Facilitating Flexible Electricity Use in the Home with Eco-Feedback and Eco-Forecasting

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ABSTRACT

Over the last decade there has been an increased focus on changing domestic electricity consumption behaviors. While the usual approach has been to facilitate reduced consumption, recent work has started looking at facilitating more *flexible* electricity use as a means of shifting consumption to more favorable times. This approach means that people may behave more sustainably without necessarily using less electricity. Exploring this emerging approach, this paper presents a study of flexibility in domestic electricity use as facilitated by an eco-feedback system with forecast information about price, availability of green energy, and grid demand. The prototype system was deployed in three households for 22 weeks. Our findings show that flexible electricity use is far from trivial to achieve in domestic households. The details of this is relevant for understanding people's ability and willingness to shift electricity consumption, and for the design of systems that facilitate doing this.

Author Keywords

Sustainability, energy consumption, flexibility, domestic.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

In the last decade there has been an increased interest in domestic electricity consumption and how to enable more sustainable in their energy consumption behavior. So far, the general focus of this work has been on facilitating *reductions* in energy use. In recent work, however, it has been recognized that the underlying goal of reduction only addresses one side of the opportunities for achieving better sustainability. While it is, of course, good to lower our use of resources, in the case of electricity, the challenge is actually more about being *flexible* with our power consumption activities, so that we use electricity when its available from renewable energy sources.

However, as domestic electricity use is usually connected to the routines of everyday life this poses a problem.

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Domestic routines are often connected to activities that primarily occur during the evening where cooking, washing and other electricity consuming activities are performed (Nyborg and Røpke, 2013). This results in peak demands, which are the result of accumulated electricity usage from simultaneous domestic activities across a majority of households. The peak demands cause two problems. Firstly, it makes it difficult to utilize the changing availability of green energy, as peaks are concentrated around specific times. Secondly, the electricity suppliers have difficulties providing electricity for the sudden demand using the existing infrastructure. Eliminating peaks requires users to alter their electricity consumption pattern, which is referred to as peak shaving, or more commonly flexibility.

An expensive solution would be to expand the electricity infrastructure (e.g., replacing power cables and transformer substations) (Hogan, 2013). The less expensive alternative would be to enable the consumers to move their electricity consumption away from peak demand periods (e.g., by running the washing machine during the night). Flexibility in power consumption can be achieved if households are able to move their consumption away from peak periods and utilize the green energy available. Flexibility can be achieved by taking either approaches but the most flexible result would be achieved by meeting both conditions, that is, utilizing available green energy when load on infrastructure is low.

Within HCI research on the topic, focus has predominantly been on reducing electricity consumption to achieve more sustainable behaviors. Facilitating flexibility in electricity consumption, however, is a relatively new approach. Most research that explores flexibility has focused on exploring technologies for automating flexibility, for example smart grids and peak shaving algorithms (Johnson et al. 2011; Mishra et al. 2013). The tendency has been that technology has more control than human agency in these designs. The impact of flexibility-enabling technologies that give control and decision making to the users has remained largely unexplored. The need to explore the impact on electricity consumers is especially important to create effective business models.

Responding to this, in this paper we present a study of a study of possible flexibility in domestic electricity use as facilitated by an eco-feedback system with forecast information about price, availability of green energy, and grid demand. We present our prototype system, eForecast, our study, and findings from our interviews.

