

It's Not All About "Green": Energy Use in Low-Income Communities

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ABSTRACT

Personal energy consumption, specifically home energy consumption such as heating, cooling, and electricity, has been an important environmental and economic topic for decades. Despite the attention paid to this area, few researchers have specifically explored these issues within a community that makes up approximately 30% of U.S. households – those below the federal poverty line. We present a study of 26 low-income households in two very different locations – a small town in the Southern U.S. and a northerly metropolitan area. Through a photo-elicitation study and directed interviews, we explore the relationship between energy saving behaviors, external factors, and users' intrinsic values and beliefs. Most of our participants are committed to saving energy for non-financial reasons, even when not responsible for paying bills. Challenges to saving energy include safety and lack of control over the environment. We discuss how Ubicomp technologies for saving energy can address some of these challenges.

Author Keywords

Sustainability, low-income, energy, domestic computing

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.

General Terms

Design, Experimentation

INTRODUCTION

Energy use and its impact on the environment have become a topic of global concern in recent years [14]. In countries with high *per-capita* energy use, such as the United States, households consume 21.7% of total U.S. energy and generate 21.1% of total U.S. carbon emissions [*ibid.*]. As a result, personal energy consumption has been studied for decades by environmental psychologists (*e.g.*, see [1]) and has recently garnered attention in the Ubicomp and Human Computer Interaction communities (*e.g.*, see [4, 6, 12, 43]). Among categories of personal energy consumption, *home energy consumption* (heating, cooling, electricity use) is one of the largest, especially for low-income families [41].

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Thirty percent of U.S. households make less than \$30K *per* year [37]. However, few details are available about the relationship between low-income households and energy, or how they manage their energy use. Without knowledge of the motivations and barriers affecting energy conservation, interventions will be less effective, and even programs that attempt to reach out to this community will fail to engage a large segment of the population.

Our work focuses on U.S. households. In 2005 the U.S. was responsible for over 20% of total world energy consumption [38]. One of the most important socio-demographic factors that influence energy use and conservation is income [39]. 'Necessities' such as housing, home energy, food, and transport are the largest contributors to energy use (and thus carbon emissions) in low-income households [*ibid.*]. As a result, low-income households spend a greater percentage of their income for home heating, cooling, and electricity than affluent households [7]. In fact, the median energy consumption for heating and cooling is almost as much as that of affluent households [28]. Affluent households have higher carbon emissions because they also spend money on elective high-carbon goods and services such as airplane travel [41].

Since low-income households tend to have smaller homes [8], it is important to understand the causes of their relatively high home energy emissions. Economic factors such as an inability to purchase energy efficient devices, and renting or owning homes in poor repair [*ibid.*], are likely to have a big impact. However, prior living conditions, culture and other factors may all play a role in the energy use of low-income householders.

Previous studies have explored energy use in "green" households [43] and "typical" households [6]. In these relatively affluent households, many participants owned their homes and were responsible for paying energy bills. This relatively narrow demographic focus makes it difficult to generalize from prior results.

We conducted a photo-elicitation study [5] with residents in 26 low-income households across two states to explore their relationship to energy use. Our results demonstrate that these households are creatively engaged in energy conservation under a wide range of constraints. Our participants' motivations were more similar to affluent green households than expected. Participants described saving energy even when they did not pay for their own energy and were motivated by habit, spirituality and

concern for future generations as much as by money and comfort. They reported more diverse and creative strategies for saving energy than either type of affluent householder. While they suffered from a lack of feedback about energy use, more severe barriers to saving energy included lack of control over other people and infrastructure, lack of money for up-front investments, and safety. Basic assumptions about responsibility for bills, building ownership, and the relationships between household members need to be reconsidered when designing Ubicomp technologies for saving energy. Designers may need to address issues such as unsupportive landlords or housemates.

KNOWN FACTORS AFFECTING ENERGY USE

Past work has shown that a range of motivational techniques such as commitment, goal setting, and feedback can lead to reductions in personal energy consumption [1]. Our study focuses on the reasons that energy consumption is high (or low) before any intervention takes place.

Some factors that affect energy use include external factors (*e.g.*, economic, social, cultural), internal factors (*e.g.*, awareness, values, attitudes, emotion), and demographic factors [22]. In other words, our behaviors are functions of our personal selves [15] and our environmental conditions.

Personal factors that may influence energy saving behaviors are discussed in socio-psychological models such as the *Theory of Planned Behavior* [2]. This model, which is often used in the environmental literature, predicts that perceived difficulty and a user's intentions will influence whether he or she takes action. This model accounts for subjective norms, attitudes, and so on in defining intention. However this model does not account for the impact of *identity* [29], or the role of *habit* [35].

