Designing Eco-Feedback Systems for Everyday Life

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ABSTRACT
Eco-feedback systems currently frame householders as *micro-resource managers,* who weigh up the costs and benefits of their consumption, and make autonomous, rational and efficient decisions. Reporting on findings from a qualitative study of three Australian energy and water eco-feedback programs utilising an in-home display (IHD) system, this paper challenges this view. The research finds that householders consume energy and water to carry out everyday practices, such as showering, laundering and cooling, which are mediated by social, cultural, technical and institutional dynamics. The paper proposes an alternative design paradigm for eco-feedback systems premised on the realities of everyday life and identifies several design directions that emerge from this new starting point.

Author Keywords
Eco-feedback, smart meters, energy, water, sustainable HCI, consumption, demand management

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g. HCI): Miscellaneous

General Terms
Human Factors

INTRODUCTION

It is unlikely that most of us, on rising from our slumbers each morning, approach every task 'rationally' by consciously weighing up the costs and benefits of a shower, or ensuring we undertake the most efficient load of laundry. In contrast, the activities of everyday life are likely to be mediated by social and cultural understandings about how we ought to look, smell (or not smell) and feel; what we've always done or know how to do; the artifacts, technologies and resource systems which enable what we do; and institutional rules and relationships associated with resource use in the home. However, in-home display (IHD) systems, which provide householders with energy and water consumption feedback, assume that individuals will act as *micro-resource managers* in their homes. By providing householders with data regarding daily, weekly and monthly consumption in both real-time and historical formats, IHDs apply the resource management dictum: 'you can't manage what you can't measure', to the home.

Eco-feedback programs such as those utilising IHDs achieve mixed consumption reductions predominately within the range of 5–15 per cent [12]. However, eco-feedback is likely to appeal only to environmentally motivated people, and conservation benefits may wane over time [8, 12]. It is therefore surprising (and somewhat alarming) that assumptions from resource management continue to dominate the design of eco-feedback systems, particularly given that HCI has a history of designing to support everyday activities in social domains and situated contexts [1, 7, 45], rather than taking existing assumptions for granted.

Of additional concern is that resource management assumptions persist even though researchers have begun challenging them in recent studies [10, 24, 26, 31, 55], including in low-income scenarios where the cost-reflective management of resources might be expected to matter most [15]. Such assumptions are further problematic given that there is *no definitive explanation or theory* of how and why people become environmentally responsible [18]. Therefore, by starting with the 'basic assumption that home dwellers lack information and general awareness concerning household energy consumption' [31]: 244 and by assuming that this information is necessary to encourage conservation, designers of eco-feedback systems may not accurately represent how and why people consume.

Addressing these research gaps is of critical importance for eco-feedback programs given that they are likely to become a ubiquitous part of our lives. Smart meters (which link to an IHD) are being delivered in nearly every developed nation, including most of Europe, the USA, Canada, New Zealand and Australia [13]. Similarly, pervasive eco-feedback programs delivered through IPhone, Google and social networking applications, are designed to elicit informed consumption decisions [16].

Drawing on the results of a qualitative study of energy and water IHD eco-feedback programs in the Australian states of Queensland, New South Wales (NSW) and

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.

Victoria [42], this research critiques the assumptions underpinning these programs and proposes an alternative design paradigm premised on everyday life. The paper begins by outlining the current divide between resource management and everyday life before discussing the methods used to undertake this research. Findings are divided into six sections discussing how aspects of eco-feedback are interpreted and incorporated into the energy and water-consuming practices of the home. The paper proposes several design pathways which emerge from the findings and concludes by calling for HCI designers to do what they do best: focus on everyday interactions and design eco-feedback systems to support them.

THE DIVIDE BETWEEN RESOURCE MANAGEMENT AND EVERYDAY LIFE

The content and design of eco-feedback systems draws predominantly on a resource (demand) management paradigm originating from the disciplines of economics and psychology. Demand management involves the use of financial incentives, market mechanisms, education, information feedback, efficiency measures, or other programs to modify the demand for natural resources [54]. It has emerged in part through a realization that it is unsustainable, not possible, and/or financial unfeasible to provide people with a continuing and unlimited supply of resources. In recent years, climate change, drought and other environmental issues have led to the emergence of many demand management strategies, such as eco-feedback.

