Understanding factors of successful engagement around energy consumption between and among households

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ABSTRACT

An increasing number of researchers are using social engagement techniques such as neighborhood comparison and competition to encourage energy conservation, yet community reception and experience with such systems have not been well studied. We also find that researchers have not thoroughly investigated how different households use these systems and how their uses differ from one another. We explore these questions in a 4-10 month field deployment of a social-energy monitoring application across 15 households, in two distinct locations. We contribute results that describe conditions under which these techniques were effective and ineffective. Our results imply that understanding factors such as a building, or community's layout, context knowledge of community members, accountability and adherence to social norms, trust, and length of residence are key for future design of social-energy applications.

Author Keywords

Home energy, social comparison, community, renters

ACM Classification Keywords

H5.m. Information interfaces and presentation: Misc.

INTRODUCTION

Residential energy use accounts for 23% of the total energy consumption in the U.S [13], and usage highly depends on the behaviors of occupants living or working in these settings [27][31]. Other factors such as who is responsible for paying electricity, who controls the dwelling (*i.e.*, is the building leased or owned), and external groups such as community members affect energy consumption [8]. Yet the designs of energy monitors have typically been limited to the individual [5], and the deployments of these devices limited

to single households.

To encourage the reduction of home energy use, researchers are moving toward understanding consumption beyond the individual and among the collective. In doing so, researchers have leveraged social techniques [15,28,36] such as historical and neighborhood comparisons [1, 15, 36], competition [15, 36], and features such as message boards [15]. One commonality among these studies is that they do not provide a rich picture of the deployment communities, the structure of these communities, and details about the participating households. It is unclear which group dynamics impact the level of responsiveness to social engagement techniques that encourage energy conservation.

To better understand these dynamics, we explored the similarities and differences in reception and experiences between two communities using a social-energy application. We deployed a community-focused, energy feedback application to 15 rental households across two distinct communities in a city known for its tapestry of neighborhoods (*e.g.,* culture, ethnicities). We staggered our recruitment and deployment over a period of 4-10 months. Households in the same community could monitor each other's average daily consumption. Households could also view their own real-time information about their energy use and use features to share home-energy reduction strategies. Though this study only represents a small sample, our results suggest that crucial factors affecting successful social engagement around energy consumption include: 1) the built environment, 2) context knowledge of community members, 3) accountability and adherence to social norms, 4) trust, and 5) length of residence.

In this paper, we contribute detailed results based on the deployment of a social-energy application across two distinct communities. Our study sheds light on social and physical factors that contribute to the success and failure of each community's engagement around energy conservation. We raise new research questions around detecting and leveraging social network structures and conclude with design implications for future social-energy applications.

RELATED WORK

We review deployments of home energy monitors (HEMs) to explore consumption beyond the individual level and within group settings. In past field deployments of HEMs that incorporate social strategies to encourage energy

reduction, we find mixed results [15,26,28,35,36]. These studies also lack household and community details that make it difficult to tease apart which communities and households are more receptive to social techniques designed to curb home energy consumption. To help us understand factors that facilitate community engagement, we also look outside the domain of home-energy consumption to field deployments of information and communication technologies (ICTs) across neighborhoods and communities.

Factors affecting successful social-energy applications
In some social-energy applications, comparison and competition have helped to reduce energy consumption. However, factors that contribute to their success are unclear. We review related work to identify factors and conditions that may play a role in the effectiveness of some social-energy applications.

Comparison with others is a way to establish standards of behavior and can lead to reduction of uncertainty [16]. Successful uses of energy comparison have occurred in office settings [35] and campus dormitories [4], yet the effectiveness of social comparison has been mixed in military and residential households [1, 26, 28, 36] and in settings that leverage competition as an incentive to conserve energy [4,15,36]. Unfortunately, information regarding community characteristics or individual household characteristics is not always available to help identify success and failure cases.

In a qualitative study of an energy-monitoring device in 16 households, Schwartz *et al.*, provided the social context of comparative data as a complement. As a result, people were allowed to draw practical conclusions about their household consumption, and their feedback was perceived as useful [31]. The researchers suggest that social comparison motivates behavior as it can increase the motivation to contribute by way of knowing that others are contributing [31]. It can also indicate a failure to conform [31].

In an energy-related workplace study [35], employees that received consumption comparisons with others saved more energy than employees that received feedback on their own conservation behavior. Perhaps understanding the context of the workplace setting influenced how well social comparison worked in this environment. Another factor that may have played a role in this setting is the hierarchical network structure (*e.g.*, managers and employees).

Military housing is another homogenous (*e.g.*, housing sizes, politics, fighting the same cause), hierarchical setting; the environment appears to be well suited for techniques such as social comparison and could lead to subsequent improved performance [26]. However, in a study using multiple interventions to encourage energy conservation across two military bases, the effect of social comparison did not lead to successful results. It was concluded that since up to half of the respondents were on post and moving within a year, there was less motivation to make one's neighborhood

outperform everyone else's and little chance to build a group identity [26].

In essence, factors found in past work that affected the success of social-energy applications have included knowledge of the social context of social comparisons [31] and the length of time spent in an area, both of which may have contributed to group identity [26] and perhaps to the hierarchical network structure.

Factors affecting social interaction in communities
We discuss how the integration of ICTs in communities can affect community interaction and under what circumstances. We also discuss other factors that influence social interaction in communities.

In a longitudinal survey of 100 households in the Blacksburg Electronic Village, researchers found that Internet use can increase: community attachment and engagement; social contacts for those with high social use of the Internet; a sense of belonging, and community activism [23]. In a study of 109 homes provided with free Internet access, researchers found that a community mailing list increased social engagement and aided in collective action against homeowners and the housing developer [21]. This study also found that factors such as the length of residence and prior computer knowledge helped to promote community-based interactions [21]. Additional factors such as norms of reciprocity and trust, or social capital [30], have been found to promote social engagement.

