HeatDial: Beyond User Scheduling in Eco-Interaction

Rikke Hagensby Jensen, Jesper Kjeldskov, and Mikael B. Skov
Department of Computer Science / Research Centre for Socio+Interactive Design
Aalborg University, Denmark
{rjens, jesper, dubois}@cs.aau.dk

ABSTRACT
There has been an interesting development within HCI for sustainability, 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.

Author Keywords
Sustainability; electricity; eco-interaction; shifting; smart grid, automation.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

INTRODUCTION

Sustainability has been a topic of much attention in the HCI community in recent years. Within this research area, the notion *eco-interaction* has recently emerged, characterizing any type of interaction that facilitates sustainable practices and behaviors [29]. 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 [7, 21] predominantly for domestic settings [6, 11, 26] but also for the workplace [8, 30]. 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 [16, 18]. 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 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* [10, 12, 17, 23, 26], or by being supported to actively schedule the running of specific appliances [1, 4].

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While *user scheduling* have proven useful for shifting usage of some types of electrical appliances, such as washing machines and dishwashers [4, 10, 23], for others appliances, such as fridges, freezers, home heating and cooling [22, 28], 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 [29] the challenge for designers, then, is balancing the control of an automated system pursuing sustainable objectives, while respecting users comfort preferences. This calls for 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 [14]. 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 [6, 7, 8, 11, 12, 21]. Most eco-feedback systems use the concept of persuasive technology, adopted from environmental psychology, as a framework to approach sustainable HCI [7, 21]. 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 [2, 9, 19, 25]. One critique is that everyday consumption behavior is not acted as conscious, rational decision-making advocated by persuasion [25], 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 [18].

Eco-interaction is a concept within sustainable HCI that recognizes the opportunities found within smart environmental supportive technology [9, 16], and also addresses some of the critique related to the use of persuasive technology alone, as a mean to influence sustainable practice. Yang et al. [29] 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. [30] 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 as not the only approach to promote sustainable living through interactions with energy-consuming systems. *Shifting* is a term from Pierce et al. [18] 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 [9]. 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 [16]. 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 then those concerning energy reduction [16]. One way to regard shifting is how to approach *user scheduling*. With user scheduling we 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* [10, 12, 17, 20, 23, 26]. 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 [10, 17, 20], 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 [4]. 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 [13, 22, 28]. 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 [22] and TherML [13] 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 [27, 28, 29], where they studied domestic heating and cooling experiences using the Nest to control the inside temperature of domestic households. Using occupancy observations, mixed with user interactions, the Nest will intelligent learn patterns of user behavior. Based on the learned information, the system will schedule a plan for running the heating and cooling system with the aim to reduce energy usage.

In their 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, living 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, had difficulties understanding the expected behavior of, and that failed to understand user intent. This resulted in some participants manually setting up the Nest schedule and most others to quickly loose engagement over time, resulting in missing opportunities to save energy.

Together these examples have shown a potential of designing eco-interactions based on automation, to reduce energy usage. However, there is a challenge in capturing different incentives in an eco-interaction design. As discussed in [29], 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 comfort and control.

THE HEATDIAL PROTOTYPE

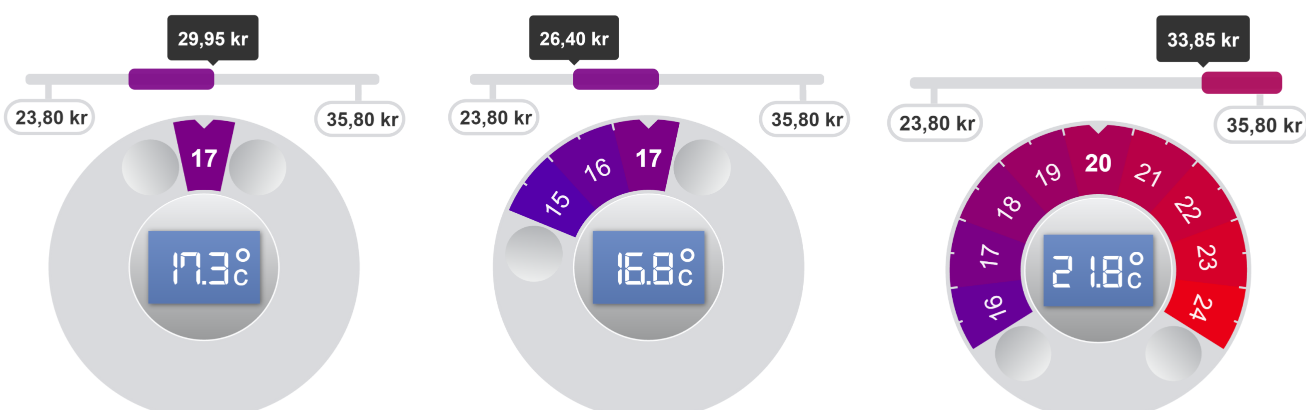
To be able to study the concept of shifting in a domestic setting, we designed and implemented HeatDial – a prototype that enables electrical heat pump owners to set the inside temperature of their house and discover the tradeoffs between comfort and cost.

