themselves, become sustainable.

5.4. LIMITATIONS

The research described in this PhD project does have some limitations. Firstly, in this project, I focused mostly on collecting and analysing qualitative data through various qualitative methods. This data was collected to gain an understanding of the status quo before the artefact interventions were deployed and to account for the impact and changes during and after the deployment. As one of the main objectives of this project has been to understand how smart home technology shape energy consumption in households, it can be argued that it is a limitation that not more quantitative energy data was collected. Gram-Hanssen, for instance, argues that multiple datasets can be useful and supplementary to qualitative data for understanding everyday practices and how energy consumption is shaped [47].

In the *hygge* study, we did not collect any energy data from participating households and therefore relied on participants self-reporting and publicly available information on energy efficiency. While quantitative consumption data was collected in the HeatDial and Box study, these datasets are not exhaustive. In the HeatDial study, we focused only on how well the system managed to shift energy consumption, while we in the Box study recorded no quantitative data before the deployment. Therefore, we were not able to quantitatively observe if the households started to use more or less energy during the studies. In case of this PhD project, having more exhaustive datasets could potentially have provided a more detailed picture of the intervention situation, and more importantly, allowed us to see if there were any differences between the datasets, which could have been just as informative [115].

Additionally, the HeatDial shows that by studying interventions long-term we can better account for the effects and complexities associated with prolonged use of these interventions. Thus, such studies can provide richer insights into what shapes the use of these technologies in everyday life as suggested by Rogers and Marshall [111]. It can be argued it is a limitation that long-term studies were not conducted with the Box and *hygge* intervention. We cannot be sure if and how the observed changes in the practices will be sustained. Having more extended studies would not only have allowed the participants to engage with our intervention more deeply, but we could also better account for prolonged experiences of living the intervention.

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CHAPTER 7. PAPER CONTRIBUTIONS

HEATDIAL: BEYOND USER SCHEDULING IN ECO-INTERACTION

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Abstract: There has been an interesting development within sustainable HCI, from passive feedback-displays towards more interactive systems that allow users to schedule their energy usage for optimal times based on eco-feedback and eco-forecasting. In this paper, we extend previous work on user scheduling of energy usage in eco-interaction with a study of heat pump control in domestic households. Aiming at using electricity when it is either cheap or green, our approach is to provide users with an interface where they can set temperature boundaries for the home, and interactively evaluate the impact of different settings on predicted energy cost. Based on this input, the scheduling of energy use is done by an automated system monitoring temperatures and electricity prices. We conducted a qualitative study of the HeatDial prototype with 5 families over 6 months. Key findings were that HeatDial supported users identifying and acting on opportunities for reducing costs, but that automation also had an impact on user engagement and highlighted a need for more feedback on how the system intended to act.

Originally published as:

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2016. HeatDial: Beyond User Scheduling in Eco-Interaction. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (NordiCHI '16). ACM Press. https://doi.org/10.1145/2971485.2971525

INTRODUCTION

Sustainability has been a topic receiving much attention in the HCI community in recent years. Within this research area, the notion *eco-interaction* has recently emerged, characterizing any type of user interaction with energy-consuming device or system [32]. Among these, researchers have earlier been concerned with encouraging energy savings by raising usage awareness and prompting behavior change through the design of *eco-feedback* systems [8, 24] predominantly for domestic settings [7, 12, 29] but also for the workplace [9, 33]. These systems typically provide a supplement to our infrequent utility bills by presenting details on current and recent consumption of resources such as water, gas or electricity on situated displays or in smartphone apps. However, as pointed out in recent research, reducing consumption is not the only way to improve sustainability [18, 20]. As electricity production moves toward renewable sources such as wind and solar power that depend on the weather, availability will fluctuate more, suggesting some consumption to be *shifted* to times of the day, where green energy is available. This recent view on energy conservation has led to research into a new type of eco-interactions that extend eco-feedback, where *user scheduling* is the focal point. This new type allows users to actively shift electricity usage to more sustainable times either by being simply informed about the availability of green energy in the near future through means of *eco-forecasting* [11, 13, 19, 26, 29], or by being supported to actively schedule the running of specific appliances [1, 5].

While *user scheduling* have proven useful for shifting usage of some types of electrical appliances, such as washing machines and dishwashers [5, 11, 26], for other appliances, such as fridges, freezers, home heating and cooling [25, 31], it may be more sustainable beneficial to let an automated system manage and monitor the scheduling within a certain boundaries of tolerance. As discussed in [32] the challenge for designers, then, is balancing the control of an automated system pursuing sustainable objectives, while respecting users' comfort preferences. This calls for more research on eco-interaction design beyond user scheduling.

Here we present a study of eco-interaction with heat pumps in domestic households where the use of electricity is shifted to times of green energy availability, but without requiring users to manage the exact scheduling. Electrical home heating is a particularly relevant case for eco-interaction as it accounts for a considerable amount of domestic electricity use today, and is projected to grow in the future. An example is in the US where 38% of all new houses completed in 2012 included a heat pump [15]. Motivated by this, we developed HeatDial - an interactive prototype that facilitates eco-interaction where users can set temperature boundaries for their home and interactively evaluate the impact of different settings on calculated costs. Based on this interaction, an automated system schedules optimal use of electricity by monitoring temperatures and electricity prices. We present the HeatDial design, describe our 6-month field study, and present and discuss findings.

RELATED WORK

The effect of eco-feedback systems, typically visualizing historical and real-time resource consumption to raise awareness and promote environmental behavior, has actively been studied in HCI community in recent years [7, 8, 9, 12, 13, 24]. Most eco-feedback systems use the concept of persuasive technology, adopted from environmental psychology, as a framework to approach sustainable HCI [8, 24]. Persuasive technology aims to intervene and support the individual in making environmental decisions by motivating and rewarding sustainable behavior. However, there are limited results in the long time effect of using persuasive technology to support and maintain a sustainable living, and recently, there has been a growing critique of letting this perspective alone, frame sustainable HCI research [3, 10, 21, 28]. One critique is that everyday consumption behavior is not acted as conscious, rational decision-making advocated by persuasion [28], but rather shaped by how we interact with existing technology located in our environments, such as appliance interfaces or emerging smart infrastructures addressing energy related issues [20].

Eco-interaction is a concept within sustainable HCI that recognizes some of the design opportunities and challenges of users interacting with smart environmental supportive technology [10, 18]. Yang et al. [32] were some of the first to introduce the term eco-interaction to HCI, which they define as the study of the interaction between energy-consuming systems and humans, including eco-feedback, intelligence, automation, control systems, infrastructures, and other technologies, with the goal to reduce energy consumption, while preserving user-perceived benefits. As an example, Yun et al. [33] user study shows, eco-interactive elements such as user control, eco-feedback, and automation, can be effective in reducing electricity usage.

However, as mentioned, reducing energy is not the only approach to promote sustainable living through interactions with energy-consuming systems. *Shifting* is a term from Pierce et al. [20] vocabulary capturing different energy conserving actions and strategies. The term itself entails intentions to shift energy usage to different times or places, often envisioned by smart grid technologies [10]. Shifting is driven by a motivation to improve the efficiency of the energy grid in regards to overcoming fluctuation in power production and consumer consumption [18]. The latter involves shaving off usage during peak times and shift loads to different times to overcome congestions on the electricity grid. The former is related to fluctuation in energy production as weather conditions such wind, waves, water, and sun often influence green power production.

User Scheduling

Eco-interaction is particularly interesting when it comes to shifting energy usage, as shifting might involve eco-interactions supporting different behavior changes than those concerning energy reduction [18]. One way to regard shifting within eco-interaction is the approach of *user scheduling*. With user scheduling, we here mean that act of actively scheduling the running of energy-consuming activities to time or place considered sustainable favorable. There are few research examples within HCI exploring user scheduling, and most of these have predominantly been focusing on *eco-forecasting* [11, 13, 19, 23, 26, 29]. Eco-forecasting is typically based on persuasive technology to forecast relevant information such as weather forecasts and grid load congestions, to enable people to shift energy use to different times. Nonetheless, as research on eco-forecasting has shown [11, 19, 23], although eco-forecasting has potential to facilitate shifting, there are challenges in shifting domestic energy use, since some household practices (cooking and entertainment) are highly resilient to shifting, while others such as doing the laundry and dishes are activities people are more willing to shift.

An example of a user study exploring user scheduling of laundry times is Contanza and colleagues study of an agent-based system that supports scheduling the activity of doing the laundry to times more sustainable favorable [5]. Similar, Bourgeois et al. investigated through a field study involving 18 households, how technology may play a role as mediator for shifting laundry routines by examining notions of automation, interactivity feedback, and control [1]. While these examples present novels ways of engaging people to actively schedule consuming activities to sustainable times, the findings also show challenges in designing eco-interactions that intercede with domestic life.

Beyond User Scheduling

Moving beyond user scheduling of energy usage in time, HCI researchers have worked with *intelligent and automatic scheduling* on various projects to reduce consumption of energy-consuming systems [14, 25, 31]. These examples have mainly utilized occupancy detection to infer user behavior intelligently and based on this, automatically scheduled running times for heating or cooling systems.

PreHeat [25] and TherML [14] are both research examples of intelligent heating systems, designed only to heat when people are home, without any direct interaction from users. Utilizing historical data and current occupation data, these systems, were able to predict and adapt heating to when people occupied their homes. Their findings showed these systems were able to reduce consumption compared to user scheduled programmable thermostats, although both studies reported no findings relating to lived user experiences with the systems.

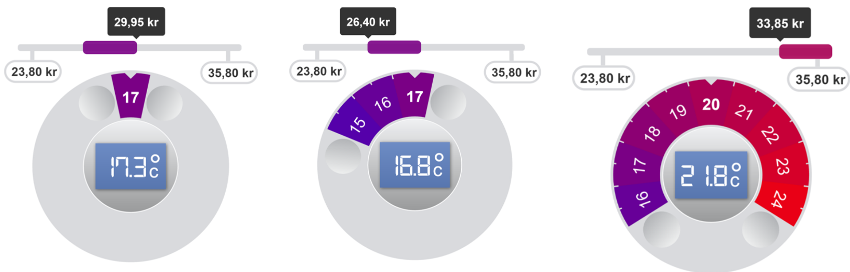
Yang and colleagues did an extensive qualitative study of lived household experiences with the intelligent Nest thermostat [30, 31, 32], where they studied domestic heating and cooling experiences using the Nest to control the inside temperature of domestic households. To reduce energy usage, the Nest will schedule running times for the heating and cooling system, by learning patterns of user behavior derived from occupancy observations and user interactions. In these studies, the authors found that while participants had the expectation the Nest would be intelligent enough to derive an ideal schedule for remaining comfortable and at the same time save energy, lived experiences with the Nest did not always live up to this expectation. Instead, participants experienced a system that did not always compute a schedule that was energy efficient and which failed to understand user intent. The same time the Nest users had difficulties understanding the expected behavior of the system, meaning some participants would manually set up Nest schedules and most others would quickly lose engagement over time, resulting in missed opportunities to save on energy usage.

Together these examples have shown a potential of designing eco-interactions based on automation, to reduce energy usage. Automation at home, however, is challenged by different barriers such as inflexibility and poor management [2] and when it comes to eco-interaction – a challenge of capturing different objectives in the design. As discussed in [32], this could be an automatic system that operates with an objective to act sustainable, while trying to maintain user-perceived comfort and control. Materializing these competing concerns in an eco-interaction design, calls for new ways of exploring eco-interaction.

Our study extends this works as we intend to explore domestic lived experiences with an eco-interaction design aiming to *shift* energy usage using elements such as eco-forecasting and intelligent and automatic scheduling based on contextual factors while still trying to maintain user.

THE HEATDIAL PROTOTYPE

To be able to study the concept of shifting in a domestic setting, we designed and implemented HeatDial – a prototype that enables electrical heat pump owners to set the inside temperature of their house and discover the tradeoffs between comfort and cost. Electrical heat pumps make an interesting use case for studying eco-interactions beyond user scheduling for several reasons. Firstly, to produce heat, heat pumps use a considerable large volume of electricity. Secondly, although they harness this



(a) (b) (c)

Figure 1. HeatDial in three different settings with price and price ranges for the next 24 hours: Preferred temp. set to 17°C with no tolerance (a), a lower boundary set to 15°C (b), and preferred temp. set to 20°C with the widest possible tolerance (c).

electricity effectively, they become a more attractive green alternative, if the electricity utilized is produced from renewable resources. Lastly, as it is possible to externally control the heat pump, we can intelligently control the running times of the heat pump.

The Intelligent Eco-friendly Heat Pump

Our primary design challenge with HeatDial was to materialize an eco-interaction design that translates the concept of shifting energy usage to the mechanics of running a heat pump. Most heat pumps regulate heat after a set temperature, typically specified by a user. The heat pump will run in hourly intervals to maintain this temperature, normally automatically scheduled by heat pumps manufacturers. In the HeatDial system, the heat pumps will be intelligently controlled to run at times sustainable favorable while trying to maintain a comfortable indoor temperature. The underlying assumption behind this approach is that most users do not care about the exact running times of their heat pump, just as long as they are comfortable when indoors.

However, a system designed to intelligently control thermal comfort will need to accommodate for the complexity of domestic heating, as thermal comfort is something that is contextual, personal and temporal [4, 27]. While several examples have utilized occupancy observations and predictions to say something about the occupants temperature comfort level intelligently [14, 25, 31], the HeatDial prototype addresses this design challenge differently. Instead of deriving comfort preferences from data sets, HeatDial allows a user to express a comfort zone of temperatures, as a *temperature tolerance range*, illustrated in the HeatDial interface in Figure 1.

Based on the temperature tolerance range and other contextual factors, such as; local weather forecasts, temperature measurements from inside and outside of the house, a mathematical model of the transport of thermal energy in the houses, predicted grid demand, and electricity prices, the intelligent system automates a schedule of best possible running times for the next 24 hours. With this design, we aim to address the challenge of involving users in controlling contextual and temporal elements in the home - regulating the temperature, while the autonomous intelligent system will take advantage of outside elements such as weather, price, and grid demand [22].

The user-specified temperature tolerance range plays a significant role in how much flexibility the intelligent system has in planning a sustainable schedule. If a user specifies a small temperature tolerance range, the intelligent system may have to make the heat pump run at a time not sustainable favorable to ensure the indoor temperature stays within the boundaries of the comfort zone. On the other hand, if a user specifies a large temperature tolerance range, the intelligent system will have more flexibility when planning a schedule as it may be able to move the running time to green timeslots and still stay within the tolerance range boundaries. This scenario is illustrated in Figure 2.

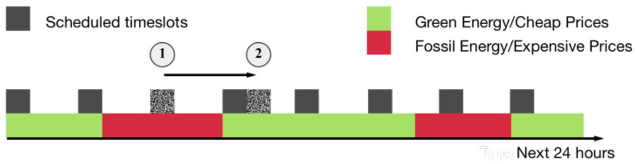


Figure 2. Planning a sustainable favorable schedule. A large tolerance range makes it possible to shift timeslot 1 to 2.

With a large user-specified tolerance range, the intelligent system is able to make the heat pump run at timeslot 2 in the green zone, rather than run at timeslot 1. However, this might increase the indoor temperature at timeslot 2 and decrease the temperature at time slot 1. Making this design choice, we let the temperature tolerance range be a mean to express an intention to shift electricity consumption.

The interaction is facilitated by price range feedback. The price range provides users with instant feedback, so the effect of the interaction is promptly illustrated. Prices are calculated from hourly prices for the next 24 hours from the Danish electricity spot market, and the intelligent system schedules the heat pump to run when it is cheapest.

Preferred and Boundary Temperatures

HeatDial allows users to specify the temperature tolerance range, by letting a user set three temperatures; namely the *preferred* temperature, and the boundary *minimum* and *maximum* temperatures, in one degree Celsius intervals. The preferred temperature is what the heat pump system aims as the ideal temperature.

This temperature is shown at the top of the dial, under a little downward notch, as illustrated in Figure 1a where it is set to 17°C. Dragging the gradient colored dial left or right sets the preferred temperature, inspired by the interaction with a traditional domestic heating thermostat. The boundary minimum and maximum temperatures signify the temperature tolerance range that the heat pump system is allowed to operate within. The user sets the boundary temperatures by dragging the indented gray adjuster dimples on either side of the temperature dial. This is illustrated in Figure 1b where the minimum tolerated temperature is set to 15°C, with the preferred temperature still being 17°C, and in Figure 1c where the minimum is set to 16°C and the maximum to 24°C. The larger the range between boundary minimum and maximum temperatures, the more optimally the system can schedule the heat pump to run, resulting in a lower price, as seen in Figure 1b.

The current indoor temperature is displayed in the middle of the interface (e.g. 17,3°C. Figure 1a) enabling the user to relate the current temperature in the house to new settings. For the study of HeatDial, the interface temperature range was defined by the capabilities of the specific heat pumps.

Dynamic Price Range Feedback

In order to facilitate exploration of different preferred and boundary temperatures, HeatDial instantly displays calculated estimated monetary cost and possible price ranges for the current setting. This is displayed above the temperature dial in Danish Kroner (1 kr. = US$ 0.15).

The two prices displayed at either end of the bar are the lowest and highest possible cost for using the heat pump for the next 24 hours that the user can achieve by changing the settings of HeatDial. In the example in Figure 1 this range is between 23,80 kr. and 35,80 kr. The lowest cost can be obtained by lowering the preferred temperature, while increasing this temperature results in higher cost. The price of the current temperature setting is displayed in the black box above the bar (e.g. 33,85 kr. in Figure 1c).

The price range calculation also makes it possible for the user to see opportunities for cost saving, by allowing the heat pump to work within a wider temperature range rather than at one preferred temperature. This is indicated with the colored rectangle hovering over the gray bar. This rectangle illustrates the price range that is achievable for the current preferred temperature by allowing fluctuations. In Figure 1a, the price bar shows that the preferred temperature of 17°C will cost 29,95 kr., but the purple rectangle also shows that this cost could be reduced toward the lower end of the range. This reduction can be achieved by lowering the minimum boundary temperature, as is illustrated in Figure 1b where this has been set to 15°C, resulting in the cost being reduced to 26,40 kr. Figure 1c shows how raising the preferred temperature to 20°C results in a higher cost, but that setting a wide temperature tolerance results in the lowest possible cost of 33,85 kr.

Technical Implementation

HeatDial runs on a tablet or smartphone and was developed as a platform independent web application. The interactive prototype is implemented as a mobile-first HTML5 web app utilizing SVG for animations. To allow for rapid software prototyping HeatDial utilizes various frameworks, such as AngularJS and bootstrap as they provide support for developers to quickly prototype web applications. The architecture of the entire system can be seen in Figure 3.

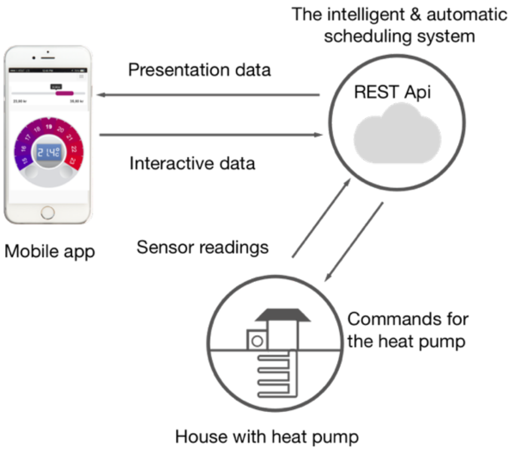


Figure 3. Overall architecture of the HeatDial system.

HeatDial communicates with the intelligent system through a REST API. Through this API, the HeatDial web app gets information such as price range calculations and the current indoor temperature, but also sends data back regarding new user settings. To provide and act on this data, the intelligent system reads different measurements from sensors installed in each individual house every fifth minute and calculates a new schedule every time a user specifies a new temperature tolerance range. This schedule is used to send commands to heat pump, so it runs according to plan. The information is available through the API, so users are presented with the newest information the instant they interact with HeatDial. All interactions with the system are stored in a backend SQL database for logging purposes.

METHODS

We studied HeatDial in a field deployment with five Danish households spanning the winter of 2014-15 until summer 2015 (6 months). As adjusting temperatures is not a practice heat pump owners normally do on a day to day basis, we deployed HeatDial over an extended period of time.

Participants

The five households in our study included a total of 10 adults and 7 children, where 8 of the 10 adults participated actively in the interviews and interaction with HeatDial. The adult participants were aged between 34 and 74 years, with both adults either working or retired, all from middle-income households. We recruited the participants from a different project on smart grid technologies, thus ensuring all of the residential households had a controllable heat pump system installed.

All of the participants lived in privately owned rural properties across Denmark, and every home had acquired the heat pump during the last 5 years, typically as a high-cost investment made in relation to upgrading the heating system and renovation of the house. In all the houses the heat pump was used in combination with floor heating, resulting in slower response times for lowering or raising the temperature. Two of the households also had a solar panel for heating utility water and produce electricity. 4 out 5 households would also use a wood burner on occasions as a regulating heat source.

Household 1 – H1: 2 parents (34 and 35 years old) and 4 children. Wood burner & solar power. Expressed a high awareness of environmental issues and were very conscious of the behavior of the heat pump (F/M interviewed).

Household 2 – H2: 2 parents (42 and 47 years old) and 3 children. No wood burner, but used programmable thermostats to regulate heating in sleeping rooms. Environmental conscious, but expressed a limited awareness of consumption and heat pump behavior (F/M interviewed).

Household 3 – H3: 2 adults (59 and 65 years old). Wood burner & solar power. Expressed a high awareness of environmental solutions and were very conscious of the behavior of the heat pump (M interviewed).

***Household 4 – H4**:* 2 adults (69 and 70 years old). Wood burner. Expressed a limited awareness of consumption and heat pump behavior (F/M interviewed).

***Household 5 – H5**:* 2 adults (69 and 74 years old). Wood burner. Environmental conscious and expressed a high awareness of heat pump behavior (M interviewed).

All household expressed an awareness of environmental issues while 7 out of 10 participants had a profound knowledge of how their heat pump operates and how much electricity their household consumes per year. They knew the approximate price per kWh, and most were capable of converting their electricity consumption into a cost.

Procedure and Data Collection

During the field deployment, we conducted two rounds of semi-structured interviews lasting approximately one hour each. Both adults from households H1, H2, and H4 participated in the two interviews while the male member of households H3 and H5 participated. Each interview was conducted at the homes of the participants. The first interview aimed at obtaining a profile of each participating household concerning heating practice, consumption awareness, and household demographics. During this first interview, we also introduced HeatDial. The second round of interviews aimed at getting different information about lived experiences of the use of the intelligent system and the interaction of HeatDial. Here participants were asked why they chose different settings of the temperature tolerance range and what would influence this choice. During the deployment period, we also logged all interactions with the system. All interviews were audio recorded, fully transcribed and analyzed using qualitative content analysis inspired by researcher-denoted concepts [16] identified through the transcription and later cataloged into thematic categories.

FINDINGS

Our study revealed a number of interesting findings related to how the household members interacted with and used HeatDial. From the user interaction logs, we discovered that our participants (households) interacted rather differently with HeatDial in terms of how frequent they used it. Household H1 had the highest number of interactions with 159 unique interactions with the system (either logins or setting temperatures) while H2 had the lowest number with only seven interactions. On average, the five households had 57.6 unique interactions. H1 and H5 used the system most frequently, and during several periods, they would actually interact with HeatDial on a daily basis, whereas H4 had a less frequent use but still continuous during the period. H2 and H3 exhibited a more scattered use pattern.

The households set the preferred temperature between 18°C and 22°C (average=20.0°C) with boundaries ranging from 15°C to 24°C. The price for running the heat pump for 24 hours fluctuated during the period, as it was typically twice as expensive to run the heat pump during the late winter and early spring months than late spring and summer, although the exact prices depended on the house and contextual factors. A concrete example from household 5 shows that the absolute price range for a 24-hour time period, would lie between 20 kr. and 58 kr. in early March and 5 and 39 kr. at the end of May. For a chosen preferred temperature there was a 11,90 kr. difference between the cheapest and most expensive temperature combination in March and a 6,10 kr. difference in May.

Not surprisingly, we found that interaction was almost non-existent during the summer period (June and July) for all households, whereas the system was used more often during late winter and spring, where there is a greater need to control and regulate the heat. Also, not surprisingly, most interactions took place in the morning, around dinner time or before bedtime. When it came to choosing a preferred temperature and boundary temperatures, the households would only choose combinations that resulted in a price within the upper third of the total price range.

Automation and User Engagement

The first identified theme concerns the balance between automation and user engagement or user interaction. As one of the acknowledged challenges in eco-interaction design is to balance between automation and keeping users actively engaged [32], we deliberately designed HeatDial to allow active exploration of opportunities for energy savings within the next 24 hours using the price range feedback. Some participants appreciated this opportunity for engaging with the system, but a few also expressed that they disliked having to make a conscious decision on their heating so often, as expressed by one of the participants:

> "But how often should I look at this? Then I have to sit and gamble on the price… I do not want to sit and regulate the heating every night." (H5 M)

However, in practice, in some households the high level of automation, and the fact that they could now set boundary temperatures and then leave the system to itself meant that they actually started engaging *less* with their heat pump control system. As expressed by one of the couples:

> "I think it is nice because then I do not have to think about heating […] we do not have to go around all the time keeping an eye and having to control it. Now it just does it for us". (H4 F)

> "Before I manually had to turn up or down the way, we wanted it. Now I do not have to that anymore." (H4 M)

While the automation was clearly experienced by these participants as a good thing, because they trusted the system to work optimally, it can also be argued that less interaction and engagement with the system could result in missed opportunities for additional monetary savings, and for increased sustainability. This lack of engagement is clearly expressed by of the couples:

> "When we come to the point of having decided on the temperatures, then that is it." (H1 F)

> "Yes, because it is not something we go and change the setting of all the time." (H1 M)

In light of this, one could imagine either pulling back on the automation, or adding an additional level of intelligence to the system, for example, by making it monitor opportunities outside the currently set range of temperatures, and prompting the users about these.

Automation and Transparency

As a related theme to the above, we identified issues related to transparency of automation. Perhaps unsurprisingly, we found that people's interaction with HeatDial revealed uncertainty about how the automated heat pump system actually operated from the preferred and boundary temperature settings:

> "If I allow it to drop to 17°C I don't know if that will really happen. I can see that it has an impact on the price, so something happens. But what?" (H1 M)

For some they would also try and infer the behavior of the system based on their experiences of the heating in the house and use this experience to argue for or against the automatically scheduled running times:

> "I have a hunch the heat pump is not running during the evening or night. It is just a hunch. That might be the reason why it is cold in the mornings. But that is ok because there is no reason to use heat when you are sleeping" (H4 M)

While it was clear to people that they were allowing temperatures to fluctuate, it was not always clear how much this would actually happen in practice. In some households, they suspected that the heat pump did not work correctly, when in fact it was striving for the preferred temperature, and had made a schedule with as few fluctuations as possible. In other households they decided to narrow the range because they feared that temperatures would fluctuate wildly between the lower and upper boundaries:

> "The preferred temperature is an average, and the 2 others are boundaries. If you have a large zone, then you allow the heat pump to be turned off until it drops to 16°C before it starts again. We also allow it to heat the house to 24°C before it stops." (H2 M)

The core of these uncertainties and misconceptions appears to be caused by a lack of transparency in the automation system. When handing over the scheduling of the heat pump to the automated system, apart from seeing the resulting price, it appears important to see how the system then plans to act within the set boundaries:

> "I think it could be interesting to see a computed temperature profile for the next 24 hours […]. If we could see the scheduled plan for the temperatures we have chosen now, then maybe we expect it to rise to 21°C at 1pm and down to 20°C and up again" (H1 M)

This finding is particularly interesting and important for the design of eco-interaction systems. It suggests that although automation can be used to hide complexity from the user, it is important to provide feedback on how the system is planning to act in response to a given set of input. Providing an interactive forecast of system behavior, if you will. This we have not yet seen explored in eco-interaction.

Setting Temperature Boundaries

Despite the transparency problems, our participants appreciated the system and seemed to understand the design. The participants expressed liking this new way of interacting with the heat pump, making them feel more in control. As one participant said,

> "In periods I have used the app every day […] I like that I can set the temperature, and I wish I could play with more settings. The more, the better." (H5 M)

For some participants, the weather would also play a role in how often they would interact with the system and set different settings. As expressed by one participant when asked to how often they adjust their temperatures,

> "It also depends on how the weather is. If all of a sudden it is warm outside, then I might turn the temperature down here." (H4 M).

Some of the participants had tried out several different settings to see how the heating in the house would respond. As expressed by a participant in a household where the temperature boundaries were set to a span of 7°C:

> "It has fluctuated at times where the heat pump has been off. The temperature would drop down to under the 20°C. But [I noticed this] only 3 times when it has been fairly cold in the morning." (H4 M)

Others had experimented less, and had set narrower spans of temperatures, reflecting more precisely how they liked the feel of the house, as expressed by a participant:

> "We like it if the temperature is around 20 degrees… Then we allow it to go down to 19°C but when it drops below 19°C then something has to happen. That's the boundaries of our comfort." (H5 M)

These findings show that there is indeed a potential for eco-interaction with heating systems where the scheduling of best possible times to run the heat pump is not something that the users need to do. People easily understand and express their preferences in lower, upper and preferred temperatures, and happily leave scheduling to the system.

Being Flexible Incentives

The participants used the price range feedback in HeatDial in various ways. The possibility of saving money was the main motivation for most participants, while the feeling of contributing towards sustainability played a secondary role, as expressed by one of the couples:

> "There has to be a saving. That is what motivates the most". (H1 M)

> "Yes, that motivates the most in this household. But also if it is easy to use, and you know that there is a benefit somewhere." (H1 F)

In terms of saving money, the idea of potentially achieving this by setting, not only their preferred temperature but also boundary temperatures, was well received:

> "If it has a big influence (on price), how you allow the heat pump to behave, then there is a great motivation for being more flexible." (H3 M)

However, this was not the only way participants used the system for saving on their electricity bill. Some also used the feedback price bar as reassurance that they were using a “correct” or “reasonable” amount of electricity, and as a potential warning if something was wrong, as, for example, expressed by one of the participants:

> “If I see some big number, then I am like, hey, I have to turn the heating down. You become frightened, because can it really be true with 89kr? So I use it like that. Because when it comes down to it, what matters is how much it costs to heat up this house.” (H4 M)

All households, however, were also well aware that this was essentially a matter of compromise between comfort and cost, and some used this actively in their decisions:

> “We will not allow it to go under 19°, because then it becomes too cold. I think we had the upper at 21° and then I moved to 22° because maybe it could use extra energy at times when electricity is cheap.” (H2 M)

In relation to this they found it very useful that this relationship was now visible with the dynamic price bar giving them immediate feedback when changing temperature settings:

> “I look at the prices. That is the most interesting. Because when I shift something, then you see the prices shift […]. But it is all a matter of a compromise between the price and our comfort […]. If I can be comfortable and get it cheap, then it is nice.” (H5)

These findings show that cost plays a central role in eco-interaction with heating systems, both as an opportunity for savings, and as an absolute measure of current heat settings. We can leverage off people’s flexibility with heating, but if we want them to compromise on the comfort of their homes, they need clear and significant monetary incentives.

DISCUSSION

HCI research has focused intensively on sustainability over last years, and previous SHCI research has stressed the importance of SHCI community involvement in smart grid technologies development [5, 18]. In our study participants were exposed to an eco-interaction design working with elements of automation and feedback to motivate shifting consumption, envisioned with smart technologies. Through HeatDial, we enabled users to set their comfort preferences for heating with an electrical heat pump while letting a system operate within these set boundaries. Our study illustrated experiences with this system that goes beyond user scheduling, by automating scheduling times without the user being directly involved with the planning. While we achieved these insights as one contribution of the paper, we also uncovered several design implications that may need to be considered by designers of eco-interactions and sustainable smart infrastructures in the future. In particular, although the case of heat pumps showed promising potential for automating the task of shifting domestic electricity usage envisioned by smart grid technologies, there are still design challenges such as balancing different objective in eco-interaction design and maintaining user engagement that will need to be addressed in future SHCI research. These design implications are discussed below.