On the other hand, Kavanaugh, *et al.,* note that factors such as life-cycle stage (*i.e.,* 35-64 years of age) and low levels of extroversion and education may lead to lower contributions of social capital and collective action [23]. Similarly, Hampton and Wellman raise concern for the increasing digital divide [21]. In terms of social capital they also express concern about the lack of interaction by underprivileged individuals [21]. These works suggest the need for further investigation of ways to encourage these populations to contribute to the general pool of social capital and collective action [21, 23].

Studies to understand social interaction without ICTs find that physical structure, or a building's layout, can affect social interaction and can help create new social networks. For example, Ginsberg and Churchman found that elevators in Israeli middle-class neighborhoods were a form of public commons [20]. This allowed for social interaction, which could help strengthen network ties. This study also found that other semi-public spaces (*e.g.,* hallways, outside of the building) allowed for social interaction.

Regardless of how frequently neighbors interact [2], those communities with a large proportion of residents who know and interact with each other are more likely to engage in surveillance, intervene in local disturbances, and develop movement-governing rules [2, 14]. Though social-energy applications leveraging social comparisons inherently rely on social interaction, researchers studying these applications have not explored the effect of these factors in their
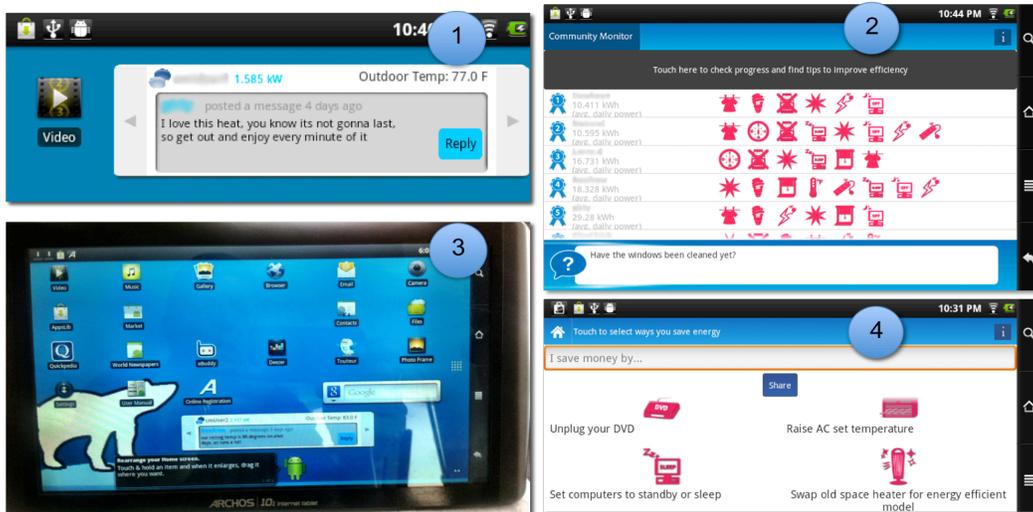
Figure 1 – Community Monitor: (1) Application widget – shows real-time energy consumption, outdoor temperature, and latest message post (2) Application main page – shows household rankings, latest community message, and ways each household saves energy; participants can send messages to the message board from this page (3) Tablet and application wallpaper (4) "Ways to Save" page

deployment communities. Our goal was to understand which factors contributed to the success or failure of our application in each community.

THE COMMUNITY MONITOR APPLICATION

Before providing application details, we provide an illustration to describe how we intended participants to use the Community Monitor. Imagine Daryl, a 35-year-old father of two, takes a look at his tablet because his children are upset that only one of the four polar bears appears on the tablet wallpaper. The family knows that they are currently consuming a lot of electricity (see Figure 1-3). Daryl asks the kids to turn off unused devices, he turns off the AC, and they see two more polar bears appear in the background. The kids are happy. Daryl, however, wants to see how he is doing in comparison to the other participants. He selects the Community Monitor application widget to take him to the main application, which shows him the leaderboard (see Figure 1-2). Daryl sees that he is ranked #5 out of 6, and consumed on average, 16.73 kWh in the past 24 hours. He sees that the Jones family is ranked #2 at 10.5 kWh. At the bottom of the leaderboard screen, Daryl sees that Jennifer posted a new comment on today's weather (see bottom of Figure 1-2). He then selects the message and posts, "Yes, it is a nice day outside! I'm going to take the kids outside to play around 6." Daryl selects the "tips" button at the top of the leaderboard for additional ways to save (see Figure 1-4). He selects the tip to save energy by using the sunlight and sees that a sun icon appears next to his average daily consumption on the leaderboard (see icons in Figure 1-2).

We designed the Community Monitor to include feedback and to encourage social engagement (through regular presence in households). Our goal was to integrate the application into an Internet tablet to build energy awareness into daily routines and habits, and to create a social

experience with our application. Our implementation was iterative and informed by past concept validation results of social-energy applications [7, 10], past research (*e.g.,*[8,9,18,19, 24,28]), and a multi-month pilot deployment. We present the *final* version of our application, which we released on January 5, 2012.

Platform Selection: Many of our participants did not have smartphones or Internet access; therefore, we selected a platform that was relatively inexpensive as well as useful for a new Internet user. Since we wanted individuals within a household to share the device, and because tablets are low cost in comparison to laptops, we chose them as the most appropriate technology medium for our demographic. In addition to Internet access, tablets provide individuals with games, email, and other appealing applications. Additionally, because tablet devices are portable, they can be placed in common areas. The versatility of tablets also encouraged frequent use. Toward that end, we modified the tablet's wallpaper background to represent the household's real-time consumption, as this strategy was successful on mobile phones [19].

Wallpaper Design: Recent studies indicate that people understand the relationship between their actions and the environment better with the use of iconic images [23]. Studies also suggest connecting individual actions to their consequences [29]. Therefore, to demonstrate real-time consumption, we displayed a single polar bear on a block of ice to indicate high consumption (bad) and a family of polar bears to indicate low consumption (good). The images are noticeable from a distance and could be seen before household members interacted with other applications (*i.e.*, games, email, *etc.)*(see Figure 1-3).

