Doing the Laundry with Agents: a Field Trial of a Future Smart Energy System in the Home

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ABSTRACT

Future energy systems that rely on renewable energy may bring about a radical shift in how we use energy in our homes. We developed and prototyped a future scenario with highly variable, real-time electricity prices due to a grid that mainly relies on renewables. We designed and deployed an agent-based interactive system that enables users to effectively operate the washing machine in this scenario. The system is used to book timeslots of washing machine use so that the agent can help to minimize the cost of a wash by charging a battery at times when electricity is cheap. We carried out a deployment in 10 households in order to uncover the socio-technical challenges around integrating new technologies into everyday routines. The findings reveal tensions that arise when deploying a rationalistic system to manage contingently and socially organized domestic practices. We discuss the trade-offs between utility and convenience inherent in smart grid applications; and illustrate how certain design choices position applications along this spectrum.

Author Keywords

Energy; smart grid; field trial; autonomous agents; real-time pricing; demand response

ACM Classification Keywords

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

INTRODUCTION

Energy systems are undergoing a shift from simple distribution grids, where energy flows from generator to user, to 'smart' grids that aim to orchestrate user demand and variable supply. As part of this shift, autonomous agent-based technologies have been proposed to support the consumer in monitoring and controlling their home energy consumption [2,3]. As well as making the grid 'smart', these technologies also make its complexity visible and require more interaction with users [27]. Our research aims at understanding how users might experience future 'smart' energy infrastructures enmeshed with the 'messy realities' of their everyday lives. In particular, we focus on a plausible future scenario in which the price of electricity varies dynamically due to interplay of demand and intermittent supply caused by renewables (e.g., wind) [35].

Specifically, we present the design and deployment of Agent B, an agent-based booking system to support effective energy use in a real-time pricing scenario. Users interact with Agent B to book timeslots of washing machine use so that the agent can help to minimize the cost of a wash by charging a battery at times when electricity is cheaper. The agent predicts the price based on weather forecast data, monitors price development and notifies the user if the price rises more than a user-defined threshold.

Our approach relies on envisioning [19,26], and prototyping future infrastructures; and, crucially, deployments to study technology as part of everyday life in order to "pay heed to the [...] routines of the home" [9:263]. We deployed Agent B in 10 households in the UK to uncover the tensions that may arise when introducing a system appealing to rational optimization into everyday life. In particular, how does a system through which users need to declare their intentions fit with existing laundry practices; and what kind of implications for everyday interaction with agent technologies in the home does this expose?

Findings from interviews and system log files of the month-long deployment offer evidence that some people can readily integrate deferring and scheduling into their laundry practices. Our results reveal how some households integrate the Agent B booking system effectively into the contingent resources drawn upon to manage the laundry (e.g., social relationships, activities, and the weather); and how others struggle to fit in the change with their more spontaneous practices. We discuss the inherent trade-off between economic utility and user convenience that systems premised on rational choice embody, and highlight design choices to inspire future HCI research and design of smart grid applications for the home.

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RELATED WORK

HCI's engagement with energy systems has largely adopted a persuasive computing approach to motivate reductions through consumption feedback [6,13]. Researchers have subsequently expressed concerns that HCI needed to be more sensitive to the framing of sustainability [7], the broader societal context [31], and the role of everyday routines, and the social order of the home [30].

Related to our work, researchers have also stressed the need for HCI to engage more with emerging energy systems such as smart grids [21]. We respond to this call by prototyping a future smart grid before the technical infrastructure is fully implemented and by deploying this 'in the wild' to understand how this might be situated in the everyday practices of the home. Our work follows on from prior research that has explored reactions to envisaged scenarios presented as animated whiteboard sketches [27]. To ground our approach, we review relevant smart grid techniques, and in particular studies of real-time pricing (RTP) and its impacts on everyday routines. We also highlight studies of 'historic' homekeeping technologies, before focusing on smart home energy systems.

Smart Grids and Real-time Pricing

As energy generation shifts to renewables and micro-generation, the interplay between supply and demand will be increasingly difficult. Critical problems such as *peak demand* can lead to power outages, and make current grids inefficient [5]. These issues will be exacerbated due to the supply of renewables fluctuating with the weather (e.g., sun, wind, waves, tide), and limited storage capacity [18]. As a response to this challenge, government agencies promote *demand response* techniques such as dynamic or real-time pricing (RTP) to incentivize shifting demand to off-peak periods through higher prices at peak times [35]. RTP, in particular, is framed as providing high potential rewards to consumers [11].

Various pilot programs report on successful aspects of dynamic pricing from as early as the 1970s [16]. A recent pilot study with nearly 700 households in Chicago reports reductions during peak hours in response to price increases, and stresses the supportive role of "energy management and information technology" [1]. A survey of 109 dynamic pricing pilots in North America, Europe and Australia has shown that consumers respond to dynamic pricing with a median peak reduction of 12%, and also finds that the availability of in-home and online displays lead to further reductions [11]. The authors also contend that consumers are now used to dynamic demand-based pricing from airlines, hotels, car rentals, and rail travel.