Heat Pumps and Beyond

electricity consumption, as they have potential for studying automatic and intelligent scheduling of energy usage realized with smart grid technologies [6, 17]. In national regions where season weather requires housing to be heated most of the year, shifting is particularly interesting, as households with heat pumps consume a significant amount electricity, but are still considered as an eco-friendly way to heat domestically. An example is Denmark where it is expected more houses will be heated by electrical heat pumps in years to come, but renewable resources, like wind turbines and solar power a likely to produce 50% of the energy production by 2025 [6]. This scenario may lead to fluctuations in the power production and an increase in electricity demand, but nonetheless a domain where shifting may help to make ends meet.

Heat pumps are likely to play an essential part in developing future smart grid strategies [6], although there is still a need to explore domestic implications of combining technologies [17]. As our study has shown when "smart" becomes transparent, is particular challenging when working with the domain of domestic heating, as interacting with our heating system is not something people do very often – especially if the consequences of the automatic scheduling is experienced without any loss of comfort or in hours or even days after interacting with the system. There are not many HCI studies that involve shifting of domestic electricity consuming practices, and only few observing lived domestic experiences with the technology with automatic characteristics supporting sustainable practices [5, 32, 33]. Our study has shown the potential of shifting heat pump electricity usage with elements of automation and feedback although there are still complex challenges to be addressed by eco-interaction designers of smart grid technologies in the future. These challenges are not just relevant for the heating domain, but could also have applications in domains like charging electrical vehicles, smart sustainable home equipment, etc.

Capturing Automation and Comfort Objectives

As discussed by Strengers [28] energy consumption is part of activities and practices that makes everyday life more comfortable and convenient (e.g. washing, heating, cooling, cooking). Although automatic scheduling provides an interesting opportunity for realizing shifting within the domain of electrical heating, we are faced with a challenge of balancing mix incentives of automation and user comfort within such systems [32]. While different objectives were part of the design of HeatDial, our study showed shifting energy usage is often a decision-making process, rational or not, involving different objectives. In our case, this entailed a tradeoff between; *cost*; saving money and/or acting sustainable, *comfort;* upholding comfort preferences, and *convenience*; hiding complexity by delegating schedule task to the system.

Costanza et al. [5] argue in favor of making design spaces where users can influence the automation to satisfy their preferences and that this is critical in the design of eco-interactive systems introducing automation of scheduling tasks. Whilst the participants in our study were in control of their comfort preferences, thus ensuring some system control on the automatic scheduling, they still felt disillusioned in how the system would act based on their preference settings. This would often result in them choosing a small temperature preference range, not allowing the system to optimize scheduling to the fullest. This finding is interesting because most participants expressed hardly any experienced discomfort in how the system controlled their heating, so this conception on how the system would act was not based on their own experience, but on fear of how the system in future might compromise their comfort preference.

The monetary forecasted cost feedback in our eco-interaction design was intended to provide an indication of system behavior. However, as expressed by most of our participants, the feedback fell short in clarifying precisely how the automated scheduling would influence their experienced comfort. Elucidating the transparency of automation is a critical eco-interactive design challenge to address in future system designs, where the automation may compromise people's comfort preference. It indicates that automation although convenient for hiding complexity, also needs to be accompanied with feedback on intended forecasted behavior, much like the information provided by eco-forecasting systems [11, 13, 33]. This line of research inquiry has yet to explored within the sustainable HCI.

Eco-interactions Beyond User Scheduling

Our study has shown that automatic scheduling is an interesting approach for designing eco-interactions that facilitates exploration of shifting opportunities for electrical heating systems. However, related to the above discussion, our study of HeatDial also seems to confirm Yang and colleagues observations [31] that balancing automation while also engaging users to act sustainable, is a challenge, which not only concerns energy conserving actions of reducing energy, but also relates to intentions of shifting. To meet this challenge in our design of HeatDial, we were encouraged to design interactions more engaging beyond how heat pump users normally interact with the heating system. We did this by providing feedback via eco-forecasting in the form of monetary cost for a 24-hour period as an incentive to engage with the system on a regular basis. While all the participants expressed price information as being a highly motivational factor for considering changing settings, our findings also showed that the times they interacted with the system varied much during deployment and between households. As expressed by most participants, it was easy and convenient for the participants to find a combination of temperatures and let the system operate on their behalf.

This lack of engagement, resulted in missed opportunities for the system to act more sustainable, as the participants would rarely explore the possible combinations for saving money and thereby the possibility for the system to shift consumption. It suggests that automation, although being convenient for many users, also poses new challenges for designers of eco-interactive systems. So how can we design eco-interactions that engage users with automatic scheduling systems? One interesting possibility could be to notify users when the terms of acting on sustainable opportunities changes. An promising line of inquiry for both informing users for times to act sustainable and balancing automation, is Bourgeois et al. [1] "proactive suggestions" and "contextual control" interventions. These different interaction inventions prompts users to act while semi-automates these actions. A future challenge might be how to design types of eco-interactions of automatic characteristics that are both engaging and intervening?

CONCLUSION

We have presented a study of eco-interaction with electrical heat pumps in domestic households as facilitated by automatic scheduling of running times based on electricity price and acceptable temperature boundaries set by the users using HeatDial. The findings from our deployment study confirm there are prospects in our interactive eco-interaction design for discovering and acting on opportunities for shifting domestic heating usage and reducing heating cost. However, our findings also uncover important implications of introducing elements of automation that have consequences for the way we design user interfaces for eco-interaction, that is what kind of information and functionality we need to consider. Automation had unforeseen impact on user engagement, motivating investigations into other ways of involving users of systems that are largely running in the background. But of particular importance, relieving the user from the task of scheduling the running of electrical heat pumps, and leaving this to automation, also highlighted a resulting need for transparent feedback on how the system then plans to act on the user's input. This calls for more research of eco-interaction design that goes beyond user scheduling.

Acknowledgment

We thank Neogrid Technologies for their input to the design of HeatDial and initial software development of the heat pump control. We also thank our participating households for their time and for sharing experiences. This work is a part of the TotalFlex project (843101) founded by Engerginet.dk and the DiCyPS project (864703) founded by innovationsfunden.

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AESTHETIC, FUNCTIONAL AND CONCEPTUAL PROVOCATION IN RESEARCH THROUGH DESIGN

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Abstract: Recently within HCI, design approaches have appeared, which deviate from traditional ones. Among them critical design introduces deliberate provocations in order to challenge established perceptions and practices. We have engaged ourselves with this design approach out of interest in understanding how to use provocation in research through design. Towards this end, we report on a field study with four families that used an aesthetically, functionally and conceptually provocative future probe. The purpose of the probe was to challenge existing energy consuming practices through provocation and make its users reflect on them. The paper describes how all three provocative aspects were addressed, and our findings demonstrate how they were experienced in the real world, and how they impacted our research through design approach. We conclude by presenting reflections on how to design provocations, and reflections on the impact of provocations for research through design in general.

Originally published as:

Dimitrios Raptis, Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2017. Aesthetic, Functional and Conceptual Provocation in Research Through Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (DIS '17). ACM Press. https://doi.org/10.1145/3064663.3064739

INTRODUCTION

We are currently witnessing a growing interest in research through design where the design itself is the means to explore and understand an area of interest [13, 21, 59]. Some of the previous research through design studies has revolved around designs where usually the purpose is to improve the utility of an artifact or a practice. There are designs though that move away from this example and are characterized as speculative [20], ludic [27], reflective [52], slow [32], counter-functional [48], value-sensitive [23], adversarial [15], as well as critical [18, 19]. These approaches are often called "provocative design approaches" [44], since they share a common goal. Provocative designs aim to challenge existing norms and attitudes, provoke discussion, and provide means for a constructive critique about the design itself, its impact, as well as the broader assumptions that characterize an area of interest. Towards this end, as suggested by [44], *"provocative design refers to design approaches that operate in a design space where asking questions is as important as solving a problem"*. For these reasons we treat provocative designs as an important element of our research work since they allow us to establish a critical-technical practice [2, 16] within the field of HCI; the split identity that we must have as researchers since we are engaged both in crafting designs as well as constructively critiquing them.

Our research in this paper investigates provocation as a means to conduct research through design. Provocation has been investigated before within Interaction Design and in particular within the DIS conference community. There has been substantial research work that relates provocation to critical design and critical theory [5], as well as, proposes ways to analyze critical designs [22]. In relation to research purposes, "provotypes" where proposed as ways to design for the future [7], and provocation was utilized to promote communal sustainability [8]. Following this stream of research our aim with this work is twofold. Firstly, we want to understand how provocation is experienced in the real world at three levels, namely aesthetic, functional and conceptual provocation [5]. Secondly, we want to challenge through provocation an existing everyday practice, the activity of washing clothes and consuming energy, and understand if and how it changes. Both aims contribute to understanding provocation under the frame of research through design. To do this we designed a provocative artifact, called The Box, and we conducted a field study with four families. Our interest stems out of curiosity for understanding provocation, from our previous work with sustainability, and from the fact that many existing solutions have had limited impact [e.g. 10, 14, 56].

Our paper is structured as follows. First, we discuss related work on provocation within HCI. Then we present in detail how we designed provocations. We continue by introducing our field study and by discussing our findings, which revolve around how provocation was experienced in use, and how it impacted our research through design approach. We conclude with reflections on designing provocations and using provocations for research through design.

PROVOCATION IN HCI

In order to contribute to better understanding the use of provocation for research through design, we got inspired from critical design. Critical design was coined in the work of Dunne [18, 19] and gained significant momentum within the Design Community. Critical design utilizes provocation as it tries *"to challenge the status quo"*, and as Dunne suggests, it is *"a form of social research to integrate critical aesthetic experience with everyday life"* [19]. A more theoretical discussion on what is critical design within Interaction Design has been initiated with the works of [3, 4, 5]. In these works, the authors highlight the importance of provocation, attempt to relate critical design to critical theory, and provide examples of critical designs. For the authors, the link between critical design and critical theory is somehow obvious, as critical theory aims in changing society in order to achieve *"human emancipation from slavery"* and *"create a world which satisfies the needs and powers of human beings"* [34]. At the same time though, and since critical design is a rather new concept for HCI, we observed a response from the Design community arguing that critical design is independent from critical theory, while highlighting that there is a danger that the new term may subsume all the other provocative design approaches, and thus narrow our field's point of view [49].

In this paper we will not attempt to define critical design, since there is an obvious need for more discussions among the communities until we reach an established definition. Our starting point in this paper is something that both sides agree on: critical designs critique the status quo and they challenge it through provocation. We believe there are three interesting questions that need to be addressed in order to understand the relation between provocation and interaction design. The first one is why to even bother to introduce provocation in an interaction design. We believe the reason is somehow simple. When an activity becomes an established practice then the involved artifacts in use, become 'invisible' [58], or taken for granted [42]. Provocation can be used to make them 'visible', thus questioned. The second question is related to how to produce a design that is provocative. Unfortunately, there are no methods and/or guidelines on how to be provocative. For example, in [4, 22] the authors suggest preliminary guidelines and tactics on how to analyze critical designs, but they also call for more research work towards this direction. Nevertheless, there are existing axes where provocation can be anchored. According to Bardzell et al. [5], an interaction design can be aesthetically, functionally and conceptually provocative. Aesthetic provocation is related to the visual look and the materials used for crafting the design. Functional provocation is related to the way it works and conceptual provocation to the idea that it tries to challenge/critique.

Finally, the third interesting question is related to the limits of provocation. How far can provocation go? Here we will attempt to make a rough distinction between two types of provocative designs based on their *purpose*. We propose that if their purpose is to challenge societal values through "provocation in first encounters" [7], then provocation may go to extremes, as it is the case with art. For example, the French artist Gustave Courbet painted in 1866 the 'L'Origine du monde' (The Origin of the

World), in order to critique the hypocritical social conventions of his time in relation to the female body. Or the Australian-based performance artist Stelarc, who was a keynote speaker at the CHI 2002 conference, provoked the idea of a permanent human body architecture, by surgically constructing a full-sized ear on his forearm that had the ability to transmit the sounds it heard, and was also a remote listening device for people in distant places [54]. In comparison to art though, not so many critical studies in HCI focused on this way of challenging societal values and considered the broader impact of technology use on humanity, even though there are papers that clearly call for more research to be steered towards this direction [17, 30, 33].

There is though, a second type of provocative designs, whose purpose is to challenge everyday practices and these are the ones typically used for research through design ("provocation in use", [7]). We believe in these cases provocation cannot go to extremes, because the designs are domesticated and therefore need to be inconspicuous, otherwise they will be rejected [7]. For these cases *"a slight strangeness is the key - too weird and they are instantly dismissed, not strange enough and they're absorbed into everyday reality…"* [18]. These provocative designs can be used: a) for research through design with the aim to understand a specific, current practice, or b) for research through design aiming to explore future design possibilities. In the first case, the provocative design acts as a technology probe [35] that has some provocative characteristics. In the second, it acts as a provotype [7, 42, 43]. The difference between a provocative technology probe and a provotype is that the first focuses at the present, while the second focuses on design possibilities for the future [7]. In both cases the designs allow us to conduct research through design, as they force us to think of new ways of looking at the world, and stimulate discourse around a challenging topic [13, 21, 53, 59].

Within Interaction Design a few studies have acted as provocative technology probes and/or provotypes for research through design. For example, in Dawn Chorus [26] the authors designed a smart bird feeder that trained birds to sing users' favorite songs and provoked the idea of human dominance over animals. The Drift Table [27] is an interactive table without a specific set of tasks that challenges using task completion times and rates as a core metric to evaluate a product. In [5] they challenged the role of the male handyman through the design of the Significant Screwdriver, and the fact that spaces are often gendered through the design of the Whispering Wall. Furthermore, the Digital Music Box approached file sharing not from a legal point of view, but as an experience centered design challenge [6]. The Switch! project focused on the production of provotypes for exposing hidden norms and values in relation to sustainability [41], while in [8] the authors utilize provocation in order to bring forth the fact that energy consumption should be addressed at the communal level and not at the individual one. A similar area is also explored by [29] and their deployed Energy Babble. Finally, provocation has also been used in research approaches for studying participants' behaviors. For example, in [51] pedestrians encountered what appeared to be an autonomous car, while in reality a driver was hidden inside a seat costume, in an effort to explore how pedestrians would react to driverless cars in the future.

THE BOX

As we mentioned before our aim in this paper is twofold. To understand how provocation is experienced in the real world (*provocation in use* [7]), and how it may challenge existing practices. For this reason, we designed and implemented a provocative design called The Box, which aims to provoke domestic laundry practices.

We chose laundry in private households as the domain for our study inspired by existing critique within sustainability research. Here users are often seen as the problem, and HCI research in sustainability often does not aim to change users' lifestyles, but tries to improve their sustainable behavior on a small scale. In order to go beyond that, there is a call to study the everyday practices of our users [46, 47], to go beyond persuasion, and to shift from prescription to reflection and from behaviors to practice [10, 38, 56]. Furthermore, current sustainable HCI research often holds the assumption that users act rationally and make intentional decisions. This view about the user is beautifully described by the Resource Man, an archetype who *"in his ultimate imagined state, is interested in his own energy data, understands it, and wants to use it to change the way he uses energy"* [57]. This perception of energy consumers has also been criticized (see [10, 38, 56]) as it has led to limited results [10, 14].

The Box was designed with the purpose to challenge every day washing practices, to make its users reflect upon them, and even change them. It also attempts to go beyond the simple presentation of information and the idea that users are always rational, by combining information with provocative elements. The Box was deployed with a research purpose that lies in between a provocative technology probe and a provotype. The Box was used to understand an existing practice (as a technology probe), but this practice was also challenged by presenting to the users a provocative, future scenario. Therefore, we characterize The Box as a *provocative future probe*. In the following we present how The Box was designed to provoke conceptually, functionally and aesthetically [5].

Facilitating Conceptual Provocation

Conceptual provocation is about an idea/belief/concept that we want to challenge or critique through a design [5].

In relation to conceptual provocation we deliberately chose to focus on two issues: a) the quite dominant and western world belief that electricity is always available and cheap, and b) the idea that there is no need to reveal the energy's production origin to the consumers [8]. The Box categorizes electricity as green and red, and the way information is presented to the users is inspired by previous sustainability research, and in particular eco-feedback systems [25]. The Box forecasts the electricity type for the next 12 hours through a simple scenario. It relates the energy type to the local wind conditions. If there is a lot of wind, then the electricity is mostly produced from windmills and is characterized as green, otherwise as red. The type of electricity is materialized through a color-coded clock. When the electricity is red then The Box cuts off the electricity from the washing machine, and users are expected to "shift" their consumption [similarly to 9, 12, 36, 40, 46]. If, for example, the wind is not blowing, users may experience a clock like the one in Figure 1(left side), where all the available slots are red. Thus, there is only red electricity for the next 12 hours and therefore they cannot use their washing machine (unless they override - details in the following section). With a bit of wind though, they may experience a clock that looks like Figure 1 (right side), where many slots are green.

Furthermore, conceptual provocation is also facilitated through the implemented price schema. The Box creates a savings account for its users. When they consume green electricity, then it is free and the money they save is added to their savings account. On the other hand, if they consume red electricity, then electricity is very expensive and the money they spent is deducted from their savings account. In Figure2b we can see a numerical LED screen which materializes users' savings account: 239 Danish Kroner (equivalent to 36USD).

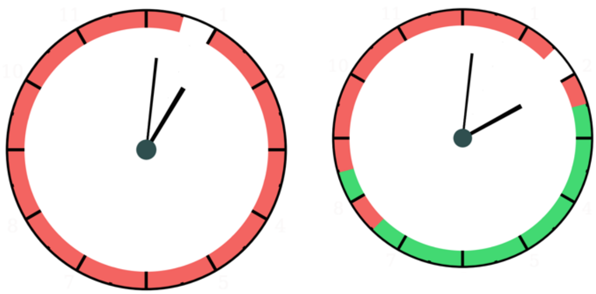

Figure 1. Examples of electricity status for the next 12 hours.

Facilitating Functional Provocation

Functional provocation deals with how far from the norm is the way a design works or operates [5].

Functional provocation was facilitated by imposing a dilemma to the users. According to [44], provocative dilemmas are triggered: a) by embodying symbols, b) by forcing users to make a choice, or c) through behavioral barriers. The Box imposes a forced choice to its users by cutting off the electricity when it is red, and providing only one physical interaction point in order to override this. For this, we adopted the emergency button metaphor that is often used in industrial equipment and the override button was placed on the bottom left corner of the box (Figure 2d). The button was purposefully selected to be red and fairly big in order to provoke a sense of reluctance, as it signals that it is something that should not be pressed accidently or without consideration. Inspired by [44], we believed that hesitation to press the button would make the users to slow down and reflect on their choices. In order to make the functionality even more provocative a second numerical LED screen was used to project how many times the override button was pressed, and thus the rules were violated (Figure2c, 16 times in the current example).

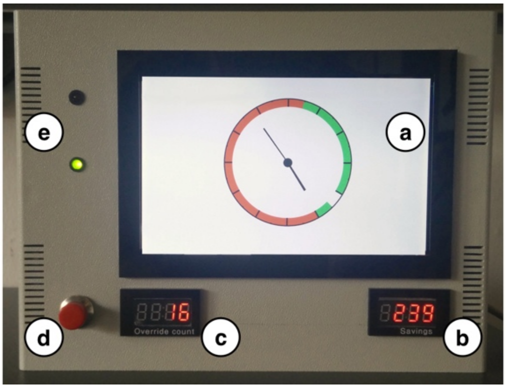

Figure 2. The Box: a) electricity status - 12 hour forecast, b) savings account, c) override button presses, d) override button, and e) electricity status at the moment.

Facilitating Aesthetic Provocation

Aesthetic provocation deals with how far from the mainstream is a design's visual look and the materials used for crafting it [5].

By browsing the sustainable HCI literature, we noticed that the majority of produced solutions are software applications either running on participants' existing mobile devices, e.g. [1, 24, 36, 40], or the mobile devices are provided as part of the study, e.g. [9, 11, 12, 40, 59]. In such studies, it is often stressed that the designs are beautiful, artistic, and conforming to the latest trends of simplicity and elegance. In a few cases, where the researchers did craft the physical form of their product themselves, e.g. [31, 37, 38, 45, 46], the majority or physical designs are also characterized as elegant as well as ambient, since their purpose was to reflect the calmness of the natural environment. Additionally, we investigated how off-the-shelf products look in terms of their physical design. Even though there are commercial products that have an industrial look, the majority of them can also be characterized as elegant and minimalistic (for example The Nest thermostat).

The Box attempts to provoke aesthetically by deviating from the norm in two ways. First, we decided to move away from the mobile application paradigm and design an actual physical probe. Second, we did not want to follow the style trends that we observed in most of related work and commercial products, namely simple, beautiful and minimalistic designs. Instead, we turned for inspiration to the past where such equipment was bulky. Several ideas were considered on how to design The Box. We experimented with different types of physical boxes, from old PC cases to even a military ammunition box. We also experimented with different layouts by attaching paper representations of the core functionality onto the boxes. In the end, we opted for an old, industrial case for electric equipment (Figure 2). Furthermore, in order to highlight the retro style of The Box instead of using nice, modern buttons and high-resolution screens, we visited various hardware stores in order to find components that had a retro look (override button and LED screens).

Creating The Box

The Box was crafted using the selected case (25 x 18 x 8cm) and by making the necessary modifications. A 7in screen was mounted and holes were drilled for the LEDs, the LED screens, and the override button. The black frames surrounding the screens were laser cut.

For the hardware, we used a Raspberry Pi with a GrovePi shield (Figure 3d) to control the override button, the LEDs (Figure 3c) and the numerical LED screens (Figure 3b). Furthermore, an off-the-shelf smart electrical plug (Energenie) was used to wirelessly control the power of the washing machine. In relation to software, we programmed in Python and used a variety of open source libraries to get real-time information about the wind conditions and for creating the interface.

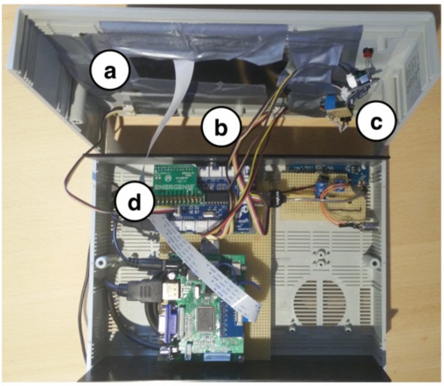

Figure 3. Internal components of The Box: a) 7in screen, b) numerical LED screens, c) LEDs and override button, d) Raspberry Pi and GrovePi shield.

FIELD STUDY

In the following subsections we present details on the results of our pilot study, the participants, the process we followed, and the data we collected in our field study.

Pilot Study

Before deploying The Box in the field, we conducted a pilot study with a five-person family for two weeks. They used their washing machine on average once per day. The primary purpose of the pilot study was to test The Box from an engineering perspective. Several software bugs were identified during those two weeks, which were addressed on the spot. Even though the pilot family used The Box for two weeks, we did not engage in deep discussions with them as the deployment period was often interrupted by software and hardware bugs and our interest was mainly in resolving them. Nevertheless, we gathered a few insights in relation to our design's provocativeness during these repairing sessions from the father. He informed us about its conceptual and functional provocativeness that *"he did not like it in the beginning but it made* him *think"*, and in relation to aesthetics that we *"could have done a better job because our design is very ugly and he wouldn't buy it if it was a real product"*. These findings provided indications to us that our design had indeed some provocativeness.

Participants

Four families participated in our field study. They all lived in Aalborg, Denmark and were recruited by snowballing within our social networks. In Denmark electricity blackouts are extremely rare and electricity prices are inflexible and cheap. Thus, in the context of the study, the perception that electricity is always available and cheap was common to the four families.

The first family was comprised by two adults (49 and 61 years old) and 3 children that were 16, 18 and 20 years old. The father was an electrical engineer, while the mother was a process coordinator at an energy company. They lived in their own relatively large house that extended into two floors. The washing facilities were located in the basement, in a utility room. The father was in charge of washing, drying, ironing and folding the clothes. They had *high* laundry needs since they were five and because they all physically trained almost everyday day. The father did at least one washing load per day, and often several during weekends (on average 10 laundries per week). We can characterize the level of environmental awareness of the first family as *medium*. They were recycling, bought a car with the main criterion of having a low fuel consumption, replaced most of the light bulbs at home with low consumption LEDs, all their new appliances were rated A+++ from a consumption point of view, and they were closely monitoring their water consumption too.

The second family consisted of a carpenter aged 51, a dental surgery assistant aged 46, and one 17-year-old boy. Two other teenagers, aged 14 and 19, were occasionally around. They also had a large dog that produced one load of washing per week. Together they had fairly *high* laundry needs (on average 7 loads per week). The family lived on a privately own rural property, where the washing machine was located in a hallway next to the entrance. The wife usually took care of laundry and she preferred washing in bulks during the weekend. The level of environmental awareness for this family can be characterized as *low*. They were mostly motivated by saving money, and thus they were buying A+++ appliances when replacing old ones, and recently changed all their light bulbs to LEDs.

The third family also consisted of two parents and three children. The father was 59 and the mother 49 years old, while the three kids were 6, 11 and 17 years old. The father worked as a surgeon at the local hospital and the mother was finishing her Master's degree in psychology while working at the same hospital too. They lived in a sizeable rural properly with the washing facilities located at one of the entrances. The father would usually wash his own work shirts and running clothes, while the mother would take care of the rest. Together they accumulated on average 7 loads a week, and they washed almost daily. We characterize the level of environmental awareness of this family as *high*. They mostly cooked with ecological food, recycled, bought energy efficient appliances and they had recently invested in a solar heat panel in an effort to *"support the environmental cause"*.

The fourth family was a young family consisting of only two adults aged 25 and 28. The boyfriend was a software engineer, while the girlfriend worked as a nurse. They had just bought a new semi-detached house, which they had recently moved into. Their washing machine was located in the bathroom. The girlfriend usually did the washing, but the boyfriend would occasionally do a wash if needed. Their laundry needs were *low* as they only washed on average 3 times a week. The level of environmental awareness for this family can be characterized as *low*. Like the second family, the main motivation for buying eco-efficient appliances and getting into the habit of turning the lights off was the prospect of saving money.

A summary of the most relevant demographic characteristics of the four families is presented in the following Table.

Family	**Persons**	**Laundry needs**	**Environmental awareness**	**Additional details**
1	5	High (~10 per week)	medium	washing machine in the basement
2	3+2	High (~7 per week)	low	washing machine next to the entrance
3	5	High (~7 per week)	high	washing machine next to the entrance
4	2	Low (~3 per week)	low	washing machine in the bathroom

Table 1. Relevant demographic characteristics.

Process

Each of the 4 families used The Box for 4 weeks. In each household The Box was placed on top of their washing machine in order to be closely related to the laundry activity. Eight, in-home, semi-structured interviews were conducted, two with each family, one before and one after the deployment of the probe. In the first interview we mainly focused on their existing laundry practices and their environmental awareness, and we introduced them to the purpose of the study.

Participants were presented with a future scenario that electricity companies are looking for ways to shift people's consumption away from carbon based sources and steer them to consume energy from windmills as much as possible. For this reason, electricity companies consider implementing different price policies (green = free and added to savings, red = double the price per KWh than the normal, and deducted from savings). Families were also instructed to use The Box in any way they thought suitable to their needs, and that their savings account would start at 100 Danish Kroner (equivalent to 15USD). Furthermore, we informed them that electricity is characterized as green or red based on the local wind conditions, but we did not exactly tell them how much wind should be blowing in order electricity to be green. We purposefully left this ambiguity in the scenario inspired by [7, 44], who suggest that some "mystery" should be maintained to allow for multiple interpretations to emerge. The second interview revolved around issues related to the usage of The Box, if and how it affected their washing practices, and their perception about its provocativeness in all three categories.

All data from the 8 interviews (each was on average 1 hour long) were transcribed (using interviewScribe) and the 4 concluding interviews were also coded (using NVivo). In all interviews both adults were present. In the families with children, we chose not to involve them in the interviews as we found out that they were not related to the laundry activity at all. We used the three provocation categories (aesthetic, functional and conceptual) as themes in order to guide the data analysis, which was conducted using a procedure known as 'explication de texte', or close reading, an analytical method that originated in the humanities [50]. Furthermore, all families' interactions with The Box were stored in a log file.

FINDINGS: EXPERIENCING PROVOCATION

Conceptual Provocation

With The Box we tried to challenge the idea of always available and cheap electricity, and that energy is often presented decoupled from its production source. We provoked the first by cutting electricity during the red, non-environmental friendly periods and by implementing a different price scheme, and the second by associating energy with local wind conditions.

In relation to the effect of the attempted conceptual provocation, we had mixed results. Families 1 and 3 informed us that had experienced in the past periods where electricity and water were scarce resources. Thus, they did not feel provoked. For example, the father in the first family informed us that he had *"experienced hot summers where you were not allowed to water your garden because there was a shortage in water"*, or that he remembered they *"were paying cheaper prices per KWh when consuming electricity in off peak hours"*. The other two families informed us that even though they did not enjoy that they couldn't use their washing machine during red periods, they chose to *"try it out"*.

In relation to the effect of conceptual provocation to their laundry practices, all the families eventually accepted the fact that electricity is not always available anymore, and they all perceived doing what they used to do before as "cheating". Three families used the word cheating to describe instances where they had a similar behavior as before the introduction of The Box. What was interesting though were the two reasons that drove them to change their practices. Families one and three, which pressed the button the least amount of times, told us that they hesitated to press the button as they wanted to *"take care of the environment"*, and *"have the feeling that you are actually doing something good"*. For them taking care of the environment was the motivating force. The second reason we identified, was the prospect of saving money. All families mentioned that saving money was an important factor, but for families two and four it was the strongest motivating force. Thus, even though they knew they saved the equal amount of *"two coffees"*, or *"a burger at McDonalds"* it was still enough for them, because *"if we do the same with other appliances we can save a lot"*, and *"it is the same as buying fuel for the car, it doesn't matter how much it is cheaper, just the fact it is cheaper is enough"*.

In relation to our decision to relate local wind conditions to the characterization of electricity and the ambiguity we introduced by not clearly defining the borders between green and red, we had two interesting findings. Since, wind is something that people can experience in the real world, for families one and three the wind conditions became a point of discussion. The father in the first family told us that he found very challenging the fact that he could not do a wash while the flag in their garden was moving: *"you know, we got a flag there and you can see its windy, and you think it should be green and it's not"*. The third family was also challenged by the fact they could see windmill farms from their living room: *"I have the feeling that your weather forecast is wrong or from another city, because a couple of times we could not wash, but we could see the turbines spinning"*. For those two families, provocation seemed to have an effect, as questions were raised in relation to how much wind is necessary in order to achieve 100% green consumption.

The second finding in relation to wind is more technical but it had important consequences for the families. In our implementation we decided to check the wind conditions and update the clock every 30 minutes. This decision resulted to situations where the families observed a green slot, for example 2 hours in advance, and when they went to wash, they found out that The Box had updated, and the slot was now red. We received a lot of critique about this and it was discussed for a long time by two families, even though the maximum reported number of times that this happened from all families was three (family one). Nevertheless, this perceived inability to properly plan became a discussion point for all families. For the example, the father in the first family informed us that he would *"immediately inform"* his wife *"whenever the bloody thing was red"*. They were annoyed by the update mechanism as *"it was impossible to plan"*, and because *"you get offended when it changes"*. Despite that, planning was also characterized by them as a *"mystery"*, *"a quite fun game"* and *"a funny race between* him *and the computer"* as he was *"sort of chasing the green slots"* as they were *"ahead of him"* and he *"constantly tried to pin them down"*. The same issue with planning was also pointed out by the second family, but more mildly as they told us that *"it should stay green"*. The third family somehow bypassed this issue, by characterizing it as a *"mischief",* while the fourth family completely circumvented it, as they had observed patterns of long green periods between 2 and 6 o'clock in the morning and they tried to do their washing then. To this end, the boyfriend informed us that his girlfriend started getting *"up early very often to put a load on"*.

Functional Provocation

When we asked the families about the functionality of The Box, most reported that they felt a bit provoked but not challenged. The first family informed us that they felt provoked because that it *"governed"* whether they *"could or could not do a wash"*, but in the end they even got *"surprised that it has not been any inconvenience"*. In the end, they characterized The Box as *"practical"*, *"functional"*, and an *"instrument to be informed on what is going on.* The second family characterized The Box as *"smart"* and *"unsmart"* at the same time. Smart because it gave them information that made them *"more conscious"* about their consumption, and unsmart as it did not provide any kind of automation in order to schedule their laundry. The third family characterized The Box as *"rational"*, *"structured"*, and *"simple"*. They decided that they were going to *"be ruled by the box"* and that they would *"only wash in green slots"*. Overall it provided *"food for thought"* and it was characterized as *"a tool to take care the environment"*. Along the same lines, the fourth family characterized The Box as *"informative"* because it provided a *"really quick overview of when to wash"*.