Main Application: The main application was designed to support communication, sharing, and social comparison. Our

goal was to allow households to see what was good or bad in terms of consumption, to whittle down issues, and to be able to have informed discussions with landlords or each other.

We used the Android™ platform to develop the tablet application and The Energy Detective (TED®, http://www.theenergydetective.com/) to collect home energy use data. We used the StepGreen API to manage data [25]. The application could be accessed *via* an Android widget.

Android Widget: We used an Android application widget (a small application view that can be embedded on the device home screen and can receive recurring updates) to provide additional information. The widget provides participants at-a-glance feedback about their current electricity usage, the outside temperature, and the latest posting to the community message board (Figure 1-1). The use of an Android widget was also suggested in [28]. Selecting the widget sent users to the main application and main application feature—the leaderboard.

Leaderboard: The Leaderboard provides a ranking of household members based on their average daily consumption (Figure 1-2).

Message Board: The Community Message Board allows participants to communicate with the rest of their community (*e.g.,* information sharing, event planning, and questions). This social aspect of the application provides an opportunity for knowledge transfer between individuals.

Shared Actions: The "Ways to Save" (Figure 1-4) feature allows participants to learn about possible actions and share information about how they save (Figure 1-2).

FIELD STUDY METHOD
We deployed our application across 15 households within two communities between 4-10 months (6-7 months on average across both locations Table 1). Prior to that, we piloted the first two versions of our application for one to four months across five participant households to get design feedback and to work out kinks in the study design and technology. Our official deployment began January 5, 2012, and our quantitative analysis for this study ended June 30, 2012. We continued recruiting participants during our pilot and main study.

In total, we recruited 15 households consisting of 31 household members, and at least 18 guests, including visiting friends and family (see Table 1 for details). In all, our qualitative data consists of approximately 176 interviews across our 15 primary participants. We conducted 1-3 interviews per month per household on average. Initial setup, survey and interviews lasted between 2-3 hours per household, but our ongoing monthly interviews lasted approximately 30-60 minutes each. One site observation occurred during a site tour provided to the main author by each site manager. However, we also made observations while interviewing participants, which were based on participant interview responses.

We selected our locations for several reasons. The primary reason for our selection was that these buildings were some of the few all-electric (*i.e.*, heating and cooling), individually metered buildings in the area. Though this limited us to rental households, these households are understudied in this domain, and provided us with the opportunity to explore landlord/tenant conflict around energy consumption.

Past work exploring energy consumption in low-income households [7] reveal conflict between landlords and tenants and identified factors such as social engagement and social sharing as possible solutions to this conflict [8]. Further, a deployment of households within the same community, or building, implied shared characteristics of each unit such as built-in appliances, building age, *etc*.

Community Descriptions: We deployed our application to two disparate communities, both maintained and managed by the same company. The development company recommended the most suitable locations based on our study and the factors listed above. Though rental units were not the same size, and the two sites were different ages, both sites used similar appliances and represented distinct community characteristics. Though the two locations varied significantly in the number of occupants per household, we saw the disparity as an efficient way to better study intra-communal communication and interaction with our application.

Community 1-Hamlet: Hamlet is a 60-tenant, mixed-income, 12-story building. The building was built in 1907 and renovated in 2008 into a set of affordable residential lofts. The building was equipped with a clubroom, which is a common area for residents to watch TV and/or hold meetings, a fitness center, and a rooftop deck and green space. Some residents paid market value rent plus a separate electricity bill. Others paid a reduced rate for their rent that included electricity (*i.e.,* these residents did not receive an electricity bill). Except for gas-heated hot water, paid for by the building, this was an all-electric, individually metered building. It is a Leadership in Energy and Environmental Design (LEED) Green Building. We recruited six households from Hamlet that includes two households that paid for their own electricity.

Community 2-Main Street: Main St. consists of 23 all-electric metered units that were newly constructed at the time of deployment; they consist of rehabilitated brownstones and newly constructed apartments and townhouses. Previously, the area consisted of a strip of abandoned buildings and vacant lots. A small community center was built six months after our study deployment and was used primarily as a place to deliver monthly rental payments. All homes are rented to low-income households and no participants paid an electricity bill. We recruited nine households from Main St.

	ID	Age (Young Adult < 25; Adult 25-59; Elderly >=60); Employment	Household Size (including frequent visitors)	Type of Household	Study Devices	Other Devices; Home Internet Access?	Change in Consumption	Key influencer?	Approx. Time in study (months)
1: Hamlet	H1	Elderly; Employed	1 Adult	Apt	1	Y; Y	Decrease	Yes	10
	H2	Elderly; Retired	2 Adults	Apt	2	Y; Y	Decrease	Yes	8
	H3	Adult; Employed	2 Adults	Apt	2	Y; Y	Increase	No	4
	H4	Elderly; Retired	1 Adult	Apt	1	N; N	Decrease	Yes	6
	H5	Adult; Employed	1 Adult	Apt	1	Y; Y	Decrease	No	6
	H6	Adult; Not Employed	3 Adults, 1 Child	Apt	1	Y; Y	Decrease	No	6
2: Main Street	M1	Adult; Employed	4 Adults	TH	2	Y; Y	Increase	Yes	9
	M2	Adult; Not Employed	4 Adults, 2 Children	Apt	2	N; N	Increase	No	6
	M3	Adult; Not Employed	4 Adults	Apt	2	Y; N	Increase	No	7
	M4	Adult; Not Employed	3 Adults	Apt	2	Y; N	Decrease	No	6
	M5	Young Adult; Employed	2 Adults, 1 Child	TH	2	Y; N	Decrease	No	5
	M6	Adult; Retired	1 Adult, 2 Children	TH	2	Y; N	Decrease	Yes	6
	M7	Elderly; Not Employed	4 Adults, 2 Children	Apt	2	Y; N	Increase	No	6
	M8	Adult, Not Employed	4 Adults	TH	2	Y; N	Increase	No	5
	M9	Adult; Employed R	1 Adult; 2 Children	TH	2	Y; Y	Decrease	No	4

Table 1– Household Profiles: Details are provided about the main participant's age and employment (our interviewees). Other devices include mobile devices, PCs, iPads, *etc.*; consumption change based on differences between average monthly consumption prior the intervention and average monthly consumption with the intervention.

