Getting to Green: Understanding Resource Consumption in the Home

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ABSTRACT

Rising global energy demands, increasing costs and limited natural resources mean that householders are more conscious about managing their domestic resource consumption. Yet, the question of what tools Ubicomp researchers can create for residential resource management remains open. To begin to address this omission, we present a qualitative study of 15 households and their current management practices around the water, electricity and natural gas systems in the home. We find that in-the-moment resource consumption is mostly invisible to householders and that they desire more real-time information to help them save money, keep their homes comfortable and be environmentally friendly. Designing for domestic sustainability therefore turns on improving the visibility of resource production and consumption costs as well as supporting both individuals and collectives in behavior change. Domestic sustainability also highlights the caveat of potentially creating a green divide by making resource management available only to those who can afford the technologies to support being green. Finally, we suggest that the Ubicomp community can contribute to the domestic and broader sustainability agenda by incorporating green values in designs and highlight the challenge of collecting data on being green.

Author Keywords

Sustainability, residential resource consumption, domestic conservation

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

UbiComp'08, September 21-24, 2008, Seoul, Korea.

Rising global energy demands, increasing costs and limitations on natural resources have elevated concerns about resource conservation [13]. Ubicomp researchers have sought to address this issue through investigations of context aware power management techniques to help buildings conserve energy [19], increasing awareness of resource consumption in the workplace [20] and building homes that adaptively control a home's energy systems for householders [27]. Still, it is not well understood how householders currently manage their consumption of natural gas, electricity and water, what their frustrations or desires are, or how they currently conceive of resource usage. More importantly, the question of what tools Ubicomp researchers can create to aid domestic resource consumption management remains open.

To begin to address this omission, we sought to understand householders' current practices around resource consumption and management, their use of technology aids in this process and their interactions with outside stakeholders for information on resource usage. In particular, we examine systems which are tightly integrated into the home's infrastructure including the water, electricity and natural gas systems. We were interested in these systems because they depend on scarce natural resources and consume the most energy in the home—for instance, appliances consume the most electricity (33%) followed by air conditioning, heating and ventilation systems (31%) and water heating (9%) [14].

The remainder of the paper is structured as follows. First, we discuss related research on environmental issues, residential resource consumption management and designing systems for the home more generally, as well as prior work on understanding how householders manage their energy consumption. Next, we outline our methods and findings from a qualitative study of 15 households' current practices around resource consumption and management in a US metropolitan area. We find that mostly, householders are unaware of *in-the-moment resource consumption,* i.e., real-time resource usage for different appliances as well as the total household resource usage, because it is so invisible to them. Because these utility systems have faded into the background of householders' lives, we suggest that developing systems that encourage householders to reflect on and re-engage with these aspects of the home's infrastructure is a research agenda that Ubicomp is well poised to fulfill.

RELATED WORK

We provide an overview of environmentally focused research first. Next, we outline research on resource management in the home and relevant domestic Ubicomp research. Finally, we show how our work builds on prior research on resource efficiency.

Environmentally Focused Research

Increasing concerns about global warming, limited natural resources and rising energy costs [13] have spurred exploratory research on helping people engage in more environmentally friendly behaviors. Yet, many of these efforts are not focused on the residential sector or on domestic resource consumption in particular.

One focus area in the Ubicomp community has been to investigate ways to decrease electronic waste from technology products, a growing problem with used and obsolete devices [37]. Huang and Troung have investigated how users are disposing of old mobile phones [21] and suggest ways to break the view of these technologies as disposable—for instance by decreasing the gap between the perceived and functional lifetime of a phone. Others have focused on profiling young technology users (18-21 year olds) and their attitudes towards technology reuse, reinvention and disposal [17]. These authors categorized their target population into 4 subsets and suggest design strategies for sustainable design based on these subsets. For example, those primarily concerned about the global collective fate of the planet are most likely to want to prolong the life of technology products. One suggested design strategy for this group is to give them tools to make informed decisions about "green" behaviors.

At a meta-level, Blevis [4] focused on rethinking the entire technology design process to incorporate sustainability as a core value. He describes a sustainable interaction design framework outlining the implications of a technology design from its creation to its eventual disposal, highlighting the ways we can better design products for reuse, repurposing and to use as inputs to the creation of new products or a "cradle-to-cradle" mentality [26]. Another research focus is to increase awareness of climate change by showing people how their behaviors affect the environment for better or worse. For instance, Mankoff *et al.* have experimented with increasing awareness on climate change using social networking sites [24].

