FROM SOCIAL DYNAMICS TO CONFLICTS: DESIGNING MOBILE TECHNOLOGY TO MOTIVATE ENERGY-SAVING PRACTICES

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FROM SOCIAL DYNAMICS TO CONFLICTS: DESIGNING MOBILE TECHNOLOGY TO MOTIVATE ENERGY-SAVING PRACTICES

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With rising global temperature, solutions are needed to reduce the energy consumption of homes everywhere. In the United States, over one third of people choose to live with non-family housemates or roommates. Whereas there is significant research on motivating individuals and families to reduce energy use, studies into non-family households is sparse and underdeveloped. Adapting previous literature involving individuals and families, I have developed, evaluated, and iterated several mobile applications to understand 1) the energy practices in non-family households through the lens of social dynamics and conflicts, and 2) how these nuances can be leveraged to motivate energy-saving practices amongst non-family households.

In particular, the first study looks at the influences of social dynamics on housemates' energy-saving practices. The second study investigates how housemates evaluate each other's energy behaviors. The third study examines the energy-related conflicts and its influences on housemates' experiences. The fourth and last study discusses strategies on supporting energy-saving practices without conflicts. In sum, the four studies suggest that taking social dynamics and conflicts of energy consumption into considerations can be more successful to motivate energy conservation. For example, different approaches are required to motivate non-family households to reduce energy consumption, e.g. tailored mobile applications rather than solely collaboration-oriented applications. Implications and future directions are discussed.

BIOGRAPHICAL SKETCH

Growing up in a hustling and bustling city in southern China, Xiying witnessed the environmental changes to her living environment due to the fast city development – waste, air pollution, sanitation, shortage of natural resources, and extensive use of fuel and energy resources to power people's life. As a concerned citizen, Xiying wants to design tools to create a greener living environment and improve people's quality of life. As a result, she became a doctoral student at Cornell University in the fall of 2011.

Xiying Wang completed her Ph.D. study in the summer of 2017, where she wrote under the beautiful Ithacan sky and listened to birds' songs every morning. From 2011 to 2017, Xiying was a doctoral student at Cornell University. She received her M.S. in Human-Computer Interaction/Design at Indiana University, Bloomington in 2011 and her B.Eng in Software Engineering from Sun Yat-sen University in 2009.

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CHAPTER 1

INTRODUCTION

For decades, household energy conservation has been a focus in the Human-Computer Interaction (HCI) community (Pierce et al., 2010). With the introduction of sustainable interaction design (Blevis, 2007), researchers and designers have examined various motivation strategies to encourage households to reduce their energy footprint. For example, a variety of tools track individual energy-consuming activities and present energy feedback, with the goal of reducing carbon footprints (e.g., Froehlich et al., 2009), water consumption (e.g., Arroyo et al., 2005; Erickson et al., 2012), and electricity usage (e.g., Mankoff et al., 2010). Erickson et al. (2012) and Froehlich et al. (2012) found that tracking individual consumption to encourage competition was a successful strategy for encouraging household energy conservation. Personalized energy feedback is thought to be effective because individuals tend to care more about energy information when it is directly related to them (Ueno et al., 2006). Customizing energy-saving goals to living conditions and personal schedules is an effective strategy for motivating individuals to save energy (Shiraishi et al., 2009).

While many tools focus on changing individual attitudes and behaviors about energy use, for many people energy consumption is a social activity in a domestic setting (Håkansson & Sengers, 2013). For example, family members influence and shape each other's energy attitudes and behaviors (e.g., Mankoff et al., 2010, Paay et al., 2013; Thieme et al., 2012; Schwartz et al., 2013). Social comparisons, such as comparing one's energy use to that of other family members, can engage family members in saving energy (e.g., Erickson et al., 2012; Froehlich et al., 2012; Kuznetsov & Paulos, 2010). Competitions can also effectively (re)-engage household members in energy-saving activities (Erickson et al., 2012). Overall, collaborating to save energy as a

family increases the household's participation in energy-saving activities (e.g., Erickson et al., 2012; Froehlich et al., 2012; Gustafsson et al., 2009; Marcus & Jean, 2009; Petersen et al., 2007; Shiraishi et al., 2009; Thieme et al., 2012).