Identification with a set of values may predict intention and behavior independent of other variables such as attitudes. For example, Sparks & Shepherd found that measures of self-identification with green consumerism contributed to the prediction of intentions independently of attitudes [29]. In Woodruff *et al.*'s ethnography of green households, participants identified with three influential motivational perspectives: Counterculture bio-centric activism; American frontier self-reliance and rugged independence; trend-focused utopian optimism [43]. However, individuals in "typical" households may not identify with any of these groups. In an ethnography of 15 typical residents of homes and apartments, Chetty *et al.* found that comfort and money were primary motivations for saving energy [6].

Habit is a type of behavior that takes place without conscious thought. Cognitive psychologists and neuroscientists believe that 95% of behavior is controlled by the unconscious mind [24]. Many of our everyday behaviors that have negative environmental consequences are habitual [27]. To account for habit and other factors, Stern has proposed a model of environmental behavior that integrates attitude, personal capabilities, habits, and

contextual factors (such as monetary incentives, public policy, and interpersonal influences) [30].

To summarize, we can expect to see a range of factors affecting energy saving behaviors from internal factors to external constraints. Indeed, past work reflects this. For example, Stern reviews ten years of psychological research and argues that factors determining energy use include energy-related attitudes and beliefs, available information, income, education, and recent events [31].

How does a low income affect these results? Financial pressure may affect how and whether an individual saves energy. However, the prevalence of charity giving among low-income households [21] suggests that financial pressures may be less important than other motives. Low-income households may have less control over their environment, and less access to information than affluent households. Unlike affluent households, many low-income households are not responsible for paying their energy bills or only receive a bill if they consume more than an allocated amount. When energy prices rise, low-income households tend to make life-style cutbacks rather than investing in increased energy efficiency [9]. Tax credits for green home improvements may not help because households may not pay enough tax to be able to claim credits. Many unanswered questions remain. How important are economic constraints (or lack thereof) relative to other motivations? What are the biggest barriers to saving energy? Our study sheds light on these questions in the context of low-income communities.

METHOD

Our study took place in two locations: a small town in the Southern U.S. (*NC*) and a northerly metropolitan area (*PA*). We sought out members of households falling under the federal poverty line (this is dependent on household size and other factors). We advertised the study online (Craigslist), by posting flyers, dropping flyers in random mailboxes, door-to-door visits, and in-person in central locations serving the low-income community. We varied the time and day of in-person recruiting, emphasizing times when many residents were likely to be available.

The goal of our study was to elicit participant viewpoints and practices surrounding energy management. We explored energy as broadly as possible to avoid introducing bias in the definition of energy or the set of practices under consideration. Our process involved a lightweight diary study with cameras followed by elicitation interviews [5]. The data included photos and transcriptions of interviews. Participants were paid \$10/hour for interviewing.

Photo Diary & Elicitation Interviews

We interviewed 26 participants in the winter months between November 2008 and March 2009. We asked participants to "take pictures of objects and/or scenarios that make you think about personal energy use or anything that makes you think about energy." To avoid any bias, our

Table 1: Participants above the dotted line are from NC, below are from PA. *Housing:* (PH: Public Housing; S8: Section 8; O: Other). *Married?* (S: Single, separated or widowed, P: Married or living with a domestic partner). *: Smart Comfort. All names given are pseudonyms to protect participants' identity.

Name	Primary Motivation	Income	Housing	Gender	Age	Married?	# Adults	# Children	Bedrooms
Monica	What can I do?	<10k	PH	F	21-25	P	2	3	2
Candace	Protect environment	10-20k	PH	F	18-20	S	2	4	3
Geraldine	Waste not want not	<10k	O	F	41-50	S	1	2	3
Nicole	Secondary benefit	<10k	S8	F	21-25	P	1	1	2
Erica	Protect environment	10-20k	S8	F	31-40	S	1	2	3
Shannon	Secondary benefit	<10k	S8	F	31-40	S	1	1	3
Cheryl	Secondary benefit	<10k	S8	F	21-25	S	1	1	2
Paul	Protect environment	<10k	PH	M	21-25	S	4	2	3
Brian	Protect environment	<10k	PH	M	21-25	S	1	0	2
Michelle	Secondary benefit	<10k	S8	F	21-25	S	1	4	3
Jacqueline	Waste not want not	10-20k	PH	F	41-50	S	1	3	3
Catherine	Waste not want not	<10k	PH	F	51-60	S	1	2	3
Anita	Protect environment	<10k	PH	F	41-50	S	1	2	2
Veronica	Waste not want not	<10k	PH	F	51-60	P	2	0	2
Angela	What can I do?	?	O	F	31-40	P	3	2	4+
Charlie	Secondary benefit	<10k	PH	M	31-40	S	3	2	4+
Lauren	What can I do?	20-30k	S8	F	> 60	S	1	1	1
Kim	Secondary benefit	10-20k	PH	F	18-20	S	1	1	2
Dave	What can I do?	<10k	S8	M	21-25	S	3	5	4+
Claudia	Secondary benefit	<10k	PH	F	26-30	S	1	1	1
*Mary	Protect environment	<10k	O	F	41-50	S	1	1	1
*Eve	Protect environment	<10k	S8	F	31-40	S	1	4	2
Yasmine	What can I do?	10-20k	S8	F	26-30	S	1	3	2
Roy	Secondary benefit	<10k	O	M	51-60	S	5	0	4+
Diane	Waste not want not	<10k	PH	F	41-50	P	1	0	1
Justin	Waste not want not	20-30k	O	M	31-40	S	2	0	3

instructions used examples from an unrelated domain, food consumption.