Residential Resource Consumption Management

Less research has focused explicitly on helping householders manage resource consumption in the domestic space using technology. Psychologists have already shown that with proper feedback, real time-information at salient times, and goal setting abilities [25,33,39], households can have up to 10% energy savings with small changes in behavior. Yet most current methods of tracking resource consumption, such as via utility bills, remain inadequate [10]. For instance, these bills often only arrive at the end of the month whereas householders need real-time feedback to alter their consumption. Even when online histories of resource usage are provided, they only allow householders to determine if they are above or below their average but not to experiment with their consumption. Commercially, consumer devices that determine the electrical consumption of appliances—such as the Kill-A-Watt or Watts Up—are available today but these devices only track individual appliances , not total household energy use [29,38].

As some researchers have suggested, taking into account the external stakeholders for the infrastructure in the home can affect Ubicomp technology design [32]. Residential resource consumption management also depends on stakeholders outside the home, such as utility companies who may directly control what resource information can be tracked. For instance, in the USA, Pacific Northwest National Laboratory is experimenting with smart monitors in people's homes that allow them to adjust their appliances to respond to real-time electricity pricing information [30]. Similar smart energy monitor systems are being trialed in the UK and Canada to provide people with more information on energy consumption [2,6]. These systems were developed from the perspective of utility companies that want to provide a better service and do not necessarily take into account what householders as consumers desire.

Legislation and public policy proposals set forth by governments can also affect resource consumption management in the home. Recently in the US, Californian legislators faced protests against a law that would allow utility companies to override and control household thermostats so as to distribute loads adequately at peak times, a move that could be viewed as technology paternalism [34]. To summarize, domestic resource management systems depend on inputs from multiple stakeholders: utility companies, the government and householders themselves.

The Infrastructure in the Home and Ubicomp

Ubicomp research has long focused on creating smart homes [18] with the recognition that many older homes will become smarter as technologies enter them in a piecemeal fashion [12]. Given recent advances in sensor and inference technologies [15,31], Ubicomp researchers are at a point where creating a home resource consumption management system (for a newly built smart home or an older house) is well within the realm of possibility. But the question of what to include for a resource consumption management display and control system remains open.

A body of research on designing domestic information displays for the home already exists. Previous domestic research has shown that information is routinely and sometimes collaboratively displayed in ways that use existing artifacts in various common areas in the home *e.g.*, using post-its, display boards, or by moving letters from one place in the home to another [9,36]. For example, ordinary household surfaces such as the refrigerator door have been proposed as one of the ideal places to present householders with information and create homes that make us smarter [35]. Many Ubicomp researchers have experimented with displays for household routines in calendaring applications [28], communication systems such as HomeNote [35] and for health related information [8]. Yet, in a study designed to elicit information on what people value in their homes, energy saving was found to be the value least related to technology [16]—perhaps because there are no widespread existing resource management tools that home occupants associate with energy savings. Understanding how householders engage in resource consumption will help inform the design of systems to aid them with this process.

Towards "Green" Homes

Research on resource consumption management has focused on making power management more efficient in the workplace [19], to increase workers awareness of energy consumption at work [20] and to help people monitor water consumption and conserve water at the sink [5]. Some researchers have also created homes that adaptively control energy systems for householders [27] and investigated how householders might install and use sensors for a home energy tutor system [3]. Others have experimented with persuasive technology gaming interfaces and automation to convince people to conserve energy [1]. However, none of these studies attempted to form a picture of how householders currently manage their resource consumption in the home. Woodruff *et al*. do [40] shed light on how motivated "green" individuals, an extreme population, who have taken explicit measures in their homes to be resource conservative, manage their energy consumption. They found that in depth learning exercises, pairing householders with "green" mentors, creating mental challenges for householders related to energy consumption are key for promoting "green" behavior.

Our work extends Woodruff *et al.*'s work by examining households that have not necessarily made a commitment to be "green" to determine their current practices with resource consumption. Additionally to understanding householders' current resource management practices, we sought to understand their use of technologies that aid them in this process and their interactions with outside stakeholders for information on resources. Our work will help Ubicomp researchers create residential resource consumption management systems.