Studies that look more closely at how people actually experience RTP are sparser, and appear to favor more simple pricing models [8]. To that end, experimental residencies in campus smart homes give some insight into how the usage of certain appliances such as the dish washer, washing machine and tumble dryer are more amenable to shifting than other activities such as cooking or entertainment [20]. However, checking prices and managing usage schedules interfered with the residents' daily routines, and a later automated solution was reportedly not trusted and overridden every time [ibid.]. These reports suggest that in practice, dynamic pricing and its interfaces can have a significant impact on people's homekeeping routines. These have previously being considered within studies of 'homekeeping technologies'.

Homekeeping Technologies

Washing is no stranger to technological intervention. The development and marketing of the washing machine was motivated by the promise to save time and labor. However, scholars have argued that with its introduction the amount of unpaid work in the home done by women actually rose dramatically [28], and that washing had become "a solitary affair between mother and the machine" [15]. Edwards and Grinter stress the relevance of such considerations for the discourse of UbiComp technologies, in that *"the washing machine encourages a critical perspective on whether smart home technologies are 'labour saving' or whether they [...] merely shift the burden of work"* [9: 265]. This is an equally important question for 'smart' grid technologies.

More recently, studies of cleaning robots such as the Roomba suggest a reconfiguration of the dynamics of cleaning responsibility and housekeeping practices and that both opportunistic and planned cleaning increased [12]. Our prototype bares analogies to the Roomba in that a mundane housekeeping activity is augmented – and changed – with the introduction of a 'smart' system.

Smart Home Energy Systems

Visions of future home energy management are often framed in terms of 'smart home' technologies. While 'smart fridges' that 'know' their contents, washing machines that are 'smart grid ready', and thermostats that learn have become product reality, researchers are developing much more proactive systems including automatic appliance control [23] and automated home heating based on occupancy in homes [29] and offices [10].

Our particular interest focuses on understanding the interaction with 'smart' energy systems that embed autonomous software agents [24]. These techniques enable the proactive 'smarts' in the system that are seen to be essential to automate some of the burden of managing demand to achieve efficient energy consumption while minimizing the impact on users' comfort [25]. Our work is aimed at relocating these technologies from labs, simulations, and model homes into actual inhabited homes to expose how these technologies are used and appropriated, and how they rub up against everyday energy practices such as 'doing the laundry'. A critical challenge for HCI will be to understand the required balance between user control and autonomy, in order to make these systems intelligible, accountable and trustworthy.

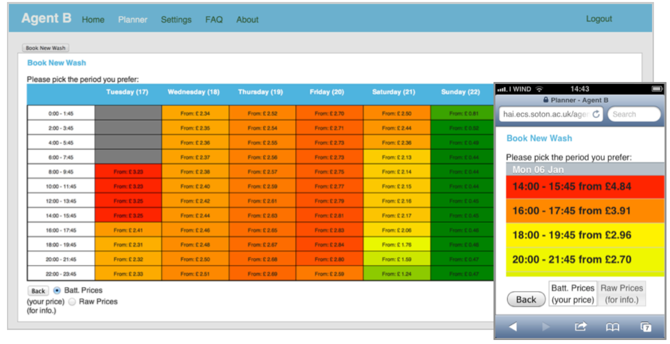

Figure 1. Booking interface showing heat-map price calendar (full size and mobile view).

PROTOTYPING THE FUTURE

Envisioning future technologies has become a staple feature of UbiComp and HCI research [26]; however, prototyping to study the *experience* of interaction with future domestic infrastructures poses significant challenges. The home setting needs to be augmented with a technology that believably realizes a vision of a future scenario the residents can relate to and interact with in a field trial 'in the wild'. Therefore, we developed a prototype that focuses on augmenting laundry practices surrounding the use of the washing machine. To ground the prototype as part of a future energy infrastructure, it is embedded in a real-time pricing scenario in which a battery is charged when energy is cheaper. The scenario is made tangible to participants through financial rewards, as detailed further below.

Real-time Pricing & Battery Scenario

Our future scenario, drawn from policy makers' current ideas, is that *electricity price varies in (near) real-time* (every 15 minutes), based on the fluctuating supply of renewable energy and the current grid demand. We define an electricity price as a function of the amount of energy generated by wind turbines in the UK and of the total aggregate national energy demand obtained from real data from public Web services [cf. 23]. While demand fluctuates in more predictable ways based on the season, time of day and day of the week, wind generation is more variable. Weather also brings forecast and uncertainty into the study in ways that participants can relate to. Exploring the issues raised through uncertainty and how participants deal with it in their everyday interaction with the system and each other was an important question for our study.