Both sites shared the same type and brand of appliances (*e.g.*, refrigerator, dishwasher, and washer/dryer in most households). Table 1 represents households and household members from each community. Key variations affecting energy consumption among Hamlet households included which floors individuals lived on (*i.e.*, higher floors tend to be warmer) and, at Main St., whether or not the household was a 3-bedroom, three-story townhome (TH) or one or two-bedroom apartment (Apt).

Recruitment Strategy: To recruit participants, we posted flyers around the building and asked management to email flyers and to slide flyers under each resident's door. We also used "snowball sampling", in which existing participants recruit others from among their acquaintances. We offered referral payments as incentives.

Our recruitment was open to all residents. We did not prohibit participation by residents who were also on staff at the development company. Realistically, inclusion of staff members reflected what was expected in a real world deployment; it also gave us some insight into landlord/tenant issues that might arise. As a result, the Main St. site manager and a Hamlet resident who helps with building upkeep participated.

Household annual income ranged from less than $10k to more than $70k; higher-income households lived in Hamlet. The first member in each row of Table 1 represents our primary participant, and interviewee. Primary participant mean age was 52 (SD=13.56). Seven were either retired or unable to work; six worked full-time or part-time; and two were looking for work. Employed participants worked in a variety of fields including administration, human resources, maintenance, banking, environmental services, and property management. Main St. (M=3, SD=.87) had significantly more household members than Hamlet (M=1.3, SD=.52) (F[1,15]=17.73, p=.001).

Data: We conducted 1-3 interviews per month with each household. In our initial interviews, we collected data about each primary participant's social ties with other community members, what they liked most about their communities, and any issues that they needed to report to the landlords in the past month. We also logged application use data, collected monthly electricity bills, and conducted site observations.

To understand participant's social ties with other community members, we collected the names of each primary householder in the community from the site managers prior to the first interviews. Using a 5-point Likert scale, we then asked participants to indicate their levels of agreement or disagreement with the statement, *"I know this person."* Participants engaging in offline communication were instructed to choose *"agree somewhat"* or *"agree strongly"*; if they did not know the person at all, they were instructed to choose *"disagree strongly."* Otherwise, they selected *"disagree somewhat,"* or *"neither,"* to indicate that they knew the person by sight but did not engage in meaningful conversations.

The goal of our ongoing interviews was to understand each household's interaction with our application and tablet. We asked, for example, "Did you engage with others, and/or share the application and tablet? Did you discuss application data or information with others in your household and/or with neighbors?"

Application data allowed us to gather how many times a feature was accessed. Logs, in addition to interviews, also helped us determine how often participants used various features of our application and gave us insight into other applications installed on each tablet.

Site observations consisted of a guided tour of the facilities by a development company representative. We captured this information in our site descriptions but provide additional context based on data from our monthly site visits and resident interaction.

Deployment Details: Our application relied on use of TED data and Internet access. In addition to the TED installation, we provided all households with free Internet and Wi-Fi access, 10" Android Internet tablets, and technical support for the system by phone and in person as-needed. To prevent
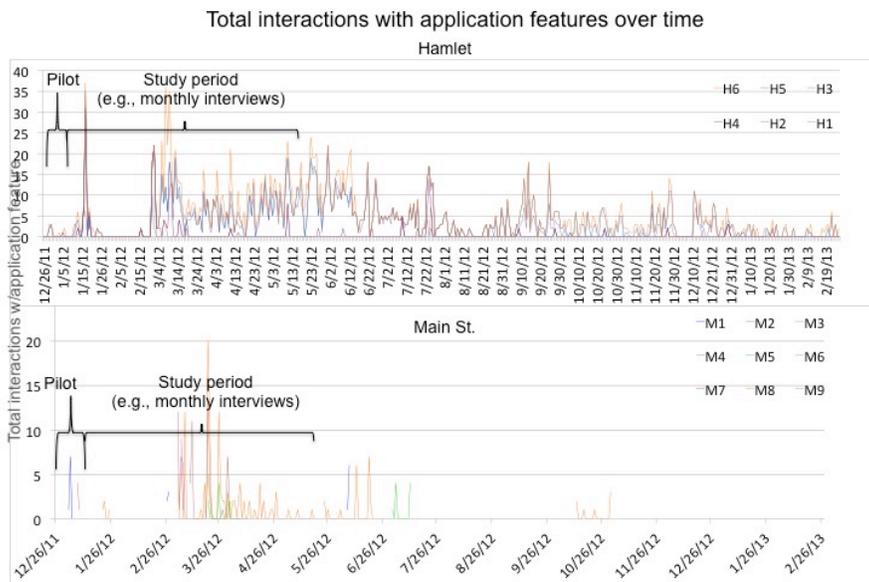
Total interactions with application features over time

Figure 2 – Application feature interaction over time. Note that some Hamlet participants continued using the application even after the end of our formal study (top: Hamlet, bottom: Main St.)

sharing-related conflicts in multiple-member households, especially those with children, we offered an additional 7" tablet.

To encourage community building, household engagement, and to increase knowledge, researchers posted messages to the board using the alias *CMBot* an average of two times per week, part way through the main study. Messages included energy-saving tips and questions about how residents save energy. The first author also organized a casual pizza party event for both communities.

Next, we present our deployment results. We refer to our participants by anonymous IDs and location (*e.g. H1* is *household 1* from *Hamlet*, and *M2 is household 2* from *Main St.*). For clarity, a primary participant, or simply *participant*, represented each household. We present data about *households* as a whole, which includes *other household members*. Where possible, we provide IDs for participant quotes. However, because some comments deal with activities or opinions that might be frowned upon by landlords or other community members, we sometimes attribute a quote only to a "participant."