METHOD AND PARTICIPANTS

We conducted a qualitative study of 15 households with 33 participants (of a total of 40 householders) between October 2007 and December 2007. Our aim was to determine individual household practices with respect to monitoring and managing resource consumption. Specifically, we examined practices around natural gas (for heating/cooling), electricity, and to a lesser extent, water.

Households were recruited through word of mouth, email lists and online postings and were compensated with a household $20 gift card at a general purpose retail store or $5 Starbucks gift card for each household member. We conducted home visits with each household, during which we used a home tour and semi-structured interviews for data elicitation, a method successfully used in previous work [7]. The visits were audio-taped and we took photos of interesting related phenomena during the home tours. Our interview questions focused on how householders currently manage and monitor resource consumption for efficiency.

All of the interviews were transcribed and coded. Codes were subsequently categorized and related for overarching themes. We interviewed families with children (3), couples (6) and households with roommates (6). Occupations varied from engineers, lawyers, consultants, a full time mother to graduate students. The age range of participants interviewed was 13-49, with most falling within the 20-30 years old age bracket. The 15 households were split into 4 apartments, 3 shared sub-divided houses and 10 single-family houses. The housing units varied in age—6 homes had been built before 1930, and only 4 homes had been built in the last 4 years. In 8 households, the occupants owned the homes. In the remaining homes, 2 were occupied by their owners and renters and 5 were occupied by renters only.

FINDINGS

Householders' resource consumption turns on their understanding of the utility systems that provide them with resources. However, the resource systems have faded so much into the background and become part of the everyday infrastructure in householder's lives that tracking, monitoring and understanding in-the-moment resource consumption is not easy because it is mostly invisible. First, we discuss how householders currently modify their behaviors and homes, or are affected by home infrastructure for resource conservation. Next, we discuss why householders want to manage their resources more actively. Finally, we discuss preliminary ideas on what householders would like to make visible about their resource usage.

Modifications for Resource Management

Householders modified their homes and behaviors for better managing resources. The type of housing unit a household lived in also affected resource consumption. We discuss each of these points in turn.

Minor Modifications for Resource Management

Participants made modifications to their homes and altered their behaviors for resource efficiency, suggesting a willingness to change the infrastructure and their practices for resource management purposes. The most common modifications were using energy efficient light bulbs (7) and installing a programmable thermostat (6). The most common behaviors were turning lights off when not in use (7), unplugging devices when not in use (5) or placing them on standby (3). Less common modifications were replacing windows (2), putting in insulation (2), sealing up windows/putting plastic on them (2) and installing tankless water heaters (1). 3 of all households kept their thermostat at a steady temperature and only half (3) of those with a programmable thermostat had programmed a schedule.

Some householders told us they considered getting an energy audit from the utility companies—this "audit" entails a team of technicians visiting a home to determine energy inefficiencies and suggest improvements. Because of the perceived price and time involved in conducting these audits, no householders interviewed had actually conducted an official energy audit.

Other participants had specifically installed programmable thermostats to manage natural gas/electricity consumption for heating/cooling but had problems with these devices. Multiple preferences for temperature settings, for instance, often led to contention in the home. One participant mentioned how he and his girlfriend often argued about different temperature settings. In many cases, this meant that a thermostat schedule was programmed by one member of the house and overridden by another member with a different preference setting. Intille [22] and others [11] have similarly raised awareness of designing a single control for home temperature and dealing with preference plurality.

Several participants also had interface issues with their thermostats and did not use them because they did not want to spend time learning how to program the device. However, these thermostats were one of the most commonly installed devices to help with resource management because they offered a finer level of control of the temperature. Designing similar installable systems for other resource controls such as electricity may be desirable as long as these devices are simple to use and install. Another common modification was installing energy efficient light bulbs to save money and be more environmentally friendly. However, participants that had installed these bulbs complained that they did not like the quality of light given off by these fluorescents:

"A: That's an energy efficient light. They give off a different quality light, and so we have some in the house in some places, but in other places it tends to actually bother us." –H13

Older adults with poor eye sight also complained that they needed more light than provided by these energy efficient bulbs. Thus, resource efficient solutions that do not match the quality of the artifact they are replacing may affect adoption if they provide an inferior service.