Such strategies are premised on the theory of rational choice, which emerges from the view (familiar to HCI researchers) that human action is determined by purposive plans [46]. The theory of rational choice assume that individuals buy, consume or use resources in a manner that provides them with the most personal gain at the least personal cost. These consumer preferences are taken for granted without further consideration of their origins or antecedents. Calculations of utility, price and time are seen to dominate the consumption decisions of individuals [28]. Demand and supply are firmly split—the former focusing on people, and the later focusing on large technical systems.

In contrast, studies of everyday life indicate that demand for resources is highly variable, socially and culturally situated, shaped by sociotechnical systems, and the product of constantly shifting and changing expectations and practices [39, 42, 45]. Changes to everyday household practices, such as laundering, bathing, heating and cooling, are well documented in ethnographic studies. For example, from the 'dry' bodily cleaning practices of 17th century France [51] to the weekly bath of the 19th and early 20th centuries [14] and, more recently, the common daily shower [23], bathing practices have gone through periods of change and flux that do not correspond with understandings of rational action.

Similarly, studies of everyday life indicate that supply and demand are connected rather than split [40, 41, 49]. For example, when we flick a switch or turn on a tap, we are indirectly encouraged to forget about how the service is being provided to us, or what impact it might have. We are faced with 'saver-unfriendly obstacles' such as the shower, which have been designed for consumption rather than conservation [40]: 458. In treating householders as somehow separate from this socio-technical context, we fail to recognise that householders' consumption is shaped by infrastructures, technologies and institutions.

Interestingly, IHDs and other eco-feedback systems are physically located at the nexus between resource management and everyday life—at least metaphorically bridging the divide between these two realms. They have the ability to extend into the home, as well as back out again, thereby potentially facilitating new relationships between the providers and users of resources. Although IHD feedback is clearly premised on principles of rational choice (e.g. providing householders with consumption data so that they can make informed and cost-effective decisions about their consumption) it can also (quite literally) illuminate the normally invisible flows of energy and water in the home, and has the potential to engage with social and cultural dynamics. Therefore, eco-feedback systems may provide new avenues for altering the course of everyday life.

METHODS

This paper draws on qualitative research conducted with 26 Australian households from three research groups (RGs): South East Water's (SEW) EcoPioneers pilot program in Victoria (9 households); the Currumbin EcoVillage housing development in Queensland NSW (5 households); and EnergyAustralia's Dynamic Peak Pricing (DPP) trial in NSW (12 households). Throughout this paper, households are anonymously identified by their RG (EcoPioneer, EcoVillage or DPP respectively) and by number (1-28).

Methods centred on a group household interview, which where possible included children and all other household members. Interviews were conducted at the household's residence along with a household tour, during which photographs of technologies and evidence of practices were recorded to reduce self-reported action bias common with qualitative research [37]. Household visits took between one to two hours. The entire visit was voice-record and later transcribed and coded using the qualitative analysis software package NVivo.

Households were recruited using a range of methods, such as through emails sent by the program deliverers, letters sent to participants by the researcher, and 'snowballing' through contact with participating households. A broad range of household types self-selected for this study

including single-person households, couples of varying ages, and families with teenage or adult children.

Data were analysed using a social practice theory framework [33, 34, 52], which viewed householders as participants in practices, rather than consumers of aggregate resources. Participants were asked if and how the IHD feedback had changed their day-to-day practices of bathing, laundering, toilet flushing, house cleaning, heating and cooling, which constitute the majority of direct energy and water consumption in Australian homes [2, 25] and OECD [30] nations.

The three RGs utilised different IHDs which had been in use by households for between one month and two years. Two of the RGs (EcoPioneer and DPP) utilised a Landys & Gyr ecoMeter IHD, which provided near instantaneous, weekly averaged and historical household consumption data for electricity (and gas and water in the EcoPioneer RG), and could be plugged into any electricity socket in the home [36; see Figure 1]. It also displayed utility tariff rates; daily, weekly and monthly consumption costs; and greenhouse gas emissions [36, 53]. Data were provided in tables and graphs. More detailed data were provided to participants through a personal website portal.