FIELD STUDY RESULTS
In this section, we discuss our deployment results. Due to several factors such as the variability across sites and households (*e.g.*, building and household size); the relatively small number of households involved in the study; the short study length; and indoor/outdoor temperature fluctuation, our consumption data did not show any significant change. Therefore, we largely present detailed qualitative results and show household change in consumption in Table 1. Our qualitative results show how differences between the two communities and interactions within each household may have affected the use of our application. However, we first

present tablet and application usage results between each community and a cursory analysis of participant interaction.

Application and tablet usage
We used our application log data to gather both application and tablet usage. Generally speaking, all participants interacted with the tablet in some way. While Main St. participants used the tablet device more frequently, Hamlet participants were higher users of all application features. Hamlet's number of community message ($F_{[1,15]}=7.59$, p=.02, M=1.5) and leaderboard views ($F_{[1,15]}=5.14$, p=.04, M=4.1) were significantly higher than Main St.'s on an ANOVA.

The leader and message board features were the most used features across both locations. Many participants read, though very few posted messages. Participants rarely used the "Ways to Save" feature. Most Main St. participants used the polar bear display to explore their consumption. Because we were not able to track how often households viewed the main screen, these actions are not accounted for in Figure 2.

To facilitate sharing, more than half (8/15) of the households kept the tablet in a common area (*i.e.,* the kitchen, the living area, and dining room). Households also used their tablets to surf the Internet (15/15), to play games (14/15), to check email (8/15), to search for jobs (3/15), and to read the Bible (4/15). Ten of the fifteen households used their tablets on a daily basis. The remaining five households had access to devices such as iPads, smartphones, and home laptops and as a result, did not use our tablets as frequently. Next, we provide a high-level social network analysis to help us understand interactions among our participants and how the two communities differed.

Cursory analysis of participant interaction
Though our deployment only spanned two communities, we wanted to understand the nature of interaction between participants before introducing our application. We conducted a cursory social network analysis to help us understand the characteristics of each community's network structure (see Figure 3). We find that Hamlet had stronger ties and that Main Street's low centrality signaled opportunities for key influencers to promote our application. These findings were also supported by our interview data.

The analysis reveals that the Hamlet households had stronger ties, which we conclude from its transitivity score, an indication of network closure and close bonds [22]. Also, Hamlet had a lower closeness centrality, which means that information could spread more quickly within Hamlet than Main Street [22]. H5, Hamlet's outlier, became a part of the network within weeks after joining the study, and as an outlier did not affect Hamlet's results significantly. Main St.
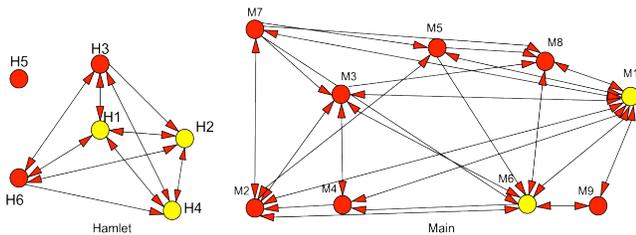
Figure 3 - Social Network Diagram (H=Hamlet, M=Main; key influencers are yellow) Degree centrality: H=.30, M=.54, Betweenness centrality: H=.02, M=.66 Closeness centrality: H=0, M=.66, Density: H=.60, M=.58, Transitivity: H=.88, M=.66, Size: H=6, M=9. Netvis analysis factors in weights of each relationship.

had a higher degree centrality, which is an indicator that there were key households in positions of influence [22]. Main St. also had a higher "betweenness" centrality, which relates to a network's ability to link together individuals that have few other ties between them [22]. This enables individuals to broker relationships between those with few connections. We add context to these findings by discussing our site observations and interviews next.

Site observations and interviews
Our site observations and interviews help us to understand community characteristics and how participants used our application within and among households. Site observations suggest reasons for household bond strength, but no insight into information flow within and among householders. Our interview results help to fill this gap.

Site observations suggest a relationship between the stronger ties in Hamlet and the use of common areas that support congregation. Similarly, our site observations suggest a relationship between weaker ties in Main St. and fewer social interactions across the full community. According to Hampton and Wellman, the physical layout does not solely determine the forms of interaction [21], but it makes certain interactions easier and others more challenging.

Hamlet had three common areas: a TV/entertainment and/or meeting room, a fitness center, and a rooftop deck and green space. Per our interviews, half of our participants regularly used one or more of these spaces and residents could watch baseball games and see fireworks from the rooftop. Hamlet was a 12-story building with two main elevators. There was also a strong dog community within the building, and many people knew owners by recognizing their dogs. The common areas, presence of an elevator, and strong dog community could increase opportunities for household interaction.

Main St. consisted of townhouses and apartments spread across one side of a single street. Toward the end of our study, the development company built a small common area; surprisingly, participants rarely used this space. On sunny days, residents sat on their front porch and interacted with passers-by as well as neighbors across the street. The site manager stated, "*Hamlet is an apartment building, it is a complex. They have facilities on site. They have things right there for them. ...this area [Main St.] [is] not a recreational place.*"

Finally, the Main St. apartments and townhomes were larger and had significantly more household members than Hamlet. This factor could also lead to less engagement with neighbors. It is likely that these physical characteristics have played a role in how residents within the community interacted and formed ties outside of the household.

We were able to identify sources of conflict at Main St. from our interviews. We used a bottom-up approach to analyze our interview data, and used saturateapp to manage our data (http://www.saturateapp.com). Due to privacy concerns, the vast majority of our participants did not wish to be recorded. As a result, the primary author captured detailed notes during each interview, and created memos after each interview. We assigned low-level codes to the data and grouped them into 19 categories. Our two most emergent categories were related to community engagement and disengagement, which shed light on application use and community interaction. Other prominent categories included "barriers to saving energy" (*e.g.,* health, safety, property restrictions), "landlord/tenant issues" (*e.g.,* maintenance issues, landlord distrust), which we discuss later. "Unwillingness to compromise comfort," which we do not discuss, appeared as a category and is similar to prior findings in this area [33].