RELATED WORK

Domestic households are responsible for a large part of the overall electricity consumption in western countries (Fisher, 2008; Fitzpatrick and Smith, 2009; Kjeldskov et al., 2012). Previous work on sustainability within the field of Human-Computer Interaction falls primarily within what Mankoff et al. (2007) refer to as sustainability *through* design, aiming to deploy technology facilitating sustainable behaviour. The majority of this work focuses on providing people with "eco-feedback" to enable or help them reduce resource consumption or environmental impact by showing them information about their usage and behaviours in the past (Froehlich et al. 2010). In the work by Froehlich et al. (2012) an evaluation was conducted of eco-feedback displays for water usage at fixture level in North America examining design elements such as data and time granularity. While showing a great deal of interest in this level of data detail, this study also showed that additional information would be needed to facilitate changes, such as comparisons over time, and with others, for contextualizing performance. Also focussing on water use, Pathmanathan et al. (2011) investigated the use of mobiles for eco-feedback promoting water conservation in Australia. This study found that although information about past water usage might reveal unknown usage patterns, and be useful as context for future usage, it is not sufficient in itself for enabling people to behave environmentally sustainably. In a similar study, Kjeldskov et al. (2012) investigated eco-feedback on domestic electricity use in Denmark, finding that in order to facilitate people changing their usage behaviour in the present and near future, other information than just retrospective data is needed. Also focussing on domestic energy consumption, based on interviews and surveys, Pierce et al. (2011) present a set of terms capturing actions and strategies of energy conservation including *shifting* it. In Pierce and Paulos (2012) this is extended with a review of energy related work in which the idea of using energy differently by, for example, shifting consumption informed by demand response system is further discussed. Also influencing the HCI research agenda on eco-feedback Strengers (2011) shows how domestic energy use is deeply embedded in non-negotiable everyday practices and not reflected well by the view on families as potential "micro-resource managers". Together, these works have contributed to defining as well as broadening the scope of interactive system design for eco-feedback and sustainability.

Responding to some of these these insights on HCI and eco-feedback, Yang et al. (2014) studied people's interactions with conventional eco-intelligent thermostats in domestic households, and propose the use of *eco-feedforward* to communicate actionable suggestions and their expected impact. Also aiming at being prospective rather than retrospective, Costanza et al. (2014) explore the use of a washing machine agent, using data on future electricity price, combined with chargeable batteries, to minimize the cost of a wash. Similarly, Schrammel et al. (2011) discuss the use of basic power generation forecasts for helping users align energy consumption with availability, and, in our previous work, Kjeldskov et al. (2015) presents a functional prototype of adding such forecasting to an eco-feedback display.

In a study together with the Danish energy supplier DONG Energy, Nyborg and Røpke (2013) investigated how flexible consumers could or were willing to be in terms of their electricity use through either automated appliances or actively shifting their consumption to different times of the day. This study found that consumers were more willing to be flexible with so-called "necessary" practices (e.g. cooking or washing), than with "luxurious" ones (e.g. watching TV).

In the work by Riche et al. (2010) it is argued that facilitating sustained behavioral change through eco-feedback, can be achieved through a three-staged approach: 1) raise awareness, 2) inform complex changes, and 3) maintain sustainable routines. In the first step, eco-feedback should make people aware of their consumption and patterns of use. In the second step, guidance should be given to enable changes to people's behavior. In the third step, feedback should be given to maintain good new practices. Because new behavior has a tendency to relapse shortly after such studies end, they also propose empirical study durations of no less than three months.

eFORECAST

We developed an eco-feedback display called eForecast to facilitate discussions with householders about time shifting electricity consumption. Whereas the idea behind eForecats is described in Kjeldskov et al. (2015), here we focus on the findings from our empirical study. eForecast is based on the two first stages of Riche et al., (2010) framework for facilitating sustainable behavior: *raising awareness* and *informing complex changes*. To raise awareness eForecast display information about the household's past electricity consumption pattern, which is very similar to other eco-feedback displays. To inform complex changes eForecast display forecasts about future electricity consumption as well as forecasts about price, availability of green energy, and grid demand. Providing such additional information is relatively new in relation to eco-feedback displays, and enables the user to assess and predict the past and future electricity consumption patterns of the household.

eForecast consists of six different screens, which the user can swipe between (figure 1). Four of these screens display different visualizations of the household's recent electricity usage combined with forecasts from external sources: price (red line on Fig. 1a), grid load (yellow line on Fig. 1b) and green energy availability (green line on Fig. 1c) against household usage (blue line). The fourth screen shows all forecasts combined (Figure 1d). On these four screens, the vertical line in the middle indicates current time, with the last 12 hours represented on the left (solid line), and the forecast for the next 12 hours on the right (dotted line). For example, on figure 1d it can be seen that the household has an expected peak of electricity use just after 12:00 and an increase in use after 19:00 (blue), and that there will be an increase in available wind power during the afternoon, leveling out