Besides these positives comments, families also felt really provoked by the functionality of the override button and the counting screen, as they proved to be focal reflection points. Families one and three commented that the override button looked like industrial emergency equipment. The father from the first family, who was responsible for the laundry, told us that he didn't want to *"cheat and press the button, unless it was absolutely necessary"*. The Box was perceived as *"a game"*, and pressing the button felt like *"breaking the rules"*. Both parents expressed their strong disappointment that they had to press the button the last day of the deployment period, because they knew that we would pick The Box up at a specific time and thus *"they felt cheated cause he had to override, otherwise he would have worked around that ... he would have waited"*. They both insisted that the last press *"shouldn't count on their score"* (even though there wasn't one). In the second family, the mother told us that when she pressed the button she would *"swear at it, because it was not fun to press it"*, that *"it is bloody annoying when you have to do it",* and that *"the screen should have stayed at zero"*. The third family informed us that they decided the first day that they would never press the button, and thus canceled from the beginning our imposed dilemma in an extreme way. They did that since the thought of pressing the button *"made* them *stubborn, so* they *just had to make it work"*. They approached the new laundry situation as a *"competition"* where *"the box and not the laundry basket is now in charge"* and they *"wanted to see if it is really feasible to be ruled by the box"*. Finally, in the fourth family they both perceived The Box as a game to beat, and breaking the rules was ok *"because it only happened when it was really necessary"*. Furthermore, the boyfriend informed us that he perceived The Box as rather *"boring"*, because its physical interaction was limited to *"one button to play with"*.

Aesthetic Provocation

We specifically discussed with the families about the physical design of The Box. First, we asked them to use three words to describe it and most characterized it as *"bulky"*, *"retro"*, *"industrial"*, and "*ugly"*. After being engaged in in-depth discussions about it, we have been told that they felt challenged since it is *"obviously not the finest design"*, and since it looks *"like something* we *have created from stuff we had available", "like an old retro arcade game"*, and *"like an amperometer from a physics school class"*. Some also *"hoped the designer did not spend a lot of effort to come up with that"*. When we told the families that it was purposefully designed to look like this, most got surprised. The first family told us that they would prefer *"something smaller, something that looks like an Apple device"*, while the third informed us that *"it is ok as long as it stays in the utility room"*. This distinction between the utility room and other rooms within a home, was often highlighted as they told us that they wouldn't like to place something that *"looks like that next to designer furniture"*, or that *"people in general do not like cables and stuff in their living room and they even hide their internet boxes"*.

In relation to specific design elements, most of the discussions where positive. The two numerical LED screens that materialized *"how many times they cheated"* and their savings, were positively received. The mother in the first family specifically pointed out that The Box was very good at guiding them in saving money and reflecting on how to be more environmentally friendly because *"the screens put the information straight in your face"*. The boyfriend in the fourth family told us that it was good that the LED screen was there *"because if nobody is counting and I pressed the button 5 times, and then "forget" 4 of them – then it would be as bad"*. Interestingly, when we asked the families whether they would have had the same engagement if its design was more modern and all the information was presented on a single screen, or in a mobile application, we got different answers. Three families stated that they would have had the same level of engagement, while the first one told us that it wouldn't have been the same because right now they enjoyed that information was tangible.

In relation to the design of the color-coded clock, which we associated it with red and green energy, we had slight different perceptions about it. The first family told us that the clock was perceived as a traffic light that guided their washing activities, where *"green means Go, red means Forbidden"*. The second family associated the colors to sustainable behaviors and for them *"green means economical and sustainable, and red is wrong"*. The third family distinguished between *"rational"* and *"not rational behavior"*, and green color meant *"throw something in the washing machine now"*, and red *"no go"*. The same "go", "no go" approach was reported by the fourth family too.

FINDINGS: THE EFFECT OF PROVOCATION ON OUR RESEARCH THROUGH DESIGN APPROACH

Through The Box we did research through design. Thus, The Box should not be viewed as a product, but as a research tool that allowed us to have a better understanding of an area of interest, in this case electricity consumption. Since in studies like ours, the most valuable source of information are the participants, we want them to be highly engaged and as reflective as possible. The following subsections present findings in relation to those two issues.

Provocation Increased Participants' Engagement

We view participants' engagement at three levels. The first is related to how much they got engaged with The Box, the second how much they got engaged with us during the interviews, and the third how much they related to our research purpose.

From the log files as well as the discussions with our participants, we understood that they got really engaged with The Box. All the laundry activities that took place in all households were conducted through The Box. Even though the participants knew that they could simply unplug it and go back to what they used to do before, none chose to do so. The Box was up and running throughout the duration of the study, except for a few instances were there have been some internet connectivity issues and it had to be reset. In detail, the first family pressed the override button 3 times, the second 19 times, the third 0 times and the fourth 3 times. They all saved money, according to our scenario, with the first family saving 6.5USD, and the rest 2.7, 3.4, and 3USD respectively. These results show that our probe was an overall success from a sustainable point of view as shifting did occur, even at extreme rates.

Furthermore, very often and with all four families, we experienced instances where we did not fully control the interviews, and the participants were so engaged that they started interviewing each other. Such instances were really useful for us, as they did not only give insights that were limited to the outcomes (e.g., how many times they pressed the button), but revealed to us their thinking behind their choices (e.g., what motivated them not to do a wash).

In relation to the third level of engagement, which is how interested they were to our research work, our findings also show a deep engagement. We experienced a similar situation as reported by Bardzell et al. [5], where our participants started behaving as researchers. Many asked questions about our research purposes and our study setup. When we informed them that we were interested in understanding provocation, we had interesting discussions in relation to its limits, and whether we did some things on purpose in order to provoke more. For example, the father of the first family told us that he *"knew there would be a green section in an hour's time, so I did go down at that time, and it was red again, so I couldn't do anything. So I began to wonder whether you did this on purpose"*. Then he asked us if we purposefully introduced these sudden changes from green to red in order to study extreme usage scenarios of The Box, since *"he would have done that"*. For him, provoking participants by making them experience extreme situations, was an interesting way to identify the limits of both provocation and interaction. Similar discussions occurred for all three provocation aspects. Finally, some of the participants shared their views on issues that went beyond our research interests in this study, such as privacy and security concerns, and existing research in electricity distribution.

Provocation Strongly Motivated Reflection

All four families got deeply engaged with The Box and tried to reflect on their washing practices. These reflections went beyond what we anticipated in the beginning of the study, and occurred by both adults on every family, even though only one of them was responsible for the laundry. They even got diffused to other areas of their life, as most reported that they demonstrated The Box to visitors, and discussed about it with colleagues from work.

Firstly, we observed that the practice of doing the laundry became visible to our participants, it was deconstructed by them, and reflections and changes occurred to their practices on almost every aspect. Our participants reflected on the amount of clothes they washed every time, the temperatures they used to wash their clothes, even on the type of detergents they used, even though The Box was mainly designed for shifting. For example, the fourth family tried to fill up their washing machine with as many clothes as possible *"because when there is a green period we do not always have the time to wash two loads"*, while the father of the first family informed us about the washing temperatures that *"I mean, I suppose, I have been hypocritical about it in the past, because you can wash in 30 now with the detergents we have"*. In relation to shifting, we did also have unexpected results as most did shift their laundry times. In an extreme example, the third family that did not press the override button at all, sent their kids to school with day-old clothes a couple of times, and their teenage son *"was annoyed that we did not wash exactly the clothes he wanted. There have been complaints about it, but he has come to terms with it"*.

Furthermore, another very interesting finding was that our provocative future probe facilitated reflections that went beyond our scenario. For example, the mother in the second family told us that she *"often just caught myself thinking, well it is now green, so now it is a good time to run the dishwasher"*. Thus, our scenario got extended to other appliances, even though they were not part of the study. The families also reported that they started discussing energy consumption and sustainability issues in general. For example, the third family used The Box as an *"example of sustainable behavior"*, and as an *"educational tool"* to inform their children on why it is important to turn the lights off when no one is in a room. Finally, all families discussed and reflected about The Box itself as an artifact. We got suggestions on how to make it less energy consuming, how to combine it with a mobile app that would send *"service messages"*, discussed ways to make the laundry activity *"automated"* and *"remotely controlled"*, and talked about how to embed our functionality into an actual washing machine.

We treat all the above-mentioned instances as strong indications that provocation can facilitate strong reflections about existing practices, which may even lead to long lasting behavioral changes. Of course, at this point we can only speculate about such outcomes from studies like ours, but we would like to highlight that such instances could also be expected from other similar studies in the future.

DISCUSSION

Our discussion section revolves around two types of reflections. Reflections on designing provocations, and on using provocations in research through design.

Reflections on Designing Provocations

We identified two important issues on designing provocations.

Designing provocations is challenging but achievable

We started our design process by having in mind that our probe should by "slightly strange" [18] and a bit "mysterious" [7] in terms of aesthetic, functional and conceptual provocation. Since there are no specific methods for designing provocations, we understand that other researchers may experience the same difficulties we had during our design process. We will highlight three approaches that we found useful in dealing with this issue. Firstly, we strongly recommend to embrace *design authorship* [49] in order to design provocations. Design authorship highlights that not all designs need to be directly linked to specific requirements and users' needs, but can emerge out of the curiosity and the intuition of a designer. Design authorship should be combined with an iterative design process where the limits of provocation will be understood within the area of interest, and they will be instantiated through conceptual, functional and aesthetical elements. Secondly, we believe that often it is useful to involve users in the design process in order to define the provocation limits. In our study, we did not do that and we believe we might have missed some valuable input on provocation alternatives. Thirdly, we recommend to look for inspiration into existing provocative designs and identify aesthetic, functional and conceptual provocative elements that are successful. In order to do that we believe there is a clear need for "annotated portfolios" [28] within the Interaction Design community that will act as exemplars for future researchers and practitioners. According to Gaver [28], annotated portfolios are collections of designs that can act as an alternative to formalized theory, by explaining in detail the concepts behind a design, and the issues, values and themes which characterize them.

Provocations in use need to be experienced in the real world

As discussed before, we see a difference between "provocation in use" and "provocation in first encounters" [7]. In our study, we wanted to understand how provocation in use impacted everyday laundry practices. For studies with a similar purpose as ours, we believe it is important to have a deployment in the field, where the actual practices are realized. Otherwise, the participants will not easily make their practices visible, and reflect upon them. Also, since ambiguity and provocation go hand in hand [7, 44], we do not believe that we would have had these findings if our study was a laboratory experiment, which may be more suitable for studying provocation in first encounters.

Furthermore, it is also interesting for us that by introducing a probe into the real world, we may actually provoke more ideas/concepts than anticipated. For example, The Box did unintentionally provoke the idea that technology makes our lives more convenient in one of the families, as they had their washing machine located at their basement. The father told us that going up and down just to take a glimpse at the clock was *"annoying"*, but at the same time *"intriguing"*, and *"a good physical exercise"*. This openness in relation to what is provoked goes hand in hand with research through design approaches, as "designers can be *prepared-for-action*, but not *guided-in-action* by detailed prescriptive procedures" [55]. Therefore, we recommend to researchers that study provocations in use, not to be strict in their research plans, but to make them as flexible as possible [5].

Reflections on Provocations & Research Through Design

We will relate our reflections on using provocations for research through design, to the proposed model of interaction design research proposed by Zimmerman et al. [59], where researchers may assume three different roles within an interaction design process. The first is that of an engineer where they need to consider which technologies to use to make the design ("the *how* knowledge", [59]). The second role is the anthropologist, where researchers are interested in exploring the field by collecting data ("the *real* knowledge", [59]). Finally, the third role is being a behavioral scientist and integrate theory and models ("the *true* knowledge", [59]).

Designing provocations impacts all three roles. First, it impacts the role of being an engineer, as the decision of which technology to utilize in a design has to be filtered through conceptual, functional and aesthetic provocation. This is the reason, for example, that we did not materialize the savings account of The Box using software on the 7in screen, but we opted for an old-school, numerical LED screen. Second, it impacts the role of the anthropologist. Since provocations make the "invisible", "visible" [58] for a particular practice, as well as, increase the engagement and reflection level of the participants, they allow us to understand more of the "real" knowledge. We believe that this is really important for any research through design study that focuses on everyday practices. Finally, provocations also impact the role of the behavioral scientist, by facilitating unanticipated effects which may feed back to theories and models. For example, if we continue studying the energy consuming practices in private households, we might better model how to achieve behavioral change.

Another issue we will address is the notion of validity for using provocations in research through design. We will address the issue in two ways. The first is its relation to the notion of experimental setup. If someone considers our study as an experiment on provocation, then he might believe that we failed in our experimental setup since not all subjects received the same treatment – they did not perceive the imposed provocations the same way. We believe though that this way of viewing research through design studies is inherently wrong, as their purpose is to understand "what is real" and not on "what is true" like behavioral scientists [59]. Research through design studies and design theory in general, are unfalsifiable as their purpose is not to falsify a theory but to provide alternatives that confirm the theory [28]. Consequently, since The Box is a research tool and not a product, our study was successful since our purpose was not to solve a specific problem, but to understand different "realities" of practice. And these practices were uncovered in rich detail not because we had a rigid experimental setup, but because we did not have one.

The second way of approaching the notion of validity is related to provocation itself. Did we really design a provocative probe? Is there any criterion for evaluating its provocativeness? Again, we treat this discussion as irrelevant for research through design studies for the same reasons mentioned above. At the same time though we recognize that through more studies on provocation, through the creation of annotated portfolios [28], and through better understanding on what constitutes a good provocative design, we will be able to design better provocations. Towards this end, we do not believe we need strict definition on what provocation is, but a better understanding on what it is not.

Finally, we want to briefly touch upon the role that provocations can play for interaction design practitioners. We believe the decision to use provocations for the design of real products should be taken after careful consideration. The reason for believing this is that provocations may not fit well with all-in-one solutions that address the general public, since they may be experienced in vastly different ways. Therefore, they may facilitate negative experiences, when for example users believe that provocations went too far. With this we do not want to argue against embedding provocations into real products, but to simply highlight the challenges that such a decision might facilitate.

CONCLUSIONS

In this paper, we report on our efforts to understand provocation in research through design, through the design and deployment of a provocative future probe.

In short, our findings showed how provocation was experienced by our participants, how it affected their practices, and how it impacted our research through design approach. Overall, even though provocations may be experienced differently by participants, they can help them to better engage with a future scenario, as well as, to reflect and question their existing practices. This high level of engagement that provocations facilitate can be very useful for interaction design researchers in general, as they will allow them to better understand the "realities" they impose to users through their designs. Furthermore, provocations may impact all three roles interaction designers take within a research through design approach (engineer, anthropologist and behavioral scientist) and may guide them to discover more of the "real" knowledge.

In the future, we want to continue researching provocation. We want to study its long-term impact on domestic practices and do more research on how to define its limits. In relation to sustainability, we plan to extend this study and go beyond the individual, by studying provocation at the community level, and by researching its effect on resource consuming practices in general.

ACKNOWLEDGMENTS

We would like to thank the four families that participated to our study. This work is part of DiCyPS project (864703), funded by Innovation Fund Denmark.

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EXPLORING *HYGGE* AS A DESIRABLE DESIGN VISION FOR THE SUSTAINABLE SMART HOME

Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B Skov

Abstract: In this paper, we present an exploratory study of *hygge* as a low-energy design vision for the smart home. *Hygge* is a Danish concept that embodies aesthetic experiences related to conviviality, often shaped by orchestrating atmospheres through low-level lighting. To explore this vision, we probe two Australian households that already live with smart home lighting technology. We report on household reflections of embedding *hygge* into everyday life. We conclude by outlining future directions for exploring desirable and sustainable smart home visions

Originally published as:

Rikke Hagensby Jensen, Yolande Strengers, Dimitrios Raptis, Larissa Nicholls, Jesper Kjeldskov, and Mikael B Skov. 2018. Exploring *Hygge* as a Desirable Design Vision for the Sustainable Smart Home. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18), 355–360. ACM Press. https://doi.org/10.1145/3196709.3196804

INTRODUCTION

Currently, two HCI research discourses shape the design visions for the smart home. First, the *desirable* smart home, as a home that enhances people's experiences of comfort, convenience, and security through pervasive technologies [2]. This vision has been supported [9,12,38,40] and challenged [24,32,39] by HCI researchers and practitioners for decades. Second, the ongoing pursuit of the *sustainable* smart home [1,18,19,31,40]. In most smart home research these visions have been pursued separately and potentially undermine each other. For example, recent studies have shown that the pursuit of desirable smart home 'enhancements' may increase consumption and outweigh energy efficiency benefits [15,17,20].

In this paper, we approach this emerging dilemma by bringing desirability and sustainability together to explore ways of steering everyday life towards desirable, lower-energy visions. We build on past work, which identified an energy-intensive aesthetic vision of 'pleasance' [36] and house-holders' different desires or 'desiderata' [20] for the smart home. This research suggests that one possible approach for HCI designers is to identify desirable low-energy visions for the smart home and explore ways of embedding these into devices and households' everyday practices.

Towards this end, we turn to the popular and less energy intense concept of *hygge* emerging from Denmark. *Hygge* has taken up a desirable position in contemporary visions for everyday life in several westernised countries [27,37]. The Danish concept of *hygge* reflects a romanticised Scandinavian lifestyle featuring cosiness and companionship. While not directly marketed as 'low energy', the vision embodies ideas of low-level lighting, minimal engagement with technology, and 'traditional' ways of keeping warm, such as using blankets or drinking hot cups of tea. *Hygge* contrasts with the energy-intensive vision of pleasance currently permeating smart home marketing [36], where new smart devices, sensors and functions (e.g. mood lighting) are embedded into practices and parts of the home, potentially creating new energy demands and outweighing any energy efficiencies [20].

Focusing specifically on *hygge*'s potential relationship with smart lighting, this paper reports on a deployment of explorative *hygge* probes in two Australian households as part of a larger study on the smart home. Through the deployment, we sought to circulate different ideas about desirable ways of life within the smart home and identify how designers can embed these into devices to help steer emerging smart home practices in more sustainable directions.

WHY *HYGGE*?

Most HCI efforts to design for sustainable outcomes have either looked for ways to do this as efficiently and effortlessly as possible via intelligent and automated technology [1,19,33], or advocated for desirable 'Going Green' visions [25] that aim to engage people with sustainable choices, either by informing and educating [5], suggesting greener alternatives [21], or proposing alternative lifestyles e.g. 'voluntary simplicity'

[13]. These approaches envision sustainability as something that is desirable by assuming that people aspire to 'do the right thing' either via optimisation or by actively pursuing a 'sustainable' lifestyle. In this paper, we experiment with a different approach for envisioning sustainability and desirability in the smart home. Specifically, we turn to *hygge*.

Lighting is central to *hygge* where natural daylight, candles, and electrical lighting all play important roles in orchestrating *hygge* atmospheres [4]. As Bille [4] demonstrates, *hygge* orchestrates desirable atmospheres of intimacy, informality, belonging, togetherness, equality, and secureness that shapes interior and exterior spaces of the home and relationships between people and things. In this way, *hygge* has parallels to the energy-intensive aesthetic vision of pleasance [36] that embeds desirable expectations of comfort, relaxation, and peace of mind into the smart home. Like pleasance, comfort and relaxation are central to *hygge*, but in contrast to it, creating the calm and convivial atmosphere associated with *hygge* tends to involve less use of electrical lighting and technology. As a result, *hygge* can be 'naturally' less energy intensive, but not generally promoted as such. This means *hygge* could appeal to a wide range of smart home adopters, including those for which environmental issues are of little interest and/or saving energy is not desirable.

In this paper, we explore whether *hygge* can engage early adopters of smart homes in a lifestyle vision and aesthetic experiences which use less energy. We explore this in a country where *hygge* is not widely understood but is gaining some traction as 'hip' and 'cool' – or desirable.

RESEARCH DESIGN

In the first phase we drew on qualitative research (photography, semi-structured interviews, and informal home technology tours [6]) with 23 Australian households that used smart lighting and other smart home technology. The main objective was to understand how smart home technology was incorporated into the everyday lives of early smart home adopters, and the energy implications [see 20].

The purpose of the second (*hygge deployment*) phase was to probe ideas of *hygge* to encourage lower energy usage without explicitly discussing energy. We designed an exploratory probe pack (Figure 1) consisting of: a digital diary, a coffee table *hygge* book, a *hygge* quiz, and a *hygge* app for the Philips Hue smart light system. The app was built by the researchers and included possibilities to create and select *hygge* mood scenes which involved minimal and soft lighting (instead of their existing lighting arrangements of mood scenes involving multiple colours). The *hygge* book and quiz also provided information on how to create *hygge* through (smart) lighting and other materials. The diary contained open-ended questions that allowed our participants to reflect on *hygge* and to share, through text and photos, their *hygge* 'moments'.

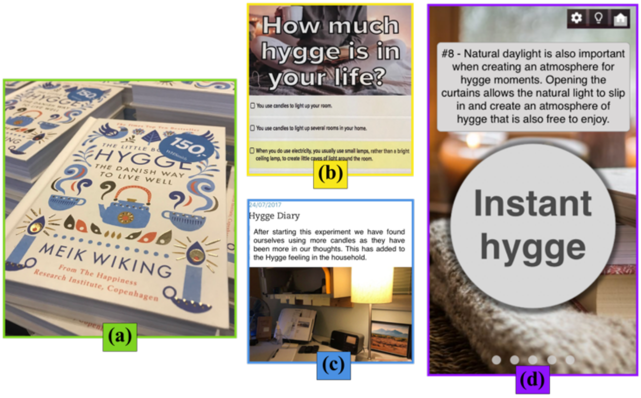

Figure 1The explorative probes; a) hygge book; b) hygge quiz; c) snippet of a digital hygge diary; d) hygge app

As lighting infuses a range of household practices, the probe pack design was inspired by Shove et al.'s [34] theory of social practice change. Shove et al. argue that one way in which practices change is by mixing up the elements (material, meanings, and competences) of practices in different ways. Thus, the purpose of the probe pack was to circulate *hygge* practice elements that would encourage participants to experiment in playful and provocative ways. More specifically, the probe pack was intended to engage householders with new (or old): 1) materials such as new scenes of smart lighting and the use of candles and natural lighting 2) meanings about what is cosy, warm, and aesthetically pleasing, and 3) competencies on how to create atmospheres, connect with others, or calm down.

Two households interviewed in phase one used the Hue system extensively and were recruited for the *hygge deployment phase* – Adam and Natalie (a couple) and Tony. Adam was an IT specialist and keen amateur photographer, while Natalie worked as a nurse. The couple had designed the lighting for their new house to include 19 smart light bulbs, two smart lighting strips, and non-smart spot lights in the ceiling throughout the house. Tony was an academic with a keen recreational interest in design. Tony's home was equipped with seven smart bulbs and one smart lighting strip. Tony's smart bulbs were placed in decorative lamps in different rooms, while spot lights were placed throughout the home.

This part of the study was conducted over four weeks in June/July 2017 (winter) and involved two interviews with each household. In the first interview, questions were directed towards their use of smart lighting. Households were also introduced to the probe pack and given the opportunity to ask questions about the probes, *hygge* and the study. In the second interview participants were asked about their understandings of *hygge* and how they used the concept/probes in the past month. Both interviews were audio recorded and professionally transcribed. The transcriptions were subsequently analysed using an emergent coding approach [23] resulting in four themes discussed below.

FINDINGS

Aesthetically Pleasing Experiences and Smart Lighting

Prior to introducing the *hygge* probe pack, households were using their lights for functional, decorative, and aesthetic outcomes. Direct electrical lighting (particular non-smart spot lighting) was mostly used to provide better visibility for chores such as cooking and cleaning. In contrast, colourful and dimmable smart lights were typically used to create attractive and comforting atmospheres via smart mood scenes. This finding reflects the dilemma of having competing desirability and sustainability visions for the smart home. One reason that households chose to install a smart light system was because the smart bulbs and strips were low energy LEDs. However, the smart lights also infused additional household practices for reasons other than functionality. Householders desired to aesthetically enhance practices such as reading, dining, cooking, television watching, and bathing with smart lights, which added beauty, nourishment, uniqueness, and playfulness to the experience. This often involved the use of more lights (lamps and strips) for more time (Figure 2 & 3) and therefore could undermine the energy efficiency benefits of LED technology.

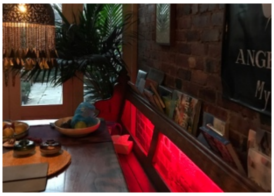

Figure 2: Colourful LED strips in the dining room

Figure 3: Smart LED used when watching television

After circulating ideas of *hygge* through the probes, participants approached their smart lighting system differently to create atmospheres that emphasised happiness, cosiness, relaxation, and warmth. In particular, Adam and Natalie engaged extensively with the probes and aspired towards *hygge* as a way of creating aesthetically pleasing experiences through lighting.

> Adam: I have actually played with the setting of the lights more than I normally do…Just thinking about it [hygge] has actually made quite a big difference in terms of my desire, real drive to create atmosphere even more.

Interestingly, these *hygge* atmospheres were mostly created by exploring scenes in their smart lighting system that dimmed or turned off electric lights. This echoes Bille's [4] finding that soft and minimal *hygge* light shapes aesthetic, ambient, and emotional experiences. These findings are encouraging because they suggest that circulating alternative design visions for the smart home can help lower electricity consumption.

Hygge and Non-Electrical Materials

Participants also associated *hygge* with the use of non-electrical and 'dumb' materials. Tony, for example, associated light from his fireplaces as a source of *hygge*.

> Tony: Really hygge, it's also when you've got light from the fire.

Candles were also associated with *hygge* and used in both households as a decorative light source to create *hygge* atmospheres. Candles were used as a supplement to dimmed electric smart lights as seen in Tony's home (Figure 4), while Adam and Natalie explored using candles as the only light source in some practices, e.g. bathing (Figure 5).

Figure 4: Mood setting with different lighting sources

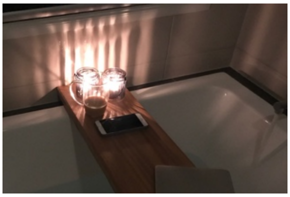

Figure 5: Candles used during bathing time

The *hygge* probe pack also made Natalie consider using natural light for situations she thought embodied *hygge*:

> Natalie: I looked outside for a while, knitted for a bit, and then looked outside, and I was just so happy, and warm, and cosy. I like the natural light, so all the blinds were up… I think it's, for me it leads to that whole feeling of hygge. Because I tend to have a blanket and I have a drink.

This shows how participants started to use or associate different materials (e.g. light, drinks, blankets) with aesthetically pleasing experiences in existing practices (e.g. knitting, cooking, entertaining). These findings demonstrate promise for the idea that non-electric materials can be used to either reduce or replace use of smart technologies, while still maintaining expectations of experiencing the smart home as a pleasurable and nourishing space. These expectations have strong parallels with the desirable vision of pleasance [36] but without the same energy-intensive implications. Moreover, these findings open up new possibilities to design smart technology that takes advantage of these (or other) new meanings of aesthetically pleasing *hygge* experiences (e.g. blinds that automatically go up when natural light is available, heating turning down when people are cooking or snuggling up underneath a blanket).

Slowing Down in The Smart Home

Because *hygge* promotes minimal engagement with technology, interacting with smart home technologies (e.g. smart lighting) to create *hygge* atmospheres might be understood as counterintuitive. This aspect was picked up by Tony, who felt distracted by smart phone notifications when changing light settings. Natalie and Adam, on the other hand, found it easier and more convenient to change light scenes from their smart phones when immersed in *hygge* moments because they did not have to get up from the *hygge* 'nest'. Participants also associated pursuing *hygge* with slowing down daily routines to allow oneself to be 'in the moment', suggesting that *hygge* competences were infusing several practices.

> Natalie: Just do you chores, maybe in a slow way, rather than in a frantic [way]… Mindful, present, happiness, and just relaxed enjoyment, of where you are at that moment.

These qualities reflect related ideas of slow technology [14] and slow energy [28] that Katzeff et al. [21] have explored as a positive framing for 'shifting' intensive energy activities in time [29]. Our findings suggest *hygge* could also be explored as productive and desirable design vision for framing slow energy.

The Dark Side of *Hygge*

The above findings demonstrate how probing participants about *hygge* might be a promising design path for mixing up elements of practices in new and 'naturally' less energy intensive ways. However, given that *hygge* is also associated with meanings of cosiness and warmth, particularly in the winter period, circulating these ideas may introduce new expectations of comfort that could further increase energy demands. For example, Adam despised feeling cold and used his automatic heating system to ensure his house was always warm.

> Adam: I'm emotionally uncomfortable with being cold.

Introducing the *hygge* concept confirmed and encouraged Adam to maintain this expectation of thermal comfort. As reflected by Natalie, this expectation was not the norm in Australia – heating tended to be used on an 'ad hoc' basis instead of on a thermostat-controlled regular basis:

> Natalie: Australians try to avoid putting the heat on at all costs, so kind of cultivating that warm, cosy environment [through hygge], I think they'd use more heating, the general Australian.

These findings stress that designers should be wary of romanticising *hygge* as a design vision for the smart home because it could also embed new meanings and expectations of comfort that may increase energy use.

DISCUSSION AND FUTURE IMPLICATIONS

Designing Desirable Low-Energy Ways of Life

A major question guiding our work is how to envision a smart home that challenges aesthetic expectations in lower energy ways, while still upholding the idea that living in a (smart) home should be desirable, pleasurable and comfortable. We are aware that (smart) lighting does not necessarily constitute a large proportion of a household's electricity usage, but this study is a step towards positioning the smart home as desirable *and* sustainable, without explicitly promoting 'Going Green' visions or invoking 'negative' connotations (e.g. 'we have to make do with less') embedded in visions like 'voluntary simplicity' [13].

Did we then succeed in probing *hygge* as a design vision for the smart home that brings desirability and sustainability together? Our findings show that the explorative *hygge* probe pack did challenge expectations of aesthetic experiences by mixing up the elements (materials, meanings, and competences) of practices related to smart lighting that could result in less energy usage. An important contribution for future designers and researchers is that interventions, which promote desirable design visions (in contrast to specific outcomes such as lower energy demand) can be useful for studies that aim to 'trigger' reconfigurations [22] of household practices, even without introducing a prototype.

Our findings also highlight the importance of understanding the different kinds of desires [26] that shape early adopters' use of smart technologies (also reported in [15,17,20]), which may be differently from the designed purpose [10,16]. The unforeseen ways that people combine elements of practice need to be considered when designing interactions that aim to steer towards sustainability [34,35]. However, we also need to be careful with the interpretation of our findings, as *hygge* may also lead to unsustainable expectations (e.g. using more lights that are dimmed or heating more) and new needs and desires (e.g. bringing more interactive energy-consuming technology into the home), which may lead to an increase in overall interactivity and electricity consumption that contradict *hygge's* 'naturally' using less approach.

Hygge, Research Through Design, and Provocation

We consider this research an initial step towards unpacking the relationship between desirability and sustainability in the design of smart technology. A suggested next phase is to attempt to 'trigger' [22], through *hygge*, everyday practices towards sustainability. For this, we draw inspiration from provocative design approaches such as critical and speculative design [3,11] to create interventions in the form of provotypes – prototypes that use provocation to explore design possibilities for the future [7]. Other research through design studies have illustrated that speculative [8] or provocative [30] designs can be used to steer practices towards sustainability.

We suggest using provotypes and provocation (on all three levels; conceptual, aesthetic and functional [3]) to further explore visions and designs for the smart home. In this study, we provoked aesthetic expectations of living in a smart home through the *hygge* probe pack. However, we also conceptually provoked, since *hygge*, to some extent, already promotes the idea of 'suppressing' the use of technology (for example, to switch off the lights and use candles to achieve *hygge* atmospheres). For future work, we suggest provoking functional aspects too, as a way forward for 'triggering' reconfigurations of household practices.