These categories help us understand how information flowed in each community and identify obstacles to information flow. We also saw interaction patterns within households, particularly among Main St. households that did not engage with the application. We explain our key categories, starting with those related to community engagement next.

Getting to know your neighbors: Though the Hamlet participant network was not fully connected at the beginning of the study, only Hamlet households were able to identify everyone using Community Monitor. H5 was initially isolated but joined the network *via* H6 once the study started. All Hamlet participants identified and spoke with other participant households outside of the application. Two of the Hamlet participants used a non-anonymous pseudonym. H1, who worked onsite, used his real name, and another used the name of the household pet—a name known in the community.

Four of nine Main St. households used non-anonymous pseudonyms such as an apartment number or pet's name. Despite this, only four Main St. participants were able to identify household participants, and only those participating in adjacent apartments (*e.g.*, next door). Knowing participating households provides additional context and could aid in information and communication flow around energy consumption.

Holding your neighbors accountable: The leaderboard enabled social comparison, which allowed households to hold each other accountable. This occurred despite the fact that the majority of our participants (13/15) did not pay their electricity bills. Though not mentioned as frequently among Main St. residents, many Hamlet participants described

holding others accountable; the first author witnessed the behavior at the community pizza party.

At a researcher-sponsored pizza party, two Hamlet households mentioned that H2 was ranked much lower than normal. In a discussion about community averages, the two households (H4 and H6) brought this to H2's attention. H2 was somewhat surprised and explained that they had already put in a work order for a broken air conditioner (AC). The H2 household asked the first author to speak to the landlord because the issue was *"messing up [their] stats."*

H6 noticed that another household's data was anomalous due to an issue with the installed TED device. During an interview, she asked what was going on with the household—she felt the daily average was impossible for the building. H5 mentioned that H6 and H4 would check up on her regarding her average daily consumption. She mocked H4 as he would always say, *"What [are] you doing up there girl? Your number is always the same."* Verifying the system also forced participants to reflect about household energy consumption.

Hamlet participants knew detailed information about their neighbors (*e.g.,* when neighbors were home, their floor numbers, and the set temperatures of their thermostats). One Hamlet participant deduced detailed information about the other participants and determined that neighbors consuming less energy had to have set their thermostat to a lower temperature [in the winter] than she did: "*I know that [my neighbor] keeps his [thermostat] around 71 and [another neighbor] is below him [on the leaderboard] so I know the people who sit around in 68 degrees or lower!*"

Main St. participant M8 mentioned that, though home much more, she was ranked higher than a neighbor who had been away all summer (M6): *"If she has air on when she's not home, I'm going to kick her *ss [scold her] – she should be number one. How am I before her and she's never there?"* These two residents (M6 and M8) shared information after receiving the application.

In essence, Hamlet households got to know their neighbors while Main St. households did not engage with each other at the same level. This is likely a side effect of another theme we saw in our Main St. data, which we discuss next.

Internal isolation: We learned from our site manager and our interviews that five of the nine Main St. households were from a recently displaced neighborhood. The site manager described the former area as "*isolated…like New Jack City.[1]*" As a result, Main St. households referred to each other as "us" and "them" and to an extent, held themselves to different standards. This may be a form of internal separation leading to weaker Main St. ties.

Community contention with the site manager and intergenerational differences may also explain the internally isolated community. Insight from the site manager and other

[1] (*e.g.,* Reference to a film about a drug infested American neighborhood).

participants led us to believe that there may have been some conflict between the site manager and the rest of the community. For example, when asked if she (site manager) discussed the application with the rest of the community, she stated, *"At first when I started, it was cool but when I became, 'the manager,' that put a wall between us... They may not feel comfortable given [my] position."* Though not well reflected in our participant interviews, the Main St. community as a whole was also a mixed-aged community, which may imply generational differences. Two participants described this difference suggesting it to be the cause for the lack of engagement. One commented, *"I attribute it to the way our society is today…a generational thing. [A] sense of community is almost gone with regards to some of the younger folk out here. You know, it's just a different atmosphere—it's different, it's just different."* M2, another influential household at Main St., stated, *"I don't know, I don't know what's wrong with the generation today. I stay to myself [on] my own porch."* This participant did report visiting her immediate neighbors but did not discuss their status on Community Monitor.

Another key household, M6, was well known in the community but was away most of the time according to her neighbor, M8. This may have taken away from her ability to leverage her position in the network regarding the use of the application. When home, M8 said she used the polar bear screen to manage her consumption; she did not interact with the leaderboard feature.

Weaker ties, internal isolation between certain households (*i.e., "*us" vs. "them" mentality), and the isolation of the site manager—who was key to effective communication—were signs that social interaction was needed in this community. Providing our application alone, with little encouragement for interaction, was insufficient.

Privacy concerns and community distrust around the message board: The message board feature was a source of privacy concern in our application and very rarely used. In one case, a Hamlet participant was upset about a message posted about him, while others were concerned about posts shared with the landlords. For example, one participant was troubled about a message posted about him because of underlying implications that he was consuming energy late at night. H2 posted *"It looks like <alias> is burning the midnight oil."* The participant unknowingly took the message out of context. Because the system was not designed to provide households with real-time consumption data about other households, the participant was upset and felt his privacy had been violated. The participant learned after confronting H2 that H2 saw him outside of the building late one evening. Though the participant resolved the issue, he stopped posting messages.

Concerns of privacy and distrust of landlords prevented participants from engaging with each other online *via* the message board. One Hamlet participant said, *"[A participant] could take this [tablet] and show him [building owner]."* Another Hamlet participant stated, *"They're*

people that go into the office a lot and talk a lot; if you say something to them, they'll take it to the office and you didn't want it there. I keep my [message board] conversations [to] general questions." Indeed, a maintenance employee was a Hamlet participant. Though Main St. did not report issues of distrust, they were still fairly absent from the message board; it was disheartening to see the lack of posts to the message board considering institutional constraints placed upon Main St. The most active Main St. participant, M8 posted, "*Come on Community!!!! Lets try and be a community!!!!*"

Lack of collective action around institutional constraints: We wanted our application to provoke a deeper understanding of complex energy-related issues, which often appear as external factors, such as institutional constraints. We found that external factors were related to building constraints and/or infrastructural issues at Main St.