In summary, participants were willing to make a number of modifications to their behaviors and homes for resource efficiency. Because the most common modifications—programmable thermostats and energy efficient bulbs—were easily installed and perceived to provide a relatively minimal investment for a large payoff in energy savings, households were willing to make these minor alterations.

Effects of the Infrastructure on Resource Management

The location, size and sharing of domestic infrastructure affected how householders engaged in resource management. For instance, householders spoke of how a move to a different housing unit meant having to learn the average consumption usage of the new home. Participants who had moved from vastly different climates also had to learn how to deal with the intricacies of resource efficiency for their new location. For instance, one family (H13) had moved from the Northern US, where they were used to dealing with harsh winters to the Southern US. In the "South", they were not prepared or knowledgeable on how to deal with energy efficiency where the climate is much hotter and more humid.

The size of the home also affected householder's resource management practices. In two cases (H9 and H14), there were two thermostats for different parts of the house where the house was large. Thus, in locations where houses are larger, providing an overview of multiple resource control systems may be necessary.

Sharing the resource infrastructure with others also affected consumption management. Some participants that lived a sub-divided house with shared utility infrastructure had more constrained choices for buying "green" energy (energy produced using environmentally friendly methods such as solar, wind or water power) because of having to negotiate this with their neighbors:

"B: Other places - we had the option of green energies, so we did green energy but here, we can't because we split it with our upstairs neighbor. Just straight down the middle. So we have to like get him to agree, and everyone to agree, and we haven't gotten that far yet." – H9

To sum up, providing a history or projected resource consumption for a housing unit would help householders' better set expectations of resource usage in a new setting. Also, providing contextual information on the types of modifications necessary for a particular location would help householders decide which modifications are best for their location. In the case of large houses with multiple resource control systems, providing an overview of resource consumption or single point of control may help occupants better manage these systems. Finally, shared resource infrastructure can make it difficult for householders to purchase "green" energy options unless they seek agreement from those they share the infrastructure with.

Motivations for Resource Consumption Management

Householders who modified their homes or behaviors for resource efficiency were most commonly motivated by the desire for comfort, monetary reasons and to a much lesser extent, to be environmentally friendly. Comfort refers to the desire to have thermostats set to most preferred temperature settings and having devices and lights on to maintain a comfortable, convenient setting over being energy efficient. Despite financial motivations, the division of labor associated with bill paying means that those not dealing with these payments were not equally motivated to conserve. These householders may never see the bill or actively track the household's general resource consumption. For instance, one householder said:

"A: For me it would be a motivator. And it may be more effective for me, but then if he [refers to partner] didn't have that feedback and have some sort of reward coming from that feedback then it would be divisive. Because I would be nagging…I would have the feedback because I see the bills." – H11

Other participants supported this view, when asked if they were aware of how much energy they use from their bills:

"*B: I think there's very little awareness.*

A: I don't even look at the bills." – H13

Responsibility for bill payments thus affected householder motivations to conserve resources since only the householder seeing the utility bills actively tracked the home's resource usage and associated costs. Paying a flat rate for utilities also affected householder motivations to conserve resources as illustrated below:

"B: I would want to be [someone] that conserves regardless but I really haven't felt the same motivation when it's not directly reflected in the power bill. Like sometimes I'll go to bed knowing that there's a light on out here. And just that's not enough to make me go turn it off which is kind of sad in a way I think. And I think that if we were paying a monthly electricity bill I would definitely do that." – H7

Apart from financial motivations, the invisibility of information on real-time resource consumption meant that some participants felt as though they were conserving resources sufficiently. These participants had no way to determine or see their in-the-moment resource usage or other's resource usage or the impact of their actions on their bills or the environment. Consequently, they often self-assessed themselves as "I'm doing enough". For instance, participants that had taken extreme measures to be environmentally conscious—such as only having one vehicle for their family or moving to live near public transportation—feel as though there is nothing more they can do to be more resource conservative as illustrated here:

"A: I think we're doing as much as we can right now. We all commute. There's 4 of us in the car in the morning and then we all come home together. Or generally lately I've been staying later at school and then I take [the train] home…I mean there's just not much more you can do besides take 4 people in a car." – H13

Others who had taken smaller measures to conserve energy or water through turning off lights when not in use or taking shorter showers also had a sense of they were contributing enough to the cause of being "green".