CONCLUSION

In this short paper, we have argued that HCI designers and researchers interested in pursuing sustainability through smart home technologies should pay closer attention to the visions of desirability that underpin them. We introduced the popular and lower energy aesthetic concept of *hygge* to disrupt and reorient ideas about desirability and sustainability in the smart home. Using an explorative probe pack, we selected two households from our larger smart home study to engage with *hygge* through their smart lighting system. Our findings show that *hygge* introduces new meanings, materials and competencies about comfortable and cosy atmospheres that can reconfigure everyday practices in less (and more) energy-intensive directions. These ideas provide a fruitful area of exploration for HCI designers interested in reducing energy consumption in households, and one which is ripe for provocation and experimentation.

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DESIGNING THE DESIRABLE SMART HOME: A STUDY OF HOUSEHOLD EXPERIENCES AND

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Abstract: Research has shown that desirable designs shape the use and experiences people have when interacting with technology. Nevertheless, how desirability influences energy consumption is often overlooked, particularly in HCI studies evaluating the sustainability benefits of smart home technology. In this paper, we present a qualitative study with 23 Australian households who reflect on their experiences of living with smart home devices. Drawing on Nelson and Stolterman's concept of *desiderata* we develop a typology of householders' desires for the smart home and their energy implications. We structure these desires as three smart home personas: the helper, optimiser and hedonist, which align with desiderata's three approaches to desire (reason, ethics and aesthetics). We use these insights to discuss how desirability can be used within HCI for steering design of the smart home towards sustainability

Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (CHI '18), Paper 4. ACM Press https://doi.org/10.1145/3173574.3173578

INTRODUCTION

Despite a tradition within HCI to focus design and evaluation efforts on utilitarian and functional benefits [31], envisioning what is desirable when designing interactions has long been recognised as an important aspect of design [42]. Towards this end, HCI research has looked for ways to embed pleasurable [30,31] and cool [27,49] experiences into interactions, acknowledging that, although interaction designs themselves can be desirable, it is the meaningful and desirable experiences they create and shape that give value to people [25]. The design challenge of creating meaningful and desirable experiences within the smart home has also been addressed within the HCI community [28,70]. Despite these efforts, how householders create and shape desirable experiences within the smart home is often overlooked in sustainable HCI studies that evaluate the use and effects of smart home technologies. Instead, sustainable HCI efforts tend to look for ways to design interactions that engage households in various issues of sustainability such as saving or shifting energy usage [34,44,60]. In this line of work, automation has been explored as the means to make sustainable changes more effortless or convenient [2,29,72], while eco-feedback has been used to persuade people to engage in sustainable change [21,34,62]. This research reflects a common framing within sustainable HCI; change is driven by a problem solving approach [42] that explores designs based on what is technical achievable and justified by the ethical (and desirable) premise that we are also solving sustainable problems.

However, as smart devices are moving into our homes, so too is a myriad of other desirable uses that extend beyond sustainability problem-solving goals. Devices are used in a variety of energy-consuming practices like heating, lighting, entertainment, and cleaning, which promote desires of comfort, convenience and entertainment [23], encompassed in the broader smart home aesthetic vision of 'pleasance' [64]. While much effort has gone into considering how these devices can be designed to make people's life more efficient and effortless [66], little attention has been given to what makes the smart home desirable and what energy consumption is tied up in that.

In this paper, we present a qualitative study exploring how desirability embedded in smart home designs shapes and enhances everyday experiences and energy consumption. More specifically, we seek to improve our understanding of desires that do not directly involve sustainability, but have sustainability implications. To do so, we draw on research (interviews, photography and home tours) with 23 households who incorporated various smart home devices into their daily lives. We analyse these data using Nelson and Stolterman's concept of *desiderata* [42] to develop a typology of householders' desires for the smart home as a helper, optimiser and hedonist. Our findings present insights into the desires embedded into the design of smart home devices and reflected in household practices, while also considering their energy implications. We use these insights to discuss the future role of HCI in designing the desirable sustainable smart home

RELATED WORK

The smart home has long been envisioned as a home comprised of pervasive, intelligent, and interconnected technology [24] that predicts and responds to inhabitants' needs for comfort, convenience, entertainment, and security [3]. The design challenges embedded in this vision have caught the attention of HCI and ubicomp practitioners and researchers [11,19]. Three HCI visions have informed this work: calm computing [66], engaging experiences [53], and the sustainable smart home [2,52].

Weiser and Brown' vision of *calm computing* promotes designs that aim to hide smart technology as much as possible. Most work in this area has focused on the design and evaluation of the utility and usefulness of smart technology that enters the domestic space [8,11,19]. On the other hand, Rogers' vision of *engaging experiences* promotes designs that empower people to extend and engage in their daily activities and pursuits [53]. Work in this area draws attention to design challenges of designing interactions for pervasive technology that is embodied within the messiness of everyday life [4]. Towards this end, Klapperich et al. [35] explore how to design more meaningful interactions with automatic coffee grinders that reconcile automation and experience of everyday practices, while Mennicken et al. [40] acknowledge that the smart home vision continuously evolves as peoples' expectations of the smart home keep changing.

The vision of *the sustainable smart home* has also engaged HCI scholars over the last decade [2,5,16,52]. In this endeavour, HCI research has explored designs of smart home technology that aim to support households to sustainably use energy, either by reducing or shifting energy usage [45]. A number of studies have investigated how smart automatic agents can assist households to effortlessly manage heat consumption [1,29,36,56,73]. Examples are Alan et al.'s three smart thermostats [1], Scott's et al.'s Preheat system [56], and Yang et al.'s [71,72] extensive user study of the NEST Thermostat (a commercial smart thermostat that promotes energy savings by intelligently deducing households' comfort needs).

Other sustainable HCI research has explored the role of smart devices in assisting households to sustainably manage their electric car's consumption [10], or other domestic practices, e.g. washing clothes [7,15]. While these studies have shown promise for smart agents to help households obtain energy savings, they also draw attention to the challenges of designing devices embedded in everyday life [15]. Importantly, what unites this work is an assumption that the sustainable smart home should uphold households' lifestyle expectations of comfort and convenience [29,72].

However, as smart home technology is finding its way into homes, so too are many challenges [68]. One is to address a potential mismatch between households' and the smart home industry's expectations of how such technology should be used. As Wilson et. al recent study [69] shows, prospective smart home users identify one of the desired benefits of smart home technology as enhanced control of energy. However, a recent analysis of industry visions [64] demonstrates how the smart home technology industry also embeds desires into these devices that promote energy-intensive comfort and convenience.

Desiderata

Desires have been acknowledged as contributing to human intent [42] and shaping expectations for how we want to live [59]. Therefore designers have long attempted to inscribe desires into designs in an effort to shape experiences to become more pleasurable [31], cool [49], and meaningful [26]. However, research also shows that people appropriate and shape their use of such designs in ways that are unforeseeable [17,26].

So how can we understand people's everyday engagements with design? One way is to look at Nelson and Stolterman's concept of *desiderata* [41,42], which loosely translates to 'desired things'. Nelson and Stolterman propose that incentives to engage with a desirable design are influenced by intrinsic motivations shaped by people's desires [42].

Viewing desiderata as a concept to understand desires embedded in design includes three strategies roughly condensed to *reason*, *ethics*, and *aesthetics* [42]. Reason is related to what a design object *is* or *needs to be*, or its purpose and the reason why it exists. Ethics corresponds to what a design object *ought to be* based on ethical and moral codes, while what we *want* a design object to be is expressed in aesthetic values of experiences [41,42]. Together these three strategies capture a more 'inclusive whole' of desires in design – desiderata – forming the voice of design [42]. However, there is never only one of these approaches present in a design, as a design consists of *"different proportions and balances among these three approaches"* [41]. For example, desires embedded in a smart thermostat could be viewed as the following: we might desire to control the temperature in our house (reason), so that we don't waste energy (ethics), while also ensuring a desirable comfortable temperature throughout the home (aesthetics). Thus, these desires together (desiderata) make the smart thermostat a desirable thing.

We combine the concept of desiderata with Shove and colleague's [57,58,59] interpretation of how desires shape expectations and in turn become embedded in (or rejected from) everyday practices. Shove [57] argues that desires have played (and continue to play) a critical role in shaping normality, by steering the kinds of 'comfort, cleanliness and convenience' (the '3Cs') people aspire towards and expect. Following Shove et al. [58], we can also understand such desires as social – arising out of and shaping social practices as part of the meanings, ideas and moods that orient everyday activity towards shared expectations. This means that 'desired things' can shape, but not determine, how people use a design or what they expect it to do. Importantly, Shove [57] argues that these have significant energy consumption effects; the 3Cs, for example, constitute 'the environmental hot spots of consumption' making them ripe for sustainable HCI scholarship.

Indeed, this approach has become of increasing interest to the field of sustainable HCI in recent years [20,39,43], as scholars seek new ways of understanding how to embed sustainability within everyday practices, and make it desirable [38,46]. We extend this scholarship here by analysing how desiderata shapes householders' desires and expectations for the smart home, and contributes to or undermines sustainability outcomes.

METHODS

The research reported in this paper is part of an ongoing 3-year qualitative study of 23 Australian households living in smart homes or using smart home technologies led by author 2. The study involved semi-structured interviews and home tours supplemented by photographs and observations. The research was conducted with approval from RMIT University's Human Research Ethics Committee.

Participants

35 people from 23 individual households participated in the study (Table1). Most participants were 25 years or older but two households included children in the interview. Most households who disclosed their incomes were high income earners. The households were recruited through technology forums and events, a project website, social media, radio and print articles, advertisements, referrals from smart home industry professionals, and professional and personal networks. Each household was offered an AU$50 voucher.

#	Anonymised Participant(s) (gender)	Adults (children)	Occupation	Age of participant(s)	Smart Home Devices
H1	Kahlil (M)	2	Software developer	35-44	Robot vacuum cleaner,TV
H2	Lindy (F), Johnno (M)	2 (2)	Education support, electrician	35-54	Alarm system, garden irrigation, windows, fans, touch screen panels
H3	Tony (M)	1	Academic	45-54	Lights, entertainment system, automated security camera, windows
H4	Jerry (M)	2	Financial Manager	55-64	C-bus, lights, TV, air conditioning, music, security cameras, garden irrigation
H5	Rachel (F)	2	Not in paid work	35-44	Automatic locks, lights, switches, music, TV, intercom
H6	Bill (M) Kristi (F)	2 (1)	Management Feng Shui and teaching	45-54	Robot vacuum cleaner, security system, lighting, blinds, pool, entertainment, Amazon Echo 'Alexa', touch screens panels, security cameras, fans, home cinema
H7	Gavin (M), Kate (F), Daughter 1, Daughter 2	2 (2)	School teacher, homemaker, Student, student	45-54 16-18	Control 4 system, lights, security cameras, windows, blinds, sound system, skylights.
H8	Scott (M), Lauren (F)	2 (3)	Engineer, radiographer	45-54	KNX system, Amazon Echo 'Alexa', air conditioning, lights, weather station.
H9	Darren (M)	2 (1)	Arcade game businessman	45-54	KNX system, lights, curtains, security cameras, doors, temperature, music, fire place
H10	Trent (M)	2 (1)	Builder (own business)	45-54	C-bus, entertainment, heating, air condition, lights, security system, touch screen panel
H11	Ted (M), Jess (F)	2	Software developer, research student	35-44	Robot vacuum cleaner, smart meter home display, fitbit scale
H12	David (M)	2 (2)	Project manager, kindergarten teacher	45-54	C-bus, lights, automatic sprinklers, security system, rain sensor, blinds, water features, audio system, security cameras, touch screen panels, home cinema
H13	Taryn (F), Matt (M) Son1, Son2	2 (2)	Full time student, researcher, Student, student	45-54 10-13	Robot vacuum cleaner, music system
H14	Larry (M)	2 (2)	Real estate business	55-64	Lights, doors, air conditioning, security system, sprinkler system
H15	Romy (F)	2 (1)	Physiotherapist	25-34	Blinds, light, air conditioning, music system, doors, gate, security cameras, sensors, garden irrigation, intercom
H16	Demi (F)	2 (2)	Teacher	25-34	C-Bus, music, irrigation, lights, touch screen panels, sensors, doors, security camera, air conditioning, roller shutters, blinds,
H17	Valerie (F)	2 (2)	PhD student	45-54	Robot vacuum cleaner
H18	Adam (M)	2	IT services	35-44	Lights, security cameras, music, smart meter home display
H19	Morris (M)	1	IT developer	35-44	Lights, gates, blinds, Google Home, Amazon Echo Dots, Robot vacuum cleaner, TV, air conditioning
H20	Kurt (M), Graham (M)	2	Economist, teacher	25-34	Lights, music, fitbit scales
H21	Cara (F)	1 (2)	Homemaker	45-54	Lights, music, blinds, air conditioning, touch screen panels, doors
H22	Pablo (M), Noni (F)	2 (2)	Ethical investment research, public service	35-44	Heating and air-conditioning, smart meter home display, robot vacuum cleaner
H23	Gabriel (M)	2 (3)	IT architect	35-44	Z-wave, Google Home, pool, lights, sensors, gates, smart meter home display

Table 1: Summary of participant households.

To be eligible for this study, each household had to self-identify as using at least one smart home device fitting Aldrich's definition of a smart home [3]. This open recruitment criteria reflects current research which indicates that the technology, visions and expectations for smart homes are a work-in-progress [40,68]. The number and type of smart devices in participant households was diverse (see Table 1) ranging from one smart device (e.g. robotic vacuum cleaner) through to fully integrated smart homes with a range of connected devices and appliances providing lighting, entertainment, security, comfort, energy management and garden irrigation. Ten households also had solar panels for hot water or electricity generation.

Data collection and analysis

Site visits lasted between 1-2.5 hours. Broadly, question topics included: participants' understandings of the smart home and its associated technologies; why they have them and what a smart home means to them; experiences of living with smart home technologies; energy consumption; and aspirations and predictions for future smart home technologies. Most (21) interviews included an informal conversational technology tour [6] during which participants demonstrated how they use their devices or smart home. Researchers asked clarifying questions and took photos if permission was granted.

Interviews and home tours were audio recorded and professionally transcribed resulting in a single transcript. As we set to investigate how householders' desires for smart home devices inform their practices, the units of analysis were desires and expectations. The transcripts were coded in two stages by author 1 (under the direction of author 2). In the first stage, we identified broad themes via inductive coding [51,54]. In the second stage, we conducted structured thematic coding informed by Nelson and Stolterman's framework desiderata [41,42], and Shove and colleagues' [57,58,59] understanding of how desires shape household expectations and everyday practices [37,38,58], focusing on those likely leading to 'hot spots' of energy consumption [57]. We used this analysis to develop a typology of smart home desires, which is a common analytical device for organising qualitative data [55]. Throughout this paper, participating households are referred to by pseudonyms and household number (see Table 1). Quotes are verbatim.

FINDINGS

Our research is informed by other studies indicating a potential mismatch between household's [69] and the smart home industry's [64] expectations for the smart home. Despite numerous HCI studies providing insights into how to design both desirable and sustainable interaction designs, there has not been any HCI research synthesizing household experiences to explore how desires shape energy consumption in the smart home. Towards this end we present findings from our qualitative data analysis.

Analysed through the lens of desiderata, we identified a typology [55] of 10 desired characteristics of the smart home informed by the households participating in our study. While these key characteristics can both conflict and overlap, we structure them into three 'smart home personas' that align with desiderata's three approaches (reason, ethics and aesthetics): *the helper*, *the optimiser* and *the hedonist.*

As these desires are informed by reflections of the participants' experiences of living with smart home devices and how they expect these desires to be realised, the three personas represent householders' desires for smart home devices or the smart home in general (see Figure 1). *The helper* captures desires related to the smart home's function and its capability to act in a helpful manner. *The optimiser* captures characteristics related to desired outcomes for the smart home. *The hedonist* captures a pleasure-seeker pursuing desired aesthetic experiences within the smart home, suiting a modern lifestyle. Figure 1 presents our typology of smart home personas and characteristics.

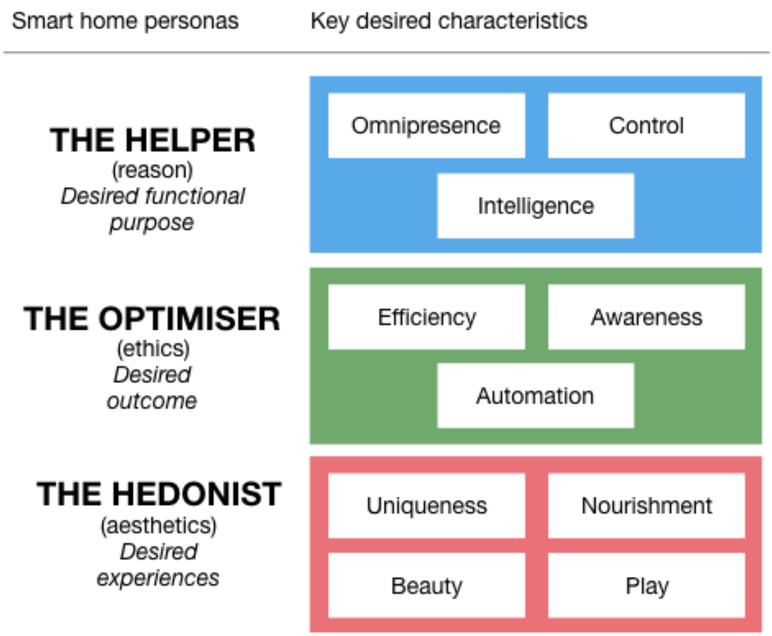

Figure 1: Households' desires for the smart home.

In the remainder of this section we present our analysis of these three desirable smart home personas and their related characteristics. We focus on the characteristics that indirectly and directly have implications for energy consumption.

THE HELPER

The helper captures households' desires regarding the purpose of the smart home expressed through functionality. What makes the helper desirable is its ability to assist households to control appliance and housing features and functionality, thereby saving time and making home life more convenient. The helper strategy is evidenced by the smart home's subtle way of combining intelligent features of different devices, accessible when needed, resulting in a controllable omnipresence throughout the house, an aspect well summarised by Gabriel:

> "Where everything is connected to everything; devices can control one another and can do so both reliably … and intelligently. Self-learning as well, so you can say if you've just bought a new oven, okay, I'll add that to my abilities of Google Home over there." Gabriel (H23)

However, attaining these desired smart features also means that new electricity-consuming devices are brought into the smart home (e.g. Google Home, Philips Hue Bridge, and robotic vacuum cleaners). Interestingly, based on participating households' experiences, most of these electrical devices do not replace others but are added to the household's fleet of devices, impacting overall energy consumption. More specifically, our analysis found that the helper's desired characteristics created new demands for electricity. We now turn our attention to these.

Omnipresence

One desired characteristic highlighted by most households is the smart home's 'always-on' ability to provide smart features when needed. This characteristic is related to Weiser and Brown concept of calm computing [66] where interactions are designed to only take centre stage when control is desired. However, providing this kind of omnipresent control also means devices are consuming small amounts of energy all the time in 'standby' mode.

Most devices present in the households embodied this omnipresent characteristic. Some were remotely controlled devices (e.g. smart fans, blinds or lights) always ready to execute commands on behalf of the household. Other devices provided pervasive control through an assembled interface. Examples included Google Home and Amazon (Echo) Alexa, devices that offer omnipresent voice control to connected smart devices and the internet. In some of these homes Alexa helped to control other smart home devices: *"like turn lights on and off, turn the fountain on and off, raise and lower the blinds"* Bill (H6). Other times 'she' helped the householder more directly:

> "Alexa has lifted the whole thing … you can ask her the weather and she does calculations. So she puts on a timer. Yeah so it's kind of like having a helper." Kristi (H6)

However, to serve household's needs when called upon, devices like Alexa and Google Home are always 'listening in' on household conversations. This uses almost the same amount of electricity compared to when these devices are actively helping householders [18].

Control

Another key characteristic of the helper persona involves providing control to the smart house. This involves allowing householders to monitor and access their home, including its physical boundaries and the property's perimeter, through e.g. lighting and security devices.

Based on householders' experiences this desired characteristic was associated with many smart home devices (e.g. smart lighting, security doors and cameras, and air conditioners). For example, security doors allowed some households to control and monitor who had access to the house when they were away, as Darren explains (H9): *"I can let them in my front door, and I can be in Glasgow"*. Most households saw this aspect of the helper as a time saving feature in a busy modern life: *"well it does save time, yeah. I don't have to go there"* Larry (H14). This also highlights a desired aspect of the helper to make home life more convenient, as explained by Romy:

> "Like when I was breast feeding … [my child], if I had to turn the air con on or off or lighting or dim the lighting or whatever, I didn't have to stop doing that to be able to go – you know, like go switch a light on or off." Romy (H15)

To be able to provide this kind of access, new energy-consuming devices are often needed. For example, the Phillips Hue Bridge is an additional device, not normally present in households with non-smart lights, which is constantly running in order to access smart bulbs from a smartphone. In about half of the participating homes, this desired accessibility was also facilitated by a centralised 'hub', allowing smart home devices to communicate with each other and the Internet.

> "So that's a switch, so that's for all the network points throughout the house, so the speakers, TV, the phones, all that is through there. That's the security camera […] That's the router, and that's the Hue, so actually quite simple, as you say, as these things go." Adam (H18)

Figure 2: A smart home 'hub' accompanied with a cooling system (H18).

Figure 3: Smart screens panels providing access to connected devices (H6).

However, not only does such a 'hub' need a constant supply of electricity to power the 'brain' of the helpful smart home but it also creates new energy demands like cooling down the server racks (see Figure 2) or entire server rooms: *"that's the air conditioner for our control room. So that's to keep all the electronics cool"* Bill (H6). Furthermore, for households wanting to maintain control over the smart home through this centralised hub, other energy-consuming devices like Alexa and Google Home were used. Some houses also used situated powered smart screen panels (see Figure 3). These displays were often placed throughout the house providing access to the smart home when desired:

> "Again, here is a touch screen. So, on the touch screen, you could have things like your favourite pictures come up. … This is a page, so it basically has the main, the front, the pool, the theatre room downstairs, outside, and then it has the tools where it shows you how to program." Trent (H10)

In other words, instead of reducing standby power consumption and the human energy required to do so, the smart home employs a range of new energy-consuming devices with the intent of saving time or household labour.

Intelligence

Most participating households also desired some level of intelligence from the helper. More specifically, they wanted the smart home to anticipate and react to new changes and conditions in the home environment. This level of desired intelligence was found in most households, where smart lights would go on/off based on movement, smart locks opened doors based on geo-location of householders, and windows opened or closed based on local conditions like weather and time.

> "I programmed the house to do certain things, like my front door, the porch light turns on at sunset and turns off at 11:30 […] It's geo-fenced, so when I'm driving home and it's after dark, that light turns on. So that's the smart sort of stuff. The blinds I'll program to open at sunrise and sunset." Morris (H19)

Households made use of the smart home's intelligence by using 'set and forget' or automated features to free up time for more enjoyable activities: *"So, we can spend more time being creative instead of having to do, yeah, manual work"* Kahlil (H1). To enable this desired reactive, intelligent mode, sensors were used to detect proximity of home occupants to unlock or light up areas of the home:

> "LED lighting underneath the cupboards as well, and that comes on with the sensor as you see. I just walked in and it comes on automatically." Darren (H9)

Intelligence was also delivered by helpful communication offered by many smart home devices that are designed to provide visual cues about the status of a device – most often accomplished via LED lighting. For example, the Phillips Hue Bridge is designed with a blue LED light that is constantly lit to communicate that it is on. Other devices like sensors told householders that movement had been detected via LED lighting. Kate and Gavin identified the light "pollution" (and energy demand) tied up in this interactive communication provided by their sensors:

> "I'd like to coin the phrase LED pollution. And that is that, when you turn the lights out and devices have LEDs to just even show standby it's such a strong light, it's such a bright light that, you really

> never get that compete darkness anymore because everything has, LED whether it's just a clock, whether it's a, standby button, whether it's – everything has to tell you it's state via LED." Gavin (H7)

What these findings show is that different desired functionality embodied in the helper also implicit have implications on electricity consumption in the smart home.

THE OPTIMISER

The optimiser is a second smart home persona. The optimiser captures desires related to how the smart ought to be used related to a desirable outcome. It is characterised by its desired ability to use energy more efficiently and with less effort while maintaining expectations of comfort and convenience. It does so by providing awareness about consumption to household members and anticipating how to use consumption more efficiently through automation.

The optimiser contrasts with the helper and hedonist by highlighting a paradox in household desires for the smart home: namely, that the smart home is a house that uses energy efficiently, but also helps (the helper) householders to create experiences (the hedonist) that reflect a modern lifestyle, regardless of their additional energy needs. Some of the participating households noted this paradox:

> "I certainly love that you can use some of this stuff to save energy, but also, you have to think about all of the embodied energy if you're getting new devices every couple of years – that's energy as well." Rachel (H5)

In the following we describe the desired characterises of the optimiser and this paradox in more detail.

Efficiency

The desire to bring smart home devices into the home was often related the optimiser's desired characteristic of using energy more efficiently and being more economical with energy consumption. The following couple explicitly expressed this desired characteristic:

> "To me a smart home would be using, would be really be very low on electricity use." Kristi "That would be an economical home." Bill (H6)

The desired characteristic of the optimiser to use energy efficiently meant that living in the smart home was also tied together with living sustainably for some households: *"So it's basically being more sustainable, that's, well that's what I'd consider a smart home, actually"* Pablo (H22). Interestingly though, most devices found in participant households do not explicitly promote sustainable energy usage in their product marketing even though householders' often used this reason as a justification for bringing these devices into their homes [65]. David, for example, explained that energy efficiency had been an important consideration when he decided to bring a smart heating system into his family's home. However, he understood that energy efficiency was the responsibility of designers:

> "I think because there's a consumer desire to minimise energy usage then the technology will support that, and yes, … [product designers will] help improve or reduce energy consumption." David (H12)

This finding demonstrates how some householders view energy consumption as a 'feature' that is the responsibility of designers, rather than seeing it as an outcome of smart home devices becoming integrated into everyday practices such as heating.

Awareness

A second desired characteristic of the optimiser was to educate household members about sustainable energy usage by prompting them to use energy more efficiently. This is connected to some householders' desires to understand their own energy usage and give them control to do something about it, as explained by Trent:

> "If I've forgotten to - or he's [my son's] forgotten to turn the lights off in his studio, and it shows up on the screen. So I can do it from my phone or do it from upstairs, turn them off, you know." Trent (H10)

In most of the participating homes, raising awareness was seen as a desired means towards more efficient energy use. Some householders thought awareness was a matter of getting to understand the smart home better, like Kate (H7): *"for me I think once we get to know the system and how to work it, I'm hoping that it will reduce [consumption]"*. Others saw real-time and historic consumption feedback visualised through their smart home system as a way to manage their energy usage. This kind of feedback for some raised awareness about spikes in energy use which Ted (H11) described as getting *"a kick out of that, just being able to measure how much energy we were using"*.

However, whether this characteristic of the optimiser is really desirable can be questioned. Adam (H18) had at first found this kind of feedback interesting but it ended up being an element which he *"set … up but haven't paid a lot of attention to"*. This shows that although this kind of feedback is initially desired, it also relies on ongoing (undesirable) householder engagement.

Automation

Despite a desire to become aware and maintain control of energy usage, the optimiser is also characterised by the smart home's desired ability to anticipate when to act sustainably through automation.

> "Our house does the same thing when you go out and we turn the alarm on it turns any lights that you've left on in the house, it would turn them off so that you didn't leave something on and waste energy." David (H12)

This aspect of the optimiser assumes that householders are busy and forgetful and thus the optimal way to obtain energy efficient benefits is through automation:

> "Some people are pretty lazy… So automation systems can be useful for people who, you can set timers. You can have a control. You can switch lights on from, on and off from a control and that will reduce your consumption." Kahlil (H1)

However, adding this kind of automation to smart home also had energy implications. For example, while Bill was aware that smart devices might not lead to more energy efficient use, *"because we've got lots of gadgets it's not as efficient as I'd like it to be"*, he believed energy benefits could be obtained by better planning how to automatically turn *"more appliances and devices off"*. This is interesting because although most households saw smartness as a means to make the home more efficient, most households reported using more electricity than they had previously.

While automation in these circumstances was a desired means to *not* waste energy, our analysis also shows that automation can undermine potential energy benefits. Johnno mentioned the energy paradox in setting up a smart home to do work on behalf of the household:

> "If you let something else do the work for you, therein lies the energy cost." Johnno (H2)

For example, in some homes a robotic vacuum cleaner was used, but because this task was efficiently carried out by a smart device they vacuumed more frequently to pursue higher cleanliness expectations as reflected by Taryn:

> "There's just the sense of the house feeling cleaner and that's a nice feeling. And it's a very personal thing to me… It has crossed my mind that maybe we're using more energy because it cleans more often." Taryn (H13)

Others continued to vacuum manually (in addition to robotic cleaning) because their robotic vacuum cleaner did not live up to their cleanliness expectations: *"on Saturday we'll have a big clean so we'll get the proper vacuum cleaner"* Valerie (H17).

This aspect of the smart home highlights one of the challenges of designing the sustainable smart home. If the optimiser is going to be successful in achieving desired sustainable energy outcomes, conflicting expectations of desired characteristics of the smart home, needs to be addressed.

THE HEDONIST

The hedonist conceptualises household desires of *wanting* to experience the smart home as an aspirational modern lifestyle, as encapsulated in the industry vision for 'pleasance' [64]. The hedonist is characterised by its capacity to create a desirable and beautiful living space that also makes the smart home more playful and cool to be in. Moreover, what makes the hedonist desirable is its ability to adapt to a household's unique lifestyle needs by creating *aesthetic* experiences that are nourishing, personal, and pleasurable, as Kristi explains:

> "So to me in Feng Shui terms a smart home would be one that reflected your soul. It would reflect exactly what you love. So it wouldn't be what's in a magazine - it would be what nourishes you and what symbolises you." Kristi (H6)

Some of the characteristics of the hedonist are afforded by the features and functionality of the helper. Interestingly though, the hedonist had the biggest impact on how smart home devices were used and experienced in households. Most had put considerable effort into designing their homes with smart devices to improve their quality of experiences both now and into the future:

> "The home needs to be sort of designed that it will meet our needs throughout life, and that security and safety and comfort and all of those things are." Gavin (H7)

However, creating and enhancing aesthetic experiences also have an energy impact as we identify in the hedonist's characteristics below.

Uniqueness

A desired characteristic of the hedonist is how the smart home is able to create experiences within the smart home that are highly personalised. For most participants, this was about the smart home's ability to fulfil the unique and personal needs to suit each household's lifestyle:

> "The house that works with you, so it's not an independent. It'll have to be a part of your life so it knows where you are. It responds, it's in keeping with your lifestyle." Kahlil (H1)

From our analysis, it is clear that most households in our study had gone to great lengths to purposefully integrate smart home devices into the design of unique, intimate, and personal spaces in their homes. David, for example, had designed a personal music experience where:

> "You can have different music playing in different zones, or at the touch of a button you can link them altogether and just have the same music throughout the house." David (H12)

David created this experience by placing energy-consuming speakers in most rooms of the house and even ensured that music could be reached to the outside area of the house. Other households used smart lighting to create unique atmospheres suiting the mood of the household. For example, Tony (H3) used his smart lighting system to create unique intimate atmosphere suiting the particular space and the moment in time: *"I will change the lighting if I think it will make a better space"* (see Figure 4).

Figure 4: Creating a cosy atmosphere at the dining table with LED strips (H3).

Figure 5: Smart lighting used to a unique atmosphere in the living room (H22).

Mood and automated lighting in particular were quickly integrated into existing practices (e.g. cleaning, dining, bathing, sleeping, and entertainment) to create a more intimate and cosy atmosphere:

> "The atrium feel, you know … just when we have dinner parties, … at 10 o'clock at night the lights dim by themselves, I don't have to get up and dim the lights, so they reduce down to 35 per cent." Trent (H10)

This meant that devices such as LED strips and other energy consuming devices were used more extensively in everyday practices as they found their way into households' TV lounges (see Figure 5) and dining rooms.