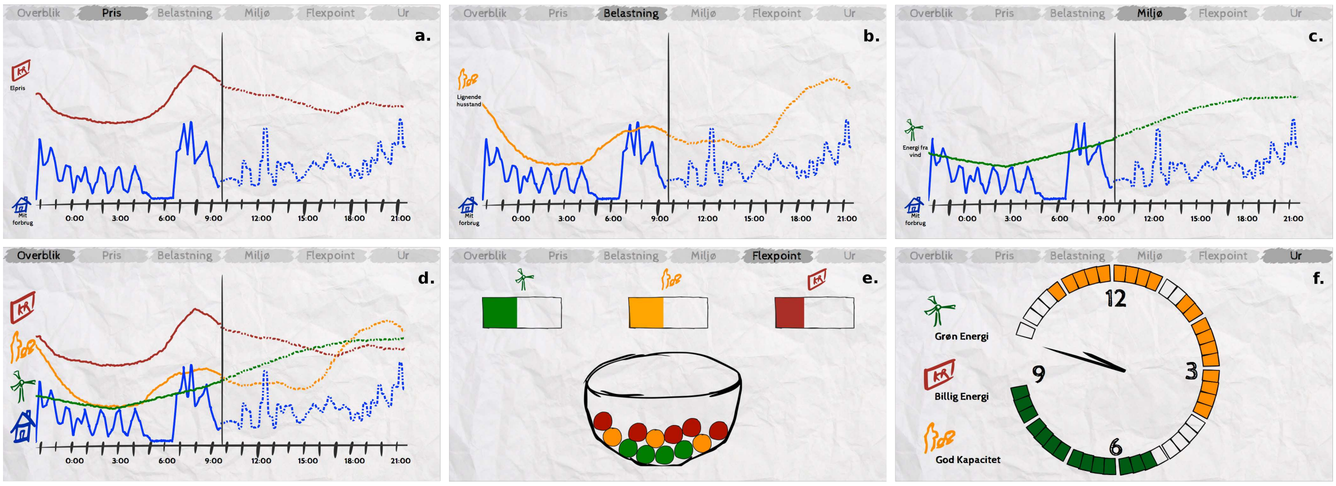

Figure 1. eForecast System views - (a) price of electricity against usage (b) load on infrastructure, (c) availability of green energy, (d) overview, (e) changing consumption visualization, (f) opportunities for further changes.

after 18:00 (green). Price will go down until 17:00 (red), and demand is expected to go up after 15:00 (yellow). It can also be seen that there is a "sweet spot" between 16-17:00 where price and demand is low while the availability of wind power is high. Based on this, one might want to delay the 12-13:00 peak by a few hours.

As well as forecast information, eForecast provides a simple visualization of how well the household has performed in terms of using electricity at favorable times. This is done through a "bowl" of "Flex Points" (colored dots) in green, yellow or red corresponding to the colors of the graphs. Finally, a clock view (Fig. 1f) shows when it will be favorable to consume electricity in the next 12 hours and what kind of benefit will be gained: financial (red), load shaving (yellow) or environmental (green).

Implementation

Electricity use data is collected from a home automation system, ZenseHome, which contains real-time measurements from the individual power outlets in the house. This is used to record, display and predict usage in 15-minute intervals. Electricity price data is collected using web scraping of Northern Europe's leading power market, Nord Pool Spot, where electricity pricing is negotiated at least 12 hours in advance. Data on the expected availability of wind power is based on weather forecasts from the Open Weather Map weather service. The expected demand on the power grid is calculated on the basis of data about similar households' combined patterns of consumption, taking into account the day of the week, and the month of the year. The household's expected energy demand is calculated in the same manner but based on their own history of use.

EMPIRICAL STUDY

We used eForecast as a technology probe (Hutchinson et al., 2003) to introduce users to flexibility related information. The probe was an instrument to facilitate discussions in in-home interviews. It was deployed in three households for 22 weeks, in continuation of the deployment of a previous study, which ran for a period of 10 weeks. Twelve in-home, semi-structured interviews, four with each household, were conducted.

Participants

Three families in the Northern Jutland region of Denmark participated in our longitudinal study of domestic electricity use. All households had the ZenseHome system required for collecting usage data installed. Household 1 (H1) was a married couple in their thirties with 3 children aged 4 and 1 (twins). Household 2 (H2) had a married couple in their early forties with no children. Household 3 (H3) was a married couple in their 40s with two children aged 10 and 16. The families came from different towns and did not know each other. They were all middle-class households, with both parents in permanent jobs.