To summarize, participants wanted to actively manage their resources to save money or for their comfort. In some cases, participants were not motivated to decrease their consumption if they felt as though they were being environmentally friendly enough because of adjustments they made to their lifestyles or behaviors that they deemed as "green". Due to the division of labor around bill paying, financial incentives alone may not be sufficient to motivate an entire household to actively manage resources. Further, business models where people are not directly paying a per usage rate for resources may also complicate financial motivations to conserve resources. Also, for those individuals who feel like they are doing enough, there may be a lack of incentive to actively manage resources, unless more information on resources is available for real-time assessment as well as comparison with others or averages.

Visualizing Resource Consumption

Participants wanted more visibility and insight into their resource consumption. They told us of their problems with current resource tracking methods, what they would like to see displayed within the home and what they would like to see about other homes.

Within Home: Inadequacies of Current Tracking Methods

Generally, participants spoke of the difficulties of tracking their resource usage with current methods. Householders told us that the utility companies usually provided monthly bills with resource usage and in some cases, where the participants had lived in a place for long time, historical graphs of resource consumption. However, this information remained problematic because often the units of measurement were not easily correlated with consumption habits or were not easily quantifiable. For instance, one participant said:

"B: I mean if you look overall about water or kilowatts, like I couldn't tell you we used x amount of kilowatts" – H13

Another complained that the units of usage, such as kilowatts, were often meaningless as illustrated here:

"B: Last month, the electricity bill dropped like in half, that's what we pay attention to is the dollar. Right? That's what really matters. So, as far as how many kilowatts you using – I don't have any clue." – H9

Some participants made estimates of resource usage based on information available to them.

"B: I would leave my computer on all the time but I don't really know how much power it draws. And when I was in undergrad I tried to estimate this based on using…like the ups [uninterrupted power supply] will tell you how many watts its drawing if it has like a smart interface or

whatever. And then I tried multiplying that by our power rates in [the city]. And I think it came out to like $40 a month which was higher than I would have expected." – H7

Others talked about creating folk theories about how much energy they think devices consume, a practice also found with thermostats [23]:

"A: I like to know as much as possible. My interest goes beyond saving money. I am just really interested to know how much energy things really take up. I have no concept of how much energy one appliance uses and another. I kinda [sic] wish I did. I think have various folk theories of how much consumption one device uses over another. I was like oh gosh it's really big deal to turn this thing off but if I leave this one on it's not a deal. But in reality it's probably the reverse of that and if I only knew I could manage it a lot better." – H2

One participant talked about the general lack of real-time tracking information for resources and how that made it difficult to comply with government suggestions for managing water:

"B: They've asked people to use like 10 percent less water. Well how do we know if we're using 10 percent less water? I mean if they really want people to reduce I don't know. I mean I think we conserve pretty well but we don't have a way to really quantify what we're doing." – H8

Participants also spoke of their desire for more real time information on resource pricing so that they could alter their electricity usage for home devices and systems based on prices for peak load—for example, by turning these systems on and off at appropriate times such as when the home's occupants were at work. Additionally, participants wanted to know in real-time which devices and systems were consuming the most energy to help them alter their behaviors appropriately. Real time information was also desired to alert homes if something was abnormal or unusual before the end of the month. One participant in H1 described how her roommate's toilet had broken but that the abnormality was not noticeable until an unusually large water bill arrived at the end of the month.

Despite gripes with current resource tracking methods, most of our participants were not aware of any devices to help them measure energy consumption in real-time for all their appliances. At least two participants in H9 and H3 mentioned Kill-a-Watt type devices for tracking the power consumption of an individual appliance. However, none of our participants had actually had bought one of these devices because they were perceived as overly expensive or as requiring extensive rewiring to work.