Nourishment

Another desired characteristic of the hedonist is its ability to nourish householders by making everyday life more convenient, comfortable and secure. The desire to feel safer was evident in many of the households we interviewed. Some used security video cameras to record movement in and around the house. Some households with smart lighting would also use programmed lighting when away:

> "When you're [on] holidays, you know, we have the simplicity of making sure the lights are turned [on] and turned off at certain times so it looks like someone's home." Trent (H10)

In other homes, smart blinds and windows were used to ensure that it would not get too warm inside the home during sunny summer days. In houses with smart thermostats, some householders would ensure a comfortable temperature when the house was occupied. Similarly, some households extended energy usage by turning the air conditioners and heaters on hours before returning home to ensure a comfortable house:

> "So it means that I can turn the air conditioning on half an hour before I arrive home and have a cool house to come home to, which is probably the most desired outcome of this whole system that I had." Scott (H8)

Bill and Kristi also pursued the hedonist's smartness to ensure a comfortable temperature in the spa before returning home: *"I'll turn the spa on and start it heating before I get home"* Bill (H6). Several households also used smart lights in new ways, such as to help them get to sleep. In Demi's household for example, they had a "kids bed button" that dimmed lights in designated places when the children were put to bed. They used a smart light to ensure that there was some nourishing light in case the children woke up and needed to visit the bathroom during the night:

> "So the button basically dims the lights in my younger son's bedroom to be the lowest dimness, so that he's got, it's kind of like having a bed light in there, I guess. As well as the hallway and the bathroom." Demi (H16)

In Scott and Lauren's (H8) house they used a "goodnight button" to ensure that all lights were off when they went to bed but still left *"the stair lights on at 10%"*.

This desired aspect of the hedonist also highlights implications of energy usage and the role of light and other nourishing energy-consuming devices in the home. As a nourisher, devices need to be on more of the time and therefore can increase energy consumption. For example, the 'goodnight button' leaves householders with the peace of mind that everything will eventually be switched off, instead of progressively switching things off throughout the day as they are no longer being used.

Beauty

The hedonist is also characterised by a unique ability to create a living space that is aesthetically pleasing. This is extended to other parts of the property, like the garden or swimming pool area.

In particular, smart lights were used by participating households to create aesthetically pleasing spaces. Bill and Kristi (H6) explained this when asked why they had decided to use LED lights in a fountain in the garden: "*it should be a very nice aesthetic advancement"*. To create an aesthetically pleasing experience by the pool, the same household also used coloured LED lights: *"both during the day and at night even more so",* a clear example of how the hedonist dominated the possible desired sustainable outcomes of the optimiser.

This domination of the hedonist was also evident in most of the other households. Scott (H8), for example, had spent much time and effort designing the lighting so it would be energy efficient but also appropriate to activities that suited his household's age and lifestyle. Decorating areas of the home gave him a lot of pleasure: *"yes, you got basic coloured lights outside around the pool. Just around the pillars. Just entertaining"*. Both David (H12 – Figure 6) and Gabriel (H23) had programmed all the outside lights to be turn on 10 minutes after dusk and turned off around bedtime because *"I always think houses that are nicely lit at night look good.*" Gabriel (H23).

Figure 6: Smart lighting in a fountain and on the outside wall of the house (H12).

Figure 7: Decorative smart lights in the kitchen area (H9).

Trent (H10) used different kinds of lights like LED strips and halogen down lighting extensively as a decorative means to create these aesthetic pleasing spaces throughout:

> "Yeah. Decorative lights […] We've turned the light - and especially in summer. And you know, it just creates a nice backdrop [...] Feature lighting. And you know, it's nice at night, it just gives that ambience, you know?" Trent (H10)

However, this desire to create aesthetically pleasing and beautiful spaces also meant that more energy consuming devices are finding their way into places where they were not used before. For example, smart lighting was being used to decorate both interior (see Figure 7) and exterior spaces, like the garden, swimming pool, and pathways.

Playful

The final desired characteristic of the hedonist is its ability to make the smart house more playful, fun, and cool. This aspect was appreciated by many households who found it amusing spending time acquiring competences to set up and use the smart home to suit their needs:

> "I did it all myself. That's the fun for me [laughing]" Adam (H18)

It was not only adults that saw this value of the smart home. For example, the teenage daughters in H7 said that *"my friends just love our house yeah. They're just like, cool!"* Other householders also saw smart home devices as toys that were fun to 'muck around' with. This playfulness and the added bonus of feeling cool was sometimes used as a justification to bring new devices into the home:

"I love it, it's totally cool! […] When the new Hue bridge comes around, I should be able to tell Siri what to do to it, […] it's like Star Trek in my living room! It's magic, and it's wondrous and fun." Rachel (H5)

This aspect of the hedonist demonstrates how play and coolness invite new smart 'desirable things' into the home

DISCUSSION

Our study has demonstrated how householders' desires for the smart home shape expectations, everyday practices and associated energy consumption. However, we do note a potential limitation to this study. While we discuss the potential energy impacts of these findings in this paper, we did not collect any energy data from participating households, and therefore we rely on self-reporting and publicly available information on the efficiency and energy consumption of smart home devices. Nonetheless, our analysis shows that households' desires for smart home devices take different forms that sometimes overlap, and both complement and contradict each other. More importantly, our findings reveal that desires shape how the smart home is appropriated in ways that also can undermine the desire to save energy. The key energy implications of the three desired personas is summarised in Table 2.

We now discuss the implications of these findings for HCI researchers and practitioners.

The helper	• New 'helpful' energy consuming devices • Devices ON 24 hours a day (standby power and remote energy consumption) • New energy demands like increased cooling and LED pollution
The optimiser	• Supports assisted living upholding desirable outcomes of comfort and convenience • Entrance of devices into home justified through energy efficiency benefits • Energy feedback focuses attention on small actions (e.g. turning lights off)
The hedonist	• Energy consumption is extended in time and place to create a nourishing effect • Energy consuming devices incorporated into entire property to create unique and beautiful living spaces • New devices enter the home because they are fun and cool

Table 2: Key energy implications of the smart home personas.

Taking a holistic approach to desirable designs

A long tradition within HCI is to focus design efforts on understanding users and evaluating users' needs through design processes like user-centered design [48]. However, when design is driven by assessing users' needs and what is technical achievable (technology-driven design [33]), designers also frame designs as problems that need solving. While such efforts can be fruitful for understanding and evaluating use and driving technical inventions, they do not capture a holistic view of what makes a design a 'desirable thing' and how use and experiences are shaped through desires [26,42].

As we discussed earlier in this paper, this problem-solving approach to design also appears to dominate sustainable HCI efforts, which falls into two broad categories. The first encompasses interactive designs that engage people to reflect on their energy-consuming practices through design techniques like eco-feedback [14,21,34]. The second involves designing smart energy technologies that aim to make the transition towards more sustainable energy use as effortless and convenient as possible [29,56,71]. While these efforts show the potential for raising awareness and saving energy consumption, their long term implications on consumption is limited [12,62].

This is interesting because managing energy consumption, and saving energy has been recently identified as the main desired benefit of smart home technology by prospective smart home users [69] – a desire also identified in our analysis of householders' desires for the smart home. So why is it that this desire to use energy sustainably does not shape appropriation of these technologies alone? A possible answer can be found in the typology presented in this paper. The three smart home personas show how different desires shape how designs are adapted and incorporated into everyday practices and ratchet up expectations. Therefore, we believe an important call for HCI designers is to analyse, design, and critique our designs more holistically, through concepts such as desiderata, before making energy saving claims.

When visions and desires do not align

One step towards such efforts could be to consider aligning conflicting desires within the smart home and the visions designers embed into these technologies. As this and other recent studies [23] show, possible sustainable benefits within the smart home are undermined by other desires householders have of the smart home. Designers within the smart home technology industry seem partly to blame for this misalignment [63] as they tend to inscribe visions into the design of these technologies that are similar to the typology presented here, without much consideration of possible energy implications [64,65]. Inscribing visions into designs may have influenced this misalignment in the participating households' desires for using the smart home. However, they do not determine how people shape the use of such designs and incorporate them into everyday life as this is a more complicated and messy process [58]. Going back to our findings we see this complicated process played out in the smart homes of our participants. What the three smart home personas show is that use and experiences are shaped by householders' different desires that may play off against each other, either by justifying or undermining each other. So, where does the HCI researcher's role lie in re-aligning desirability and sustainability?

Designing the desirable smart home as low consuming

A possible approach for HCI researchers is to explore different ends towards desiderata. Inspirations in this direction could explore different desirable expectations of what meaningful low energy-consuming experiences are within the smart home.

One research opportunity could be to challenge the enhanced expectations of comfort, convenience, and cleanliness that also lies embedded in the visions of the smart home [64], and also evident in our findings. Inspirations towards this end could be to speculate [9] or provoke households [50] though design to consider if these expectations are also meaningful and aligned with desires of sustainable energy consumption. A few HCI studies have already looked for possible ways to challenge expectations of comfort through smart technology. Clear et al. study of drifting [13] points to different opportunities to design smart thermostat by exploring alternative means embedded in heating practices to pursue comfort, while Pink et al.'s [47] design intervention 'Acclimatiser' automatically lowers the temperature by one degree over an extended period in effort to establish a new 'norm' of thermal comfort over time.

While these studies seem promising we also suggest that considerations are put into reimaging how to design pleasurable and aesthetic pleasing experiences within the smart home that promote lower energy consumption. As desires are reproduced through social practices [58], it is experiences, moods and meanings that shape how people use designs within the home, thus we see this as a promising way towards designing the sustainable smart home. Aspirations towards this end could be to explore an alternative take on the hedonist. While the hedonist embodies connotations of a pleasure-seeker where the pursuit for happiness, through consumption, is the most important thing in life, alternative hedonism, as suggested by Soper [61], recasts the hedonist as an anti-consumerist that challenges conceptions of aesthetically-pleasing life.

Hallnäs and Redström's concept of downtime or slow time [22] could open further opportunities to reimaging the hedonist in the design of the smart home as the 'desired thing'. The slow time concept aligns well with Pierce et al.'s [44] idea of 'slow energy' that encourage more thoughtful energy consumption embedded into everyday practices. Wessman and colleagues [32,67], for example, explores the concept of slow energy as 'peacetime' through design. Their design invites households to partake in 'inspiring alternative activities' without requiring any electricity. We see this as a promising end towards households' pursuit of creating less energy intensive, but still desirable, meaningful and pleasurable moments within the smart home.

CONCLUSION

In this paper, we have analysed the different desires embedded in smart home technologies as interpreted by 23 participating households. Drawing on Nelson and Stolterman's concept of desiderata we developed a typology of different desires for the smart home. We structured these as three smart home personas: the helper, optimiser and hedonist, which align with desiderata's three approaches to desire (reason, ethics and aesthetics).

What our findings show is that different desires embedded in the smart home also shape household expectations and practices to impact energy consumption in different ways. Most interestingly, these desires both compliment and contrast each other, highlighting an energy paradox in the desirable smart home. While smart home technologies afford households aesthetically pleasing experiences that reflect a modern lifestyle, they can also undermine the desire to live sustainability.

Based on these findings, we conclude that if designers of smart home technology seek to aspire towards sustainable change, we need to approach the desirable smart home more holistically through concepts like desiderata. Towards this agenda, we suggest that HCI practitioners and researchers engage with aspirations to both challenge and enhance desirable everyday experiences that also promote more sustainable energy.

ACKNOWLEDGMENTS

We thank all the participating households for opening their homes to us and sharing their experiences. This research was supported under the Australian Research Council's Discovery Early Career Researchers Award funding scheme (project number DE150100278) and Innovation Fund Denmark (DiCyPS project number 864703).

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ASSISTED SHIFTING OF ELECTRICITY USE: A LONG-TERM STUDY OF MANAGING RESIDENTIAL HEATING

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov

Abstract: Shifting is an energy-conserving interaction strategy for moving energy consumption to times where it is sustainably favorable. This interaction strategy is attracting increasing interest within sustainable HCI studies. While most of these consider how interactive technology can change household behavior, only few report on how shifting is experienced in everyday life when assisted by automation. In this study, we investigate an interactive technology that assists households to shift electricity consumption to times when electricity is cheap or more sustainable. Our study was conducted as a long-term field deployment for 6 to 18 months with eight households, each living with an interactive prototype that shifts running times for a heat pump within user-defined boundaries. Our findings show that managing heat pumps towards assisted shifting was well-received by all households because it was a convenient way to shift electricity consumption. Shifting electricity use facilitated price savings of 6.8% to 16.9%. Nevertheless, our findings also reveal a conflict between the system design, and how householders actually interact with their heating system and experience assisted shifting. Based on the eight households' experiences we present three overall themes of *convenience, control,* and *complexity* that each describes different aspects of long-term real-life use of automatic technology assisting households to shift electricity use. We discuss the broader implications of these findings and the role of design and future sustainability technology in everyday life.

Originally accepted as:

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov. 2018. Assisted Shifting of Electricity Use: A Long-Term Study of Managing Residential Heating. *ACM Transactions on Computer-Human Interaction* (TOCHI), 29 pages, ACM Press (Accepted April 2018).

INTRODUCTION

Sustainability has received much attention from the interaction design and HCI community in the past decade. Within this research work, studies have focused on raising awareness about energy consumption through eco-feedback [27,34,68] and eco-forecasts [33,57,63] in an effort to persuade people to change behavior. Although these studies show that feedback and forecasts can be informative ways to notify people about their energy consumption and the benefits of maintaining sustainable routines, they also demonstrate limitations in achieving desired change [11,23]. Within this research effort, there is little doubt that our knowledge base on sustainable HCI contributions is growing within the community [36]. However, to contribute more significantly to this body of knowledge, a suggested next step by Silberman et al. [62] is to: "build, support, and shape systems people use in their everyday practices and do studies that inform the design and operation of such systems" [62].

Today there are numerous large scale projects that build solutions to widespread sustainable problems [13], including shifting [26]. Shifting is an energy-conserving interaction strategy that involves moving energy use in time or place [51]. This need to shift consumption stems from an increased use of energy produced from renewable resources such as wind and solar power and changing demand profiles that generate fluctuations in the power grid. Smart grid technology is often portrayed as a supportive technological means to overcome these fluctuations. Electric domestic heating powered by heat pumps is anticipated to play a significant role in realizing smart grid scenarios because heat pumps are seen as high consuming, but an energy efficient appliance capable of integrating smartly with the power grid [41,46].

Although much effort has gone into developing smart grid technology, two areas of critique have inspired our work. Firstly, little attention has been placed on how people use and experience these technologies in residential and everyday life [31,52,68]. Secondly, only a few user studies [10,14,16] report on how shifting, and in particular assisted shifting, is experienced in a real-life setting long-term. Hence, as a community we need more insights into how households experience smart grid technology assisting them to shift consumption in real-life settings, so we are better equipped to shape the interaction design for these scenarios in the future [62].

The purpose of this study is to address these research gaps by investigating the long-term experience of assisted shifting in a real-life context by studying a prototyped smart grid technology, named HeatDial [30]. The work presented in this paper extends an earlier study [30] where we introduced the design of the HeatDial system and gathered initial feedback on the interface from a small group of users. In this paper, we provide a different perspective, where we look closely at how householders experience the short and long-term impacts of living and interacting with a smart grid technology assisting them with shifting heat pump electricity consumption. For this purpose, we systematically studied assisted shifting through the HeatDial system with eight households over periods of 6 to 18 months. The study is set in Denmark, where electric heat pumps and smart grid technology are viewed as important means in the transition towards an electricity production reliant solely on renewable resources [20,47]. The HeatDial system assists households to shift their electric heat pump consumption to times when electricity is cheap or renewable electricity is produced. To do so, households need to specify temperature boundaries, and the prototype will then automatically shift electric heat pump consumption in time, while maintaining the temperature of the home within these boundaries. Our study makes two overall contributions to HCI: 1) a long-term real-life study of the experiences of people living and interacting with a smart grid technology, and how this affects them and their households in the short- and long-term. 2) Empirically-based insights into the use and experiences of assisted shifting in heat pump electricity consumption expressed through three identified themes of *convenience, control,* and *complexity.* Additionally, we discuss our findings in relation to future design of smart interactive technology aiming to tackle sustainability challenges in everyday life. In particular, we illustrate the tension between calm and proactive technology for assisted shifting and electricity use.

RELATED WORK

Shifting domestic household electricity consumption is increasingly being investigated within the sustainable HCI research community. Shifting is part of what Pierce et al. [51] call a vocabulary of energy-conserving interactions. Within this vocabulary, shifting is seen as an interaction strategy for using energy at a different time or place, to overcome fluctuations in the power grid. Shifting is often used in relation to smart grid technologies and dynamic pricing schemes.

The smart grid is a broad term often used to describe visions for future electricity grids that are more intelligent, interactive, and capable of better balancing fluctuations in power usage. The transition into this future demands not only new technology but also upholds an expectation that households will become active participants in integrating this technology into everyday living [31]. The vision of aligning domestic living within a shifting strategy is often conceptualized through dynamic pricing schemes. Here, market mechanisms are expected to encourage household members to change behavior according to real-time electricity prices.

The impact of embedding smart grid technology and dynamic pricing schemes into domestic living has been studied in various HCI studies [7,8,10,17,57]. However, this perspective on shifting has also been critiqued, particular within social science studies [13,26,29,46,65]. These studies often argue that the design of smart grid technologies are better suited to fit Strengers' Resource Man — an archetype empowered by this technology who adjusts his behavior accordingly — rather than how everyday life is actual performed [66,67]. While this body of work shows that there is a potential for smart grid technology to make us more sustainable, it also highlights a need to broaden our understanding of the implications of embedding such technology into everyday life and the role of interaction design and HCI in facilitating this [31,52,62,68].

Sustainability Through Monitors and Managers

Home energy systems aiming to support householders to act sustainably can be divided into two main categories; monitors and automatic managers [18]. Monitors are systems that monitor consumption and through feedback inform households by raising awareness, but leaves the actual action to the householder, while automatic managers assist householders to control how energy consuming devices operate.

Systems that monitor and provide feedback are often adopting some form of persuasive technology [27]. Persuasive technology has its root in behavioral psychology and assumes that given the right information, people will change their behaviors. Most studies pursuing the energy conserving-strategy of reduction have done so by visualizing past and present consumption to prompt behavioral change – also known as eco-feedback [27,34,35,58]. Similarly, recent research work has explored shifting through eco-forecasting, where predictions of consumption, cost, and grid demand are visualized on situated displays to indicate the 'right' time to use electricity [33,49,57,63]. The effectiveness of utilizing persuasive technology to advocate sustainable behavioral change has been studied within sustainable HCI research for over a decade [11,23]. This work has shown that, as a community, we still have much more to learn about how we can make use of technology and interaction design to influence householders to develop and maintain sustainable energy-conserving routines and practices [24,31,39,52,68].

Recently, sustainable HCI research has also studied automatic managers that prototype different smart grid scenarios aiming to shift domestic activities that consume electricity. An example is the activity of doing the laundry studied by Bourgeios et al. [8] and Constanza et al. [17]. In both these studies, the objective was to actively assist householders to shift the timing of laundry activities to align with renewable energy production. To assist in planning and executing laundry activities, both studies investigated the possibilities of automatic managers playing an active part in both informing and controlling when it was the right time to wash. Another example of prototyping a smart grid scenario is Alan et al.'s [2] field studies of two different prototypes that allow householders to choose different levels of automation that assist with shifting energy tariffs simulating a dynamic price market of electricity. While their results demonstrated a promising potential of householders being willing to adopt intelligent energy systems into their lives, their studies also highlighted a design challenge of balancing user and autonomous control.

Recently, assisted shifting has been studied with respect to charging electrical vehicles (EV's). Brush et al. [10] did an experiment where they measured the effectiveness of shifting EV charging to off-peak times while utilizing the EV's battery for household consuming activities during peak times. Similarly, Bourgeios et al. [7] explored shifting in relation to EV use and people's willingness to align car trips, charging times, and solar power production. In this study, it was found that planning household tasks to accommodate flexibility to allow for shifting daily routines is a complex endeavor that requires management and negotiation amongst different householders and between different domestic activities.

Informing and Assisting Householders to Conserve Heat

Designs for both informing and assisting householders and workplaces to conserve heat have also been studied within sustainable HCI. An example of informing users to conserve heat through design is Constanza et al.'s [16] three-week workplace study of regulating heating by giving feedback on temperatures rather than the actual energy consumption. Their results showed that information visualizations can get people engaged with existing heating patterns through reflection.

There has also been an increased interest to study different types of intelligent technology aiming to assist households to adapt indoor heating towards sustainable use of energy. An example is Fischer et al.'s [25] study of using intelligent technology to gather information about the indoor climate, which was proven useful for energy advisors. Preheat [59] and TherML [37] are other prototype examples of intelligent technology that without any direct user involvement can predict when people occupy their houses and then heat based on occupation patterns facilitating a reduction in energy consumption.

Similarly, The Nest is a commercial thermostat that aims to reduce consumption related to heating and cooling by deriving user preferences intelligently. Yang et al. [70–72] did an extensive user study of the Nest. They observed that while the Nest manager played an active role in assisting householders to adopt sustainable routines, conflicting user and system objectives dampened the effectiveness of maintaining these. In response, the same authors developed the ThermoCoach prototype [73], promoting eco-coaching (personalized recommendations, eco-forecasting, easy invocation, and user control) assisting users to continuously reconfigure the Nest to reduce consumption.

There are also a few HCI studies that have experimented with intelligent technology with the goal to challenge people's thermal comfort in order to shift consumption. One example is Clear et al.'s [14] study of 'drifting' thermal comfort zones facilitated by assistive technology. In this study, the authors report on positive results on letting intelligent technology assist in motivating and engaging users towards sustainable heating habits, but they also discovered design challenges in how to reshape existing norms and expectations of indoor heating. Another example is to operate heating devices after cost explored by Alan et al. [1]. In their study, they examine how users perceive trading comfort for a price, as they correlate each temperature with a cost. In SmartThermo [1] users can actively decide what temperature they prefer based on these dynamic prices or let the system derive preferred settings through machine learning. Although they reported limitations on how users perceive the different models, they also discovered that by deploying prototyped smart grid technologies into a real-life setting, they were able to provide valuable insights into how people adopt, perceive, and experience future scenarios and technology. Pink et al. [53] suggest a more practice-oriented lens to approach sustainable interaction design that challenges domestic heating practices. In this study, the authors demonstrate how sensory ethnography can be utilized as an analytic framework to understand how material and social elements of people and environments can inform a sustainable interaction design.

FIELD STUDY

The contribution of this paper is a field study done with eight households that used the HeatDial system to control residential heat pumps to warm the inside of their homes. Our aim was to study assisted shifting in an everyday residential setting over an extended period to broaden our understanding of how householders respond to using an interactive system that shifts electricity consumption on their behalf. The study was conducted as a long-term field deployment where half the households participated for 18 months, while the other half participated for six months after being added to the study after 12 months (see fig. 2). In the following, we present background information on electric heating in Denmark, the design rationale of the HeatDial system, a description of the eight participating households, and a description of the study design.

Electric Heating in Denmark

A heat pump is a device that utilizes heat variations and electricity to transfer heat to either cool or heat a place. In Denmark, most domestic heat pumps are used for heating the indoors by transferring heat from the external air or ground to an internal sink of heated water. The heated water is typically circulated through a bigger heating system where the water runs through the floor and radiators, effectively heating the house or used as utility water for showering etc. It is common to expect four weather seasons in Denmark with frosty winters and moderate summers. This means that most heat pumps will heat the house during autumn, winter, and spring, while only being used to produce utility water in the warmer summer months. A heat pump regulates the temperature through technology that is already semi-automated. The most common scenario is that the technology will aim to keep the same temperature specified by the household. Most Danish heat pumps homes are found in rural and outbound city areas as these property owners must acquire and manage their own heating system. Buying a heat pump in Denmark is a relatively high-cost investment, often done in relation to larger energy-efficient renovations. Consequently, most Danish heat pump homes are also well-insulated, which can result in long response times when households regulate the temperature.

Together this means that heat pump homes will consume large amounts of electricity as their heating is produced by using electricity. Thus, choosing a heat pump for heating in a Scandinavian climate may appear unsustainable as households will significantly increase their overall electricity consumption. Nonetheless, electric heating and heat pumps play a significant role in future Danish smart grid visions and the transition towards a greener energy production [20,47]. The reason for this is three-fold. Firstly, electric heating is an attractive form of heating if the electricity is drawn from renewable resources like wind and sun. Secondly, as Danes have become accustomed to a stable power grid, the heat pump is an attractive device to exploit in a smart grid scenario that aims to balance fluctuations [47], because the heat pump's controllable features make it possible to align the running time of heat pumps to when environmental friendly wind or sun power is produced [44]. Thirdly, in 2012, the Danish parliament approved an ambitious green transition plan promising to deliver 50% of the nation's electricity from wind power by 2020 [20]. The Danish government also backs the transition towards electric heating financially, by subsidizing some of the cost of every consumed kWh that is above a yearly threshold of 4000 kWh in homes that are electrically heated. Based on these reasons in Denmark residential electric heat pumps are seen as a green alternative to fossil fuel-based systems like oil furnaces or wood pellet boilers.

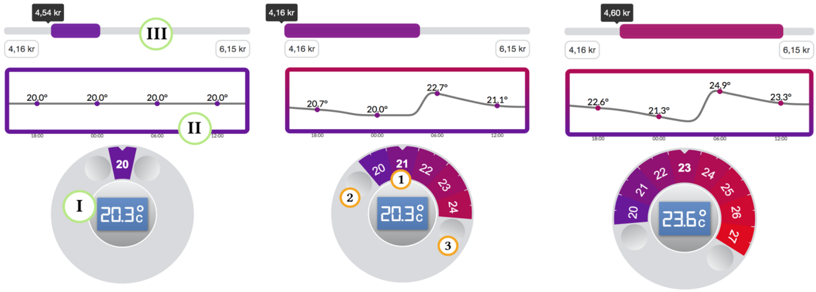
The HeatDial System

While our prior work [30] introduced the initial design of the HeatDial system and the underlying technical platform, we will in the following present and add more specific details to our design rationales behind HeatDial. Inspired by Yang et al. [72], our objective with the HeatDial system was to create a "mix-initiative system that primarily allows users to pursue their own individual and immediate goal of comfort within certain system-defined bounds" [72]. However, unlike the Nest Thermostat [71] that intends to reduce energy usage, the aim of the HeatDial system is to assist households to move or shift energy usage to times where it is sustainably favorable. This is a different challenge to get householders engaged in, because shifting requires different behavioral patterns than those related to reduction [50].

To address this design challenge, HeatDial is a two-part system: an interactive web application that runs on any type of mobile device, and an automatic manager controlling the running time of a heat pump. The automatic manager is distributed between an in-house control system and a centralized heat pump server that calculates optimized running times for the individual houses. A local smart grid technology company (here referred to as NG) had the responsibility of developing and maintaining the automatic manager for this study. For further details about the technical architecture of the system, please refer to [30].

User Specified Boundaries and The Automatic Manager.

In the interactive HeatDial interface, users can specify three temperature settings (fig. 1B). The first temperature is a preferred temperature (21°). This setting works as a user-specified ideal temperature for the home. The second temperature (20°) is a lower boundary temperature, and the third temperature (24°) is an upper boundary temperature. The two latter temperatures define a tolerance range (4°), basically specifying their boundaries of comfort, which the users allow the system to operate within. The idea of operating heating boundaries of comfort is often envisioned as one



(1A) (1B) (1C)

Fig 1: HeatDial with three different settings. In 1A the preferred temperature is set to 20° and no tolerance range with a price at 4.54 DKr. In 1B the price has been reduced to 4.16 DKr. due to a larger tolerance range, while the indoor temperature is expected to fluctuate more. In 1C the preferred temperature is raised resulting in an increased price of 4.60 DKr .

way to engage Danish households in shifting and smart grid scenarios [20]. The automatic manager schedules the heat pump to run when the price is lowest on the 24-hour Danish electricity spot market. A low price on the Danish spot market is often an indication that there is a surplus of wind power production. However, as only 15% of the total electricity bill is made up from actual usage (the rest of the cost goes to duty, tax, and subscription [19]), electricity bills in Denmark are rather stable, and only vary slightly as a consequence of electricity market price fluctuations.

Unlike SmartThermo [1] and the Nest [71] that use machine learning to derive individual users' preferences, the HeatDial system uses different information sources to learn more about the individual houses including its householders' temperature preferences. This information includes the three user-specified temperature settings, the 24-hour spot price, different sensor information available from the houses, a thermal model of each house, and a local weather forecast.

The HeatDial system uses this information to regulate the temperature after a shifting strategy that aims to keep the inside temperature as close to the preferred temperature as possible. However, the system will allow the temperature to either drop or rise if a lower price is available within the next 24 hours. The system does so by continuously scheduling running times for the heat pump by using all this information. The three user-specified temperature settings influence this schedule as follows:

If the tolerance range is changed, the automatic manager will try and shift electricity consumption to different times, but only if the price is low and it can keep the temperature within the tolerance range. Hence, if a user chooses a larger tolerance range, the automatic manager will be more likely to find times to run the heat pump at a lower price. In this case, the heat pump will use the same amount of electricity, but the times the heat pump runs will be shifted. This shift may result in temperature fluctuations. Nonetheless, the manager will only alter the heat pump's running times, if it can find a price that is low, and temperature fluctuations stays within the tolerance range.

If the preferred temperature is changed, so is the amount of consumed electricity. In this case, the automatic manager schedules a plan that either reduces or increases the consumption. This occurs because the automatic manager will always keep the temperature as close to the preferred temperature as possible. Hence, if a user chooses to increase the temperature, the heat pump will run more often resulting in an increased use of electricity and vice versa.

Informing Users of the Benefits and Consequences

The HeatDial interface also provides two types of eco-forecasted information elements, informing users of the consequences or benefits of choosing different temperature combinations. The first element (1A-III) shows a cost price for running the heat pump for the next 24 hours with the current settings. The second element (1A-II) is a visualization of expected temperature fluctuations for a 24-hour period. The latter element was added twelve months into our study. Our preliminary study [30] suggested that although an automatic manager can assist in hiding the complexity of shifting from a user, it is equally important to give some kind of feedback on how the system plans to behave. This insight led to the design of the second eco-forecasted information element that visualizes the expected influence the automatic manager has on the indoor temperature. The HeatDial interface also displays the current temperature (1A-I), so the user has a reference point when exploring different settings.

In addition to the HeatDial prototype, the participating households also had access to the website 'control-your-heat-pump', which provides historic and current information about heat pump performance, in-house measurements such as indoor and outdoor temperatures and electricity consumption data, and the amount of heat the heat pump produces.

Participants

We recruited eight households from Denmark. The eight households were recruited through a user database from a related project on smart grid technologies, where the heat pump had been controlled for other purposes. The requirements for participating in the study were: (1) the households had to use an electric heat pump as the main source for heating the house; (2) the heat pump had to be controllable by NG, the local company specializing in smart grid technologies; (3) they had to have a device with an internet browser for accessing the HeatDial app; and (4) they had to be willing to use the HeatDial app for regulating the temperature of their home.

The recruited households all owned their house, and all lived in rural areas. This meant they were not connected to the city central heating system and therefore responsible for their own heating needs. In order to use a more 'eco-friendly' source of electricity, they had all purchased their heat pump five to six years ago as an investment upgrade to their heating system. Prior to this, they relied on different fossil fuel devices to power the heating system. Most houses were also well insulated. The householders had used the first years with the heat pump to adjust technical settings – although the approach differed depending on how skilled they were in this domain. All the householders were well aware of the amount of electricity they consumed per year. This awareness became an intuitive concern because upgrading the heating system to a heat pump resulted in an increase in the overall household electricity consumption.

To keep an eye on the electricity consumption of the heat pump, they would use both quarterly utility bills and past data from the 'control-your-heat-pump' website. All the houses were equipped with floor heating, mostly just in one room, while radiators would warm the rest of the rooms. Six out of the eight households also used a wood burner as a secondary resource for warming the house, while four households were also equipped with solar panels. We classified five out of eight households as having a high awareness of the technical aspects of heat pumps, while two households were classified as being above average in terms of their environmental motivation. See table 1 for a summary of each of the households.