Participants were told to think of the camera as a personal diary and encouraged to take pictures inside and outside of the home. Three starting photos were required: their thermostat, a family member or close friend using energy, and where their energy comes from. Participants were assured that there were no right or wrong answers to the task and were given a minimum of a week to complete the task.

After developing the film, we conducted a photo-elicitation interview [5] with each participant. These lasted 1-2 hours and focused on each participant's thoughts and actions around energy. We discussed each photo the participant had taken and also discussed community involvement and some participant-driven issues. We took extensive notes during each interview and all interviews were transcribed.

Approach Used for Analysis

At the end, we had 370 photos, ~24 hours of interview data, and a total of 216,494 words transcribed. We created physical posters containing case studies of each participant including photos, key facts from interviews, demographics and income. We hung all of these in a working space where we met as a group to explore this data. We also conducted iterative coding of the data. We created initial categories by

organizing the photos into similar groups and discussing the case studies. Based on this, one of the authors assigned low-level codes to the transcribed data in a grounded fashion using a text coding tool [34]. We met multiple times as a group to refine and coalesce these codes into higher-level categories. These categories were also influenced by psychological theories of habit and motivation (described above). Finally, we used the case studies and the results of our coding to discuss and extract common themes.

Description of Participants

We recruited forty participants; fourteen dropped out, due primarily to the length of the study. Of the remaining twenty-six (see Table 1), five were interviewed without photos for technical or logistical reasons. Most participants were female (20). All but one were younger than sixty (twelve were younger than thirty). Most participants (22) were African American, including all in NC. Most participants (21) had one or more children living in the household (max: 5). Households consisted of nuclear families (2), single parents (18) and a mixture of parents and other adults or extended family members (5). Most participants (18) earned \$10,000 or less, seven earned \$10-30,000 and one unknown. The majority (10) were unemployed, eight worked part-time (cashier, administrator and, teacher's assistant, accountant, landscaping, house-keeping), two worked full-time (food service, clerk assistance), and six were self-employed or retired. Five were fulltime parents and six were students (sometimes in addition to other things). Over a third (9) of the participants had completed high school; twelve had some college courses, four had completed college, and one had taken graduate courses.

Description of sites

We recruited from two complementary locations. Seventeen participants lived in a small town in eastern North Carolina, NC (population less than 30,000; median income ~\$37,000 [25]). Nine participants lived in a (relatively) large metropolitan area in Pennsylvania, PA (population ~311,000 [26]; median income ~\$32,000 [36]). For comparison, the national median income was \$50,740 in 2007 [ibid.]. Our interviews took place during the winter months (average low ~32°F and ~22°F, respectively [40]).

Publicly subsidized low-income housing falls into two primary categories: Large buildings with built in community centers commonly known as *Public Housing* (e.g., see Figure 1), and scattered apartments commonly known as *Section 8 Housing*. Eligibility is defined by states and includes low-income families, the elderly and individuals with disabilities. Both types of housing may include high and low rise apartments and single-family



Figure 1 Public Housing Communities in a metropolitan area of PA (**left**) and a small town in NC (**right**).

homes. The primary difference between Section 8 and Public Housing is whether a resident has a choice about where to live (Section 8 may provide vouchers that can be used with any landlord that accepts Section 8 tenants, including but not limited to Public Housing units). Public housing in both cities is 97% or greater African American. Women head most of these households.

Nine participants live in the 218 unit, 29 building NC Public Housing, a complex built in 1941 and expanded in 1953. The facility is located on waterfront property, and borders downtown and historical sites. The neighborhood is unsafe, according to outsiders, and some participants mentioned gang violence, tagging (graffiti) and drug activity. Over 50% of residents we spoke with have washing machines, but the facilities are not wired for dryers (the housing authority provides clotheslines). HUD requires community service of residents who are not working, in school, or elderly/disabled and the housing authority provides opportunities for residents to complete this requirement. The community has a small, rarely used computer lab with broadband access (we only observed one or two people using the lab during a two month period). The community center holds workshops such as homeownership and money management. Participants described the community as tightly knit.