Within Home: Linking Resource Usage to Impacts

Aside from problems with current tracking methods, participants also wanted more information on the impacts of their resource usage on saving energy, reducing costs or helping the environment. In H1, a participant mentioned how knowing whether she was above or below her own average would promote more reflection on resource consumption and on what behaviors are causing the change. Another participant spoke of how they had discovered that turning lights off saves energy:

"B: Myth busters [a television show] did a special...Does it actually save money to turn the light off or does the energy required to boot it back up offset that? And they did determine that it saved minuscule amounts over a long period of time to turn lights off as you leave the room." – H11

Others wanted to know the impact of their actions on the environment, suggesting a need for increased education and awareness of resource usage in different conditions and settings:

"A: Everyone assumes you know you use more power, ,it's negative. You use water and it's negative. like it would be cool to know like if you use less, how is that helping something in the greater [area] or power in [the city] or water or something? Especially right now. Especially if I think that if I take a shower half as long that will help lake [a local lake] like have less." – H1

Within Home: Engaging Creatively With Resource Usage

Aside from seeing the impacts of their actions on resource consumption, the bills or the environment more clearly and in a timely fashion, participants spoke of engaging with resource consumption information in a playful manner. Some wanted to optimize their own resource use, getting information at decision points on how to do a particular activity in a more efficient manner. Others wanted to play games against others in the house or in the neighborhood or to see if they can create energy to power devices in the home. For example, one participant (in H3) talked about wanting to optimize resource consumption, by knowing how long devices have been on for and how much energy they might be wasting. Other householders mentioned wanting a game that could track individual householder's resource usage and create competition within the household to see how they could improve their own consumption:

"A: I think it would be neat like how much [change would it make] if we didn't watch TV for, you know. If we cut it down by an hour every week or something how much [of a difference] would it…would that make [a difference]...that would be cool" – H14

Several participants expressed an interest in getting more information about when they were doing something positive and not just about their levels of resource usage. For instance, one participant talked about how she would like to create energy if possible or at least know when her actions are having a positive effect. She talked about the Toyota Prius's display where one can see when energy is being consumed or created by various actions:

"A: So I love the Prius in that you can see when you're making energy and when you're not. So if I could see something like this is how it's being done. Like if you ran the washer at this time you'd save this. And like make more of like a game, like how much could you save" – H8

Within Home: Context Sensitive Information

Some householders also wanted information to be provided at key decision points in activities to help them to determine the most resource efficient course of action. One participant (in H1) talked about having information when she is at the sink and about to do the dishes. She said that if she knew the energy and water required to do the dishes by hand or using the dishwasher based on the amount of dishes to do, this context sensitive information may motivate her to choose the more efficient course of action. Participants also desired finer control over resources than is available at present. For instance, several householders mentioned that having a simple device that could to turn off all the lights in the house at once or to track what state all devices and appliances were in (on/off /standby) would help them with being more electricity efficient.

Within Home: Summary

To sum up, participants complained that current resource tracking methods are inadequate because the units of measurement, such as kilowatt/hours, are meaningless, the information is not real-time and thus the impact of actions cannot be determined in a timely fashion. Further participants wanted to engage with resource consumption in a playful manner to optimize their usage and see positive aspects of resource usage.

Betweeen Homes: Benchmarking Information

Participants not only desired more visible and real-time information on their own resource consumption habits but also wanted ways to benchmark their consumption against others. The granularity of information desired about others varied. Some wanted information on the county, regional or neighborhood level for comparative purposes. Others mentioned wanting to benchmark their resource consumption based on similar demographics and household type. For example, participants who lived in apartment complexes desired benchmarking information on how much energy they are consuming based on the layout and floor plan of their apartment unit. One participant mentioned getting averages based on the county or region to determine if more politically liberal areas conserve more.

Most people did not want to necessarily know about the conservation habits of their direct neighbors, respecting their privacy and also because they would not take any action as a result of such information, despite being curious about neighbors habits. For example, one person was dismayed that a neighbor on their street had a pristine lawn during a drought and was curious to know more about that neighbor's water consumption. However, beyond curiosity, none of our participants felt like they would act on the information to tell their neighbors to conserve more. Some actually felt they would be upset if they knew their neighbors were being wasteful. Yet, neighbors and their resource usage were still intriguing:

"A: Our neighbors next door own a hummer and an SUV. I'd be curious to see how much energy they're producing in comparison to us or just our neighborhood." – H4

Between Homes: Privacy and Identity Management Issues

Like many other Ubicomp technologies for the home, participants were also mindful of the privacy implications of sharing information on their resource consumption with others beyond their household. For example, some were concerned about what could be inferred about one's lifestyle. One roommate in H1 expressed dismay at other people in the house or elsewhere learning about her eccentric habits because of increased monitoring of an individual's use of resources such as when and how much they are consuming:

"B: I guess I wouldn't necessarily want all people to know all these odd habits that I have" – H1

A participant in P2 joked about gauging water consumption by the number of toilet flushes made by each person in the household but then felt this would be invasive since a person's hygiene, eating habits and behaviors could be inferred from this information. Participants also did not want to be viewed as a wasteful:

"A: The natural reaction is for protecting privacy. I am trying to think if I would actually care. But the natural reaction would be sure I want everyone else to see [my consumption habits] but...If I consider myself as a more wasteful power user, I might not want people to see." – H2

Betweeen Homes: Summary

In summary, participants desired information on other household's resource consumption for comparative purposes but were also mindful about what could be inferred from sharing this information with others.

DISCUSSION: UBICOMP AND SUSTAINABILITY

We presented three classes of findings around behaviors, infrastructure and management, householder motivations to manage resource usage and how resource consumption is currently understood. First, we showed that people currently make minor modifications to their behaviors and homes to be more resource efficient and that conversely, the types of homes they live in affect their resource management. Second, we described common motivations for making these modifications that varied from saving money, desiring a comfortable home environment and to a lesser extent to be environmentally friendly. Third, we discussed how current resource tracking methods are inadequate because they do not allow householders to see resource consumption usage in real time or in meaningful terms. Householders desire more real-time information about their own and others' resource usage. Based on these findings, we discuss five themes around how designing for home resource conservation affects a design and research agenda for Ubicomp and sustainability.

Designing for Resource Consumption Visibility

For householders to truly appreciate the magnitude of their resource usage on the bills and the environment, they need to understand the production and labor costs associated with the energy they use. Arguably, since resource infrastructure has been adopted into standard homes, householders are no longer able to equate their consumption habits with labor costs. For example, no longer does one have to equate how many buckets of water are needed to clean a load full of laundry or how much coal should be burned to power a laptop. Instead, in contemporary times, consuming a resource may be as simple as plugging in a laptop without knowing how much energy it uses, how the energy was produced or the impact of that device's use on our energy footprint. Where once it might have been the case that people did not care to know, we suggest that public attitudes towards conservation are changing and many now desire the ability to inspect and learn how much work it takes to produce energy.

One design agenda for Ubicomp, therefore, is to consider how to make in-the-moment resource consumption visible in terms that make the costs of production and the units of consumption more clear. Literally taken, this may mean visual systems that equate our resource usage with units of production, for example, buckets of water, bags of coal, stacks of wood, as well as a monetary amount. A visual correlation may help householders can build a better mental model of how they are using energy throughout a month. More complex solutions would incorporate more information, which would necessarily require the inspection of the infrastructures that produce many of the resources that we consume. Again, as initiatives like carbon footprinting take off—measuring not just the cost of production, but also transportation—so we see a nascent demand for individuals to see into bigger infrastructures, a point we return to in the next section.

Designing for Individual and Collective Agency

Along with making the units of production and consumption more visible, designing for sustainability in the home may require supporting both individual and collective agency in "green" behavior change. By this we mean that households are made up of individuals with varied interests in being "green", different bill paying responsibilities and preferences. Systems that automate energy systems do not always support multiple preferences or allow individuals in a household to see how they are contributing to the overall household consumption. Designing resource consumption information systems that give individuals in a household a sense of agency in controlling a home's energy footprint is therefore desirable to motivate all household occupants.

Further, not only do individuals in a household need to feel like they have agency to change consumption habits, there needs to be some representation of an entire household's energy footprint and how it compares to others in a neighborhood, county or city. By benchmarking themselves against others and seeing more of how the aggregate and projected long term energy savings for a community depends on individual households, householders may be further motivated to take collective action for sustainability.

This collective suggests a re-examination of what we define as *domestic infrastructure*. Traditionally, we have taken a *within* household approach to infrastructure, emphasizing systems that will make our homes smart. But households are connected to a variety of infrastructures beyond the home. Much research on such infrastructure has focused on the *Internet*, but sustainability makes other socio-technical infrastructures visible.

In actuality, houses are connected via infrastructures to commercial corporations and governmental agencies that not only produce, but also sell, regulate, and move resources around that determine the exact costs of consumption. For example, electricity can be generated using coal, water or wind (each with different costs for the environment), but the type of electricity a household consumes is determined by governmental authorities that control the flow of electricity on the grids they manage. Without knowing how producers generate their resources, households cannot fully understand the costs of consumption.