Due to concerns related to excess electricity consumption, the development company enforced a policy preventing Main St. participants from raising their thermostats above 71ºF. At least three residents mentioned this to be a problem in interviews because the temperature was too cold. Even at the highest temperature, residents felt cool air coming from the system. Participants blamed the geothermal heating system, and some of those reporting discomfort in the winter admitted to using the oven to heat households. Tenants who wanted a temperature increase from 71 to 74 had to sign a lease addendum and agree to not use electric heaters. After signing the agreement, some residents continued to use their oven for additional warmth, as it was still too cold. In this case, we need to understand how the social network structure contributes to a lack of collective action. Though participants had access to Community Monitor, they did not use it as a way to negotiate household restrictions.

Variation in households and application usage: Figure 2 clearly shows differences in how the two communities interacted with our application. In analyzing our interview data, we identified three distinct groups: most active users, households with prior computer knowledge, and shared device households. We discuss the characteristics of our most active users next.

Our most active users represented our "best-case" usage model. Three of our Hamlet users (H1, H4, and H6), and only one of our Main St. users (M8) fell into this group. H4 and H6 reported checking Community Monitor's leaderboard as a part of their daily routine. For example, H4 says he checks his tablet every morning to see *"who's in first place."* He does this along with his morning devotional period: *"I [eat] my daily bread, and then I pray, and then I read the Bible…It takes about 45 minutes."* Similarly, H6 says, *"I wake up and grab the tablet, I check the Community Monitor first to see if anyone responds [to prior posts] and then I read the Bible."* She sees where people are in terms of their energy consumption. Although H1 did not check the application on a daily basis, he would use the application to confirm that there were no issues: *"I look at it every other day or so. I'm usually 2ⁿᵈ or 3ʳᵈ. If my numbers are*

similar it's okay. If they were different, then I'd wonder why." M8 was the most active Main St. household and she engaged all household members with the application. For example, M8's daughter stated, "*I can say that I used to fall asleep with my light on but now I turn my light off when I go to bed. My mom unplugs the microwave. We try to keep things unplugged when they are not in use.*" M8 was also the only family in this category, and the fact that all members were over the age of 18, may have contributed to higher levels of engagement. Three out of four routine users lived alone and three of the four were either unemployed or retired. H1 held multiple jobs.

A second group of users included those with prior access to and knowledge of technology. Six households (H1, H2, H3, H5, M1, M9) had their own computers, iPads, and/or smart phones, which they preferred using. This does not mean that they did not use our application; in interviews, members from this group reported looking at the polar bear screen and using the main application features. However, their personal devices were already a part of their daily routines, and managing one more device was perceived as impractical. For example, when asked about his thoughts on the application and tablet, H2 stated, "*It seems like H4 really likes it. It's great for people that don't have computers. We're [H2 household] oversaturated with computers.*" H2, however, did like glancing at the tablet wallpaper to see how much he was consuming.

M2-M7, M9 represent our last set of users and are probably the most challenging to engage. We characterize shared device households, as those with a primary participant that managed and/or competed with multiple tablet users such as kids, loved ones, and guests. As a result of emphasizing social engagement across households within a community, we failed to successfully engage individuals within a household. Further, our application failed to compete with popular applications such as YouTube and Angry Birds. Moreover, for low-income, unemployed households, job hunting took precedence over use of our application. As M9, who was looking for work reported, "*I don't have to go to a job center or library.*"

Finally, four of our participants (M2, M4, M5, M6) used the tablet as a form of entertainment for young children (*e.g.*, their own children, grandchildren, and friends' children). At least three (M2, M3, M7) of our participants were seen sharing their tablets with their friends. M4's son used our tablet application to see how turning on devices changed the polar bear background; however, he only did this activity a few times. Many times, the tablet became a source of entertainment. When asked for application suggestions, M2 stated, "*more kids' stuff.*" M2's grandchildren used the tablet and often taught her how to play games. On one occasion, she discussed how they (1ˢᵗ and 2ⁿᵈ graders) downloaded games that she had no idea were available. According to M3, "*All they [the kids] know is videos, videos, videos—They don't want to go outside, they want to see this…*" Though the tablet as a platform worked as expected, *i.e.,* it was

shared within households, our core application features (*e.g.*, leaderboard) were ignored.

Finally, the first author observed visitors during regularly scheduled interviews on several occasions (households M2, M3, and M7). Visitors used the tablet for job hunting and checking email; none were aware of Community Monitor.

DISCUSSION AND DESIGN IMPLICATIONS
Based on the application usage and qualitative data, our results suggest that factors such as the built environment, context knowledge of community members, and accountability and adherence to social norms as seen in Hamlet, attributed to social engagement around our application.

On the other hand, issues of trust and length of residence may have contributed to a lack of social engagement around our application. We also found that access to prior technology may have played a role. In addition, the sharing of devices among multiple household members and guests may have played a role in the failure of some households to engage socially around our application.

Discussion
We found from our site observations that common spaces (*e.g.,* TV room, rooftop deck space, fitness center, elevator) allowed more opportunities for social interaction among Hamlet than Main St. residents. Without opportunities for community members to get acquainted, development of trusting relationships is less likely [3]. A small common space became available at Main St. late in our study; however, no participants reported using it. Information from the site manager and certain residents suggest isolation among some residents and little social interaction.

Sernhed*, et al.,* report that users are less interested in comparisons with other households without context knowledge about the households to which they are being compared [32]. Comparably, Schwartz found that comparative feedback is perceived as useful when social context is provided as a complement [31]. We draw similar conclusions from our results. For example, M8 was able to contextualize and find issues with M6's results because she knew M6 had been away all summer. Similarly, a Hamlet participant was able to estimate thermostat settings in other households based on her knowledge of her neighbor's settings.