Large capacity batteries also play a key role in future energy scenarios with fluctuating supply; proposals range from making use of electric vehicle batteries to micro-storage for household usage, for example for off-grid homes [3]. In our scenario, we deploy a *virtual* battery that can be charged when electricity is cheaper, so that consumption can take place regardless of whether the actual real time price is high. We employed a leakage model based on the chemical property that batteries self-discharge (the reasons why batteries 'go flat'). As keeping the battery charged is associated with a cost, it is best to charge it as late as possible before consumption, requiring the system to known when users are likely to use energy.

Agent B

Our scenario is instantiated through a booking system through which residents book *washing slots* in advance. Each slot is shown to users as incurring a different cost depending on energy price and battery status. The system prototype combines three key interactive elements: a calendar based ***slot booking interface*** that allows users to schedule washes; a ***software agent*** running in the background that monitors and predicts the price and charges the battery when electricity is cheaper; and a ***notification system*** for reminders and price change alerts. User and agent interaction and participant's energy usage in their homes is captured to provide a detailed log.

Software agent

Planning when to charge the battery is a task well suited for a software agent because of the repetitive and tedious nature of continuously monitoring the changing energy prices and computing the price forecast. The agent calculates a charging schedule for the battery based on the current 7-day price forecast and the user's bookings, taking into account the booking's duration and energy. The price forecast is based on energy demand and weather forecast (to estimate renewables supply) information obtained from the Internet. The prices displayed to the user are based on the price forecast and charging schedule.

The charging schedule is also updated every 15 minutes, taking into account changes in the pricing forecast or the user's bookings. In effect, the agent re-plans every 15 minutes and decides whether to charge or not. It is worth highlighting that in charging the battery the agent does *practical* work for the user, rather than, for example, just providing a suggestion about when to do things.

Booking interface

A web-based booking interface was designed to let users schedule washes (Figure 1), on the basis of which the agent can then optimize the charging schedule. The design was informed by existing web-based booking systems, such as those for booking flights and grocery delivery time slots.

To book in a load of washing, users select the washing program they wish to run, upon which the agent calculates and displays a 7-day calendar, showing the predicted price of the selected program at each possible time slot both in terms of cost in GBP as well as in heat-map style (ranging from green to yellow to red to indicate low, middle or high prices; see Figure 1). The interface also optionally displays "raw prices", i.e., how much it would cost to run the wash at real-time prices without optimization (i.e. no agent, no battery). The raw prices are provided for reference, and to make the benefit from battery and agent salient to users.

The web interface also includes a dashboard page that shows the next scheduled booking, together with its price

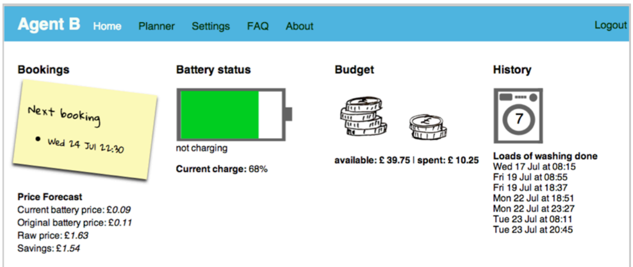

Figure 2. Agent B Dashboard.

forecast, the battery status, the current spent and available budget, and a summary of the washes done so far in the trial (see Figure 2).

Notifications
Agent B also sends two types of notifications via email or SMS: alerts and reminders. As the booking price is based on a forecast, the agent monitors price increases. If the price rises above a certain user-definable threshold (w.r.t. the original price), the agent will alert the user and suggest the nearest alternative time to run the washing when the price is lower. In addition to alerts, reminders are sent 10 minutes before a booking starts. Through the system settings page, users can adjust the price increase threshold, choose SMS and/or email to receive notifications, or disable them altogether.

Technical Implementation
The system was implemented as a web application using open source tools and open APIs. The front-end is optimized for both desktop and mobile web browsers. The agent runs every 15 minutes – at these intervals the battery charging schedule is updated as outlined above.

Off-the-shelf energy monitoring
Energy consumption is monitored through off-the-shelf digital networked electricity meters (AlertMe). These meters receive washing machine consumption data from a plug socket sensor, and through a home broadband connection transmit the information to the provider's server. The data is then retrieved by Agent B at regular intervals, stored in a database, and used to calculate the users' washing costs based on battery and real-time prices.

Real-time price predictions
The formula used to define the energy price per kWh, *p,* is:

$$p = \max\left(0, k_1\left(d + \left(\frac{2}{w+1}\right) - k_2\right)\right)$$

where the demand *d* and the wind *w* are normalized values for total wind generation and national grid demand in the UK. In effect, higher demand leads to higher prices, and higher winds lead to lower prices. Two parameters k_1 (set to 5) and k_2 (set to 0.2), are introduced to adjust the price range to the reward amounts used in the trial by taking into account typical amounts of energy used by domestic washing machines. The price was fixed to zero when the formula result was negative (as per the maximization). It is worth highlighting that while the relation of wind and demand to price is fictional, its variations and the uncertainty of its forecast follow actual weather forecast data, thus providing realism.