Procedure

Semi-structured interviews were used to allow a more open discussion towards flexibility. At the same time allowing us to explore in depth issues where the focus was on users' motivations and understandings towards shifting electricity consumption. The interviews were conducted in the participants' households to keep them in the context of their electricity consumption and their everyday settings. It was mostly the adults in the households who participated in the interviews. We conducted four interviews with each household. At least two members of the household were present at each interview. In the first interview we introduced them to eForecast and the concept of flexibility. To make sure that the information in eForecast was seen often we asked participants to place the display in a central spot in the home (Fig. 2). We guided them through the six system views and explained the meaning and purpose of each. We also gave participants a small user manual to use if they had any questions. The first interview introduced them to the price (Fig. 1a), load (Fig. 1b) and green energy (Fig. 1c) views. After each subsequent interview a new view was added to the system in the following order: composite view (Fig. 1d), Flex Points view (Fig. 1e) and further opportunities clock view (Fig. 1f).

Figure 2. The eForecast prototype in use

As participants became more familiar with the idea of shifting their consumption, we ask them more in depth questions on topics such as motivational factors and usage of eForecast. Each interview started with an introduction to subjects that would be discussed this time. The first part of the interview asked for any new thoughts on shifting their electricity consumption, and the last part focused on the use of the system and its features.

Interview Setup and Data Analysis

Interviews were conducted by three researchers and audio recorded for later transcription and analysis. The technology probe was also used to log information about the use of eForecast (e.g., which views were used and for how long), which enabled us to validate participants' statements with actual interaction data. During the study period we logged a total of 631 interactions. Household electricity consumption data was also logged giving approximately 2.4 million electricity consumption data entries, 4058 price entries and 1475 wind data entries.

FINDINGS

In terms of persistent changes in consumption behavior during the study period, we did not find evidence of this in any of the households. However, we did find examples of an increase in consumer awareness and understanding towards flexibility.

Understanding Flexibility

It was generally difficult for the participants to understand flexibility, as they had never thought about the peak demand problem before. When discussing electricity consumption participants' main focus was towards conservation, in terms of financial savings and reducing environmental impact. People thought that by simply turning off appliances during peak periods they could become more sustainable, *"Well, we can turn off appliances during the peak demand hours"* (H1), which is true, but they were surprised by the idea that the same could be achieved by shifting their electricity usage to a non-peak or green energy time.

Generally, participants' reasoning for shifting consumption was good even though most were clearly driven by a conservation mindset. Throughout the study several participants kept referring to conserving electricity. They all had a high level of awareness of their electricity consumption through prior experience with their smart home metering systems. In thinking about flexibility, most participants focused on larger appliances such as the washing machine or the dishwasher. These appliances were seen as the obvious candidates for shifting their operating times, as they consumed large amounts of electricity and were not so dependent on daily household routines.

Learning Flexibility

The study period was characterized by a steep learning curve. It was difficult for the participants to understand why they had to shift their electricity consumption. This was related to their attitude towards consuming electricity. They saw electricity as a service offered by the electricity suppliers. Participants mentioned that since they paid a fixed price per kWh, they wanted to be able to use electricity at any time. After we explained that given current usage trends, expanding the infrastructure would most likely result in an increase in the electricity price, they began to understand the consequences of not shifting their electricity usage. However, even by the end of the study it was difficult for participants to understand why they do not necessarily have to conserve electricity to become sustainable and that by shifting some of their electricity consumption to more favorable times of the day, they would also achieve more sustainable behavior.

It was quite difficult for participants to relate to the fact that they could use the same amount of electricity as they already did, or even more, if they just did it at a more favorable time. However, as we introduced possibilities such as automated appliances and dynamic electricity pricing one of the participants mentioned:

> *"An appliance might consume more per year than an average matching appliance, but it consumes at more favorable times of the day, which over time will result in a financial saving. Then it would be worth investing in the flexible appliance."* (H2)

It was difficult for participants to understand, why shifting heavy consuming activities would make a difference, as they perceived their electricity consumption as just a small part of the overall infrastructural load. Participants stated that they believed that their actions would not affect the peak demand periods, as they believed the impact of their usage to be insignificant. After we explained that perhaps communities making a joint effort could make a difference, they started to reflect on how shifting their electricity consumption might influence the national consumption.