More generally, the contributions households that make to general levels of sustainability can only be fully measured by knowing the commitments that commercial and governmental institutions have also taken. Our participants wanted to know whether the county in which they resided had met its goal of reducing water use by 10%. Yet, without knowing their own, their neighbor's, or that of the commercial and governmental agencies in the county, it was impossible for them to answer that question, or know their contribution with respect to that of others. In summary, sustainability opens up the question of infrastructure not just as a set of technical arrangements that provision the smart "green" home, but also as a set of commercial, legal, and governmental arrangements in which resource consumption is framed.

Avoiding a Green Divide

In creating systems to help households conserve resources, we as designers also have to be wary not to create a sustainability divide between those who have the means to pay to be "green" and those that do not. If the very systems we design to help households monitor their resource consumption and that of others more closely, are expensive, they will only be available to some. Rather than create a divide between those who can afford to conserve and those who cannot, we should ensure that the technologies we design for resource consumption management are economically viable for the majority of households (or that other pricing arrangements could be put in place to increase the accessibility of our solutions to all). Only if most households can conserve will the collective energy savings in any domestic sector be realized. Systems that reuse existing infrastructures (for example see [15, 31]) may help monitor resources in affordable ways. Again, sustainability, and its need for broad participation, highlights the need for accessibility to technologies, which makes it a particularly interesting intellectual agenda for this community.

Incorporating Sustainability As A Core Value in Design

We also wish to note a particular irony in creating technology to aid sustainability. Specifically, proposing technology to support increased domestic sustainability and energy conservation is open to the criticism that the solution consumes the same resources being managed. For example, a solution requiring a visual energy feedback display to be plugged in all day seems to detract from the ultimate goal of reducing a home's energy footprint. Similarly, even if there are solutions that reuse existing infrastructure such as a power line, they may require at least one or two sensors which also require power. We as a community need to rethink energy sources for our domestic solutions perhaps substituting solutions that use alternative energies such as solar power, or that power themselves through mechanical energy. We say this because the sustainability design movement can potentially gain from the Ubicomp community in this regard. One concern that has permeated a variety of applications is battery life and understanding energy consumption needs of devices (to ensure that they will be "alive" for long enough). The knowledge acquired in those efforts could potentially have much to offer the construction of low- or no-impact technologies for sustainability.

Sustainability and Methodological Challenges

Finally, we highlight one methodological challenge associated with domestic sustainability research which may apply more broadly. Throughout our study, we encountered difficulties with making our participants feel comfortable discussing issues around being "green" because they associated their answers with indications of their fundamental morals. Those with a more liberal bent towards conservation were more than happy to discuss their habits with us. However, for the majority, people expressed guilt and shame at admitting they did not take great pains to conserve resources. In some, the thought of being "green" incensed a strong reaction against conservation, because of negative associations of conserving with "hippies" and "tree-huggers". Our last suggestion for the Ubicomp community is thus to investigate new and improved methods for stimulating discussion and collecting data on "green" issues—methods that do not alienate those providing us with information so that we can get closer to the ground truth.

CONCLUSION

We presented the results of a qualitative study to understand how householders currently manage resource consumption in their homes. We find householders modify their homes for resource efficiency for saving money, maintaining a comfortable setting and to a lesser extent, to be environmentally friendly. Specifically, householders desire insight into the impact of their changes to their homes and behaviors on resource usage and more visible real-time information on *within* the home resource consumption. They also desire more information on *between* homes consumption and the collective impact of their actions on wider causes like the environment.

Our findings suggest that sustainability is related to improving the visibility of real-time resource consumption and its production costs. Further, home sustainability may turn on resource management solutions that support both individual and collective agency in behavior change. In all, we need to wary of creating a "green" divide between those who can afford to conserve resources and those who cannot through our system designs. We can also incorporate sustainable values in our designs, for example, by not relying on traditional sources of fuel. Finally, we highlight an inherent methodological challenge in sustainability research, that of collecting data on an issue closely associated and easily conflated with people's morals.

ACKNOWLEDGMENTS

We thank our participants as well as our colleagues at Georgia Tech, our shepherd and reviewers for their insights. This work was supported by NSF CNS #0626281.

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