Figure 1. ecoMeter IHD displaying green traffic lights
Source: www.ecoMeter.com.au/ (an updated version of the ecoMeter is available from Landys & Gyr)

The ecoMeter also included a light-emitting diode (LED) 'traffic light' display for electricity consumption see Figure 1). A green light indicated lowest demand (for the EcoPioneer RG) or an off peak rate (for the DPP RG), orange indicated medium demand or a shoulder rate, and red indicated high demand or a DPP 'event' where the price rose between 20-40 times the off-peak rate for a four hour period.

Unlike the EcoPioneer and DPP RG participants, who volunteered to be part of a free trial, residents of the EcoVillage were contractually obligated to purchase and install an EcoVision IHD, which is described by its designers as a 'home resource management system' [17; see Figure 2]. This device provided additional feedback on solar power and energy production, rainwater usage, recycled water usage, gas usage, water level in potable water tanks, room temperature in two rooms, outdoor weather conditions, and hot water temperature.

A potential limitation of this research was the high level of reported participant environmental motivation, particularly in the EcoPioneer and EcoVillage RGs. However, as the findings below indicate, householders' environmental motivation served to highlight how IHD feedback can be limited even when 'preaching to the converted'.

FINDINGS

Converting data into meaningful information

Householders expressed difficulty in understanding data provided through their IHD, a finding reported in other eco-feedback studies [11, 24, 32]. Some householders

Figure 2. EcoVision IHD inside an EcoVillage household
Source: EcoVillage, 10, 25 April 2008

were unable to understand the resource language used:

> On the ecoMeter it says 2.7 tonnes per day. What is a tonne? ... What is two tonnes? There's no description (EcoPioneer, 6).

> We're pretty intelligent, but it's still googalldygook (DPP, 15).

> It says you've used so many kilowattevers (DPP, 17).

Householders could more easily translate the resource management unit of 'litres' into a meaningful unit, through analogies with buckets and bottles:

> When I see a photo of 140 litres in buckets and I think every person uses that, I think that's ridiculous. When I see 80, I think, how can I justify that? Forty—that's four big buckets of water every day! (EcoVillage, 10).

However, when householders were able to understnad their feedback, they often misinterpreted of misapplied the data. For example, because appliances such as an electric kettle, toaster, hair dryer, or oven made the IHD 'scream red' (EcoPioneer, 2; e.g. display a red light or spike in consumption), householders assumed that these appliances consumed the most electricity in the home:

> The main thing was that jug. I can't believe how much power it pulled! … It was more than the air-conditioning! (DPP, 21)

This was not necessarily true, because householders often did not use these appliances for extended periods of time. Consequently, other more ubiquitous appliances, such as the fridge, freezer or hot water service, which are in use most of time but may not cause a sharp spike in consumption, were often overlooked.

Some householders were also unclear how they could use the eco-feedback to answer questions about specific practices or appliances:

> How do you do a formula? How do you work out the answer to that question? I understand that I could read what the gas reading is, but that doesn't answer my question about which is better for the planet... having the whole house going [on gas], or just having that nasty little [electric] heater thingy that's not that warm (EcoPioneer, 1).

In other cases, householders were able to make this link:

> I have a look every morning after I make it out of the shower to see how much we use in the shower and that's how I know it's 30 litres for the two of us; 180 for the washing machine (EcoPioneer, 8).

However, as discussed below, this did not necessarily mean that householders made changes in response to this new information.

The non-negotiability of everyday practices

There was a sense of irrelevance associated with IHD feedback because it alerted householders to practices considered non-discretionary:

> I don't see the point [of the IHD] because we're now aware of which appliances create red lights and *they're all things that you need to use anyway* so …it's not like you're going to say, 'I'm wasting, so let's do something about it' (EcoPioneer, 7, emphasis added).

> It might be nice to know that the toaster is this and the kettle is this, but I don't know what I'm supposed to do about it—have cold tea? (EcoPioneer, 8)

Thus, even when householders were able to link their IHD feedback to specific practices, many dismissed this information.

Some householders believed they were already doing everything they could to reduce their impact. In these cases, the IHD feedback was deemed superfluous:

> I don't think of it at all. … We just ignore it. ... We know how we're living. As I said we have plenty of water, we're heating it as cheap as we possibly can, we've paid initial money to buy solar panels, the house is nice and warm and cosy, and we don't need *that* [pointing to IHD] to tell us how wonderful our lives are, and that we're not actually using too much water [or] electricity (EcoVillage, 13).