Five participants live in the 420 unit PA public housing, a complex built in 1940 and expanded in 1954. Churches and hospitals surround the neighborhood, which is severely depressed. We were told to recruit in the community center instead of door-to-door for safety reasons. Participants who live here are concerned about issues like safety, drugs and guns, teen pregnancies and youth violence. The community has a well-used computer lab with broadband access. The community center runs programs such as resume writing workshops and computer technology classes. Energy-efficient light bulbs are provided free, and programmable thermostats are currently being installed. Participants described the community as tightly knit.

An additional seven participants lived in scattered apartments and five lived in rented houses, mobile homes, or townhouses. One participant was a homeowner. These residences varied in their facilities. Most had no dishwasher; some had washer/dryer facilities; some had central air and heat; none had programmable thermostats.



Figure 2 (**left**) Candace’s TV, electronic devices and lights can all be controlled by one switch. (**right**) Roy troubleshoots a furnace. Figure 2 and subsequent images were taken by participants as part of the study.

Interesting and common themes that arose included motivations for saving energy, common energy saving behaviors and reasons for missed opportunities to save energy, sharing and other social factors, including impact of a person’s past on their behavior, and approaches to monitoring use. The following sections cover these results.

MOTIVATIONS FOR SAVING ENERGY

As discussed earlier, households that identify as green are influenced by cultural trends, such as bio-centric activism or trend-focused utopian optimism, that fall outside of more mainstream motivations [43]. Spirituality and the health of future generations are also important in green households [*ibid.*]. In contrast, “typical” households are motivated by saving money, comfort, and to a lesser degree, environmentalism [6]. We found some similar sources of motivation in the low-income community.

Some of our participants were financially motivated. However, because of public subsidies, only four participants paid their own energy bill. Nine participants only paid when they exceeded a set allocation of kilowatt-hours *per* month. Eight received stipends (for part of the rent and/or utilities). Five had access to free, unlimited energy. Interestingly, these differences had little effect: not paying for energy did not stop participants from saving it. Spirituality, protecting the environment for future generations, and prior training/habits were the primary reasons most participants saved energy. A smaller number of participants reported saving energy for financial reasons.

Protecting the Environment for Future Generations

Although only two participants used the word “green” in their interviews, concern for the environment for the sake of future generations was prominent among seven – “[*for our daughter*], and her children and grand children,” – Brian (from NC). This form of environmentalism was also found in affluent green families [43], but motivations focused on the earth/climate or inward on the person (*e.g.*, self-reliance) were not discussed by our participants.

Many of the participants’ concerns for future generations extended beyond the environment. For example, Eve, who cared for four children at home, volunteered for a sustainable garden program, volunteered for Head Start, and helped to run a neighborhood crime prevention event.

In Figure 2 (left), Candace, (from NC) who learned to be environmentally conscious because of her mother and a

teacher, is illustrating how her TV, electronic devices and lights are all connected to one switch so that they can all be turned off at once. Candace uses this switch to enforce her rules regarding energy use on other members of her household:

Candace: When you hit the switch, the TV and everything else goes off, and my daughter doesn't know that, so when I'm not in there, I will hit the switch on the wall, and if she tries to turn the TV on, it won't turn on.

Waste Not, Want Not/Live Within Your Means

A moral aversion to waste, driven by a deep connection to God, motivated six of our participants. For example, Roy commented, *If you love your house, you'll fix things up.... If your faucets is leaking, fix them.* In Figure 2 (right), he is fixing the furnace to help his landlord, and also to help residents in all of the apartments to save energy. Like many of the participants who wanted to avoid waste, this ethic came from his connection to God: *"My motivation is really focused on God..."* Similarly, Jacqueline (from NC), who accidentally wasted energy during Thanksgiving, commented *"And I need to break out of that, because I'm wasting."*

Our results do not explain the prevalence of or reasons that spirituality and environmentalism are linked, but it is not unique to our population: In more affluent green households, this also occurred [43].

Secondary Benefit: Money or Personal Preferences

Other participants engaged in energy saving behaviors as a side effect of their need for money, or personal preferences. This was a primary cause of energy savings for nine participants. Five of these were focused on saving money. Many other participants with other primary motivations also mentioned money. A few dollars a month has a large budgetary impact when the budget is small.

Candace: I notice a lot of people out here that tend to leave the porch light on... and they have no [idea] it goes to the house electricity bill. ... so I don't mess around with the porch light, unless I'm outside, and I always make sure I turn it off.

Although Candace was primarily an environmentalist, she reported removing bulbs from her chandelier for comfort reasons (Figure 3, left).

Candace: I like to go to lower watts, which just seems to have actually a little yellow tint to it, and it actually keeps the light just light enough, not disturbing you, or, you know, when you're watching TV, it's not a glare... It's very comfortable.