Battery model
The battery capacity was modeled to provide 1kWh of energy to the washing machine, roughly corresponding to 1.5 to 3 washes depending on models and programs. The charge rate was modeled so that the battery can be fully charged in about 40 minutes. The battery leakage rate was set to 2W. The agent needs to take into account the trade-off between low energy prices and delay between storage and usage time. It is worth emphasizing that the point is not to attempt and accurately model a real battery, but to create a credible situation from a user's point of view (that we will revisit in the findings section).

THE STUDY
Laundry practices involve more than simply washing and drying clothes; they are enmeshed in the ordering of people's everyday routines [31] and hinge upon a multitude of factors external to the laundry itself, such as occasions and activities for which clothes are washed, or when it is favorable to dry clothes. Asking people to schedule their laundry requires them to *plan ahead* to book loads of washing. This is likely to rub up against a 'system of practices' dominated by contingent demands. We are interested in the extent to which this impinges upon tacit and taken for granted expectations and disrupts the ways in which "the structures of everyday life are ordinarily and routinely produced" [14]. We wish to elucidate the socio-technical issues involved in realizing the advantages offered by smart grid technologies by elaborating how users actually understand a future smart grid.

Participants
We recruited 10 participants to cover a range of lifestyles (see Table 1). The duration was framed in terms of 15 hours of washing machine usage, rather than a fixed number of days, to be fair to people's differing amounts of laundry.

Budget and Reward
Participants were allocated an online budget of £50 at the beginning of the study from which their consumption cost was taken over the duration of the trial. At the end of the study, participants were rewarded with the amount of money left in their budget. The rationale was both to offer an incentive to engage with the system, and to make saving have an actual, tangible impact on participants. The idea of using monetary incentives to simulate dynamic energy pricing is in part based on an early study in which participants received payments of the value of electricity saved [32]. In addition, participants received £30 as compensation for the time spent on the study.

Procedure
Upon registering interest and verifying that participants met our criteria of having an accessible washing machine plug, we visited them in their homes to install the monitoring

	Occupants		Occupation	Property	Loads/ week	Does laundry for…
H1	**Alexa**	F(40s)	Teaching assistant	rented	2-3	self
H2	**Rob** **Jean** Angela	M(20s) F(20s) F(40s)	Club Security Youth worker n/a	rented	2-3	all 3 - -
H3	**John** **Jane** Frances	M(40s) F(40s) F(10s)	Caretaker Caterer Student	owned	3+	- all 3 -
H4	**Don** **Laura**	M(30s) F(30s)	Sports instructor Teacher	owned	3+	both both
H5	**Mark**	M(25)	PhD student	rented	1-2	self
H6	**Natalia**	F(20s)	Researcher Sociol	rented	2-3	self
H7	**Oscar**	4xM(20s)	UG students CS	rented	1-2	self
H8	**Valerie** Anne	F(30s) F(20s)	Researcher Psych n/a	rented	1-2 n/a	self self
H9	**Donna**	F(30s)	Lecturer	owned	1-2	self
H10	**Carl** Tim	M(20s) M(20s)	Clinical analyst n/a	owned	2-3	both -

Table 1. Participants. Bold names indicate interviewees.

equipment, conduct an entry semi-structured interview and demonstrate the system to them. The demonstration included both the desktop version and the mobile version, if participants had a smartphone. We also explained the real-time pricing battery scenario and answered any questions.

After participants had completed at least 10h of washing we invited them to take part in a semi-structured exit interview (due to differing washing habits some had not completed 15h when we had set time aside to do interviews). The interview focused on their use, adoption and understanding of the system.

FINDINGS

We report findings from the semi-structured interviews (through thematic analysis [4]) and present information on system usage based on automatic interaction logs.

Entry Interview – Existing Laundry Practices

The initial interview explored participants' existing laundry practices. When asked when they typically do the laundry two participants said they preferred midweek, while three preferred weekends; but most (5) told us they did it at any time, often referring to the accumulated amount of laundry or the lack of clean clothes.