Due to the perceived non-negotiability of household practices and/or the seeming irrelevance of the IHD feedback, many householders discussed how they no longer used their IHDs regularly, if at all: 'The novelty wears off after a while' (EcoPioneer, 5). Similar findings are reported by Pierce et al. [31]: 247 in their study of eco-feedback systems, who conclude that the seemingly fixed nature of some practices 'point unambiguously to the fact that awareness does not imply conservation action'. Taking this argument further, this research suggests that disinterest occurs due to the *disconnection* between resource consumption data and the perceived non-negotiability of everyday practices.

Saving visible consumption, overlooking ingrained practices

Despite many practices being deemed non-negotiable by householders, there was a concerted effort to avoid waste and 'save' energy and water where possible, as reported in other studies of eco-feedback systems [24, 26, 32, 55] and thus accounting for the 5-15 per cent savings reported in most studies [12, 13]. To achieve this reduction, householders attempted to make their practices more efficient by, for example, switching from hot to cold water in the laundry:

> I used to wash in hot water to kill germs and bacteria, which is silly because if you put it in the sun it does it all for you really. … I like clean clothes when I wash them. And I suppose growing up in the UK it's just instilled in me,

> *but I've changed that now since seeing the spikes* (EcoVillage, 12, emphasis added).

In particular, householders were concerned with turning the lights off in response to IHD feedback: 'When it's red you have to go around and turn off all the lights, then it goes green and you think, "phew!"' (EcoPioneer, 9).

Householders talked about lighting a great deal during the interviews, *even though they were never directly asked about it*. However, lighting is not the largest consumer of electricity in Australian households [2], and participants could have been aware of this by correctly interpreting their IHD feedback. Gram-Hanssen [20] found a similar focus on lighting in her ethnographic study of routines, which she attributes to lighting's heightened visibility in the home, as well as its historical association with electricity usage. Several householders supported this claim: 'I was brought up in an era where leaving a light on was such a no-no that I just turn them off. I'm a shocker for that' (EcoPioneer, 8).

Householders' keen interest in lighting can also be attributed to the significant attention lighting receives in energy-saving campaigns, where it is considered a relatively easy and inexpensive practice to change [3, 48]. Consequently, lighting has become synonymous with new understandings of 'wasteful' consumption, leading householders to use this practice as a benchmark for their environmental commitment: 'Our house uses next to nothing compared to other houses. They're always leaving lights on' (EcoPioneer, 1).

IHD feedback is framed within this context, which affects householders' ability to make rational decisions. Rather than identifying the most resource-intensive practices in the home and changing them, householders interpret their IHD feedback within a normative framework about what it means to be green or sustainable, undertaking actions such as turning off appliances when not in use, buying more efficient appliances, shortening showers, washing full loads of laundry, and changing light bulbs. Shove [38]: 271 warns against this focus on visible and efficient consumption, arguing that when 'energy is in the spotlight, the services it provides are in the shadow'. In the case of IHD feedback, 'wasteful' energy and water consumption (such as leaving the lights on) is brought to the fore, while other consumption activities (like eating or cooking) silently slip into the background.

The problem with this approach is not that it does not achieve energy and water efficiencies (it clearly does), but rather that it overlooks the taken for granted practices householders engage in, and that these may change over time [39]. For example, turning off appliances at the wall does not change the practices these appliances are implicated in (although it is arguably a new practice in its own right [21]), just as installing a water-efficient showerhead is unlikely to transform the practice of showering. Therefore, eco-feedback does little to discourage the emergence of new and more resource-intensive expectations. It is unlikely, for example, to detract from an aspiration to purchase a Plasma TV or home theatre system, which may detract from the efficiency gains achieved by turning off standby power from entertainment appliances.

Acceptable and unacceptable consumption limits

In both the EcoPioneer and DPP RGs the effect of the traffic lights was the same: it contained a normative benchmark for acceptable and unacceptable electricity consumption, which in some cases applied to specific practices: 'You can see what colour it is so you can tell whether you're doing right or wrong' (EcoPioneer, 8). Traffic light feedback was therefore an important visualisation tool encouraging householders to reduce, and in some cases, increase their consumption. Thus this type of feedback has a similar role to other ambient devices, such as those developed by the Static! project, including the Power-Aware cord which illuminates electricity consumption flows into appliances [6, 22].