	# Children, # Adults	Age of Adults (F/M)	Occupation (F/M)	Location of floor heating	Wood burner	Solar panel	Awareness of heat pump behavior	Environmental motivation	#Winter seasons, #Months
Household A	(2,0)	(70, 69)	Both retired	Living room	Yes, regularly	No	Limited	Normal	18 (2)
Household B	(2,4)	(35, 34)	Project leader Mechanical engineer	Downstairs and upstairs bathroom	Yes, occasionally	Yes	High	Normal	18 (2)
Household C	(2,0)	(74, 69)	Both retired	Living rooms	Yes, occasionally	No	High	Normal	18 (2)
Household D	(2,3)	(47, 42)	Correspondent Bank specialist	Living rooms	No	No	Normal	High	18 (2)
Household E	(2,2)	(54, 53)	Health consultant Social educator	Basement	Yes, rarely	No	Limited	High	6 (1)
Household F	(2,0)	(68, 78)	Both retired	Living room	Yes, occasionally	Yes	High	Normal	6 (1)
Household G	(2,0)	(58, 62)	Nursing Project manager	Bathroom	No	Yes	High	Normal	6 (1)
Household H	(2,0)	(53, 57)	Nurse Sales director	Living room	Yes, occasionally	Yes	High	Normal	6 (1)

Table 1: Summary of details describing the individual participating households

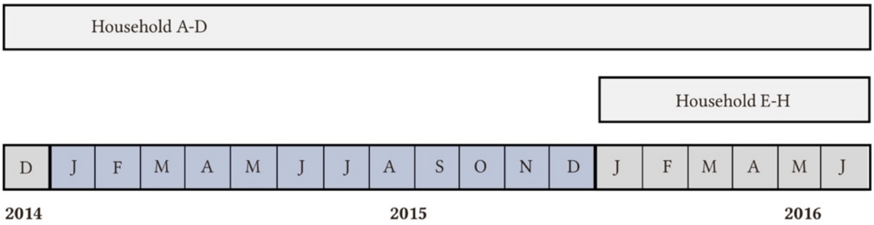


Fig 2: Household participation in the HeatDial study.

Study Design and Data Collection

As our study aim was to investigate assisted shifting over a prolonged period of time, we conducted 20 interviews over 18 months. Households A-D took part in the study for 18 months including two winter seasons, while households E-H participated over six months including one winter season. A timeline of household participation in the study can be seen in fig. 2.

Methods

We started the study with an in-home semi-structured interview with household A-D lasting between 45 and 115 mins. This introductory interview was conducted to gain insight into each household's heating practices prior to the study, as well as giving us an opportunity to introduce the HeatDial system and explain the focus of the study. In the introductory interview, we mainly asked questions regarding the household's current heating practices, how they interacted with and understood their heating system, and their awareness towards environmental issues such as shifting. During the introduction to HeatDial, we explained the different elements of the system and allowed the participants to experiment with the interface, while we were present. This was also an opportunity for participants to ask questions about the system and the study. We explained the purpose of shifting and using electricity at times when it was favorable, and we clarified how shifting was facilitated in the HeatDial system.

During this first in-home interview, we also conducted a conversational technology tour [6]. On this tour, the participants guided the researchers through the setup of their home heating system, the heat pump, and how they currently interacted with the system. There were two reasons for conducting this tour. Firstly, we as researchers gained insight into how individual householders would interact with and perceive this complex heating setup. Secondly, it gave the householders an opportunity to explore and divulge their implicit routines and perceptions regarding their interaction with the system. During the tour, the researchers took notes and photographs of the technology (see fig. 3 and 4). We conducted a second interview with Household A-D after six months, focusing mostly on how the participants experienced the interaction with the elements in the HeatDial interface. Some of this is reported in [30].

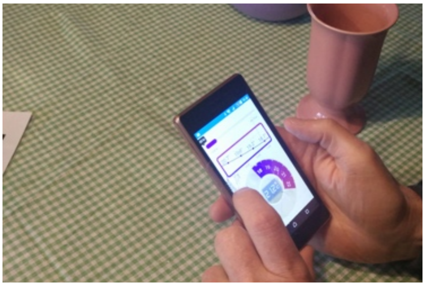


Fig 3: One of the participants using HeatDial on a mobile at the dining table.

Fig 4: An air to water heat pump at one of the participating households.

After twelve months of successful deployment, we decided to recruit an additional four households (Household E to H) in order to gain supplementary perspectives on the use of the HeatDial system. We conducted the same introductory interview with these four households. For practical reasons, mainly due to extensive travel times to people's homes, these interviews were conducted by phone rather than in person. As we had already established a good understanding of household heating practices, these interviews turned out to be very similar to the in-person ones. The interviews lasted between 30-60 minutes. In the same period, households A-D were introduced to the new interface elements of HeatDial.

During the entire study, we logged interactions with the HeatDial system. In the last two months, we also sent out text messages to each household, asking them questions about who and how they used the HeatDial interface, and with information reminding them about shifting features in the system. These logs and answers from the text messages guided the final round of interviews [40].

The last semi-structured interview was conducted during summer 2016. Interviews with Household A-E were conducted in-house, while interviews with Household F-H were conducted by phone. These interviews lasted between 60-110 minutes. As the key interest in this study was to observe households' understandings and perceptions of automatic shifting, we focused these interviews on how the households experienced shifting through the control of the HeatDial system.

In addition to the interviews, we also gathered quantitative data from NG (the company responsible for maintaining the automatic manager) on how the households' heat pumps operated over the duration of the study. This included temperature readings from the house, heat pump power consumption, obtainable price savings, and settings of the three temperatures in HeatDial.

Data Analysis

All the 20 interviews were audio recorded and a total of 21 hours of audio was transcribed using interviewScribe. The transcriptions were subsequently analyzed inspired by content analysis [42]. This was accomplished in four steps. First, we read the transcribed interviews to become more familiar with the data. Second, we identified suggestions for codes inspired by the terms in the literature (e.g. 'comfort', 'feedback', 'assisting'), or through in-vivo codes [42] provided by the participants (e.g. 'roles', 'steering', 'convenience'). Thirdly, we added specific codes to the transcribed interview quotes (e.g. the code for 'feedback' to the quote *"I think about the price because I see a number and it will have an impact on whether the number increases or decreases?").* Lastly, extracted quotes were affinity diagrammed [5] in a repetitive process that led to a set of themes. In the following, we describe three overall themes that illustrate different aspects of assisted shifting experienced long and short-term in a real-life context, namely; (i) assisted shifting as convenience, (ii) staying in control, and (iii) complexity of heating in real-life.

FINDINGS

Our findings stem from all 20 interviews with the households, interaction logs, operation data from the heat pumps, and measured indoor temperatures. While regulating the indoor temperature is not something that is done on a regular basis in Denmark, we still logged a total of 940 interactions with HeatDial. Unsurprisingly, most of these interactions happened during the heating season, most predominantly in the winter months, while hardly any interactions occurred during the summer months where the heat pumps mostly produce hot utility water. Households C, E, and F had ~150 interactions (Household B had close to 400), with Household E and F participating for the shorter period of the study. Household A ran into technical problems for a couple of months in the second season, but we managed to log ~30 interactions altogether from this household. Household D, G, and H had the lowest number of interactions with ~20 to 40 interactions each. For the households participating for 18 months, Household D had the lowest number of interactions. There were approximately 10 of these interactions per season. From the interaction logs, we also see that half the participants mostly used the HeatDial interface just after getting introduced to the system. A finding in accordance with Yang et al.'s [72] study of the long-term usage of the Nest Thermostat. But more interestingly, the other half kept engaging with the system over longer periods.

In the following sections, we first present findings on how well the system worked in terms of shifting electricity consumption and affecting the comfort of the participants. We then present our three overall themes summarized as convenience, control, and complexity that each illustrates different aspects of how our households perceived and experienced shifting assisted by using the HeatDial system.

Shifting Electricity Use and Affecting Comfort

Based on the data collected on heat pump operation, it was clear that the participants during the study specified temperature tolerance ranges wide enough to make shifting possible. Hence the HeatDial system was able to shift electricity use to cheaper times for the benefit of all participating households throughout the study. On average, the participants specified tolerance ranges between 1.7° and 6.4° and achieved price savings of 6.8% to 16.9% (table 2).

Household	A	B	C	D	E	F	G	H
Average tolerance range (°C)	5.9°	2.1°	1.7°	3.0°	4.4°	4.2°	6.4°	1.8°
Average preferred temp. (°C)	20.2°	20.4°	19.5°	19.9°	18.6°	19.4°	21.3°	20.9°
Average electricity saving	8.54%	8.25%	10.12%	16.91%	6.24%	9.54%	6.85%	8.50%

Table 2: Average tolerance settings, preferred temperature, and energy savings obtained.

One of the notable things from these numbers, however, is that there is not a direct correlation between preferred temperature, tolerance range, and the obtained electricity saving, when compared across households. While one might expect that the highest tolerance range would automatically result in the highest possible saving, reality in the actual households is not as simple as that. The reason for this is that the households are very different, and the obtainable savings from a particular preferred temperature and tolerance range in one household can therefore not be compared directly with another. While for all households, allowing a tolerance range was what enabled the system to obtain savings from shifting electricity use, other factors of each individual household influenced how big this saving ended up being. These were factors such as the level of house insulation, type of heating system (floor heating, radiators), electricity market trends, local weather, and even household routines, such as showering in the morning (affecting the heating of utility water while electricity is usually expensive). These factors all influence the performance of the individual heat pumps differently, so while it is clear that some saving is achieved in all households, the exact saving differs too.

To illustrate how the HeatDial system obtains price savings in an individual household, fig. 5 shows the heat pump data collected from Household E on a single day in April 2016. On this day the tolerance range was set to 18-23° and, the preferred temperature to 19°. From the obtainable price saving data (fig. 5 top), we see that most money can be saved around 5 o'clock in the morning, after which there is a drop (A). At the same time there is a measured drop in temperature in the house, nearing the 18° lower boundary (orange line on fig. 5 bottom).

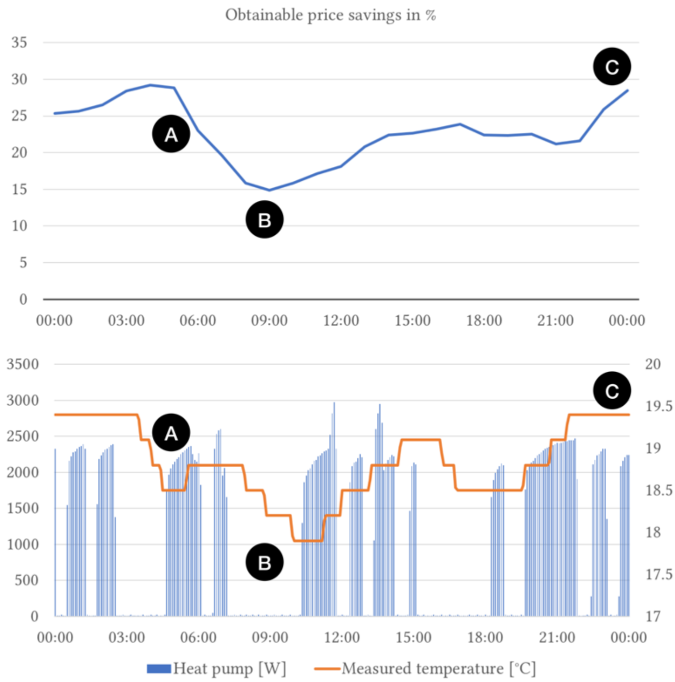


Fig 5: Data collected from Household E over 24 hours on 18 April 2016. The top graph shows the obtainable price savings. The bottom graph shows the measured indoor temperature (orange line), and the electricity consumed by the heat pump (vertical blue bars).

The HeatDial system therefore schedules the heat pump to run at this time, and for a couple of hours (blue vertical bars on fig. 5 bottom). The HeatDial system then schedules the heat pump to go on standby for 3 hours between 7:00 and 10:00 while the price saving is low (B). During this time, the measured temperature in the house again drops close to the 18° lower boundary, triggering the heat pump to run again around 10:00 when the obtainable price saving has increased. As the obtainable price saving peaks upwards after 22:00 (C), the HeatDial system heats the house above the preferred temperature of 19° in order to make use of residual heat in the house the next morning, when the price goes up again.

From the data collected on heat pump operation and measured temperatures in the households, we also get an overview of how the HeatDial system affected the comfort of the participants in terms of indoor temperature fluctuations (see table 3).

Household	A	B	C	D	E	F	G	H
Average tolerance range (°C)	5.9°	2.1°	1.7°	3.0°	4.4°	4.2°	6.4°	1.8°
Average fluctuations (°C)	1.63°	1.99°	1.48°	1.27°	2.73°	1.4°	2.22°	0.78°
Average fluctuations	8.11%	9.46%	7.68%	6.13%	13.79%	7.16%	10.54%	3.72%

Table 3: Average tolerance settings, and fluctuations in measured indoor temperature.

The first observation from this is that no household, at any time, specified a tolerance range of zero (essentially using HeatDial as a standard thermostat). Rather, they allowed tolerances of as much as 6.4° on average over the duration of the study (household G), with 5 of the 8 households (A, D, E, F, G) on average allowing a tolerance of 3 or above. This shows that the fluctuations in temperature, resulting from the HeatDial system shifting electricity use, did not negatively affect participants' comfort to a degree where they wanted to disable this. While allowing tolerances of up to 6.4°, looking at the measured temperatures in the households, the actual fluctuations were very rarely that large. In fact, temperatures only fluctuated on average between 0.78° and 2.73° (between 3.78% and 13.79%) from the desired temperature specified, with a maximal fluctuation of 8.91° (Household B on 5 June 2016). This shows that even though the HeatDial system was able to obtain notable energy savings, by allowing temperature fluctuations, this did not influence comfort much negatively. This observation is also confirmed by our qualitative findings, and discussed further in relation to the themes of staying in control, and complexity of heating in real life.

As with the energy price savings, the measured temperature fluctuations were not only influenced by the tolerance ranges set in the HeatDial system, but also depended in the characteristics of each individual household. For instance, Household D and Household A recorded minimum fluctuations despite having allowed tolerance ranges of 3-6° on average. In these cases, both households made regular use of additional means of heating in some areas of the house, which of course had some effect on how the HeatDial system could operate. Household A made regular use of a wood burner, and Household D controlled radiators in the bedrooms with thermostats. Nevertheless, Household D was still able to obtain the highest energy saving of all (16.91%). The lowest fluctuations (0.78°) were experienced by Household H (fig. 6 top). In this case, participants had specified a rather small tolerance range (1.8°), and also sometimes made use of a wood burner to keep the temperature in the house at an almost constant comfortable temperature of 20-21°. The largest fluctuations were measured in Household E (fig. 6 bottom), where temperatures fluctuated up to 7.28°, with an average of 2.73°. In this case, the HeatDial system operated primarily through radiators rather than floor heating. This resulted in short response times when heating up the house, leading to larger fluctuations. Hence, as can also be seen from fig. 6, during some of the same months (e.g. February to April) Household H experienced small fluctuations and Household E larger ones, whereas during others (e.g. May to July) both households experienced very similar fluctuations. The latter was caused by generally warmer weather, affecting the indoor temperature as the HeatDial system does not provide cooling.

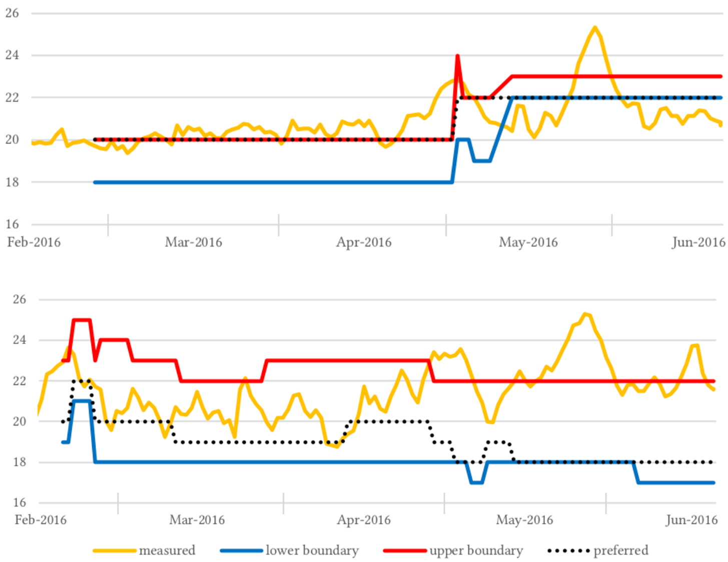


Fig 6: Fluctuations in measured temperatures for Household H (top) and Household E (bottom) in relation to tolerance and preferred temperature settings. The peak in June shows a period of warm weather, where the outside temperature sometimes exceeded the upper boundary set.

In the following we shift focus to how HeatDial was experienced and understood by the households, both short and long term, structured by the three themes of convenience, control, and complexity.

Assisted Shifting as Convenience

Our first theme relates to how the households experienced the automatic features of the HeatDial system that assisted them to shift electricity consumption as convenience. The shifting capability of the HeatDial system was a feature well received by all the households and our findings show that this positive reception mostly came down to an enhanced experience of convenience. There were three main reasons for this. First, all the householders thought that deciding the exact running times of the heat pump was a mundane task to engage in. Second, experiencing the system for a long time resulted in householders becoming confident that the system could automate shifting on their behalf while still making them feel in control of the indoor temperature. Third, by automating the decision-making on how to shift, householders did not need to frequently seek to take action for shifting to part of their heating practices. We present more details of these three aspects of assisted shifting as convenience in the following.

When Shifting is Mundane

Our findings show that all householders perceived heating as something that was already conveniently controlled by the semi-automatic heat pump device. Thus, unsurprisingly, all our households reported that having to find times to shift consumption was a task they would rather avoid having to do by themselves:

> Household F — "I'm very supportive of it – I like to have others running it because I cannot sit and watch prices of electricity. It is much better to let some others do it – this is not something I can keep an eye on all the time."

This feeling of convenience influenced the householders' willingness to allow the HeatDial system to assist with shifting. Other studies [12,33,57] have looked more carefully at the kinds of domestic activities householders are willing to shift. These studies suggest that activities become more shiftable when some of the tasks involved in the activity are already managed by semi-automated technology. An example is the activity of washing, where some tasks have been semi-automated by washing machines. We can verify this but also add to this understanding of shiftable activities. For example, Household D saw a benefit in automating shifting times for heating compared to other semi-automated household activities, like clothes and dishwashing, because heating was not something they engaged with on a daily basis:

> Household D — "I prefer automating the running times for the heat pump. I think it would be something else if it were the dishwasher or the washing machine we had to make run at sensible times. Like starting it at 10 instead of after dinner, because it's something you go and do and grab and handle every day. But heat is not like that - it should just take care of itself."

Most households had the same understanding of shiftable domestic activities. This suggests that people are more willing to be assisted with shifting through technology if they perceive the activity as something: a) that is mundane; b) where some tasks have already been semi or fully automated; or c) that they seldom engage in. This finding is interesting because it suggests that assistive technology can be experienced as a convenient way for households to shift energy-related activities — especially if these activities are considered too mundane to engage with on a daily basis.

Non-Intrusive System Behavior

Along the same lines, we also discovered that convenience was related to not feeling intruded on by the automatic shifting features of the HeatDial system. This aspect was generally related to householders becoming more confident over time that the system was able to conveniently control the indoor temperature. This confidence was more evident in households that were less aware of the technical aspects of how a heat pump normally operates. They started to feel more assured because the heat pump was now controlled by a system or people from the 'outside' that were more skilled to optimize when to run it:

> Household E — "Now someone is keeping an eye on it and observing if it is running as it should. And if it doesn't, then there is probably someone out there who is interested in making it run properly."

This confidence was strengthened by experiencing the non-intrusive behavior of the system for a long time. Although the participating householders allowed the indoor temperature to be controlled by the HeatDial system for 6 and 18 months, only a few had scattered memories of the system not behaving as they expected. The non-intrusive behavior of the HeatDial system meant that assisted shifting became an integrated part of heating the house, as explained by the wife in Household A where the HeatDial system operated for 18 months:

> Household A — "I now think of it as something that has never existed. It just runs."

Another aspect of the system's perceived non-intrusiveness was related to the way shifting was implemented in the HeatDial system. Unlike the Nest [72] or SmartThermo [1] that through machine learning will try and explore users' needs and constraints of comfort in an effort to reduce or shift consumption, the objective of the HeatDial system was to shift consumption by balancing the temperature within the user-specified tolerance range, using information about the individual houses. This meant that HeatDial's shifting strategy did not necessarily lead to big fluctuations in the indoor temperature, but mostly occurred as small fluctuations in line with the preferred temperature. Consequently, most householders rarely experienced significant variations in the temperature, because the HeatDial system managed to effectively use the information about the individual houses to regulate the temperature in line with the preferred temperature. Yet, not being able to experience these variations meant that some of the households got disengaged from interacting with HeatDial interface over time because they did not experience the effect of changing the temperature boundaries. This was explained by the husband in Household C who during the first six months was very enthusiastic about interacting with the HeatDial system, but after 18 months was less engaged:

> Household C — "When I turn these boundaries – can I then experience some difference? – And I must confess that I cannot […] But maybe the system has been able to utilize running the heat pump at different times but we still have the same good heat – so it is not something we have felt. Therefore, it is difficult to understand what happens when you set these boundaries."

Nonetheless, the non-intrusive behavior of the system was the main reason why all participating households kept using the HeatDial system to assist with shifting because it was similar to how a heat pump would normally regulate the temperature. Despite some households believing they did not experience fluctuations when changing the temperature boundaries, none turned off the HeatDial system during the six and 18 months they were living with the system. This indicates that experiencing the non-intrusive behavior over time only strengthened the association of convenience with assisted shifting. This is interesting because, although HeatDial controlled an element central to residential living, the non-intrusive behavior also meant that participants came to trust the system over time, allowing shifting to become part of their daily life.

No Need to Take Action

Our findings also suggest that the feeling of convenience was very much related to how the automatic features of the HeatDial system were designed to shift consumption, and how these features already fitted with established routines and expectations of heating. For a householder to take full advantage of assisted shifting in the HeatDial system require frequent exploration of different settings of the temperature boundaries. However, because the HeatDial system can operate without continuous interaction, householders were not required to change routines to keep the system operating. The HeatDial system would just keep taking care of shifting when settings had been chosen. These automatic features fitted well with already established routines of regulating the temperature in these households. When a household decided on a setting, they expected the system to steer after this without them having to keep monitoring the system. An example of this aspect of convenience was found in Household D. They explored a few different settings when first introduced to the HeatDial system and then quickly decided on boundaries for the tolerance range:

> Household D — "I regulated the settings in the beginning. But we do not like it to get colder than 19°. I think a had the upper boundary at 21° in the beginning and then I moved to 22° later so it could heat those times when the electricity is cheap or it makes sense for the system to run. We can just air out if it gets too hot."

This household did not see the need to regularly change these settings in the 18-month period they participated in the study. They explored a few settings throughout the 18 months, but they always ended up going back to this particular setting. This behavior fits with already established routines of how the households regulated the temperature in their homes, even those not considered very sustainable (overheating and then letting the heat out). Because these householders were not accustomed to changing the temperature on a regular basis, they did not feel the need to start considering this after the introduction of the HeatDial system. While some of this disengagement can be explained by not experiencing any change in the temperature, there is no doubt that the households thought it was convenient not having to concern themselves with shifting and specific running times, especially households with many children:

> Household B — "The more automatic the system is, the easier it is for us."

These findings challenge the mixed design intentions of the HeatDial system. Our findings suggest that the HeatDial's automatic features made it convenient for the householders to shift because the control of the automatic features of the HeatDial system fits well with already established expectations and routines of heating. This interplay between control and domestic routines is also highlighted by Davidoff et al.

[21] as an important aspect of households appropriation of automatic assistance. However, our findings also highlight a challenge of balancing the notion of convenience and people's willingness to engage with the system and set user boundaries that will allow the system to optimize the designers' intentions. But perhaps this perceived convenience should be seen as the real success of the system because it did not require householders to take frequent action nor high engagement for the system to continue operating under these user constraints. In light of this, one could imagine adding another level of intelligence to the system that does not require householders to frequently engage with specifying temperature boundaries, but only prompts householders when their engagement is needed.

Staying in Control

While the automatic nature of the HeatDial system was experienced as an enhanced convenience, our study also found that another aspect of assisted shifting was related to being able to stay in control of how the system operated. This is quite interesting because it adds contrast to the first theme. In the following sections, we explain different aspects of this in more detail.

Shifting as Three Temperatures

Although all households liked having a system that automated shifting for them, our findings also suggest that the households appeared to appreciate being able to define and control boundaries that the system was allowed to operate within. The main aspect of this was the ability to feel in control of the temperature in the house facilitated by the three temperature settings in the HeatDial interface. For example, the wife in Household B did not care about specific running times of the heat pump, but clearly wanted to feel in control of the temperature of the house:

> Wife Household B — "So, if you can somehow move some power to where it is more appropriate, then it is fine with us. As long as it does not destroy the comfort for us!"

This wish to stay in control of the comfort boundaries was evident in all the households. Some described choosing settings in the HeatDial system as a 'shifting contract' between the households and the system. The husband in Household F explained this: *"If you can keep the temperature within the interval that I have accepted, then it makes sense to let the automatic control decide when to supply me with electricity."*

While most householders did not change these boundaries very often, they still used the three temperatures to steer how the HeatDial system ran. This meant they also used the two temperature boundaries to specify a tolerance range. As all households on average specified a tolerance range above 1.7 degrees, the HeatDial system was able to shift consumption in all the households. Interestingly though, over time most ended up with a smaller tolerance range, despite not experiencing any unexpected or uncomfortable fluctuations in the indoor temperature. Household E-G, using the system for six months, had at the end of the study chosen tolerance ranges of 3-6°, while Households A-D, after 18 months, settled on ranges of 2-4°. Most of these households had a larger tolerance range in the first six months of the study but changed to a lower range. When questioned about this, some reported that the tolerance range was chosen randomly due to not being able to experience any consequences of changing settings:

> Household B — "Yes, maybe I could have had a bigger span – I'm in doubt why we ended up with having a span of 3. But we tried different things and did not notice a difference. Even though we allowed it to go down to 18 degrees, we never experienced that it has gone that far down."

Others chose a smaller range as a safety option because maintaining comfort was perceived as being crucial for residential living. This was apparent in some of the homes that did not have a secondary heating source. Household D, for example, disliked choosing a lower boundary far from the preferred temperature because the heat pump could be rather slow to warm if they started to feel uncomfortable. They were more flexible with the upper boundary because it was quicker to amend overheating the house by opening the windows and airing out. Thus, the householders described choosing a low temperature boundary as a risk they were not willing to take because they saw this as a threat to their comfort:

> Household D — "Yes, our [tolerance range] ended up being quite small – I think it would be different we had one more heat source. We have a slow reaction time because of the floor heating, so we had to reduce the range. Otherwise, we risk that someday the temperature will go all the way down."

Another aspect of controlling shifting was a confusion about which energy-conserving strategy [51] the three temperature settings facilitated. Our findings showed that despite an attempt to capture shifting as a tolerance range controllable by a household, this did not intuitively lead to an understanding of shifting:

> Household G — "If the gap is large, then I guess I use less power?... Or that is what I believe happens as I have observed the price will drop if I make the gap bigger. Is that not understood correctly?"

While the householders understood the concept of shifting, most had difficulties distinguishing between reduction and shifting when changing the boundaries of the tolerance range. Whereas it was intuitive that lowering the temperature leads to a decrease in price because they used less electricity, it was less intuitive that decreasing the lower temperature boundary would result in a reduction in price because of shifted electricity use. In fact, long-term use seemed to make householders ignore or forget that the boundaries led to shifting, whereas they did not forget that the HeatDial system was a tool that allowed them to control the comfort in the house. This finding illustrates the importance of communicating the sustainable intentions of the system, so long-term engagement and understanding can be sustained.

Foreseeing the Future

To overcome some of the difficulties of understanding and controlling shifting, we purposely designed the HeatDial interface to include information about the consequences and benefits of assisted shifting through eco-forecasts. Forecasts like these are discussed by Yang et al. [72] as a mean to *"suggest courses of action that align with system goals while allowing users to stay in control"* and are not currently explored in the Nest [72]. While eco-feedback and eco-forecasts show little promise of longitudinal behavior change unless people are already motivated [74], the forecasts for HeatDial were designed to provide transparency into the automatic nature of the HeatDial system. They were also designed to nudge householders to consider different temperature boundaries, by showing them possible cost savings.

Although our findings revealed that the visualizations of forecasted cost and temperature variations data did provide some awareness of the benefits and consequences of having the HeatDial system to assist with shifting, our findings also showed that the visualizations of price over time had little effect on nudging householders to make decisions about changing the tolerance range boundaries. This is interesting because while most householders in the first part of the study [30] stated that price was the most important incentive when having to negotiate comfort, it became clear that over time the price had lesser importance when these householders negotiated a larger tolerance range against comfort. An example was householder C who over the 18 months became less enthusiastic about the importance of the price:

> Household C — "I think about the price because I see a number and it will have an impact on whether the number increases or decreases – but will I consider it?"

The temperature forecast was designed after 12 months based on feedback from the four households participating for 18 months. This element was added to the HeatDial system to help households foresee the influence of household inputs on the HeatDial system's strategy to shift consumption, thus giving them more information to stay in control of the assisted shifting. However, our findings revealed that there was a sense of irrelevance associated with this forecast element and some described it as something you could not be sure would happen. This aspect was explained by the husband in Household A: *"It is a prognosis – and therefore not something you can really count on. A bit like the weather forecast – you can never count on that either"*. This meant that most householders were somewhat indifferent to the impact of having forecasted temperature variations in HeatDial. However, few did describe these as a help to foresee consequences of choosing different temperature boundaries, although the short-term forecasts did not fit with how often they regulated the temperatures:

> Household B — "The fear of choosing a lower boundary is waking up in the morning, and it is freezing. Now, in principle, we can foresee this, but it requires that we go in and check this every day."

For most householders, the provided information just confirmed that choosing different settings was a negotiation between comfort and money. Moreover, nothing in the data provided a clear incentive to consider negotiating comfort, and besides, for some householders, the price information was not enough to determine the 'best' setting:

> Household G — "I just don't know what the best setting is. So, I don't really know what to choose. The price is not enough because I would say it is already rather cheap."

These findings confirm similar findings found in other studies on eco-feedback systems, specifically that providing monetary incentives rarely leads to a behavioral change that is maintained [46,64,68]. This underpins the challenge of engaging people with sustainability issues, but also shows that some information can be used to provide transparency of an automated system operating in a complex environment like people's homes.

New Routines

While the forecasting elements did not encourage householders to engage in shifting on a daily basis, our findings, surprisingly, showed that half the householders kept using the HeatDial interface regularly during the six to 18 months of our study. However, we discovered that they were often using the interface for other purposes than regulating the temperature. Prior to getting a heat pump, our households owned heating systems that required dirty and physical labor, such as chopping wood, filling coal and oil into burners. Getting a heat pump and being introduced to the HeatDial system instigated new routines that became more about overseeing the automatic work performed by the HeatDial system:

> Wife Household E — "Well – one could say that you now use your time sitting and checking [HeatDial], but it is not the same hard physical work that we used to have."

> Husband Household E — "I look at it a lot because it has become one of those rituals where you turn on your computer and just take a little peek on the various sites. But it's also a way to keep an eye on whether it really works out there."

This need to oversee the work of the system also established new routines related to interpreting numbers. Only Household D rarely looked at any information because the cost of running the heat pump was: *"clearly stated on the utility bill"* and *"the novelty wore off quite quickly"*. The rest of the householders routinely checked different sources for information in an effort to make their own interpretations on how efficient the HeatDial system ran the heat pump. Half of them also started to collect their own information in monthly and even daily logs (see fig. 7), from different sources including the HeatDial interface, the heat pump itself (see fig. 8), and the 'control-your-heat-pump' website.

This finding is interesting because it tells two stories. First, although the householders perceived assisted shifting as a convenience because they did not have to engage in finding running times for the heat pump, half of them did not see any inconvenience in spending time locating, collecting, and interpreting these numbers. Second, engaging in these numbers seemingly gave these householders a sense of empowerment over the system as explained by Householder C: *"I use these numbers, so I know how much it controls and how hard it controls the heat pump."* Nonetheless, this also meant that in most households, only one person was in charge of choosing settings for the HeatDial system because the control became a matter of who had the interest or competence to understand and interpret these numbers:

> Household D — "I haven't used the system. I don't get turned on by numbers in that way. So, I just let him control it. It will also turn messy if we both start to change settings. That just doesn't work."

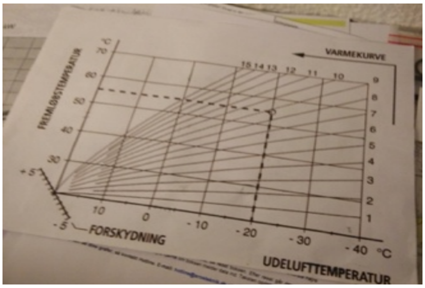


Fig 7: Daily logs of heat pump performance made by one of participating households.