An important issue was *how they decide when to do the laundry*, and who else might be part of that process. This often involved coordination with others (e.g., understanding when partner's clothes are needed or sharing the washing machine with housemates). Activities or jobs can also affect when people decide to do the laundry:

"Well, with my night job at Forest on a Tuesday and Thursday, I've got to have that kit washed and ready to go. And then obviously with college, being a physical activity… teacher, I rack up a bit of kit that way." [Don]

'Having time' is a reason stated by many, particularly in relation to hanging it outside to dry (only one of our

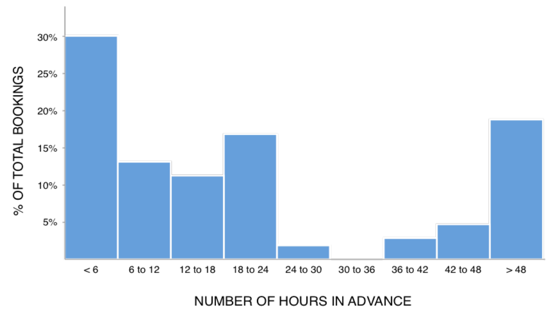

Figure 3: The distribution of booking advance notice hours throughout the trial (from automatic interaction logs).

participants uses a tumble dryer). Unsurprisingly, the weather played an important role in external drying:

"If the weather's nice in the morning then I can put a wash on in the evening or through the night and it's ready to go out in the morning, so I don't have to use tumble drier then." [Jane]

The interviews confirmed that a participant's decision when to do the laundry is contingent on factors relating *to the laundry itself* (having enough for a load or needing clean clothes), and *to a multitude of external factors*, such as involving others and fitting in with their routines, activities that create different loads or requirements for clean clothes, having time specifically with regards to hanging to dry (a common practice in the UK) and ironing, and the weather so that clothes can be hung outside.

System Usage from Automatic Interaction Logs

Participants lived with the system for at least a month. They accessed the system in almost equal measure from smart phones (45% of page views) and from desktop computers (41% of page views), a smaller number of accesses were from tablets (14% of page views). Access took place on average every two to three days, with some participants accessing the site almost daily and some as infrequently as once every 10 days. The two main pages, the dashboard and the planner, were loaded approximately as frequently as each other. Overall 155 bookings were made, corresponding to an average of 15.5 per participant and a booking every 5 days. The bookings were made on average 25.95 hours in advance (SD: 31.04), with a rather varied distribution, as illustrated in Figure 3. The majority of times (77%) participants booked their washes, only 26 washes were done without booking.

The log data shows that participants' punctuality of washing varied: while 5 participants were never more than approximately half hour off-schedule, others were less precise, between half an hour and one hour early or late, and occasionally several hours off. Figure 4 illustrates how punctual the washes were over the entire study.

Understanding Use

While log data demonstrates the extent to which the system was used, interview data was analyzed to understand how

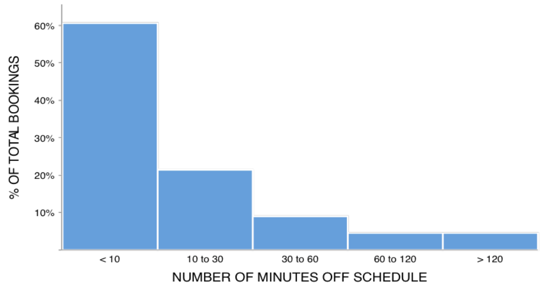

Figure 4: Punctuality of washes, the distribution of minutes washes were off schedule throughout the trial.

people understood the system. All participants reported the system interface made it very easy to make bookings and most of them commented that the heat-map style color-coding to indicate price levels was helpful.

When asked about the purpose of the system and the booking procedure, most participants highlighted it as a tool of organization *("I think it organizes, it's trying to organize you." [John]),* with a particular emphasis on an awareness of cost and economic budgeting: "*It did make me more aware of what I was spending, and by looking at it and thinking about the different prices, then, yes, it did make me think about when I was going to do my washing." [Alexa]* The comments show that most participants found the system easy to use, whilst beginning to reveal an orientation towards the economic utility of the system as well its impact on personal laundry management (e.g., 'it's trying to organize you'). Indeed, the economic benefit was sometimes mentioned explicitly:

"*[The system] helps you save money and do things a bit more economically. Think about how you're washing things and how much money you're spending and how economical you can do things." [Rob]*

Fitting with Everyday Routines

Even though everyone found the interface very easy to use, we recorded a wide variety of reactions regarding the integration of Agent B in people's everyday routines. For those who were already structured in their laundry routines the system made sense and was readily adopted and even helped structure their planning further:

"We probably plan our washing anyway, just because he can wear like three outfits in a day. So, if I don't… keep on top of my washing, I end up with a big pile. [...] Not like rigidly plan or like even to a piece of paper. [...] Because we already think about how we do our washing anyway, it didn't... it's just like an extension of it.." [Laura]

Others reported more of a process of 'getting into the habit' of using the booking system:

"Once you get into the habit of doing it... I must admit, the first couple of times I thought, oh, I need to wash. I'll check. ... Now I don't. I just think, right, I need to do some washing. I'll have a look at it [the interface], and it's just... It has become second nature." [Alexa]

Two participants told us how they liked the scheduling introduced by the system. Oscar, for example, described the adoption of booking as an improvement of their existing practice:

"[Booking] probably helped resolve any build up issues I had with washing. […] Before, I would just realize I've got no clothes the night before I'd go to bed, so I'd shove it in, and then it would get dried for an hour, and then I would have slightly damp clothes whereas now, where I'm doing it structured. I was doing it always in the morning, when it had time to hang up and dry, and yes, so it's definitely improved the way I think about doing the washing" [Oscar]

One mentioned the more active involvement in managing one's budget as his main reason to adopt this kind of system in the future:

"You feel like if you're sort of managing a bit better, sort of, you know, you can actually save money yourself rather than just assume the power company's going to save you money. […] Yes, I was managing it more, saving a bit more money and actually sort of doing something active to actually save that money" [Mark].