Household-level design interventions are effective in part because energy-related activities are shaped by family dynamics (Håkansson & Sengers, 2013; Strengers, 2011). For example, there is often a "family leader" who is in charge of managing energy use (Strengers, 2011). This person pays attention to other family members' energy needs, and adjusts the energy settings (e.g., the thermostat) accordingly.

However, we do not know if these strategies will work in non-family households such as housemates or roommates. Statistics shows that more than 32% of American adults live with roommates or housemates (More American households doubling up as rents rise, 2014). Preliminary evidence suggests that these kinds of households manage energy differently than families do (Dillahunt et al., 2014). Instead of having a "family leader" in charge of energy management (Prost et al., 2015), housemates often consider each other equally responsible for consuming and managing energy (Irwin et al., 2015). For example, they can independently use any household appliances without attending to housemates' energy needs (Liu et al., 2013; Irwin et al., 2015), whereas family members tend to be more mindful of others' energy needs (Prost et al., 2015).

Preliminary evidence also suggests that applying design strategies for families to roommates or housemates may not be successful in motivating energy conservation. For example, some housemates felt discouraged and stressed when their energy-consuming activities were made visible to the entire household (Petkov et al., 2011) or when they got blamed for consuming more energy than others (Froehlich et al., 2012). Unrelated housemates can be

concerned about others reading and possibly misjudging their consumption data (Blevis, 2007; Erickson et al., 2012). Those who use less energy than their housemates may be upset about the situation and ask others to pay more for utilities (Broms et al., 2010).

There are many open questions to be explored and answered under the umbrella of housemate energy consumption, particularly those related to personal and social experiences of energy-consuming activities (Brynjarsdottir et al., 2012). How can certain motivation strategies succeed in families but may fail to encourage housemates to save energy? What is the best way to motivate housemates to conserve energy? Why would motivation strategies motivate some household members to save energy but discourage others? What causes undesirable effects like stress, frustration, and tension, and how can we avoid these while still motivating energy conservation?

Much energy consumption is directly related to personal or social activities and experiences, e.g., air conditioning, heating, lighting, and consumption of electronics. Sometimes, use of energy brings personal comfort (Wang & Fussell, 2014), e.g., having air conditioning in a hot summer. But it is not always up to a single person to decide the temperature of a household. Housemates who live together may need to discuss and negotiate what temperature is most suitable (Liu et al., 2013). By taking personal and collective experiences of using energy into consideration, we may be more successful in encouraging housemates to reduce their energy consumption.

Research Goals and Approach

This dissertation attempts to understand household members' personal and social experiences of energy use, particularly the undesired effects of collective energy conservation, and to explore design opportunities to encourage sustainable practices based on those

experiences. The work has three key components: *understanding* the housemate dynamics of energy use; *understanding* shared energy management and related conflicts of housemates, and *designing and evaluating* interactive applications to encourage energy-saving practices. Specifically, I address three sets of research questions:

1) What do housemates feel, experience, and expect, when consuming energy? What encourages them to pay attention to energy use and conserve energy? What may demotivate them?

2) What do they feel and experience when other members of the household consume energy? How do housemates manage energy use as a group? Do they encounter frustrations, tensions, and conflicts when managing energy together? And, how do they react to these undesired effects?

3) Taking those energy experiences into consideration, how can we design interactive applications to motivate housemate energy conservation? How do housemates think about the applications? What works and doesn't work for them? Can we establish general design strategies for promoting household sustainability?