The Non-Flexible Nature of Electricity Consumption

Electricity consuming activities are tightly connected to everyday domestic routines. Shifting electricity consumption to more favorable times of the day thus involves changing these routines. Participants stressed that some of these routines are highly interdependent:

"The everyday life of a young family is crammed with electricity consuming activities, which are dependent on non-domestic activities." (H3).

Shifting electricity consumption therefore means altering the structure of domestic life, making flexibility in electricity consumption difficult. A general attitude towards electricity consumption was that different activities could influence when appliances had to be operated. Some activities have a very strict deadline (e.g. making breakfast or getting children ready for school), while others have non-specific deadlines (e.g. doing the laundry or dish washing).

Shifting the use of appliances with strict deadlines was not a possibility. Participants stated that devices, such as the TV, stove, kettle and coffee machine, were examples of appliances with strict deadlines. Because of the role of these appliances in the daily routine and their impact on other activities, they cannot be moved. For example, postponing the use of the stove would influence, when they were able to attend non-domestic activities. Participants mentioned that toasting bread could not be planned as it is driven by sudden needs, making the activity less likely to be moved. As Household 1 said:

"You cannot be flexible with the toaster, because you toast bread when you toast bread." (H1)

Consequently, the use of coffee makers and toasters is tightly coupled with activities requiring strict timing and are therefore seen as non-flexible in their use.

Morning activities have stricter deadlines than evening activities, where the time schedule is more tolerant:

"The mornings are characterized by a tight schedule, whereas evenings have no strict deadline." (H2).

The main reason for this is that evening activities do not depend so strongly on non-domestic activities, (e.g., leaving for work). However, activities like preparing dinner can have strict deadlines in households where family members participate in evening non-domestic activities (e.g., leisure sports).

In cases where everyday routines are deviated from or completely abandoned, electricity consumption is more likely to be shifted. These deviations mostly occur on weekends or during holidays, where scheduling is not as important or reliant on outside events as in weekday life. For example, one of our participants decided to shift his electricity usage during a period where he had time off from work. We found that during periods where participants deviated from routines there was a greater tendency to attempt changes in their consumption.

Flexible Appliances

Activities, such as doing the laundry or operating the dishwasher do not have the same level of temporal importance as activities that are more directly connected to strict deadlines. Appliances that operate with limited user interaction relieve them from being an activity with strict timing and therefore open to greater flexibility of use. Similarly washing and drying clothes can be done relatively independent of other activities. One of our participants shared that on a few occasions he had planned to shift dish washing to a different time. Another stated that he had postponed doing the laundry. When participants were asked why they could shift usage on these appliances, they replied that operating them did not require them to be present at the times they were consuming electricity. This pattern repeated across a number of appliances.

The appliances with the greatest potential for flexibility were battery-powered devices (e.g. tablets and laptops). The reason for this was that they store electricity, so the need to charge it was not as urgent and could easily be planned for. As Household 3 said:

"You can be very flexible with the portable music player as it is battery-powered. Because of this you aren't dependent on its here-and-now energy usage since it is charged or has energy accumulated." (H3)

The use of battery-powered appliances is not limited to times where they are connected to an outlet. Battery-powered appliances can be used throughout the day, and can be charged over night, makes them easy candidates for helping to shift electricity consumption without affecting household routines.

Even though the usage of some appliances could be moved, participants explained that appliances that could automatically consume at favorable times would be a preferred solution. They stated that devices, such as the washing machine, dishwasher and dryer, were examples of appliances that could be automated, but added that it should always be possible to overrule automation:

"The tumble dryer could be automated, however, you must have the option to overrule and start it right away" (H2).

A frequently given example of how to be more flexible, was to start the dishwasher and set it to finish within some time range, when the clean dishes would be needed. The idea was that it should automatically decide when to wash within that time range depending on price, load and green energy constraints, but again, they wanted the option of overruling the automation in case they needed dishes right away.

Encouraging Flexibility

The motivation that participants gave as main incentive for shifting consumption was the price of electricity:

"In my opinion the price is clearly the primary motivation. If the price was doubled in the high load hours, I would definitely start to move my electricity consumption." (H1).