These statements show how the system's requirement to plan ahead was readily integrated into routines that already entailed planning, were made a habit, improved existing practice or provided a sense of empowerment.

Fitting with the Slots

Some participants' statements suggest the booking of slots changed existing laundry practices in a disruptive way. In particular, two participants found the system difficult to fit into their laundry routine:

"It was hard to figure out when I was going to do a wash and book it far enough in advance anyway. Because you don't know when you're going to have enough clothes [...] to put in or when the towels need doing [...] so apart from like booking the towels in every two weeks or whatever and getting into a routine with it, I couldn't see like an easy way of doing it. And it was almost as if I'd have to plan my washing around my normal routine rather than just doing the washing whenever you had time sort of thing which is how I normally do it. Like I work from home as well four days a week so I just do it whenever the sun's out.." [Carl]

This participant struggled to fit to the slot. For them the contingent nature of laundry made early prediction of when they would have a washing difficult. In contrast, one of our participants started to schedule her washing around the slots, sometimes even going a great deal out of the way to comply with the bookings.

"It stops, makes you think. […] It makes you have to plan things a lot more. …it does create more work, yes, because, I mean, when you're washing and you've got a family, I

mean, you can't, you don't expect loads of washing, you can't plan exactly when you go to wash." [Jane]

Accounts by this participant indicate that as a result of high prices she would even not do the washing at all:

"I did find it, as I said, there were some times when I wanted to be doing washing, and I thought well no, because it's a really high price, so... I just left it." [Jane]

Others also reported fitting washing to an available slot, sometimes even deferring a washday: "*I looked on Wednesday and the Thursday prices were really quite high. So then I did it Friday. I think I did it Friday morning." [Alexa]* Deferring would also happen on a much more fine-grained level, in order to fine-tune the price in the region of pennies.

Sometimes the slot prices would take precedence over other factors that are normally considered when planning laundry, such as the weather:

"A few days ago when it was really nice, and I could wash some curtains and whatever else, and put them outside to dry... I thought no, I'm not going to, because it's, you know, it's on a really expensive time, I'll wait until there's a cheaper time to do them. But then you don't know what the weather's going to be like." [Jane]

As well as changing times to fit with the cheaper slots participants also reported how forward planning affected the size of loads and separation of laundry:

"I found I was doing smaller loads, because I wasn't doing as... I wasn't just saving it up and putting it in, because I had to think about when I was going to actually do it. Whereas I would maybe wait while the washing basket was full and then split it into two loads and just do it when it was ready." [Jane]

These quotes indicate the extent to which participants were prepared to go in response to dynamic pricing. At the same time, a tension emerges between the rational planning required to use the booking system and the contingent ways in which laundry is organized. Furthermore, the apparent orientation to the cost of bookings suggests that our experimental method of using a budget as a study reward worked in making real-time pricing tangible.

Booking Strategies

Participants elaborated on the various factors that needed to be considered when booking a slot, including having free time, piling up of dirty clothing, as well as price:

"Pretty much when the washing filled up, that was when I just went ahead and booked it in. [...] I tried to make it fit around my day. If not, I tried to do the cheapest one. I tried to get a good price. If I could get the cheapest one, I'd get it. If I couldn't, I'd just get something in between. Try not to go for the most expensive." [Rob]

Statements also indicate how the UIs heat map color coding was drawn upon as a resource: *"[...] you looked at it and went, that's green and that was pretty much my strategy, going for the greenest one that was available." [Oscar]*

Most participants booked 18 hours or less in advance (Figure 3). Booking earlier required more complex forward planning and in this case participants would frequently book extra slots and several back-to-back slots for more flexibility: "*I found that I was booking quite far in advance, like three or four days. I was booking more slots to cover washing I would have in the future.." [Oscar]*

These statements illustrate strategies adopted to make the system more malleable around people's routines. The latter quote in particular illustrates an attempt to work around the rigidity of booked slots into more flexible time frames that could accommodate rescheduling and the uncertainty of how washing would accrue. Rescheduling was also prompted by the system, which would provide notifications to users when significant events occurred.