Fig 8: A householder viewing electricity consumption on the heat pump interface.

This is interesting because having to find the 'best' settings clearly left some household members empowered, while others became disengaged. However, our findings suggest that just because one person was in charge of interacting with the HeatDial system, this does not necessarily mean that only one person decides the indoor temperature. In our study, other household members would inform the 'technology responsible' person when they felt uncomfortable, thus 'passively' informing the settings of the system. Categorizing households roles in 'home technology responsible' and 'passive user' when intelligent and automated control moves into the home, correspond well with earlier findings by Mennicken and Huang [43]. Thus, these findings emphasize a need to carefully design interactions for intelligent and automated home technology, so that it becomes accessible and engaging for all members of the household — especially when the entire household is affected by it.

Fooling the System

The last aspect of staying in control is related to how some householders started to 'trick' the HeatDial system to behave in certain ways that could not normally be controlled through the system.

Most of these examples were concerned with how to ensure that there was enough hot utility water for showering. For example, Household B learned over time that the HeatDial system sometimes ran at times that did not guarantee enough hot water on Sunday mornings when they usually bathed their four small children. The husband discovered that if he turned the preferred temperature up high a couple of hours before the planned bath, the heat pump would continue to produce enough water to bath all four children in the household. After a while, the wife found a 'turn off' feature in the HeatDial interface, so she started to deactivate the system on Sunday mornings and activated it again when all the children had their baths. Household D with three teenagers also had a water problem when all family members occasionally had to shower close in time. They tried to overcome this problem by being careful not to use any hot water in the kitchen beforehand.

The husband in Household E experimented with ways to trick the HeatDial system into thinking it was colder than it actually was, to make the heat pump warm the house faster. He did this by placing one of the setup sensors in a cold place, and even experimented with this in different cold places around the house:

> Household E — "If it is really cold in the living room, I sometimes put the [sensor] in the fridge for a while. Or in the hallway, where it is only 16 degrees."

This suggests that although most of these householders with time became conscious of the limitations of the HeatDial system, some of these householders also started, over time, to find creative ways to make the system operate to suit their needs, not always intended by the designers. These findings show there is a need to provide better ways for a household to temporarily influence the behavior of the system, especially when system shortcomings have been experienced over time.

Complexity of Heating in Real-life.

Extending the above findings, our study also showed that many aspects of the householders' experiences with assisted shifting were more than just how the system operated and how they interacted with it. To capture a more holistic view of experiencing the HeatDial system in residential living, we also report on our participating households' interpretations of comfort, conventions, and the materiality of the individual houses that captures the complexity of shifting heating consumption in a real-life setting.

Comfort

While the households were willing to let an automatic manager shift heat pump consumption to favorable times, comfort was clearly a big concern for all the households. Although the HeatDial interface allowed households to control their boundaries of comfort through the tolerance range, our findings also illustrate that how we label our experiences with an indoor climate, such as 'comfort', is quite complex:

> Household F — "If it is 20 degrees in the living room and perhaps freezing and windy outside, then you might feel quite cold anyway. And this not immediately because of the temperature degree – it is also a feeling – or comfort you can call it."

This suggests that comfort is not an experience only related to a specific temperature. When people try to label this experience, Shove [60] argues that labeling comfort is an individual interpretation of one's body and the immediate physical environment. These types of interpretations were also evident when the householders interacted with HeatDial and experienced specific temperatures as explained by the husband of Household G, *"the temperature has to suit my day to day life, my daily routines, and what I'm currently doing."* These interpretations would also differ between members of the household, leading to discussions about a comfortable indoor climate as explained by the husband of Household E: *"[the wife] is warm-blooded and I'm cold-blooded, so we have some discussions about what a comfortable temperature is"*.

Another aspect of comfort was related to context. We found several contextual factors impacting how the householders experienced the comfort of indoor temperature. One of these was the current weather conditions and the variety of the seasons. Some households described that a windy day would make them feel cold, especially if it was the winter season. Others mentioned that the sun shining on a cold winter day might make them feel warm, although the temperature inside stayed the same. Some households also described that their comfort would fluctuate based on what activities the household members were currently engaged in. If they felt uncomfortable, most would use wood burners to make it warmer quickly. Household E was different to the others in this respect. They did have a wood burner but rarely used it. Instead, they would: *"just put on some extra socks and an extra sweater and hide under some blankets."* To help quickly cool down some households would just open windows:

> Household A — "If the sun begins to shine in the middle of winter and it is about zero degrees outside – then all of a sudden it becomes more than comfortable in here... And because it takes a long time to reheat the house after you turned down the temperature, we just air out instead."

HeatDial was rarely used in situations where it was necessary to quickly regulate the temperature. However, some would use the information found in HeatDial interface to help them interpret feeling too warm, too cold, or just comfortable:

> Household G — "Sometimes I feel cold or warm – then I'll check the app. Well, it says it is 21 or 22 degrees. So, I must be feeling cold because I'm coming from outside. Or if you are sitting still you might be feeling cold. Then I might check the app to see what the temperature is – and then it is not that cold anyway."

Our findings illustrate that comfort is something households experience differently due to different factors such as weather condition and activities. Thus, people make different meanings of comfort, which are both personal, and temporal. While the HeatDial system did use information on local weather forecasts, and individuals could capture comfort not just as one temperature but as a range of temperatures, the system did not fully capture the routines people go about to regulate the temperature. Considering this, one could imagine a system that better captures these routines and even challenges the idea that people's established routines are the only actions that can be used to make them feel comfortable, as discussed for example by Strengers [64] and Clear et al. [14,15].

Materiality of the House

Previous studies have reported on how the *physical* characteristics and the layout of a house — materiality of the house — can play a significant role in how people experience and adapt to sustainable technology in their daily routines [12]. Our findings showed that the complexity of experiencing shifting was also associated with the materiality of the house. The physical characteristics and layout of the participant's houses played a major role in the householders' willingness to explore different variations in the indoor temperature within the HeatDial system. One reason for this was that the response time for regulating their houses was slow, because the houses were well insulated and tended to have floor heating in the rooms they occupied the most. On average, it took 24 hours to increase or decrease one-degree of temperature in these houses. If they had experienced this in the past, it made them more conscious of not making the temperature boundaries too large.

> Household D — "I really don't want to play with it, because if we allow it to go down to 16 degrees, we know it will be cold on our feet. It will take a day or two to go down, and another day or two to return."

A few others were less aware of this because the heat was mostly distributed through radiators that regulated the temperature faster than floor heating. An example was household E that did not worry too much about variations in the temperature: *"because our house is quick to warm up"*. As fluctuations in the indoor climate did not worry them, they asked for more ways to regulate the heat during the day to match when they occupied the home.

The layout of the house also influenced how householders understood the controllable temperatures in the HeatDial system. In some households, having just one number represent the preferred temperature did not always correspond with how rooms were used and the layout of the house. Household D, for example, preferred a warm living room and cooler bedrooms:

> Household D — "If you take the entire house – then you have a difference in the desired temperature depending on what room you occupy … We like it warmer in the living room, less in this [conservatory] room, even less in the kitchen, and not very warm in the bedroom – we are not interested in having 21-22 degrees in the entire house."

To accommodate this, the household installed intelligent thermostats directly on individual radiators in the bedrooms of which they wanted tighter control of. With these thermostats, they could regulate each bedroom differently, meaning that the HeatDial system was not able to work optimally in these rooms because the system knew nothing about these individual settings.

In other households, the three temperature settings were used to find a compromise of temperatures that fitted all the rooms, as explained by Household B: *"we had to adjust the temperature settings, so it matched the temperature we wanted in all the rooms. So, we have the same comfort in all rooms. It required some adjustment in the beginning"*. These findings show that physical elements of the houses played a major role in how householders experienced regulating the temperature, hence their flexibility of allowing a system to fluctuate the temperature within their homes. Together these findings indicate that factors such as physical characteristics and layout of a house played an important part in how assisted shifting was experienced by the householders.

Conventions

Related to the above, our findings showed that experiencing heating through the HeatDial system was very much related to conventions of comfort. Shove argues [60] that the definition of comfort is constantly undergoing new revisions as the conditions for how we understand comfort are changing along with the technology we interact with [60]. New standardizations and conventions for comfort are often specified by the scientific community in an effort to craft better models to control the indoor climate in cooling and heating appliances. A fact also observed by one of our householders:

> Household H — "We have been brought up expecting 20 degrees as the norm […] I think it comes from the old Danfoss thermostats where it was supposed to be on 3 strokes, which I believe is equivalent to a temperature of 20 degrees. But as we have gotten older we like to have it 21 degrees in the living room."

To some degree standardization and conventions of comfort were also implicitly present through the interactions with HeatDial. HeatDial allows householders to specify temperature boundaries of their comfort through lower and upper-temperatures in one-degree intervals. This design rationale was an effort to make a definition of comfort as concrete as possible, so both people and system could interpret its meaning. While the automatic manager worked well with this rational definition for specifying comfort, our findings showed that the interpretation for a few of the householders was less clear-cut, as explained by Householder E: *"I really don't know what they [the temperature boundaries] mean, but they seem to be something that is needed to be able to control the heat pump"*.

However, more interestingly, most of our householders started to talk about comfort being measured in zones after interacting with the HeatDial interface for some time. When regulating the heat, the husband in Household F explained that *"it is the comfort zone that we regulate when it becomes too cold. When we come under the comfort zone of 18 degrees, we must somehow find a way to counterbalance it."*

This is interesting because it shows that after interacting the HeatDial system and specifying ranges of temperatures over time and during different seasons, the participating households also used this convention to understand their indoor climate. This illustrates that households started to change their understanding of comfort and actively use the tolerance range convention to regulate the temperature in the household, instead of the one temperature setting they used before being introduced to the HeatDial system. This indicates that conventions can be designed and hence influence how households experience comfort, introducing new and different ways for intelligent technology to assist householders with shifting.

DISCUSSION

Our study has revealed interesting insights into eight householders' use of a prototyped smart grid technology assisting them to shift their electricity consumption to more favorable times. The study showed that households were willing to allow an automatic manager in the HeatDial system to assist with shifting as they perceived this as a convenience. However, our findings also demonstrated that it is not a trivial endeavor to design interactions for assisting households to shift electricity in an understandable and meaningful way.

The aim of this research was to study how householders experienced an eco-manager assisting them to shift electric heat pump consumption long-term. The results of our study clearly showed that the participating householders appreciated both the non-intrusive automatic features in the HeatDial system and being able to control the system boundaries. These two features were the main reasons why assisted shifting became an integrated part of how these householders heated their homes. The design idea of a mixed-initiative system design "where the system pursues the goal of energy savings, and the user is free to pursue their goal of immediate comfort within certain system-defined bounds" is raised by Yang et al. [72] as a way to balance competing objectives. This design strategy was followed in the interaction design of HeatDial, where users could set boundaries of comfort, while the system pursues the goal of shifting a heat pump's running times. However, while our participants appreciated both the automatic and control features in the HeatDial system, our results show that there are still challenges to be addressed in these kinds of mixed-initiative systems. We address these in following sections.

Missed Opportunities for Acting Sustainable

One of these challenges is how to inform householders to choose the 'best' setting, so an assisting eco-manager can operate within the users' specified boundaries while also optimizing energy conservation strategies, like shifting. To help householders with such choices eco-feedback and eco-forecasts can both provide awareness, as discussed in [28,34], and also be used to close the gap between values and actions, as found in [22,74]. While the eco-forecasted elements in the HeatDial system aimed to provide information to raise awareness of both the benefits and consequences of living with the system, these elements were also designed in an effort to improve the scrutability [32] and accountability [4] of the intelligent HeatDial system operating in a complex environment like peoples' homes. However, our findings showed that providing the 'right' information within the framing of 'smart' technology adds complexity to how such information is understood and experienced in the context of everyday life, also discussed by Norman [45].

In the HeatDial study, the feedback information was designed to frame the interaction as a 'seek and explore' scenario aiming to appeal to the curious heat pump owner. This interaction design did allow these householders to explore and control system boundaries, but it did not fully capture householders heating routines. With this form of interaction, it is expected that a householder is willing to use 24-hour forecasts to explore what would be the 'best' setting by experimenting with different temperature settings. The challenge here is that the information is only available for the next 24 hours, while regulating indoor temperatures is not something these householders do on a daily basis, due to the physical characteristics and layout of their houses. Moreover, this scenario made it difficult for our householders to determine what the 'best' setting was, as they became unsure what effect changing temperature settings would have on their homes long-term. Consequently, these boundaries were sometimes chosen at random or as a safety option fearing a worst-case scenario.

This problem with users understanding the exact effect of interacting with an eco-manager is also reported by Alan et al.'s [1] study of the SmartThermo and Yang et al.'s [72] study of the Nest thermostat. However, unlike both these studies, where users had difficulties understanding how their interactions served the machine learning features for regulating the temperature, the householders in our study had difficulties understanding why their interactions hardly had any effect on their comfort. The main reason for this was because the HeatDial system was efficient in using different sources of information about the individual houses so it could implement a strategy of balancing shifting around the preferred temperature. Using this kind of different individualized information about the house and context rather than trying to derive user preferences meant that shifting hardly ever led to unexpected fluctuations in the temperature.

Furthermore, the expectation of daily engagement, framed in the feedback elements in HeatDial, conflicts with householders' experience of assisted shifting as non-intrusive system behavior. However, it was this attribute of the HeatDial's behavior that led to a feeling of convenience and thus was successful in making shifting part of these households' everyday life. For the householders, this feeling of convenience was built over time, by continuously experiencing the non-intrusive behavior of the system and becoming confident that the system could enact shifting while still attending to their comfort needs. Asking householders to engage daily with the system did not fit convenience because it would interrupt already established routines of how often they regulate their temperature.

Tension Between Calm Technology and Proactive People

The above observations underpin two challenges that need to be addressed when designing interactions with eco-managers that aim to smartly assist householders to sustainably consume energy namely (1) how can we design eco-managers so they are appropriated into the routines that constitute everyday life in a household, while still ensuring that householders do not miss out on opportunities to engage and retain sustainable settings of an eco-manager? And (2) how can we balance the difference between disengagement in sustainability issues and householders' confidence in allowing an eco-manager to act sustainable on their behalf? We believe that these two questions relate to a broader discussion on the role of designing interactions for ubiquitous computing in everyday life. More specifically, they relate to the tension between, on one hand, Weiser and Brown's vision of calm computing [69] and, on the other hand, Rogers' vision of creating proactive and engaging experiences through computing [55].

This tension was evident in our study of HeatDial and also present in similar studies [17,72]. Thus, we see this tension as relevant for HCI researchers and practitioners engaged in the design of future eco-managers. In our study, assisted shifting became part of the householders' heating routines, as they experienced the HeatDial system as non-intrusive in their everyday life – a quality that fits well with Weiser and Brown's vision of calm technology [69]. However, one can question if this behavior is enough if we want people to retain and engage in shifting or other sustainable practices. While our findings highlight that the HeatDial system successfully automates shifting conveniently, this behavior of the eco-manager also hides awareness of shifting as an environmental challenge that needs to be addressed in the expected future. Designing engaging and proactive experiences is addressed by Rogers [55] who suggests moving beyond the idea of the 'proactive computer' towards supporting 'proactive people'. Rogers envisions ubiquitous technology to "not to do things for people but to engage them more actively in what they currently do" [55]. Because of HeatDial's automatic non-intrusive nature, the presence of the system does not, in itself, change people attitudes or behavior, engage people, or raise questions about sustainable energy consumption. Thus, we believe there is a need to explore how to balance an eco-manager that performs routinized and mundane tasks in cohesion with household members, and the interactive features and information that assist householders in engaging and retaining sustainable energy consumption.

Finding a balance between these visions in the design and development of eco-managers opens up for new interesting directions to be explored. One noteworthy direction could be to explore designs of eco-managers that assist people to be more proactive in their control of the eco-manager. Towards this end, we suggest exploring engaging designs that combine automation with recommendations like those proposed in ThermoCoach [73] or Temperature Calendar [16], where users are given recommended settings for their eco-managers. One could even envision deriving these recommendations using additional smart technology to produce sustainable guidance [25]. In this scenario, proactive suggestions can be sent to households when circumstances change, e.g., energy prices or the local climate, without having to engage users in finding the 'best' setting on a daily basis. However, we need to see how households will appropriate sustainable recommendations served this way long-term, before being able to see if the results are different from when households are presented with conventional eco-feedback [68].

Another interesting direction is to use a more holistic understanding of how energy-consuming routines are performed, challenged and changed through our design interventions. As our findings show, creating a design that has to be adapted into established routines and at the same tries to challenge the meaning of these routines, is complex, because these routines are shaped by the materiality, social norms and other interrelated practices within a household. Therefore, we believe more efforts need to be put into making practices the unit of design [38,52,53,64] when designing, developing, and evaluating eco-managers that aim to change how domestic practices are performed. Towards this direction, we suggest considering the different aspects of practices [61] to better direct the design of eco-managers that aim to both intervene and be appropriated into household routines in an effort to better them as sustainable *co*-managers of everyday practices. However, to take the practice-oriented approach further, an interesting line would be to challenge household routines through eco-managers as explored by Clear et al. [15]. In this direction, designs could either provoke [54] or speculate [9] about practices to proactively engage households to adapt eco-managers as co-managers in everyday life.

Supporting Social Interactions

While eco-feedback seldom leads to behavior change that is maintained long-term, some studies have shown that eco-feedback can also be viewed as a resource that people can engage with. This engagement can lead to more open discussions and reflection about sustainable practices within the home [68] or within the workplace [16]. However, Hargreaves [29] argues that while the eco-feedback can lead to open discussions about sustainable electricity usage, acting sustainable is often the result of more complex, social negotiations between different members of the household. One reason for this is that individual, specific actions are not isolated incidents but rather a part of a more complex set of cultural and social practices [11]. So while eco-feedback can be argued to be limiting in persuading the individual to change, and perhaps more importantly, maintain this behavior [11,23,52,68], eco-feedback also has a potential for influencing practices because it can open up discussions within the household.

Our findings showed that while HeatDial's eco-forecasted elements rarely led to a discussion of what shifting is, the presence of the HeatDial system did lead to discussions about how assisted shifting could influence the heating in the households. Thus, we found that an assisting eco-manager can provide some of the same properties as eco-feedback. By allowing the HeatDial system to shift, this technology became part of creating an indoor climate experienced by all members of the household. Although we found that it was predominately one person in a household interacting with the HeatDial interface, negotiations about comfort took place amongst the entire household. That family structures play an import role in negotiations about sustainable behavior in the home is also discussed by Barreto et al. [3]. Moreover, as our study show, design and technology take part in shaping people's understanding of, e.g., thermal comfort. However, what is more interesting, is that after the HeatDial system was introduced in our study, our participants started to refer to comfort using the convention of our designed tolerance range, even those household members that did not interact with the HeatDial interface. So instead of just heating their houses after one temperature as they did before, the householders would understand their comfort within boundaries of temperatures after living with the HeatDial system for a while. Some of the participants have even continued to use the HeatDial system after this study has ended because the interaction design of the eco-manager served their needs for specifying comfort.

What we can determine from this is that by experiencing the system long-term, the participants understood and would regulate their heating based on boundaries of the tolerance range – a convention design by us – instead of the one temperature setting they were used to. This just shows that conventions made by designers can influence how households perceive and potentially regulate their indoor climate, opening up new ways for technology to challenge people's perception of, e.g., comfort and convenience.

Long-Term Studies

In this research, we aimed to study our eco-manager long-term in real-life residential settings having four households involved in our study for 18 months, while four other households participated for six months. We chose to conduct a long-term study to ensure that our households would experience different weather seasons while interacting with the eco-manger. Spring, summer, autumn, and winter are quite different for Danish households in terms of heating. But conducting long-term research studies also have a number of embedded practical limitations as argued by Rogers [56], stating that conducting long-term studies is usually stacked up against the cost of researcher tenure and the fact that "papers must be written and research budgets are tight". In fact, Rogers [56] argues that today's burning question within HCI research is "How long should my study run for?" and she continues by saying that some researchers argue in favor of a few weeks, others say several months, and finally some even stress that more years are needed to demonstrate sustainable and long-term effects. This is also evident if we consider the study duration of papers in our related work section. For example, in the Tariff Agent project, they ran two separate but related studies where the first study ran for two weeks, and the other study ran for six weeks [2], while the FORE-Watch study was seven months long [35], and finally the SINAIS study was more than one year long, with 20 households [48]. However, Rogers' question on how long a study should run still remains unanswered.

Our long-term study enabled us to observe how our participants interacted, experienced, and adapted to an eco-manager over an extended period of time. While there can be issues of deploying such technology into homes, as described by Pereira et al. [48], we do believe we need time to observe how households adapt to such technology after the initial excitement has settled, to supplement existing knowledge about the potential such technologies have to solve sustainable problems. As both our study and Yang et al.'s [70–72] Nest study show, when residential life takes center stage, it can be difficult to motivate householders to engage and negotiate comfort. But as we argued through our findings, the real success of the HeatDial system is that the system kept being used long-term by all our householders. They kept using the tolerance range in the HeatDial interface to specify comfort and although they may not have regulated these as often as it is necessary to take full advantage of the shifting, experiencing the non-intrusive behavior of the system meant that shifting became and remained a part of these householders' lives.

CONCLUSION

In this paper, we have reported from a study of a prototyped smart grid technology, HeatDial, deployed with eight households for a duration of six and 18 months. HeatDial is designed to assist householders in shifting electricity consumption of their electric heat pumps. Through the HeatDial system, householders can specify temperature boundaries while letting an automatic manager handle the shifting of heat pump operation to more sustainably favorable times. HeatDial also provides feedback in the form of 24-hour eco-forecasts so that householders can foresee the consequences and benefits of allowing the automatic manager to enact shifting within their user-specified boundaries. From shifting electricity use, HeatDial was able to facilitate price savings of 6.8% to 16.9% While doing this, average fluctuations in measured temperatures were still kept between 0.78° and 2.73° on average, and comfort thus largely maintained.

Through our study, we found that the HeatDial system three themes, summarized as *convenience, control,* and *complexity,* each illustrating how the eight households interacted, experienced, and adapted to the HeatDial system assisting them to shift heat pump consumption over time. We found that householders were happy to let an eco-manager shift heat pump consumption, as they were not interested in engaging with such mundane activities on a daily basis. Because HeatDial was able to enact shifting in a non-intrusive way, assisted shifting became part of these householders everyday heating practices long-term. However, our findings also suggest that although our HeatDial system was a convenient tool for controlling shifting, willingness to challenge temperature boundaries was often influenced by the complexity of heating practices, mainly influenced by the materiality of the house, weather season, and understandings and meanings of comfort. These findings have broadened our understanding of how eco-managers can assist with shifting electricity consumption for heating. However, for smart interactive technology and eco-managers to reach their full potential of supporting domestic householders to act sustainably in their daily routines, there are different still issues that need to be addressed by HCI researchers and practitioners.

1) In designing the functionality and information representations of eco-managers, HCI practitioners should look closely at the diversity of household roles and structures, and through their designs attempt to accommodate for these. Sustainability solutions, such as eco-managers, are often designed for the person in the household who is 'responsible for the home technology'. However, to engage other 'passive' members of the household, who are perhaps less technology-engaged, eco-managers may need to cater for other roles and needs in the household. 2) In designing interactions for eco-managers, HCI practitioners should explore different balances between calm technology interactions, and interactions that support people in being proactive. Striking such balance is important for supporting households in doing their everyday practices in a more sustainable way through eco-managers, while at the same time feeling in control of their eco-manager. 3) In broadening our view of what eco-managers might do, and what they might look like, HCI researchers should prototype designs that are deliberately different from what we have already seen, and study them in real life, before integrating ideas into commercial products and infrastructures. 4) In studying eco-managers in use, HCI researchers should increase focus on the long-term implications of design interventions, to better understand what shapes the use these technologies in everyday life, and account for the effects and complexities associated with prolonged use of them in residential settings.

Based on our experiences of conducting the HeatDial study, and also confirmed by recent work in sustainable HCI [24,39,52,53,67], sustainable interaction design stands at a crossroads between informing design by looking towards more practice-oriented methods or continuing to look for ways to improve our designs that are not connected to a particular time and space. Thus, one of the biggest challenges facing HCI researchers and practitioners of smart grid technologies for residential settings is in making these sustainability interventions, sustainable themselves.

ACKNOWLEDGMENTS

This research is a part of the TotalFlex project (843101) funded by Energinet.dk and the DiCyPS project (864703) funded by Innovation Fund Denmark. The authors would like to thank Neogrid Technologies for their input to the design of HeatDial and initial software development of the heat pump control. We also thank our participating households for the time they have spent on this project and for sharing their experiences with HeatDial. We thank Jeni Paay and Yolande Strengers for valuable input on the paper, and Lefteris Papachristos for input on the quantitative data. We also thank all the anonymous reviewers for their detailed and insightful comments.

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WASHING WITH THE WIND: A STUDY OF SCRIPTING TOWARDS SUSTAINABILITY

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Abstract: Within sustainable HCI research, we have witnessed a growing interest in studying interaction designs that support households to 'shift' energy usage to times when it is sustainably favourable. In this paper, we investigate shifting through a purposely provocative and scripted design, which challenges the idea that renewable electricity is an always-available resource for households to consume. To do so, we made electricity for washing laundry either free or not available. We conducted a detailed qualitative study with four families that experienced our intervention for a month. We present five themes that illustrate how families adapted, reflected, and formed new routines and expectations related to washing practices. We discuss the broader implications of combining scripting and provocation as a means to intervene, disrupt and understand energy consuming practices within the home.

Originally published as:

Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Conference on Designing Interactive Systems* (DIS '18), 1387–1400. ACM Press https://doi.org/https://doi.org/10.1145/3196709.3196779

INTRODUCTION

Designing interactions to support sustainable energy usage has received much attention from the HCI research community in the last decade [6,21]. Within this effort, various interaction strategies [50] have been suggested to steer household energy usage towards sustainability. Among these, *shifting* [48,50] presents interesting design challenges, as it differs from the traditional approach to sustainability of simply using less. Instead, shifting refers to moving energy usage to times when renewable resources are available. In this scenario, the householder is expected to play an active role by changing their energy-consuming practices [54,58] (e.g. heating, laundry, dish-washing) in order to respond to, for example, availability of electricity from wind turbines and solar panels. Towards this end, HCI studies have explored designs that raise awareness about favourable times to use electricity. Some investigated designs that visualise forecasted resource consumption on situated home displays [37,54,58,62], while others have looked more specifically on how to support shifting of domestic practices e.g. charging electric cars [7,10], heating [14,31], or washing [8,17,39].

However, most of the studies aiming to support shifting through such designs report that it is challenging to instigate and sustain practice change [11,51,61]. Based on this observation, we identified two design opportunities. Firstly, it appears that the everyday practices we attempt to change are often not disrupted enough, as most designs do not make people reflect on their broader energy consumption practices. Secondly, many of the energy-consuming appliances people interact with in their homes are not actually scripted to help people act sustainably [50]. For example, when the typical default setting for a washing machine is a high-consuming program instead of an eco-friendly one, people must intentionally deviate from the suggested script to use a low-consuming program.

In this paper, we address these two design opportunities for shifting through an intervention called 'the Box'. The Box extends the interaction with a washing machine by deliberately making it hard to use outside times of renewable energy availability. Both opportunities were instantiated in the design of the Box, inspired by literature on provocation [3] and the concept of *scripting* from the work of Akrich [1] and Pierce et al. [50]. In short, the provocative elements we designed with the Box allowed us to disrupt the washing practice of four households. In combination with a script purposely designed to guide households to use sustainable energy, these provocative elements allowed householders to reflect on and change their washing practices.

The paper is structured as follows. First, we present related work on shifting and scripting. Next, we present our study, including the scripted design and the four participating families. We then continue with our findings that are organised in five themes, and we discuss the broader implications of our results on shifting and scripting within the domain of sustainable HCI.

RELATED WORK

Shifting as A Sustainability Strategy

The design of digital interactions and interventions that support and encourage sustainable energy use is a challenge we researchers and practitioners have engaged with for at least a decade [6,19]. Work within HCI has predominately focused on how to change behaviour by raising awareness through eco-feedback designs [21] or support sustainable change through intelligent and automated agents [55].

Attempts to design eco-feedback have shown potentials of raising people's awareness towards sustainable consumption, especially if people are already motivated [74]. Eco-feedback designs are typically framed on the assumption that sustainable behaviour can be shaped by providing people with the 'right' kind of information like Strengers' Resource Man [64,65]. Most work in this area looks at the different design challenges surrounding materialising invisible and intangible energy resources and tailoring feedback on the consumption of these [47]. In order to achieve this, designers and researchers have visualised past and forecasted consumption data on mobiles [38,59] or in-situ displays of electricity [45,58,62,67], heating [16], water [22,46], and food [15,74]. Others have also explored ambience and art [24,56], lighting [33,34], and physical materials [9,36,68] as feedback techniques.

Despite these efforts, other studies show that the impacts of eco-feedback are difficult to maintain over time [11,66]. DiSalvo et al. [19] highlight that one reason for these limited results is because most work within this area sees the user as the main problem, where design solutions attempt to improve user behaviour, rather than focusing on impacting people's everyday practices. This view is supported by other works [23,35,51,61,66] suggesting most decisions involving energy usage are usually not informed by rationalities concerning resource consumption but rather connected to a *"larger, complex sets of social and cultural practice"* [11]. Thus, there is a mismatch between the intentions of eco-feedback designs and the real-world actions of people. This has led to a growing critique in sustainable HCI [51] highlighting a need to go *"beyond persuasion and shift from prescription to reflection"*.

In an effort to overcome some of the shortcomings of eco-feedback designs, we have recently witnessed attempts to automate some of the decision-making on energy consumption through smart home technology. Almost all of these attempts are examples of automatic agents that manage and assist people to follow different consumption strategies. Examples are the commercial NEST thermostat studied by Yang et al. [69,70], Alan et al.'s Tariff Agent [2], Yun et al.'s Intelligent Dashboard [73], and Jensen et al.'s HeatDial [31]. These are all examples of smart agents that assist households to either reduce or shift resource consumption. While these studies show a promise of the agents' automatic abilities to sustainably manage energy use, they do also report a loss of engagement over time that leads to missed opportunities for householders to act sustainably. To combat this, studies have explored designs that encourage engagement, such as the proposed recommender system ThermoCoach by

Yang et al. [28,71], Fischer et al. [20] situated sensing technology that tailors energy advice, and Clear et al.'s [14] study of 'drifting' thermal comfort zones in effort to support heating practices. However, most of these studies also report that when smart technology becomes embodied in people's lives, we as designers are challenged on how to design interactions fitting within the messiness of everyday life [5].

Scripting Towards Sustainability

Shifting is an energy conserving interaction strategy [48,50] that recently has attracted significant attention within HCI studies. Design solutions to support shifting are often envisioned through smart grid technologies and dynamic price schemes [13,48]. But as explained by Costanza et al. [17], it can be challenging to obtain 'in the wild' experiences of people interacting with these envisioned technologies. One way is to envision future scenarios [55] and explore them through prototypes. Recent HCI studies have engaged in such endeavours. Some through the design of eco-forecasts [37,49,54,58,62], while others have engaged with designing interactions that are directed towards specific energy consuming appliances, e.g. washing machines [8,17], electrical vehicles [7,10], and heating appliances [14,16,31].

Towards this end, Pierce et al. [50] suggest that *scripting* can be used as a conceptual tool for researchers and designers to help define what constitutes 'normal' behaviour when designing sustainable interactions for appliances. Pierce et al.'s concept of *scripting* is based on Akrich's notion of a script [1]. According to Akrich [1], a *script* defines the process of designing and inscribing a vision or scenario into the use of a technical object [1], that is more explicit to the *"values, social norms, and ethics"* reflected in the designed object. This highlights an opportunity since by adequately scripting our designs, we can be more explicit about communicating sustainable values and norms through the interaction with energy consuming appliances [50]. For example, in a typical car, the dashboard provides feedback information to drivers about condition of the engine (revolutions per minute - rpm) through a dial. Pushing the engine too much (high rpm) is highlighted through a red area on the rpm dial. Thus, the car's dashboard is scripted to protect the engine, instead, for example, to assist the drivers in adopting a more eco-friendly driving behaviour

THE STUDY

In this study, we designed and deployed a scripted design we call the Box. The purpose of the study was to get 'in the wild' experiences of a scripted design aiming to intervene in an established energy-consuming practice (washing) and script interactions with the washing machine for shifting.