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 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 occupying the inside of their homes.

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 [3, 24]. While several examples have utilized occupancy observations and predictions to say something about the occupants temperature comfort level intelligently [13, 22, 28], the HeatDial prototype addresses this design challenge differently. Instead of deriving a user 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.



(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)

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.

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 temperature tolerance range boundaries.

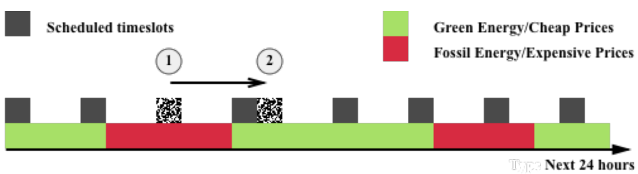


Figure 2. Planning a sustainable favorable schedule. A large tolerance range makes it possible to shift timeslot 1 to 2.

This scenario is illustrated in Figure 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 temperture.

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 has been 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.

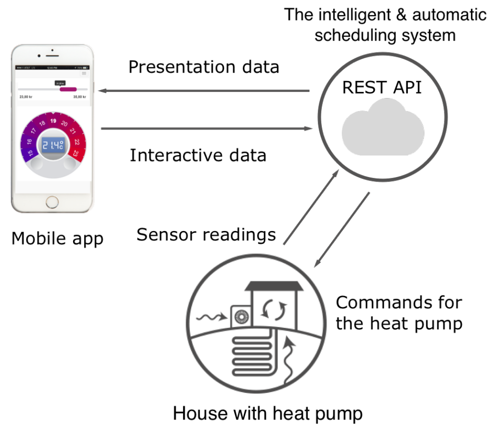


Figure 3. Overall architecture of the HeatDial system.

HeatDial communicates with the intelligent system through a REST API. Through this API, HeatDial get 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.

METHOD

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 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 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. Expressed a high awareness of heat pump behavior and would manually log electricity consumption every day (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 were fully 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. During the deployment period, we also logged all interactions with the system. All interviews were audio recorded, fully transcribed and analyzed using qualitative thematic content analysis.

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 price example from household 5 shows that the absolute price range for a 24-hour time period, would lie between 58 kr. and 20 kr. in the beginning of Marts and 39 and 5 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 Marts 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 much 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 chose 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 [29], 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 the computed temperature profile for the next 24 hours […]. If we could see the scheduling 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 degrees. 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 but when it drops below 19 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 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 some 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 the previous CHI research has stressed the importance of HCI community involvement in smart grid technologies development [4, 16]. 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. We found that while participants appreciated automatic scheduling of heating, it further uncovered uncertainties and misconceptions regarding system behavior, which could lead to missed opportunities for the system to plan a more sustainable schedule. While we achieved these insights as one contribution of the paper, we identified a number of themes that constitute a second contribution. This will be discussed and illustrated in the following.

Heat Pumps and Beyond

We chose heat pumps as a case for our study on shifting of electricity consumption, as they have previously proven useful for studying automatic and intelligent scheduling of energy usage in an eco-interaction design, because of the way they produce heat and consume electricity. 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 will produce 50% of the energy production by 2025 [5]. 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 [5], although there is still a need to explore domestic implications of combining technologies [15]. As our study has shown when "smart" becomes transparent, is particular challenging when working with the domain of 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 practices, let alone observing lived domestic experiences with the technology supporting sustainable behavior with automatic characteristics [4, 7, 25, 29]. Our study has shown the potential such interaction deployed in the field and is essential for obtaining a better understanding of the challenges eco-interaction designers of smart grid technologies face in the future. This approach is 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 [25] 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 excellent 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 [29]. 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*; letting the system act sustainable, *comfort;* upholding users comfort preferences, and *convenience*; hiding complexity to the user by delegating schedule task to the system.

Costanza et al. [4] 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 peoples' 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 [10, 12, 30]. 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 effective and useful 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 [28] 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 the usefulness of our eco-interaction design for discovering and acting on opportunities for reducing heating costs in the home.

Our findings 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.

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