Even a behavior that many view as a burden such as drying clothing on a line can be driven by for personal preference:

Catherine: I don't like dryers.... in the North you don't have lines to hang on. You have a laundry room and a dryer... But to get back and put them on the line and just-- ooh, that felt so great. I really love it. I love it.

What Can I Do?

Similar to some of the participants in Chetty's study of "typical" households [6], a few participants (5) either didn't



Figure 3 (left) Candace removes bulbs from the chandelier for comfort. **(right)** Catherine enjoys line drying her clothes.

care, or felt they were already doing enough. For example, Lauren, an elderly woman from PA who lives alone in a small one-bedroom Section 8 apartment stated:

Lauren: There's nothing else that can be done. I mean I do laundry once a week. I do dishes once a day. I watch television so many hours a day. I'm not home for a lot of hours a day. Then I'm in bed for the rest of the hours of the day. I'm doing it.

SAVING ENERGY—TRENDS AND PROBLEMS

A recent survey of 2,000 Americans found that changing to energy efficient light bulbs and turning the thermostat down in the winter and up in the summer are common energy saving behaviors [23]. Recent interviews with residents of 15 "typical" households found similar behaviors, as well as installing a programmable thermostat, turning lights off, and unplugging devices [6]. Participants in our study mentioned similar behaviors although up-front costs, negotiations with housemates, and structural inefficiencies sometimes stood in their way (as described below). Participants also mentioned many other ways of saving energy:

- *...continually complain to management to repair kitchen door seal and cork holes in wall. (Catherine)*
- *Decorate your house with candles and light those... (Nicole)*
- *I make the clothes, because I cannot afford to pay the light and buy clothes. So I make that. That's energy saving whether you think it is or not. It is. (Lauren)*
- *Another thing I save in energy is your timing. When you get up in the morning, everybody get up at the same hour. You line up, you go to the bathroom. Take your turn.... Turn the light on and everybody through, turn that light back out. (Lauren again, on managing 7 kids)*
- *...take that same bucket, wash them walls, wash them dressers... Clean all the dirt around the house, then you mop your floor. That's saving on your hot water. (Lauren)*
- *...we plant things, and you can actually use things like food stamps to buy seeds. That is one way to save energy, is to grow your own food instead of incurring all the fuel and environmental [costs]. (Eve)*
- *I love to fish. Matter of fact, went yesterday. (Charlie)*

Barriers to Saving Energy

Extrinsic constraints that affect environmental responsibility among affluent green homeowners include the quality of public transportation and the availability of environmentally friendly products [43]. In contrast, the primary barriers identified by our participants were financial issues and structural inefficiencies. Availability of



Figure 4 Barriers to saving energy: (left) Brian keeps a sheet under the door to prevent air from coming inside. (right) An energy inefficient light bulb. Brian commented that this is all he can afford (and had in “real-life”).

products, habit, the choices of other household members, and safety were also important.

Financial issues were especially problematic when saving energy had an up front cost. For example, Angela, who lived in an NC household with three adults and two kids, could not afford to refill her “gas tank” (cost was \$600-\$1200). Instead, she placed space heaters around her home, saying “if I had, you know, the gas on, then the electricity wouldn’t be so high because I wouldn’t have to use the space heaters.”

Participants spent a great deal of effort making up for the structural inefficiencies of living spaces. For instance, Brian, a participant living in an old and drafty NC Public Housing apartment (shown in Figure 4, left):

Brian: I keep a sheet up in the door, so the most of the air won't come in, but it's still-- that's on the bottom of the door, but the air still comes in from the side.

Monica (NC Public Housing) had similar concerns. Other participants overcompensated for air leaks by turning up the heat:

Catherine: Our windows....ooh baby, air blows right around up in them just like it do this door. We can't feel the little heat until we blast it to 80, which we're uncomfortable with...but we don't want to get real sick.

Some energy saving products were unavailable. As shown in Figure 4, (right), Brian uses inefficient light bulbs because they are inexpensive, but when asked if he knew what the differences in costs were he said... “I never really did the research or went out to the stores. I haven’t seen one in real life. I’ve seen it on TV...”

Similarly, Claudia (PA public housing) complained that she could not recycle because it was not available. Eve, one of two participants who had received a free energy audit, energy education, and some home improvements, such as weather stripping, was frustrated by her inability to implement improvements she was told would help:

Claudia: This is a Section 8 rental apartment. They told us to go get rid of the really old refrigerator that we had, that it's a big power hog. They went through and strongly hinted to the landlord that she should replace the stove. That didn't work, but we modified our behavior.... They had a lot [of suggestions], but unfortunately, a lot of those things are out of my control....

Participants noted that some waste was the product of routine or accident. For example, out of habit Monica, an NC Public Housing resident slept with her fan on every night, even in the cold winter months.