Several householders described traffic light feedback as a consumption limit, similar to speed limits on the road:

> It's like the speedo on a car. Years ago, people would drive at whatever speed they wanted to. But now we understand that there's a limit. Unfortunately there are repercussions in terms of driving over the speed limit. I suppose in terms of power, in terms of the cost, it should be the same. It might not come as a fine, but it will come as a cost to you (EcoPioneer, 1).

In the EcoPioneer households, this 'cost' was a moral one, encouraging householders to feel either 'good' or 'bad' about their current consumption. In DPP households, going over the 'limit' during a DPP event had both moral and financial repercussions [43]. However, participants from both RGs responded strongly to the presence of a red light, even though DPP households were being charged significantly more money for their electricity consumption during a red period, whereas EcoPioneer households were not.

The presence of a yellow or red light was the most effective form of IHD feedback, encouraging householders to reduce most of their electricity consumption, albeit for a short time—the precise outcome desired by deliverers of such schemes. Some householders described how a red light disrupted and temporally suspended *all* household consumption by creating a feeling of urgency or danger:

> If it's four red, [my daughter] will have a panic attack! … We call that redlining. … if we see the thing redlining or on three yellows we see what we can do straight away to bring it back down to green (EcoPioneer, 1).

In addition, the effect of an orange or red traffic light was only applied during specific periods of time, potentially endorsing practices undertaken at other times of the day (creating load shifting). Although load shifting is desired by electricity companies to reduce peak demand [43], it does not necessarily encourage conservation.

The effect of a traffic light could also be reversed, with the a green or orange light being seen as *approval* for existing activities. One householder described how traffic light feedback legitimised her existing practice of laundry drying: 'I was always worried about using the dryer so much, but I figure it doesn't make it scream red so it's OK' (EcoPioneer, 2). Pierce et al. [31] express similar concerns with the unintended effects of eco-feedback in their review of these systems.

Divergent interest in eco-feedback

Eco-feedback is premised on the assumption that the people interested in it are able to instigate change. The findings from this and Hargreaves et al.'s [24] study challenge this assumption, finding that consumption takes place through manipulation and debate regarding particular practices within the household. Furthermore, the householders interested in feedback may not dominate household consumption. For example, while men and children in this study were reportedly more interested in monitoring the day-to-day consumption of the household, women and teenagers were often disinterested in the feedback: 'I don't know how to use it. It's got nothing to do with me' (EcoPioneer, 7, woman)

While this research did not aim (nor does it claim) to accurately represent age or gender, other studies indicate women control and undertake the majority of cleaning activities in households, and are often more sensitive to understandings of presentability, body odour, hygiene and cosiness [19, 24, 29, 35]. For example, a mother and her children debated hair drying during an interview:

> SON: No-one uses the hair dryer anymore.
>
> DAUGHTER: Mum forces me to. … It's because she doesn't like the way it looks if I don't blow dry it.
>
> MOTHER: [Laughter] It takes about two seconds, I'm not going to stop because of that [referring to IHD] (EcoPioneer, 1).

Such issues raise an important methodological concern regarding evaluations of eco-feedback, which predominately employ survey methods [8, 53] that may inadvertently target those householders most interested in the feedback, rather than those who dominate the everyday practices of the household. The group interview method employed in this research went partway to alleviating this concern, highlighting a potential discrepancy between householders interested in analysing and managing the consumption of their household, and those who manage and/or dominate the practices within it. Had the research only focused on those householders interested in the IHD, the householders that 'don't know anything at all' (DPP, 20, woman) about this device would have been excluded, even though they were heavily involved in the day-to-day running of the household, and therefore the consumption taking place within it.

Household resource management dynamics

There was some evidence to suggest that householders act as micro-resource managers by weighing up the costs and benefits of their consumption as eco-feedback assumes:

> Sometimes I'll just glance past and have a look at what sort of rate we're on at a certain time and so forth and just to calculate how much, particularly in summer when the air-conditioning's on, how much we've used a quarter, … because I expect it to be about 100, 120, so I often look and think, we're at $80 this month so we're doing really well (DPP, 23).