Participants mentioned two scenarios of how the economical aspect could influence their choice. There should either be an economic benefit for flexible behavior (e.g., reduced electricity bill) or a cost for non-flexible behavior (e.g., higher cost per kWh). Both the environment and the load on infrastructure were mentioned as negligible in terms of their influence on the choice of shifting consumption. Reducing environmental impact was, however, mentioned as an additional benefit.

Despite the fact that the environment was stated to be a negligible motivating factor, one of the participants mentioned that he had used information about the availability of green energy to shift his use of the washing machine. He explained that it was due to the lack of daily routines on the weekends and the fact that the price didn't have any direct correlation with their electricity bill. In this case choice of shifting the usage of his washing machine, was motivated by a concern for the environment. Less structured routines on weekends and more spare time available makes it possible to encourage families to coordinate and plan the electricity consumption of some appliances to be more flexible.

Discouraging Flexibility

One problem with eForecast was that even though it visualized real data, participants did not react to it because it had no consequence for them:

> *"You would probably have to punish people, because if I'm avoiding these things and my neighbor has that 500 watts light bulb on all the time with no consequence [...] I would feel that my struggle was for nothing."* (H2).

Most participants said that one of the discouraging elements against shifting electricity consumption is that they pay for a service that the electricity suppliers provide. They mentioned that it is the suppliers that have a problem, and therefore it was not of direct concern to them. One of the participants said that if the electricity suppliers gave them information about the consequences of not shifting some of their usage, it would probably make them reflect more on their electricity consumption patterns.

Participants also mentioned that there is a big difference between the choice of conserving electricity and shifting electricity consumption. They explained that they saw conservation as a one off investment - usually accomplished by replacing old equipment with new sustainable equipment. After the purchase of such equipment they were no longer required to invest more time or money in the project to be more sustainable. The choice of shifting electricity consumption would interfere with consumers' daily routines, and would be very time consuming as they would have to coordinate between the daily activities to see which usage could be moved.

Obstacles for Flexibility

One of the major obstacles for shifting electricity consumption was the lack of time that families often experience. One of our households was a small family of two. The participants in this household expressed that they were more likely to be flexible, because they did not have any children to take care of. However, another one of the participating households had an especially busy schedule with three young children. While they did look at the display from time to time to get information, they said that they failed to act upon it due to lack of time. They explained that in a busy schedule, activities often depend on routines, and changing these would require a substantial effort and time, which they didn't have:

> *"As our life situation is right now, with 3 kids, it has to be automated. We don't have the time in our daily life to study the information and act upon it."* (H1).

In Household 1, electricity had to be consumed at a specific time as the result of a sudden need. For example, at night if their children were awake, it was not possible to shift electricity consumption as warming a bottle of milk was important at that moment. Likewise, there are other similar examples of electricity consumption that participants were not willing to move due to immediate need (e.g. making a cup of coffee).

As a result of using eForecast one of our participants had already thought of shifting his electricity consumption:

> *"Sometimes we decided to postpone the dishwasher, however, we forgot to start it later on." (H2).*

The motivation for his planning was the price, but he said that then he needed some indicator or reminder of when to start the dishwasher. He explained that he decided to postpone the dishwasher, but then he was caught in some other activity and forgot all about the dishwasher. He told us that shifting his electricity consumption, at least on the dishwasher, wouldn't be a problem if the system had notified him.

Another obstacle that made participants less inclined to move their electricity usage was the lack of information about the problem of peak demands. Some of the participants said that the availability of information related to shifting electricity consumption through eForecast made them reflect upon their electricity usage behavior. When we introduced participants to the concept of shifting electricity usage, they were not aware of the problem. The problem was out of sight, and therefore it was difficult for them to relate to. As a consequence, several participants initially thought that the problem might not directly affect them or that their effort would be insignificant. Later, when participants were properly introduced to shifting electricity usage, they began to reflect upon their earlier thoughts. Participants said that being informed by electricity suppliers about the consequences of not shifting electricity consumption would eventually direct their attention towards the problem. They also agreed that to make consumers change their electricity consumption behavior, information about the problem was not in itself sufficient.

However, information was considered a necessary starting point, if they should invest time or money in technologies that facilitate shifting electricity usage.