The Box

Inspired by Akrich's [1] and Pierce et al.'s [50] concept of scripting, we purposely scripted an interaction design aiming to intervene in laundry practices. While the works of Costanza et al. [17] and Bourgeois et al. [8] explore how to make shifting washing times more convenient and effortless, the aim of this study is different. The aim of our scripted design is not to provide easy and convenient support for changing washing times, but to help households reflect upon it. So, instead of focusing on how to make shifting effortless, we focus on making shifting more disruptive by utilising provocation [3] and scripting [50]. We choose to intervene in laundry practice, because it is a practice rich of household routines and social norms, and because other studies have previously identified washing as a practice that people are willing to shift [12]. In order to script shifting as a disruptive element in the practice, the Box highlights a new 'right' behaviour to householders, summarised as:

> *"If it is not absolutely necessary, the washing machine cannot be used unless electricity is produced from renewable resources"*.

Our design is comprised of a physical device and a smart wireless electricity plug (Energenie). The Box consists of a 7in large screen, two small LED screens, and a physical interactive button (Figure 1). For its physical form, we opted for a bulky, old-school, physical style inspired by the work of Bardzell et al. [3] on critical design and provocation. More details on how we utilised provocation in our design are described in [53].

Figure 1. The Box: a) current electricity status, b) override button, c) override button presses, d) savings account, and e) 12 hour colour-coded clock.

Every half an hour the Box checks the local wind conditions through an online weather service. We framed the design on the assumption that when there is a lot of wind, electricity is mostly produced from wind turbines and thus comes from renewable resources. When wind is blowing electricity is characterised as green in the design, and when not, as red. This information is materialised as a colour-coded clock that projects the next 12 hours (Figure1E). While electricity is red, the smart electricity plug disrupts the washing practice by completely disconnecting the washing machine from the grid. When electricity is green, the washing machine can be used without disruption.

The only way to use the washing machine while electricity is red is to push an override button (Figure1B), and 'declare' that there is a necessity to do a wash. For this, we purposefully adopted the emergency button metaphor to script a sense of reluctance on pressing it, as we wanted households to realise that it is something it should not be pressed without considerable thought. Finally, the Box also projects through a LED screen how many times the users pressed the override button. In Figure1C we can see an example where the override button has been pressed 9 times. This LED screen then materialises the number of times households deviated from the new imposed norm and 'violated' the rules.

Our script also brings in a disruptive price schema in relation to how electricity consumption is typically priced in Denmark. When electricity is green, each wash costs nothing and the amount of money the household would normally pay for electricity to power the washing machine is added to a savings account. On the other hand, when the washing machine is used in a red slot, then the cost of a wash is double the normal amount, and the cost is deducted from the savings account. The cost of each laundry is calculated based on the electricity the washing machine consumes, measured via the smart wireless electricity plug. The Box materialises the savings account through a second LED screen. In Figure1D we can see an example where the savings are 121 in Danish Kroner, equivalent to approximately 19.5USD.

In terms of hardware and software, we bought an off-the-shelf case for electrical equipment which we modified to fit the LED screens, the 7in screen and the button. All components are connected to a Raspberry Pi with a GrovePi shield that runs our python code. Finally, inspired by the Bourgeois et al. [8] study that reported that contextual control - interacting in situ - led to a deeper engagement, the Box was placed on top of peoples washing machines.

METHODS

The study was conducted a field study with four families who experienced the Box for a month each. Our motivation for introducing the Box into the lives of the participating families was to intervene in already established washing practices and provoke households to reflect on their practices. Thus, the Box acted as a technology probe [28] allowing us to collect insights on how practices were carried out during the intervention. Since washing clothes is a practice consisting of rich household routines and various social norms, we view each family as a separate case that is highly unique with quite complex social and physical structures [72]. Finally, we position our work as a research through design [18,75] study, as the design itself (the Box) is means to do research on an area of interest (shifting for sustainability).

Figure 2. The Box in situ in each of the four households. From left to right, families 1, 2, 3 and 4.

Participants

The recruitment of participants was achieved via snowball sampling through our social networks. There were three requirements each family had to fulfil to participate, namely: (1) the laundry room should have had access to a wireless internet connection that the Box could use to check the wind conditions and characterise the status of the electricity; (2) the possibility to install a smart plug between the washing machine and the connection to the grid to enable the Box to control and monitor the power supply; (3) heterogeneity in the family's characteristics in relation to their washing needs and routines (how often they washed, when they washed, who washed, etc.).

Out of ten families that volunteered for our study, we managed to recruit four of them. In the six families, we did not recruit, we were not able to install the smart plug that controlled the power supply in five of them, and one did not have wireless internet. The four recruited families lived in Denmark, where it is expected that electricity supply is very stable, and electricity prices are inflexible and reasonably cheap compared to other parts of the world. Each of the recruited families had different routines and habits of their washing practice, and the physical location of their washing machine also varied – see Table 1.

In the first family, Sam was responsible for doing most of the washing, while Marcy would occasionally help. The family had high laundry needs since they all worked out most days during weekdays and weekends. They usually dried their laundry in a tumble dryer. In the second family, Gaby was in charge of the laundry, while Scott would occasionally chip in. Out of three children, only one permanently lived at their house, while the other two would visit every second weekend. They also had a large dog that would yield enough dirty laundry for one wash a week. They also did their drying in a dryer. In the third family, Diana was in charge of the family's washing, while Robert would do some washing when necessary. If the weather was nice, they dried the clothes outside. If the weather was bad, they normally dried it inside as they tried to avoid using the tumble drier. In the last family, Kate was mostly in charge of washing. Both Kate and Peter worked out 3-4 times a week, so they usually produced three washes a week. They did not have a dryer, so weather permitting, they would dry clothes outside or otherwise use a drying rack inside. In all three families with children, none of the children participated in washing chores.

Throughout this paper, we refer to the participants by their pseudonyms and family number – see Table 1.

Family	Demographics	Household Roles	Laundry routines	Location
F1 *Competitive*	Sam, 61, electrical engineer Marcy, 49, process coordinator Three children: 16,18,20	Sam in charge of washing, while Marcy occasionally helps Marcy in charge of paying utility bills	~10 washes per week Wash daily and during weekends	Basement
F2 *Laid back*	Scott, 51, carpenter Gaby, 46, dental surgery assistant Three children:14, 17, 19 large dog	Gaby in charge of washing while Scott occasionally helps Gaby in charge of paying utility bills	~8 washes per week Wash in bulks during the weekend	Entrance
F3 *Determined*	Robert, 59, surgeon Diana, 49, student Three children: 6, 11, 17	Diana in charge of washing while Robert will wash when he needs clothes Robert in charge of paying utility bills	~7 washes per week Wash in bulks during the weekend	Entrance
F4 *Young ones*	Peter, 28, software engineer Kate, 25, nurse	Kate in charge of washing while Peter occasionally helps Both in charge of paying utility bills	~3 washes Wash randomly	Bathroom

Table 1. Demographics and laundry routines (pseudonyms are used)

Data Collection and Analysis

The Box was deployed in the four families for a month. We positioned it on top of their washing machine, as seen in Figure 2. To obtain an in-depth understanding of how the scripted design influenced each household, we conducted eight semi-structured interviews, two with each family, which we systematised via interview guides [42].

Both adults from each family and two researchers participated in the interviews. The first interview was conducted before deployment and questions included topics of existing laundry practices and household routines. At the end of the first interview, the families were introduced to the Box. During this introduction, we explained to them what shifting is and how it is facilitated by the Box. The families were being told to use the Box in any way that suited their needs. In our setup, the savings account for each family started at 100 Danish Kroner (~16USD). The second interview was conducted at the end of the deployment period. In this interview, we discussed each family's experiences of washing with the Box, and if and how it had influenced their washing practices.

Apart from data collected through the interviews, we also logged their interactions with the Box, including the washing machine's power consumption, the number of times the emergency button was pressed, and a snapshot of the status of the clock every

30 minutes. Since it was impossible to collect data on when participants looked at the Box and decided not to use their washing machine without violating their privacy, we provided each household with a diary and asked them to write down these instances, along with any additional thoughts and/or suggestions. Furthermore, for each deployment, we had an open email and SMS line with the families in case they wanted to contact us. This led to few entries of how the Box was experienced. Each of the eight interviews was fully transcribed. We conducted a content analysis using an emergent coding approach [43] on all the transcribed interviews focussing on the practice of washing and its energy consuming implications. We used this analysis to develop a thematic understanding of how the families experienced living with the Box, how they understood their interaction with the scripted design, and how they adopted their routines to the intervention. The results are structured into five overall themes discussed below.

FINDINGS

First, we would like to highlight some of our logged results, and then we present our qualitative findings from our analysis. From the interaction logs we discovered that family F1 and F4 pressed the override button 3 times, family F2 pressed it 19 times, and family F3 did not press it at all. All families also saved money according to our scenario. Based on the order of presentation in Table 1, each family saved 43, 18, 22 and 20 Danish Kroner respectively (~6.9, 2.8, 3.5, and 3.2 USD). These results demonstrate that the families did indeed engage with the Box, and let the scripted design become part of their washing routines during the study. In the following, we present the five themes that emerged from our analysis on the qualitative dataset.

Awareness and Engagement

Overall, our analysis showed that the presence of the Box created a large amount of curiosity, awareness, and engagement within all families. To accommodate this, all the scripted design elements of the Box played a significant role. Unsurprisingly, the design element that influenced awareness most was the colour-coded clock. This element made the participants aware of shifting being an environmental challenge as the participants fittingly understood this design element as something symbolising when renewable electricity was available for washing: *"the green states that we are both sustainable and economical aware"* (Diana, F3). Visualising shifting as a forecasted colour-codes clock was also experienced as a clear-cut strategy to follow. For example, Sam (F1) undoubtedly understood the green colour code as:

> "Well, time to do a wash. It's clear to go, good to go. Like you know, like the traffic light." *(Sam, F1)*

Likewise, Diana (F3) *"wanted to wash when it is green as it would be the logical thing to do"*, while Peter (F4) stressed that when the clock "*finally shows a green slot then you know you should do a wash because otherwise it might take another week without being able to do any washing"*. Using forecasted information as a means to raise awareness is also reported in other studies [37,54,58,74]. However, choosing to script shifting as 'normal behaviour' in the Box was also supported by cutting the power supply off during red time slots and making the override button the only physical interactive element. Both these design elements had a high impact on how the families engaged with the scripted design, as it made shifting wash times *"easy and simple to follow"* (Diana, F3), and *"easy to understand"* (Gaby, F2). Moreover, by designing the override button using the emergency metaphor, we also made all families reluctant to press it *"because it states that we wash at a bad time"* (Kate, F4). This was further enhanced by visualising the savings and showing the times the override button was pressed through the LED screens raising awareness of deviated behaviour:

> "Without those two small displays, it is just an overview of green or red. Without them I wouldn't care as much and just wash. If no one is counting and you pressed the button five times but 'forgot' the fourth, then it would not be 'bad'. So, the displays create awareness when you look at it." (Peter, F4)

The third family decided not to press the button at all and only to do their washing during green slots. To achieve this, they almost abandoned their old washing routines, and washed only when renewable electricity was available:

> "It became a sport. We wanted to see if it was possible – and now we can say – yes it was possible to be 'ruled' – be ruled by the box." *(Diana, F3)*

However, while three families went far to change their washing routines to fit with the colour-coded clock, the second family was more reluctant to do so. They deviated the least from their old washing routines and pressed the override button 19 times *"because the green slots just never fitted into our plan"* (Gaby, F2). However, they were left in no doubt what scripted design was envisioning – especially if a red slot was currently active and the power was cut off when they wanted to wash:

> "But you swear at it because... ah it could have been more fun to wash in the green period – because we lose points every time we press the button, no?" *(Gaby, F2)*

The two displays made all the families experience the scripted design as a game that illustrated some 'benefits' and 'consequences' of washing during green and red time slots. However, because the Box was experienced as a 'game to beat', it made all the households more engaged to wash only when renewable electricity was available. For example, Marcy (F1) started to take a keen interest in checking if the washing machine ran in green slots because:

> "I'm getting really competitive now with the washing. We have only saved money so far. Not spent any. Seeing the prices really makes me competitive." *(Marcy, F1)*

However, the incentive to shift washing times was different for her husband Sam as *"the prices don't say to me that much. But the green and red colours really turn me on"*. He was motivated to *"do the right thing"* and despite experiencing some frustrations, he mostly washed when renewable electricity was available as it was *"intriguing to try and be one step ahead of the Box"*. However, what is interesting to observe is that it was not the desire to *"earn money"* that motivated him, but rather a desire to participate in the *"game"*. In general, while the savings account raised some awareness about washing being an energy consuming activity, it also had another effect. Some were surprised by how cheap it was to wash, even though the price was doubled during red time slots. This was for example expressed by the second family:

> "I actually thought it was more expensive to wash. We have done this for a month now and we have saved about 3$. 3$ is less than a burger meal!" *(Scott, F2)*

These findings illustrate that various design elements (feedback, metaphors) can be used to raise awareness and engagement with sustainable challenges, like shifting, by purposely scripting disrupting elements into routinised interactions with energy consuming appliances.

Disrupting and Adapting

The scripted design clearly disrupted the way the four families planned their washing. Before the intervention the families washed when it fitted with their busy family life. Now, they were reliant on the availability of renewable electricity for the next 12 hours. Thus, trying to shift washing times also meant that the families had to plan carefully, meaning they established new routines. Before the deployment, the families either used the status of the laundry basket, or the time of day as indications on when to wash. The introduction of the Box changed this, and the families started to use the Box as a planning mechanism:

> "We have experienced big fluctuations from green to red. But we decided not to press the button. We have been stubborn […] We went from letting the washing basket deciding when to wash, till where the box decided when we should do our washing." (Diana, F3)

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The colour-coded clock played a big part in assisting them to adapt to this new disruptive planning mechanism. That meant that they got engaged with a new habit of frequently probing for the status of the Box, like Diana (F3) who *"checked it 3, 4 times a day I think"*. The same routine occurred in all four families. In the first family, Sam told us that he developed a new routine, summarised as *"go home from work, go down and check"* and Gaby (F2) told us that *"when I was at home and had nothing else to do I would go and look at the machine"*. Robert (F3) had previously been washing his own shirts, usually the day before a business trip. Now, he made a habit of checking the status *"3-4-5 days before since now it is the time to wash"* because he could never be certain when a green slot would come up.

For these probing strategies, the location of the Box played a significant role. The second family's washing facilities were next to the entrance, so it was easy for them to probe the status of the Box when getting in and out of the house. The was also the case for the third family. Its location in the entrance made the Box *"natural to look at as you enter the home and then you can decide what to do"* (Diana, F3). The fourth family's machine was located in the bathroom, and they made it a routine to check its status since *"you cannot avoid it"* (Peter, F4).

Our findings also suggest that new routines were created through the presence of other appliances and materials, which were related to the Box and contributed to the way it was used. For example, the Sam (F1) noticed, after going up and down the stairs a couple of times, that he could see the reflection of the clock on the utility's room door and thereby get a quick overview *"because there is a reflection on the door you can tell if there is a lot of green or red"*. Checking this reflection in the door was appropriated into an everyday routine as he would often check the status of the Box from the top of the stairs. There was also a similar situation within the second family, who reported that they started using the emitted light of the Box at nights, instead of the hallway light, as it could light up the hallway. Additionally, Scott questioned the sustainability of our design as *"it properly uses a lot of electricity to send out that light – properly everything we saved on washing."*

While most of the families were not interested in jeopardising their sleep at night by changing sleeping routines, this did not hold back the fourth family in their effort to adapt. They had observed that green slots often occurred during the nights and early mornings. To accommodate this, they started to routinely check the Box at night and wash early in the mornings instead of washing after returning from work, as they used to. It had the consequence that Kate would get up earlier than normal just to use the washing machine, even on days she was off work:

> "We just had a week where it was red all the time… Otherwise, is has been green between 1-2ish until 7am. And sometimes it has been green all the way till 9 in the morning… But you can see it in the evening – now it is green again in the night" (Kate, F4)

This theme illustrates that disrupting scripted designs can lead to adaptations of existing established practices, and the formation of new routines. This is interesting because it shows that by simple design means it is possible to go beyond the limitations of eco-feedback systems [21,37,66]. However, our findings also demonstrate that a scripted design can be appropriated in several ways that do not necessarily fit the designed purpose of the script. This is illustrated in the next theme.

Unscripted Routines

So far, our findings have revealed that new routines were formed based on what was deliberately intended via the scripted design. However, our findings also show that there were also some routines that were created without our intention. While some of these routines turned out to be more sustainable, others would challenge the meaning of sustainable washing within some of these families.

Some of the new routines were related to other activities embedded in the families' washing practices, like drying clothes, while others were connected to how they used the washing machine. Sam (F1), for instance, started to use more sustainable programs on the washing machine, although this was not part of the scripted design. Before the deployment of the Box, he did small, quick washes to "get things out of the way", but now he often had to wash in the nights to fit with the green time slots, so he switched to using the long, low consuming 'Eco6' program:

> "The thing I didn't do before was to use the long Eco6 program that lasts 3:30 hours. Now I put a wash late at night, head down in the morning and put them in the tumble dryer. I suppose I have been doing more washes late in the evening than I was doing before." (Sam, F1)

The families also reported that because they tried to wash in the green slots made them think of ways to better appropriate the use of their washing machine. This resulted in some of them considering the size of the washing loads:

> "I think I have been more aware of filling the machine when we finally could wash. So, I have properly filled the machine more than you would otherwise have done. I have certainly filled the it to the brim making the portion as big as possible." (Kate, F4)

Despite efforts to use the washing machine more efficiently and sustainably, the scripted design sometimes contradicted itself, and this led to new routines that can be considered unsustainable. Unlike the first and fourth families, the second family started to use a short program more often. They had, for example, experienced an entire week where every time they checked the Box, the status was red. In their effort to only run the washing machine during green time slots, they postponed all washing to the weekend. However, when the weekend came, Gaby (F2):

> "I had so many loads of washing, so, I had to choose a short program, which actually uses more power than the long program. But I had to do this to get all the washing done." (Gaby, F2)

Thus, the scripted design started to challenge the meaning of a sustainable washing practice, as it sometimes contradicted what the families believed was environmental practice. Trying to adapt to the scripted design also created dilemmas about sustainable washing practices in the other families too. For example, the second family were very environmentally conscious and did most of drying outside. However, they had difficulty in synchronising drying clothes outside with the available green time slots:

> "There have not been many designated green times slots where we could dry it outside, because when it is green, the outside weather has not been drying weather. That meant we had periods with poor indoor air quality because the clothes were dried inside because otherwise we have used the power of the dryer. So the question is - what is the right thing to do?" (Diana, F3)

The same issue was experienced in the young fourth family. They thought that synchronising washing tasks was even more problematic because they had no electric dryer and relied only on the weather to dry clothes. In the first family, this issue of synchronising washing and drying made Sam *"sometimes ignore a green slot because I had a lot of clothes to tumble dry and fold"*. This resulted in missed opportunities to use renewable electricity because not all the washing-related appliances followed the same script.

This demonstrates the importance of looking at the entire practice and related practices when designing and evaluating scripted interactions as people will shape the use of such designs in unforeseeable ways.

Collaboration and Reflection

In the first interview, all families reported that one person was mostly responsible for the laundry. This did not change much after the deployment of the Box. For example, Sam (F1) informed us *"that was my job before, so we wouldn't change it"*. What did change though, were the activities and the level of reflection surrounding the laundry practice. While the colour-coded clock introduced a clear-cut strategy to follow, the scripted design also introduced a certain amount of uncertainty as to when it was possible to wash beyond the forecasted 12 hours. This meant that some of the family's washing needs now had to be discussed among the family members. In the second family, Scott got more involved with washing than before. While he was *"a man that can figure out stuff by himself"*, he was now often asked to check for green slots and then start washes early in the morning before leaving for work.

This collaborative reflection of the washing also happened within the fourth family. Here Peter would often ask to be informed about their savings after each wash because *"now it is visible – that is fun!"*, and he also started *"to check if any clothes needed washing when green slots came around"*. In the first family, the parents often talked about the status of the Box, particularly when it was red, as Sam would immediately inform Marcy that *"the damn thing is red"*. They also often discussed the status of the Box in the car, while coming back from work, since *"it was always a bit of mystery, what it was going to be"* (Marcy, F1). Although Marcy did not take more active part in washing, she would now help to check the status of the Box. Furthermore, our findings also illustrate that the decisions the parents took in relation to the Box, affected the entire household. This for example was explained by Robert (F3):

> […] Our son has been annoyed that we did not wash exactly the clothes he wanted. We had to explain to him why we unfortunately couldn't do so." *(Robert, F3)*

These findings demonstrate that the scripted design started to influence practices beyond individual change. One reason for this was because the presence of the Box opened up for discussions and reflections within the entire household – a quality of eco-feedback that Hargreaves et al. also report on [25]. Secondly, because we introduced disruptive interaction elements via the Box, planning washing became a collaborate task more family members engaged in. Moreover, these findings also demonstrate the potential of using provocative probes to obtain valuable insights within families [29] to help designers and researchers understand how scripted designs are reflected upon and adapted into practices of the entire household.

Challenging Expectations

Because the scripted design introduced disruptive elements into the washing practice that influenced all members of the household, the intervention started, surprisingly, to challenge existing expectations related to washing. Most noticeable was the families' expectation of *cleanliness* and their understanding of how clean clothes should be. This is interesting because as Shove [60] argues, expectations of cleanliness have sustainable implications for e.g. washing.

Particular two families changed their understanding of what clean clothes were during the one month deployment period. As the third family had restricted themselves to only wash during green slots, their new washing routines started to influence their expectancy of clean clothes. What is interesting here, is that these new expectations of cleanliness became a relevant topic for the entire family including the kids that did not participate in any washing activities:

> "Normally the girls always have freshly clothes on every day for school. But now – if the clothes are not dirty, they can wear them for another day" *(Diana, F3)*

Furthermore, the Sam in the first family reflected a lot on which temperatures would make their clothes clean:

> "I suppose I have been hypocritical about washing temperatures in the past. You can wash in 30° now with the detergents we got [and still have clean clothes]."

This expectation of cleanliness also influenced the parents and their routines of washing. For example, would Robert (F3) reflect upon the cleanliness of his own clothes. That meant that some clothes did not need to be urgently washed after a first wear as normally happened before the introduction of the Box. Instead, he sometimes would wear the same clothes multiple times because he wanted to wait with washing to suit the scripted design:

> "I worked with the chainsaw in the garden the other day. I would normally have washed my clothes immediately, but then I realised they can wait." *(Robert, F3)*

This new understanding was then diffused to the entire family, and they started separating clothes into the ones they could postpone and the ones that were more urgent to wash. Sam (F1) developed a similar routine. Previously he would go to each of the children's room every day after returning from work to look for dirty clothes. He would then immediately put on a wash in an effort not to let dirty clothes pile up in the laundry baskets. This meant that the children of the family were used to have their clothes cleaned almost immediately after they had used them by the 'washing fairy'. After being introduced to the Box, Sam reported that he often was thinking about the necessity of having all clothes clean all the time:

> "Well, do I need to do it? Is there anyone wanting these clothes at that particular moment? And in most occasions, they weren't important." *(Sam, F1)*

What these findings demonstrate is that by disrupting existing routines through provoking scripted designs it is possible to challenge existing expectations related to practices, which also have sustainable implications like, for instance, cleanliness. This is interesting because as Shove argues [60], it is by challenging these kinds of expectations that change practices beyond individual behaviour.

DISCUSSION

Overall, our study demonstrate that the Box served its purpose as an intervention in two ways. Firstly, by introducing a purposely provoking scripted design to four families, we managed to disrupt established washing practices that both sparked reflections and created new routines and expectations of that practice. Secondly, the scripted design allowed us to get deep and insightful understandings of the richness, diversity, and complexity of the four families' washing practices. The main contribution of this work lays in the five themes presented in the findings and the combination of scripting and provocation as a means to disrupt and understand energy consuming practices within the home. We now discuss the implications of these findings for HCI researchers and practitioners.

Provoking Routines and Expectations

Purposely scripting an energy-consuming appliance to shift energy consumption is not an easy task from a design point of view. The door of a refrigerator may be scripted for *trimming* (to be closed) [50], but this can be easily embedded within domestic routines as it requires a minimum amount of effort, and poses a small challenge from a design point of view. At the same time, as a research community, we tend to engage with designing and evaluating the sustainable benefits of our interventions by focusing on how effective, effortless, and convenient these benefits come about and use this as a criterion for evaluating the successfulness of our designs [2,32,70]. However, as our findings show, more complex practices like washing, pose other challenges of scripting sustainable values as a default into the interaction of energy-consuming appliances. While we framed 'the right' shifting behaviour via the different interaction elements of the Box, our findings demonstrate that household's routines are encompassed by social norms and expectations that shape how people use energy consuming devices.

Nonetheless, what the presence of the Box managed to do, was not only to raise awareness of shifting (other eco-feedback studies show the similar results [37,54,58]), but also to intervene in established routines and spark reflection that challenged expectations that involved the entire household. These findings are in line with the Hargreaves et al. study [25] illustrating when families are provided feedback, consumption becomes a reflective "negotiation that is a social and collective rather than individualised" [25], and the design "stages experiences and debates" [44].

Moreover, our findings demonstrate that by combing scripting and provocation, the participants started to adapt to the scripted design by reflecting upon their washing practices and other interrelated practices too (e.g. drying clothes). And interestingly, all families got engaged with washing at times when renewable energy was available, even though they all believed in the beginning that adapting to the scripted design would be an inconvenience. Some even stated that they got positively surprised with themselves for managing to change their washing routines, and this change felt to them like a natural thing to do. Through these reflections, new laundry practices emerged, such as starting to use a long, low-consumption laundry program at night to accommodate shifting. Likewise, expectations, like cleanliness, were also challenged, leading to other sustainable implications (apart from shifting), e.g. trimming of washing loads, lower washing temperatures, water consumption and reflections on how to use other related appliances, such as the tumble drier.

These changes were not accomplished by scripting the interactions with the Box to be as effortless as possible. Instead, we believe this was accomplished by purposely provoking and thus disrupting established routines through the scripted design. By combining different provocative and scripted interaction elements (the emergency button metaphor, cutting off power), we also added some complexity to the interactive elements themselves [30]. This complexity made shifting a 'game to beat' that family members wanted to engage with (similar findings reported by Bourgeois et al. [8] and Costanza et al. [17]). This also led to the development of new routines such as checking the status of Box whenever there was a chance, despite not being designed to be efficient and convenient (most participants had to physically walk up to their washing machine, and plan far ahead).

Together it highlights that the assumed expectation of sustainable change is something that must come about as effortless and convenient as possible (perspective often penetrating our research and design evaluations efforts) might not be the only evaluation creation for our sustainable interventions. Thus, we believe the way forward is perhaps not to design these kinds of interventions as effortless and convenient as possible, but to provoke and disrupt practices in ways that open up for new interpretations and expectations.

Scripting and Research Through Design

Usually, in research through design studies, a possible outcome is an extended understanding of a situation. We create interventions and then acquire insights into a research domain based on how our interventions are experienced. We will not touch upon how provocation was facilitated in the scripted design since extensive reflections on the relation between provocation and research through design are reported in [53]. However, from our research through design effort that utilised scripting in a provocative intervention, we collected a number of 'lessons learned' that we will highlight in the following.

When designers attempt to script specific behaviours into designs, they sometimes also unintentionally design for imaginary actors with specific values, norms and ethics [1,50]. Thus, they make assumptions and these assumptions find their way into their designs. What this and others studies [63] illustrate, is that a scripted design will, to some extent, be experienced and appropriated differently, independently from the intentions and assumptions of a designer [27]. For example, in our scripted design, we assumed that a sustainable washing practice implies washing should be aligned to times when electricity is produced from wind turbines. However, when looking holistically at washing as a practice, different weather conditions will dictate different actions to be sustainable. While wind may be good for running the washing machine at the 'right' times, windy weather can sometimes be bad for other activities (drying clothes outside) as windy weather often carries rain. Thus, some of our assumptions contradicted specific households' efforts to move towards more sustainable routines (e.g. using the wind to dry clothes, instead of the tumble dryer). Such challenges to our design assumptions are an excellent point of discussion with participants to better understand a research domain.

Despite the few instances where there was a mismatch between our design assumptions and how washing was carried out, our study also demonstrated that a provocative scripted design can be used as a probe [29] to understand a practice in a family better. This is particularly relevant for research through design studies [18,70] aiming to either understand an unknown practice or explore possible future scenarios for known ones. Thus, a scripted design needs to be prototyped, evaluated and reflected upon in order to understand how it is adapted in practice (also highlighted by Silberman et al. [61]).

We want to highlight a dilemma related to our decision to script for shifting, which occurred to us after the interviews with the households. Our motivation with the Box was to move the burden of negotiating the 'right' shifting decisions from households to designers through a purposely scripted design. However, by doing that we also put the burden of acting out shifting onto the households. But should shifting be a concern of households? This issue is also highlighted in Strengers' [63] study of feedback systems attempting to align household's electricity consumption. Here the system introduced a feeling of danger within the households, as accountability of shifting was transferred to them (shifting is a not a problem most households face in everyday life, but a problem electricity providers are challenged with). We believe this highlight competing dilemmas researchers and designers should expect when conducting their research through design process. The outcome of such studies is not only one-directional (we not only collect enough insights a domain), but omnidirectional (our findings allow us to reflect on our research). Thus, scripted interventions should also be treated as a point for critiquing our own research aims and values.

From Disrupting to Sustaining Change

As the purpose of this study was to obtaining rich insights of scripting for shifting we purposely disrupted a targeted practice. What we usually want to achieve in a design process, is not only to disrupt a practice, but to sustain change. This transition is not always straightforward.

To produce a product that encapsulates the findings from our interventions, we need to have the interrelated practices in mind. For example, in our case, we did not design for the whole washing practice, but we only focused on a part it; washing clothes. Thus, we ignored that participants needed to dry their clothes as well. Although this was useful in the level of intervention since it allowed for insightful discussions with our participants, such an issue would have been difficult to tolerate in a product; our households would probably have rejected it. We believe the only way to overcome this challenge, is to adopt a practice-based approach [51] and make the practice the unit of design [40]. This way, we may be able to move from detailed understandings of a domain, to sustained practice change. For this reason, we recommend to try to design holistically for a practice, in a similar way as Kuijer et al. [41] (bathing), Pink et al. [52] (heating) and Bates et al. [4] (shifting heating) and study the implications long-term as Hasselqvist et al. [26] (transport).

Furthermore, to better design products that facilitate these sustained changes for the years to come, it is important to gather knowledge that goes beyond the novelty effect our participants' might experience through our interventions. For example, in our case, we collected enough data from our intervention as our participants experienced it for an entire month. But we cannot be sure if and how the observed changes in the washing practices will be sustained. One way to overcome this is to move towards even longer studies that allow participants to deeply engage with our interventions and for us researchers to gain richer understandings of our intervention, as recommended by Rogers and Marshall [57].

CONCLUSION

In this qualitative study, we deliberately disrupted existing laundry practices of four families through a purposefully provocative, scripted intervention called the Box. The four families experienced a situation where electricity was either for free, or not available based on how it was produced, as well as, a new 'norm' for sustainable behaviour.

The main contribution of our paper is our findings. They show that the four families not only shifted their electricity consumption, but the scripted design also provoked changes in their existing washing routines as well as the creation of new ones. The process of adapting and reflecting upon the scripted design raised awareness and engagement that challenged existing routines of an energy consuming practice. Furthermore, we contributed beyond our findings by discussing the broader implications for HCI researchers and designers. Our discussion highlights that by purposely provoking established routines we can challenge expectations that both have energy consuming implications (cleanliness) and how such changes could be designed and evaluated (going from effortless and convenient towards provoking and disruptive). We believe these contributions to be useful to researchers and practitioners beyond the sustainability domain.

ACKNOWLEDGMENTS

We would like to thank the four families for opening their homes to us and sharing their experiences. This work is part of DiCyPS project (864703 - Innovation Fund Denmark).

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ISSN (online): 2446-1628
ISBN (online): 978-87-7210-240-5

AALBORG UNIVERSITY PRESS