In this sense, the IHD was used as a tracking device to keep households at or below a designated benchmark. It was also used to police and control 'excessive' householders: 'You could tell, like in winter, when the kids have too many heaters on—"turn the heater off!"' (RG4, 63). Householders used their IHD to regulate particular appliances and household members, predominantly young children and teenagers. In this sense, the IHD can be more accurately described as a *household* management tool.

A notable exception was found in several EcoVillage households, where this device *was* used as a resource management tool to assess whether their demand for energy and water was matching their supply: 'I quite often look at it five or six times a day to see how we're going or what we've got in the tank' (EcoVillage, 10)

In these cases, householders' role can be more accurately described as *co-managers* of supply and demand [9, 44]. Evidence of this role was rarely found in EcoPioneer or DPP households, who were dependent on resources managed by an external authority. A similar finding is reported by Woodruff et al. [55]: 316 in their study of households living in 'sustainable' homes, where participants were engaged in 'active home management' and interested in obtaining data to understand and improve the performance of their homes.

However, even within the EcoVillage RG, there was not universal acceptance of the co-management role, at least not in the sense that it required data monitoring:

> That's how I drive a car but it's not how I'd live at home. I look at monitors all day, I'm not going to come home and look at this one as well (EcoVillage, 14).

Resource management assumption	Findings from everyday life
Householders understand and respond to resource management units such as kilowatts, greenhouse gas emissions and litres.	• Householders often cannot understand resource management units. They may draw on visual analogies (such as buckets of water). • Householders are likely to change practices considered discretionary or wasteful and overlook those considered non-negotiable or taken-for-granted.
Householders will correctly interpret and analyse eco-feedback.	• Householders often misinterpret eco-feedback and/or only apply it to practices that display 'spikes' for short periods of time (like the kettle and toaster).
Traffic light feedback will 'slow down' high-consumption practices.	• Traffic light feedback can 'slow down' *and* 'speed up' consumption, potentially endorsing some practices.
Householders interested in eco-feedback have the ability to change the household's consumption.	• Householders interested in eco-feedback may not control the consumption practices in the home. This may be related to gender (with males and children more interested in data and women dominating household practices).
The efficiency gains achieved through eco-feedback will be sustained over time.	• Eco-feedback is unlikely to challenge changing expectations and aspirations in households (e.g. for central heating and cooling or plasma TVs). • Eco-feedback may have a diminishing return as new expectations emerge.
Householders behave like micro-resource managers when provided with the 'right' information.	• Householders may act as co-managers of resource supply and demand if they have their own resources to manage. • Eco-feedback can be used as a household management tool to police high consumers or track bills.

Table 2. Resource management assumptions contrasted with findings from everyday life

These findings challenge the notion of the micro-resource manager. However, they suggest that householders do engage in the co-management of their supply and demand *if they have their own resources to manage*. Similarly, householders engage in the household management of resources, but this involves dynamics that extend beyond rational decision-making processes.

DESIGN IMPLICATIONS

An alternative paradigmatic starting point

While eco-feedback is successful in reducing or shifting consumption, there are potential problems with this strategy. These can be understood as a product of the resource management paradigm dominating the design of eco-feedback programs. When contrasted with an understanding of everyday life—that is, the way people consume energy and water in order to carry out day-to-day practices—this paradigm is exposed as inadequate. Table 2 summarises the assumptions underpinning the IHD feedback programs discussed in this paper and contrasts these with household findings.

Table 2 highlights the need to rethink the role and design of eco-feedback, rather than simply 'improving' feedback within the existing paradigm. Worryingly, householders may react negatively if more 'bells and whistles' are added to IHDs to enhance and sustain consumption reductions: 'If it started making noises I would smash it with a hammer. … and I'm serious about that, it'd be out the door' (EcoVillage, 13). The following subsections provide brief examples of several design directions that emerge from this alternative starting point.

Redefining the role of eco-feedback

In re-thinking the role of eco-feedback, HCI designers can take inspiration from broader definitions of the term. One alternative form of feedback might involve 'scripting' [4] sustainable interactions into appliances and artifacts, such as making cold water wash the default setting on a washing machine. Similarly, designers of energy and water systems could attempt to reverse the 'fantasy of endless supply' [40]: 456 embedded into technologies such as the shower, by focusing on making energy and water visible. Inspiration can be taken from the Static! project [6] for less data-oriented forms of feedback.