DISCUSSION

Our study introduced the participating households to information such as the electricity price and the availability of green energy. Participants reported on how and why they used the information. The information made available to them related to shifting electricity consumption through eForecast made participants reflect upon their electricity usage behavior. We argue that eForecast made the concept of flexibility more tangible by exposing them to information making it possible for them to shift their electricity consumption.

Members of the participating households reported that they occasionally moved some of their electricity consuming activities to other times of the day. An example of this is that one household moved the laundering activity to later that day as the availability of green energy was increasing over the day. Another household stated that on a few occasions they had postponed the dishwashing activity as a result of a reducing price of electricity during the evening.

Changing Routines

Our findings indicate that it is difficult to make consumers move their electricity usage. Making electricity consumers consider when to shift usage forces them to reflect more on their daily routines. It poses a challenge to consumers to continuously consider when to consume. We argue that consumers need to change the way they consume electricity for the idea of flexibility to become a reality. As electricity consumption is an integrated part of everyday life, consumers will need to continuously consider their consumption behavior during the day until they have created a routine where flexible appliances can be operated at favorable times.

Family composition can influence the structure of routines. One of the participating households consisted of two adults and three small children, while another household consisted of only two adults. Their family composition clearly influenced the way they thought of their ability to move electricity consumption. The family with three small children was very much constrained by their daily routines as the children had to be fed at specific times. In contrast, the household with only two adults said that they had a greater potential for shifting usage, because of their different family composition. It would seem that family composition and routines are relevant, when considering the potential of shifting usage.

When examining the possible flexibility of domestic activities, some appear to be potentially more flexible than others. Activities closely linked to deadlines, (e.g. breakfast and other ”getting out the door” activities) are less likely to be flexible, and therefore electricity usage connected with these activities is also less flexible. Users mention that these activities are often placed in the morning. Other activities such as cooking are placed in the evening and should be considered as possible candidates for shifting. It appears that morning routines are more difficult to affect, because they are well defined and users do not have the time to reflect on them in a busy schedule. Evening routines are in some cases easier to influence, because the evening schedule is more tolerant to change. This difference means that some activities will most likely not be considered when aiming to shift electricity consumption.

Motivation in Everyday Life

Motivating users can be difficult without them having knowledge of the problem of peak demand periods. Participants mentioned that the first thing electricity suppliers should do is to make consumers more aware of the problem by giving them information. Without informing electricity consumers, they will not be aware of the peak demand problem and therefore they won’t be able to take action. Electricity suppliers have not yet had any real focus on making users move their electricity consumption. We argue that raising awareness of peak demand problems definitely should be considered in the future as one of the first steps in shifting electricity consumption. A large part of the three-staged approach suggested by Riche et al. (2010) is concerned with giving information. He argues that information about the electricity consumption behavior should be given as the first stage. Furthermore they argue that additional information is needed on the second stage.

Motivating flexibility in everyday domestic households is not a trivial task. Our earlier work indicated that people conserved electricity because of the price or saving the environment. Price was perhaps a dominant motivation, however, the concern for the environment was still of importance. This has changed as the focus shifted from conservation to shifting electricity consumption. As focus changes to flexibility, the price becomes the sole motivating factor. A possible explanation is that shifting electricity usage is a time consuming and routine interrupting challenge. Our findings indicate that interrupting these routines could create the necessary window of opportunity to motivate users in other ways, such as consuming electricity when green energy is available.

Price as Motivation

As stated earlier there are two ways to cope with peak demands from a flexibility point of view. One can either move electricity consumption away from peak demand periods or consume when there is a large production of green energy. These factors are, however, mentioned as negligible from the consumers point of view when concerning shifting electricity usage, as such actions interrupt daily routines. Our findings suggest that price is the strongest motivational factor to enable the consumers in shifting their electricity usage. The current problem is that peak demands do not directly influenced by the price of electricity, as price is currently fixed.

The question then arises of how to use electricity price so it directly influences peak demand periods. We see two ways of achieving this with a focus on price. Firstly, it could be achieved by making the price depend on either the load on infrastructure or the availability of green energy. Secondly, it could be achieved by making the price depend on both. Such initiatives could motivate users by reducing their electricity bill and allow them to shift their electricity consumption away from peak demand periods for reasons of personal gain.