More than one participant mentioned that other household members caused excess consumption:

Candace: The most savings from here would be basically the television...Well, things that I think of, things like the television and games, stuff that actually pulls a lot of energy from the home. My boyfriend uses it [television] when he plays the game.

Erica also mentioned her daughter’s use of the television and Nicole discussed her boyfriend’s need to go to sleep with the television on. Angela, a mother of two, mentioned:

Angela: ...the kids leaving all the lights on all the time, I'll think about it, you know, how much electricity we're using and I'll go through and I'll turn things off.

In addition to excess consumption, the actions of other residents sometimes led to reduced opportunities to save. In particular, participants reported concerns about safety and destructive actions directed at their activities. For example, Claudia volunteered for a garden program that was later cancelled because:

Claudia: We buried the flower bulbs and every time people go and trash it and throw trash in there and they destroy it because they used to grow flowers, pumpkins, watermelons and now it's just destroyed and we can't do it no more because they shut the program off.

When asked if she continues to garden, she said “No. Because there’s nowhere to grow or do gardening.... Usually people, they just walk on the grass anyway. They don’t care.”

Lack of safety also affected participant behavior. Brian, a NC public housing resident who had to hang his clothes outside to dry, complained “Some of it is a bad thing [hang drying clothes], because people will steal clothes off clotheslines these days.” Claudia described leaving the lights on to ... just let people know that I’m in the house [when] I’m not in the house. Balancing conflicting concerns such as safety, saving money, and saving energy is a difficult task.

Although safety is much more of a day-to-day concern among our participants, residents in more affluent homes also mentioned the use of light to increase safety, along with the importance of a way to call for help (“a line to the outside world”) [18].

The barriers to saving energy we observed were at some level all caused by lack of control: Services (e.g., recycling), control over the home itself, other household members, and members of the broader community.

SHARING AND OTHER SOCIAL FACTORS

Participants from NC reported sharing information with their friends, family, and/or neighbors about energy bills and strategies for saving energy. This was true even outside of the tightly knit Public Housing community. For

instance, Cheryl, a Section 8 resident from NC was well aware of some of her family members' energy bills:

Cheryl: Now, my cousin, I can tell you her bill was 400 and some change. My friend down there, her bill was 300 and some change. My aunt's light bill was three and some change. I guess it's just because we could, because you know what I'm saying, we compare stuff...

Geraldine, also from NC, describes a situation in which one of her neighbors consulted with her about her energy bill and asked for advice on how to lower her bill:

Geraldine: There was one time when one of the young ladies came to me and she told me her electric bill was almost \$300 because of the windows and everything because, you know, and mines was like \$171, so I said well look-- so I told her about it [small space heater] and I even took her to the store and I showed her which ones to get, and I said "You don't have to put them [small space heaters] on high because the rooms are small. You can put it on low, and once it gets to a temperature you feel comfortable, you set it there and that way it will automatically do just the same thing."

In contrast, participants from PA typically did not discuss their electricity consumption and/or behaviors with neighbors. One participant from PA, Yasmine, felt as if she were being intrusive by asking for this information about how much her neighbors paid in electricity bills:

Yasmine: I guess 'cause people think you are in their business. Or if you're not paying their money- if you're not paying their bill then you don't need to know.

People living in rural areas have a higher level of social trust than those who live in cities, though it's unclear if any causal connection exists [33]. Increased social trust may help to explain the difference in sharing in PA vs. NC.

Sharing also took place in other ways. Participants described trying to educate members of their own households and also their broader social network. For example, Kim, who saves energy even though she does not pay for it at her current PA residence, told us:

Kim: [My friends] know that I used to pay light, so just turn it off when you leave. That's it. Sometimes they get mad, but now the ones that are closest to me that know me, they know to do that. But other people I still have to explain to them that I just don't leave my lights on all the time.

Impact of a Person's Past on Their Behavior

Woodruff *et al.* discuss the fact that green household members fully maintain habits formed during previous phases of their environmental challenges [43]. Our results show that this finding is also valid in low-income communities. Participants' past experience and habits have a strong impact on behavior. Lauren (from PA) describes learning many energy conservation behaviors as a child:

Lauren: I learned how to make my own clothes by hand. We didn't have machines when I grew up. Everything was done by hand. I learned to cook on the outside, not inside the house. In the summertime I did most of my cooking on the

outside because it's better for you anyways, much healthier for you. And I learned this in Rome, Georgia. All this in Rome, Georgia when I was a little girl growing up.

Similarly, Candace talked about how her mother was strict growing up and enforced energy saving behaviors at home:

Candace: Yeah, and also my mother was always the type to say, "That light better be off." And when I began to move out, and pay my own electricity bill, I see what she meant, from my first apartment, when I got the light bill.