We saw that our social comparison feature (the leaderboard), led to Hamlet households holding each other accountable for their consumption (as reflected in their rank). Schwartz notes that social comparison can motivate behavior because it signals failure to comply with accepted social norms [31]. The leaderboard influenced two out of the three most active Hamlet users to become watchdogs who held other households accountable for their leaderboard positions, which in their eyes, became the community norm. In our pizza party, for example, H4 and H6 held H2 accountable for his increased consumption, which led H2 to report the

issue. We posit that our application's leaderboard combined with Hamlet participants' social connections and context knowledge influenced social norms, which increased participant accountability.

Neither community expressed privacy concerns around sharing their average electricity consumption. Nevertheless, we saw decreased message board activity in both communities. M8's post to the community to *"Let's try and be a community,"* suggests that there was no attempt to be a community. We suspect that the presence of the site manager at Main, and maintenance at Hamlet, led to community distrust that resulted in decreased message board activity in both communities. Siegel's findings support the suspicion—privileged individuals have negative impacts within a network only when they are powerful (as the case of our site manager) [34]. However, leaders that do not have control over their networks have diminished power; therefore, leadership presence does not always dictate a lack of motivation, or action. Further, without opportunities for community members to get acquainted, there is less chance for households to build trusting relationships [3].

Kavanaugh *et al.,* suggest a lack of group or self-efficacy may cause a lack of collective action [23]; they also express concern about inaction for younger or older adults with less education and less group interaction. Similarly, Yin suggests that heterogeneity in interests can have a significant effect on the expected participation level in collective action [38]. It is likely that generational differences, or lack of self and/or group efficacy in the Main St. community were associated with the lack of action.

Past research also proposes that the length of residence [21, 26] may also play a factor into household engagement. As stated earlier, Main St. homes were newly constructed at the time of deployment. Perhaps there was not sufficient time to build group identity among residents. This, in addition to its larger households, may have led to more intra-household interaction and decreased inter-household interaction at Main St. One could also reasonably speculate that since Hamlet participants had a significantly lower number of household members, loneliness, or even boredom could have contributed to increased interaction in the community.

Next, those with prior access to technology did not engage as much with our application as our most active users. Perhaps a cross-platform application would have been more successful with this group (*e.g.,* Android and iOS).

Finally, we observed external guests and families interacting with the tablet device, but not the application. Among shared device households, the wallpaper was effective at capturing people's attention, but it failed to engage external stakeholders such as visitors and guests.

Future social-energy applications must consider factors such as the built environment, context knowledge of community members, accountability and adherence to social norms, trust and length of residence for successful reception of social engagement around energy consumption. Our results lead us

to conjecture that perhaps more connected communities might be more influenced by social-energy applications.

Limitations
Though our study lasted longer than similar studies [5], we suggest a period of two years or more for collecting electricity consumption data across multiple communities. Further, our study was not randomized, and the number of household participants was low. Finally, the number of our participants was too small to conduct a more proper and more representative social-network analysis; tracking the changes among interactions may have been more intuitive. Despite this, our rich qualitative data provide us with insightful results.

Design Implications
Ensure knowledge of social context from social networks and the built environment. Existing research [6,12] demonstrates the ability to detect network structure using sensors such as Wi-Fi and to detect location using GPS or GSM. Further, existing location services, such as Google Maps Floor Plans (http://maps.google.com/help/maps/floorplans/) could help researchers analyze the built environment. With the rise of social-energy applications and mobile Internet tablets, are there ways to identify social network structures using these capabilities? If so, can we identify which populations are likely to have context knowledge of each other that would lead to effective social comparisons? Can we adjust our applications accordingly when deployed in areas that may not be as conducive to social-energy applications? The built environment may have played a role in how households interacted with each other, which may have influenced their interaction with our application. Can we use the latest location services to detect physical building infrastructure? Leveraging information such as user check-ins could provide additional context.

Future applications should encourage accountability through social comparison and social roles. Social comparison was effective in our application because of context knowledge and also as a result of our routine households holding others accountable for their leaderboard rank. Perhaps using social comparison across other aspects of the application, such as message board posts, would have been effective (given knowledge of other community members' settings, characters, and schedules).

In a way, households, especially Hamlet households played roles similar to investigators and neighborhood watch. As mentioned in [14], those communities with high resident interaction are more likely to engage in surveillance behavior and intervene in local disturbances. This type of behavior is desirable in applications leveraging social comparison to help identify excess consumption. Social comparison enables these social roles, which allows for accountability for behaviors. Roles portray how people in certain positions are expected to behave [16], and these roles come with normative beliefs (perceived social pressures to engage or not to engage in a behavior). Taking on these roles

may have influenced how our participants dealt with external factors, such as broken air conditioners. Applications can infer and report potential issues to the community to enable members to take on roles (*e.g.,* investigative) to identify problems. To encourage and support these social roles, applications could leverage characteristics from social network structures to identify key influencers and focus interventions on targeted households.

Future social-energy applications should support shared device households: We saw how multiple person households played a role in the use of our application. The introduction of our technology enabled outsiders to search for jobs, and served as entertainment for household members. It is plausible that the introduction of a new technology and Internet capability increased our householders' overall consumption. In hindsight, bringing householders and guests together in one place to share resources may help to reduce consumption. Future social-energy applications could support these dynamics.

CONCLUSION
As Dourish argues, HCI must consider the political, cultural, social, economic, and historical contexts of the technology it produces to effectively address complex issues such as environmental sustainability [11]. Our paper details our longitudinal deployment of Community Monitor, a social energy application, across two distinct communities. Our results confirm prior findings that factors such as context knowledge of community members, accountability and adherence to social norms, are key for successful reception of social engagement around energy consumption. At the same time, we consider new factors that affect social engagement around energy. These include the built environment, trust, and length of residence. Our findings lead us to speculate that more connected communities might be more likely to engage in social-energy applications.

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