Notifications and Rescheduling Slots

The system sent two kinds of notifications, reminders 10 minutes before a booking, and price change alerts when the price of a booked wash went above an adjustable threshold. No one turned off the notifications by text message (SMS), and few opted in to additional email notifications. Most left the price increase threshold at the default value of 50p, even though some decreased the threshold (resulting in more frequent alerts).

All participants told us they found the reminders useful, for example: *"I didn't forget all the time but a couple of times I did forget and it was like, oh... So, it was quite helpful to have a text message, just a quick reminder." [Rob]* or: *"the reminders were good, especially when you were booking a couple of days in advance." [Alexa]* Reminders also provide reassurance that the system was working as intended, thus increasing trust.

The price change alerts were oriented to in different ways, in that they provided a mechanism to monitor the real-time price fluctuations.

"The alerts were definitely helpful. It was interesting to know when something was changing [...] I quite liked being out the house and getting notifications of what's happening back in my house. So, that was quite a nice aspect of the notification." [Mark]

In some cases the alerts prompted participants to reschedule the booking to a cheaper time slot. Some SMS alerts offered the option to reply 'GO' to automatically rebook the wash at another cheap alternative time slot. However, none of the participants made use of the alternative slot suggested by the agent:

"I wanted to see which slot would be cheaper myself, rather than going for the next cheapest one, on the system, but I suppose, if I was using the system for a longer period, I

would have just started to be like, I would... I don't need to go, the planner will sort it out for me" [Oscar].

Notifications were appreciated for their function to remind and alert to price changes. However, participants preferred to retain control of rescheduling rather than just accepting the system's automated option.

DISCUSSION

Our study exposed participants to an envisioned future energy system in their own homes. The participants' reports of the ways in which they adopted the system and made it fit in with existing routines suggest that participants were able to experience the envisioned energy scenario and reason about the challenges of adopting such a system in real life. This is critical given the long timescales involved in developing energy supply infrastructures. When combined with the design of an experimental reward it was possible to exploit simple hardware to develop and deploy a prototype that made a future scenario with local storage and variable pricing *visible* and *tangible*, echoing related work that explored a 'local energy' storage scenario [22]. The heat-map representation of pricing was appreciated by our participants for raising awareness of the trade-off between convenience and cost of washing. Further visibility was provided by the SMS notifications, reassuring that the system was *doing work* and enabling lightweight monitoring of its operation.

Our study confirms that deferring can be readily integrated into existing laundering practices [22,33]. However, while the findings show that all participants used the system fairly regularly, their orientation to the system and the ways in which they situated it within their everyday routines was quite varied.

Orienting to the Agency of Agent B

Agent B foregrounds the complexity of the grid by exposing users to a real-time pricing scenario, and at the same time it attempts to alleviate such complexity by optimizing the battery utilization. However, users did not relate to the booking system's purpose in terms of charging the battery in response to the pricing. The complexity of the autonomous agent continuously monitoring electricity pricing and its forecast to arrange the charging of the battery remained 'hidden' to most participants. Instead, participants oriented to the booking system as *a tool to organize* their laundry, they understood the purpose of the booking as a schedule for them (to be more organized, to remind them etc.) rather than as a schedule for the system (so that the agent could optimally charge the battery).

The Booking System as a Contingent Resource

A striking feature of the accounts offered by our participants was the ways in which they fitted the booked slots to their laundry practices, and vice versa, the ways practices were adapted to accommodate the bookings. The booking system became a further resource drawn upon in managing the negotiated activity of planning and doing the laundry. The system was adopted into the contingent "ordering of everyday routines" [31]. Participants drew upon the booking system alongside other contingent resources, such as social relationships (with house mates and partners etc.), commitments (e.g., jobs and activities), the weather, and planning the time to do further laundry-related activities (hanging to dry and ironing).

Of course, different personal circumstances played an important role in whether the system was supportive or disruptive of people's routines; to evoke a few, the students in their early 20s (h5 and h7) enjoyed the more active involvement in managing their budget and the way the system made them have to schedule, and as a result be 'more organized' with their laundry. The couple in their 30s (h4) who plan their laundry and share the task appeared to be able to readily integrate the scheduling system almost as a direct support of their existing scheduling practice. On the other hand, the busy late 20-something with the irregular working hours (h10), as well as the Mum who does the laundry for her daughter and husband (h3) sometimes struggled to fit in the system with their perhaps more spontaneous and less predictable ways of managing the laundry. These experiences are indicative of the tensions raised by the requirement to *plan ahead* for an activity that may ordinarily be accomplished in more ad hoc ways.

In particular, when considering laundering as a "sequential enterprise" that includes the ordering of multiple laundry-related activities within the flow of everyday life [31], the booking system introduced a *rational planning* requirement into a network of contingencies. This created potential interactional problems, including **a) making the booking** (negotiating laundry and drying/ironing time, price and weather forecasts, planned activities, commitments etc.), and **b) 'performing' the booking** (loading and turning on the washing machine on time, emptying, drying and otherwise concluding the laundering). The arising tensions mirror fundamental challenges in HCI; expressed by Suchman as "the relation between the activity of planning and the conduct of actions-according-to-plan" [34: 21].