This effect was strong even when participants were not responsible for paying electricity bills. For example, as mentioned earlier, Kim pays no electricity. Here, she describes why she still turns things off:

Kim: Yeah, like when I used to stay with my grandmother she had to pay light and gas and stuff like that, so she was really into us turning the TV off and the lights and stuff. If you're not using the TV unplug it and things like that. Like I said, it's just stuck with me. Now it's like a habit that I can't break I guess.

MONITORING ENERGY USE

Despite the known benefits of providing end users with data about their own energy use [1], participants in the study received little or no feedback about energy use. Participants with unlimited electricity received no feedback. Those with a set allocation received none unless they exceeded the allocation. Those who received bills felt they contained too little information too late. Perhaps as a result, they did not describe tracking energy use in the detailed fashion that Woodruff *et al.*'s green participants did [43]. Despite this, some participants monitored what they could out of necessity.

Participants had creative suggestions for how to provide real time feedback, and they also learned to use what little feedback they had. Erica, who paid for some of her own electricity and made \$10-20k *per year*, used her thermostat as a means of gauging how much her electricity bill would be each month: "I think of, okay, if I keep this [thermostat] on between 72 and 75, I'm going to have a low light bill."

Angela, whose light bill ran anywhere between \$350 - \$500 *per month* learned to read her energy meter: "The faster it spins [energy meter], the more it costs. The more energy you're using, the higher your bill is."

Geraldine, who paid for energy despite making less than \$10k *per year*, showed the same idea in Figure 5 (left):

Geraldine: That's where you find out how much energy you use in your apartment.... that lets you know how much energy you're using in your house, and it can give you, if you care, then you'll look at it and see it. If it's higher than what you think it should be, then you can make adjustments in your house to slow it down, you know. [If it's] going real fast you can make adjustments to slow it down and save energy.

Interestingly, Jacqueline, a public housing resident from NC who made \$10-20k *per year*, had a more sophisticated meter in the kitchen of her apartment (see Figure 5, right). She was the only participant to mention such a device:



Figure 5 Energy monitors (left) Geraldine uses her energy meter as a monitoring device to let her know how much energy she is using. **(right)** An “Energy Saver” device that Jacqueline uses to help determine how much energy she’s using. For Jacqueline, the device specifies three colors: Yellow = “Caution”, Green = “green light is fine” and Red = “You’re getting a light bill”

Jacqueline: This is what they call, in our apartments, our energy savers.... The yellow light comes on and lets us, know that we’re just about to exceed over our energy. The green light is fine, it’s fine. The red light is what you worry about when that comes on in your apartment. That means you’re getting a light bill because you are over. <laughs> If you are over. And it helps a lot. It helps a lot.

Although children are not responsible for paying the energy bills in the home and unaware of the exact usage and cost, Justin (from PA) suggested having children pay part of the electricity bill with their allowance:

Justin: When that bill comes, go in their pockets and say, “You’re half on this.” ...They aren’t going to want to be giving their money up to pay these bills, so they’ve got to turn them lights off, open them blinds.

DISCUSSION

Our results illustrate a community that includes individuals strongly engaged in energy saving behaviors. As summarized in Table 2, low-income householders had a surprisingly broad range of motivations that went beyond money. Our comparison shows that many of the

motivations present in affluent households are also valid in low-income communities.

Saving energy happened regardless of whether participants were responsible for their energy bill. Approaches to saving energy could be characterized as more creative and diverse among low-income households than affluent households. All types of households shared a wish to monitor energy use, though access differed across groups. Our participants resembled typical households most in the barriers they encountered, though they faced more, severe challenges than affluent households of either type.

Technology could address some of those barriers. For example, sensing and feedback technologies used by the Ubicomp community to support energy savings (e.g., [12]) could allow participants to effectively engage with landlords about inefficiencies. These technologies could also encourage the participation of unsupportive household and community members [6]. Below, we discuss some ways that common Ubicomp approaches to saving energy might need to change to support low-income households.

Feedback

Very few participants, regardless of whether they paid for their own energy, knew the amount of energy consumed each month. Chetty *et al.* found similar results in “typical” households [6]. Our participants wanted feedback, but those whose energy was subsidized usually did not receive a bill or feedback of any kind. Even simple policy changes like showing residents their bills could have a positive impact. However, feedback represents a particular challenge in communities where *per* unit energy information may not even be available to the utility or landlord. Novel sensors that can extract unit-level information are needed.