Existing electricity price does have an influence on electricity consumption behaviors. Several of our participants were well aware that the actual electricity price was a small amount of the total amount paid for electricity. Participants mentioned the possibility of dynamic pricing. Our participants stated that there would need to be a substantial amount of gain for shifting their electricity consumption to a better time, before they would consider it. This supports the eFlex project finding that users were more likely to move electricity consumption if the price fluctuated a substantial amount (Nyborg and Røpke, 2013).

Maintaining Sustainable Routines

We developed eForecast as an example of a flexibility-enabling eco-feedback display to obtain knowledge about consumers' motivation, understanding and interests to move electricity consumption. We designed the system based on the two first steps from Riche et al. (2010): raise awareness and inform complex changes. The third step of the approach presented by Riche et al., maintaining sustainable routines, requires the user to continue flexible behaviors. From our experience we can see that for this to happen, the technology deployed needs to fit the home, and the users evolving information needs. We found that in some cases participants actually did plan to shift electricity consumption, but forgot it later. eForecast did not support notifying users when they have planned to shift electricity consumption. We believe that technologies should be have this facility so that they can help consumers shift their electricity consumption. This would involve technologies that issuing notifications to remind users to consume at favorable times, or systems that make postponing the use of flexible tasks and appliances easier.

Improving Current Devices

Previously we discussed factors that should enable users to shift electricity consumption. We found that the use of appliances that are used for activities, which are a result of a sudden need have less potential of being shifted. Coffee makers, kettles and toasters are examples of devices that users see as having much less potential for flexibility. This makes sense as using such appliances cannot be postponed for any great amount of time (e.g., you need your coffee now and not in four hours).

Appliances such as the dishwasher or phone charger, are often less routine dependent. They are easier to move as the usage can be planned and are often not involved in daily routines. Shifting electricity consumption on devices like the dishwasher or phone charger are more likely, as they only need a minimal amount of user interaction and can be postponed for longer periods of time. One possible reason for this is that the storage capacity of these devices provides users with a greater window of opportunity for shifting electricity consumption. We found that the consumer can plan usage on such devices, but they tend to forget to implement it. To prevent this, automation could be used as a tool to move some of the responsibility away from the consumers to the appliance, so that they would not have to remember when to use electricity.

Several of our participants mentioned that they did not have the time to continuously shift electricity consumption. It could therefore be questioned whether asking consumers to shift consumption is the right approach. Shifting electricity consumption can be achieved in two ways (Nyborg and Røpke, 2013). The first, active flexibility, relies on users taking an active part in shifting it. The second, automating flexibility, relies on integrating functionality into appliances that can shift electricity consumption without user intervention. By automating appliances you move the responsibility away from the consumers and enable electricity suppliers to gain some control of when those appliances are allowed to consume electricity. But should electricity suppliers focus on active or automated choices?

Even though our participants expressed that they wanted automated appliances, they did not want to lose control. An example could be the dishwasher where they wanted an overrule option for sudden dishwashing. We argue that the solution should be found somewhere in between an active choice and fully automated appliances. We argue that electricity suppliers, in the future, should focus on appliances where usage can be scheduled and require less user interaction (e.g. setting a timer), but remain under user control in terms of when they are set to operate.

CONCLUSIONS

We have presented a study of users' motivations, understandings and interests towards shifting electricity consumption to either save money, reduce load on current infrastructure or use green energy. We used eForecast, a flexibility-enabling eco-feedback display, as a technology probe with the intent of facilitating discussions about shifting consumption.

Our findings show that electricity consumers have a difficult time understanding and learning why they should shift their electricity consumption to different times of the day. We found that shifting usage was difficult for them because it required them to move routinized daily activities. Shifting electricity consumption was more realistic for appliances where usage could be planned ahead of time or required limited interaction to operate (e.g. the phone charger or the washing machine). We found that the main motivation for people bothering to shifting their electricity consumption was saving money.

To get users to shift electricity consumption to more sustainable times requires the right motivation, which we argue requires both information about the problem and an economic benefit for consumers. We argue that electricity suppliers should focus on appliances where usage times can be scheduled and where less user interaction is required, providing a balance between automation based on sustainable energy forms and users making active choices about shifting their electricity consumption.

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