Although an exception, Oscar's strategy to turn the rigid booking slots into more flexible time frames (by booking back-to-back slots) is an attempt to accommodate the inherent uncertainty in scheduling contingent activities. In future, it seems that designers could mitigate some of the problems associated with introducing (explicit) scheduling of contingent activities by allowing for flexibility in when exactly the scheduled activities are to be performed.

Trading Utility for Convenience?

Our study has revealed the tensions that arise when deploying a rationalistic booking system to manage people's washing. Agent B is part of a family of systems that are premised on rational choice. Fundamentally, such systems embody a trade-off between utility and convenience. The assumption is that people want to save money, and are willing to explicitly use a system to help them with it. For example, in order to maximize the utility afforded by the booking system (monetary savings and efficient grid operation), people have to do extra work to schedule and perform bookings on time. Legitimate concerns have been raised that people struggle to rationalize their energy consumption; people consume energy as part of convenient and comfortable practices [33]. However, in the face of dwindling resources it is very likely that we will have to compromise in future, and our societies will have to make a choice whether and how much convenience to trade in return for visibility and control of more sustainable infrastructures. We believe that HCI is well positioned to strike the right balance through studying deployments of prototypes *before the infrastructures are fully in place* [21].

DESIGN FOR SMART GRID APPLICATIONS

Whilst automated and autonomous systems may offer great opportunities for interaction with future energy systems, the richness of contingent behaviors in our study suggests that no computational model or smart agent can fully cover the complexity and spontaneity of everyday routines. So we argue that to take advantage of automation it is critical to design interaction around automated systems in ways that make space for users to appropriate the technology to their practices. The findings from our deployment of Agent B offer examples of how users accomplished this.

Future design efforts will need to balance the contingent realities of domestic life with the need for a-priori understanding of energy use. This will include the balance between autonomy and appropriation, between delegating agency and retaining control [17]. A particular balance that will need to be struck is between the grid's need for fixed and optimal energy demand and users' desire for flexible and convenient energy consumption. To provide a starting point for designers to articulate and understand this balancing act we call attention to a design spectrum that exists between utility (in an economic sense) and convenience of use for smart grid applications.

At the utility end of this spectrum users would need to declare their intentions when exactly they wish to consume, enabling the infrastructure to maximize utility for the grid and the user at the cost of convenience for the user. However, the implied limited flexibility can also lead to loss of utility if users are later unable to realize the intentions exactly as declared. Alternatively, to maximize convenience for the user, designers may for example employ learning agents to predict user behavior, similar to the Nest thermostat; thus freeing users of the burden to declare their intentions explicitly. However, research has shown this comes not just at the cost of utility, due to incorrect predictions, but also at the cost of user trust, if the system is not legible and cannot be interrogated [36].

A compelling future HCI research challenge, then, is to identify the design strategies that achieve a balance between utility and convenience for users to adopt in their everyday lives. Systems need to allow self-regulation and flexible adoption strategies, e.g., allow over- or under-booking, back-to-back slots or time frames instead of rigid slots.

Our study revealed that some of the changes encouraged by the dynamic prices went against conventional energy conservation attitudes, as when Jane ran smaller laundry loads to make planning ahead easier. Are smaller loads sustainable if run off-peak? Or does the price distract users from the bigger energy picture? Future research around energy systems should address such dilemmas. Finally, this design space should be extended to taking into account communities of users. Whereas Agent B was designed for individual households, community-facing systems take the burden off the individual households and distribute it among communities. Examples of community systems include bulk purchasing and sharing co-operatives, community demand response and virtual generators.

CONCLUSION

Laundry is a socially organized practice that hinges on a multitude of factors in addition to the laundry itself, such as activities, relationships and the weather. Our findings confirm that laundry is suitable to be shifted in response to real-time pricing, but making and performing bookings can at times prove difficult for people to align with spontaneous practices and the uncertainties of everyday life.

The premise of our booking system, and any smart grid system for that matter, is based on rationalistic assumptions that people are willing to trade-off convenience for utility. We have argued that HCI is well positioned to study the configurations of these trade-offs to achieve a compromise that users will accept in their everyday lives, and have suggested a design spectrum for smart grid applications.

Our deployment in the wild also shows how we can learn about the ways users integrate future infrastructure into their everyday domestic practices. Prototyping future infrastructure enables us as HCI researchers to design and evaluate interactive and autonomous systems to mediate and facilitate this integration. Therefore, we argue that the HCI community should move this line of investigation forward. HCI should engage with policy discussion to envision how infrastructure may evolve, and continue to explore radically new ways for people to interact with energy and other limited resources.

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