Table 2: A comparison of key findings in our work and studies of more affluent households

Result	More Affluent Households (Green [43], Typical [6])	Our findings
Reasons for saving energy	Green: Future generations; Activism; Religion/ethics, Trendy utopian optimism; Rugged independence; Self-reliance; Habit Typical: Money, Comfort, Environment; What can I do?	Future generations; Religion/ethics; Habit; Money; What can I do?
Approaches to saving energy	Green: Pairing household members with “green” mentors; Creating mental challenges for household members related to energy consumption; In depth learning exercises Typical: Better bulbs; Programmable thermostat; Lights off & unplugging things [6, 23]	Some examples: Repair work/stopgap measures; Efficient & minimal use of appliances/lights; Re-use and Do It Yourself (DIY); Gardening/fishing
Barriers to saving energy	Green: Quality of public transportation; Availability of products Typical: Money (e.g., for energy audits); Poor technological interfaces (e.g., programmable thermostats); Inferior service of new technologies (quality of CFLs); Limited decision making as a result of sharing infrastructure with others; Household members; Safety [18]	Control: Living space inefficiencies; Availability of services; Availability of products; Habit; Household members; Limited decision making as a result of sharing infrastructure with others; Community members Basic Needs: Safety; Money (<i>esp.</i> up-front costs)
Sharing	Green: Enjoyed expressing their identities Typical: Interested in “benchmarking” energy consumption against others, not necessarily sharing behaviors due to privacy	More common in NC, less so in PA. NC residents shared ways to save energy to help relatives and compared their electricity bills with others.
Monitoring energy use	Green: Detailed tracking among “green” participants Typical: Would like real-time information to help save money, have comfortable homes, and be environmentally friendly.	Almost no data available to participants; Some monitoring by necessity (e.g., watching thermostat settings, meter dial speed)

To be accessible to a large number of low-income individuals easily, feedback might need to leverage the (relatively) ubiquitous cell phone as a display device (e.g., [13]). Although more than 50% of low-income households use the Internet [19], only 30% have access at home where it would best support frequent feedback. In contrast, about 60% have access to mobile phones [32].

Getting from incentive to habit

Feedback is valuable, but ultimately, change requires learning new habits. Even when there is no financial incentive to save energy, participants' habits still keep them saving. To the extent that habits encode longer-term behavior changes, Dahlstrand and Biel argue that unfreezing old habits, or creating new habits, is vital for change [9]. Habits form over time through procedural learning [16], and may be learned by observing others around us [3]. Although the notion of breaking habits is not called out explicitly by Woodruff *et al.*, the "bright green" individuals they describe are reflective about their choices and continuously evaluate their behaviors [43]. Reflection and evaluation can help to break old habits and build new ones. Technological interventions can have more long lasting effects if they also support this process.

A deep connection to God strongly motivates energy saving behavior in some participants, while others wish to help their children and their children's children succeed. Both of these motivations are an integral part of participants' lives, and affect many things outside of energy use. Past work shows that religious households may creatively appropriate technologies to express and follow their beliefs (e.g., [42]). Similarly, green households use technology to support a different set of values [43]. By developing technologies that integrate with these values we may be able to support and enhance conservation.

Engaging all the stakeholders

The prevalence of complaints about the impact of other household members on saving energy demonstrates the importance of involving the entire household in conserving energy. The varied relationships among household members in the population we studied need to be addressed (boyfriend, roommate, spouse, grandparent, kids).

The presence of sharing among our NC participants demonstrates the value of engaging with other households as well. In a study of low-income individuals and healthy eating, Grimes showed that participants enjoyed sharing information, and felt empowered by their success in improving their diets [17]. Perhaps this same sense of empowerment can be achieved by technologies promoting energy saving tips to communities open to sharing.

As with affluent households, willingness to share and concern for privacy varied, with PA participants being less open. Although these concerns echo those found among affluent users of other social technologies, any exploration

of sharing in the low-income communities we studied must be especially sensitive to concerns like safety.

Many participants were simply unable to save energy due to structural inefficiencies, lack of access (e.g., to energy efficient bulbs) and lack of support from other stakeholders (e.g., landlords, other residents). On the other hand, some lived in communities that were fairly progressive with regard to saving energy. More exploration of the forces behind these differences is needed, as is policy and advocacy work to increase support for green practices. Technology that could help residents measure and calculate the potential for savings from an investment in more efficient structures or appliances would be of great value.

CONCLUSIONS AND FUTURE WORK

Energy use and energy saving behaviors take place across all sectors of our society. Our work focuses on a group that is often left out of the mainstream sustainability debate, low-income households. Our results help to demonstrate that existing types of motivation generalize to low-income communities while highlighting differences in emphasis and strategies for saving energy. Through our photo-elicitation study, we were able to explore a range of factors that influence energy use in this group. Many of our participants were environmentally motivated, while others wished to save money or to comply with a moral and spiritual aversion to waste.

We show how real-world constraints such as renting, safety, and unsupportive household or community members affect participants' control over their energy use. We argue that a successful intervention may need to overcome these barriers by engaging stakeholders such as the landlord, other household members, or community members. Our next step is a participatory design process aimed at creating viable Ubicomp technologies that address these issues.

We hope that our work will inspire further ubiquitous computing research into low-income communities and lead to the development of technologies and solutions for energy conservation that embrace the full range of our world's diversity.

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