Non-negotiable practices and changing expectations

HCI designers should be wary of immediate efficiency benefits that overlook householders' changing expectations and aspirations—a topic discussed in depth by Shove [39]. Programs and devices that specifically target non-negotiable practices or changing expectations could be developed. For example, Intille [27] reports on a study recommending when to open and close a window and turn on/off an air-conditioning unit in order to save energy associated with household comfort. This study provided practical knowledge to householders so that they could 'learn how to control the environment on their own' [27]: 76. Thus, eco-feedback might involve practical recommendations that lead to new practices which challenge taken-for-granted notions of normality.

Co-managing resources and consumption

This and other studies have found that householders with their own energy or water supply systems are more likely to co-manage their resources and consumption [5, 9, 44].

Eco-feedback can potentially assist in this regard [44, 55]. Similarly, there may be opportunities for eco-feedback to facilitate a co-management relationship between householders connected to mainstream energy and water supply systems by communicating water supply levels, progress towards electricity or greenhouse gas targets, and other resource management aims using language that is meaningful to householders. For example, IHDs could report on progress towards government targets, such as the Victorian Governments' highly successful '155' water campaign in Australia [50], which encourages households to consume less than 155 litres per person per day.

However, in pursuing these opportunities, HCI designers would do well to remember that the household management of resources involves complex dynamics and social expectations both within and beyond the household, rather than the purely rational decision-making processes of the largely fictitious micro-resource manager.

Designing for everyday life

Suchmann et al. [47]: 392 contend that 'to understand technologies ethnographically, it is required that we locate artifacts within the sites and the relations of their everyday use'. Their advice is particularly warranted in regards to eco-feedback systems, where research is required to identify *what people do in their homes*, *how people use energy and water* and *why*, within specific and locally contingent contexts and communities. Research should include those householders dominating consumption in the home, rather than those currently most interested in eco-feedback.

HCI designers can learn from the vast amount of social, cultural and anthropological research discussing how practices change in everyday life [for examples see 19, 20, 32, 39]. These studies report that practices change in relation to past experiences (e.g. growing up in a resource-constrained situation); interactions with family members and peers; and through new technologies entering and exiting the home. Such research provides new directions for eco-feedback systems, including its potential role as a facilitation tool for sharing practical knowledge about alternative ways to conduct practices (such as *how* to take a short shower, shower less or cool a home without air-conditioning), or for encouraging debate within peer networks about what is normal and necessary.

Most importantly, studies of everyday life point to the *non-environmental* focus of consumption practices [39]. This suggests that in order to alter consumption practices; it might not be useful to focus on consumption or the environment at all. For example, if the goal is to reduce water and energy usage in the laundry, one would first need to understand why people wash laundry frequently (e.g. for reasons of hygiene, brightness, freshness or presentability) [29, 39]. The aim would then be to demonstrate how these desired outcomes can be achieved with fewer resources (or to attempt the more challenging task of questioning these expectations).

CONCLUSION

The design of eco-feedback is currently framed within a paradigm of resource management, where principles of efficient and rational decision-making are applied at the household level. However, as this and other studies demonstrate [24, 32], these assumptions obscure other explanations and dynamics of household consumption.

This should not lead us to conclude that eco-feedback is ineffective—it can and does achieve significant resource reductions (and every bit surely counts). However, this approach potentially masks the practices that energy and water consumption is implicated in, legitimises those that don't 'scream red', and overlooks the rise of new resource-consuming expectations and desires—leading to diminishing returns over time as new practices take hold. Without refocusing attention on everyday life, IHDs are likely to remain limited in their scope and potential audience, appealing only to those householders interested in saving energy and water, and achieving a diminishing return over time as new non-negotiable 'needs' emerge.

In taking these findings forward, this paper has suggested that designers of eco-feedback systems must begin by studying everyday interactions and designing devices to support them—a job in which the HCI community is well-versed [45]. Framing the problem (and solution) through a paradigm of everyday life will necessitate paying closer attention to the dynamics within and between households, the practices consumption is implicated in, and shifting expectations of normality.

ACKNOWLEDGEMENTS

This research was conducted within the Australasian CRC for Interaction Design, established and supported under the Australian Government's Cooperative Research Centres Programme. The research was also supported by the Australian Housing and Urban Research Institute (AHURI). The author is grateful to the participants of this study and the anonymous reviewers of this paper.

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