I use a variety of methods to address these research questions. First, I use a design research approach to examine personal and social aspects of energy conservation, including designing and evaluating a mobile application based on existing literature and reflecting the design choices with real users. Second, I use a mixed method approach to understand the user experience of energy management and related conflicts among housemates, including *surveys and interviews.* Third, I engage in *a set of design activities*, e.g., brainstorming, sketching, wireframing, prototyping, iterating, and building, to design interactive applications based on my findings, and conduct field studies to evaluate designs with real users, e.g., in-home visits, *photo*

journals, *interviews*, and *inviting people to use it in real context* to understand their feedback and experiences of using the applications and reflect the design choices.

Research Contributions

This dissertation provides new understandings of the energy experience of housemates and discusses insights on designing tools to motivate unrelated households to conserve energy.

First, I provide new insights into the dynamics of households consisting of unrelated housemates and show how these dynamics influence energy use. To do so, I design a mobile application EnergyHome and evaluate its impacts on housemates' experiences of energy conservation, which leads to the understanding of social dynamics on the motivation strategies.

Second, this dissertation enriches our understanding of the personal and social experience of household energy use through the lens of conflicts. I invited 50 housemates to discuss their understanding of housemates' energy activities and household energy management. I find that housemates are not able to identify activities that would lead to large reductions in energy use but instead focus on simple daily repeated actions like turning off lights. Conflicts may take place when they misjudge other's energy activities, care more about personal needs than others' needs, worry about utility costs, or when their personal boundaries are violated. Depending on their personal values and relationships to others, housemates may choose to ignore, stay silent, refuse to change, or collaborate to solve the conflicts.

Third, based on my findings about household dynamics, I design, develop, build and evaluated a mobile application called EnergySense that is intended to support housemate energy-saving practices with fewer conflicts. A field test of EnergySense shows that proposed strategies like identifying private and public boundaries, making energy adjustments identifiable, and

automatic control over shared energy responsibilities can create a positive energy-saving environment without creating stress, frustrations, or tensions.

Finally, this dissertation engages HCI and design audiences in a broader discussion of how to encourage sustainable energy practices while considering social dynamics and conflicts.

Outline

The remainder of this dissertation is structured as follows. In Chapter 2, I discuss related literature on persuasive sustainable design, people's experiences of using energy at home, and energy conservation. Chapter 3 describes the design and field evaluations of my EnergyHome iOS application, which is intended to motivate housemates to save energy. Chapter 4 discusses how housemates evaluate each other's energy-consuming activities and how those evaluations influence energy conservation. Chapter 5 further explores housemate dynamics surrounding energy use through the lens of conflicts, which leads to a discussion of the role of conflicts in promoting sustainability. Chapter 6 describes the design and study of an iOS application called EnergySense, which draws on the strategies for motivating energy conservation without conflicts that are proposed in the previous chapters. Chapter 7 summarizes and further discusses the design opportunities for promoting housemate sustainability in light of the role of social dynamics and conflicts. Finally, Chapter 8 summarizes my dissertation research and provides thoughts for future work.

CHAPTER 2

RELATED WORK

In this chapter, I start by reviewing Human-Computer Interaction (HCI) research on persuasive design strategies that encourage households to adopt sustainable behavior. In particular, I examine those strategies used in family contexts and present preliminary evidence about how well these same strategies work for unrelated housemates. Then, I discuss research on interpersonal dynamics and social aspects of household energy use.

Persuasive Sustainable Design Strategies and Evaluations

Since persuasive technology (Fogg, 2002) and sustainable interaction design (Blevis, 2007) were introduced to HCI, various persuasive designs to promote sustainable behavior have been proposed and examined. *Near real-time energy feedback*, *energy consumption at the individual level*, *interruptions*, *comparisons, social influence, competitions, and collaborations* are common design strategies that have been successful in promoting household energy conservation. In the remainder of this section, I discuss these persuasive strategies to motivate household energy conservation and summarize what we know about them and how successful they are.

Detailed energy feedback

One common and promising way to encourage household energy-saving practices is to show detailed energy consumption data and related information (e.g., Brewer et al., 2011; Emeakaroha et al., 2012; Erickson et al., 2012; Filonik et al., 2013; Froehlich et al., 2009; Froehlich et al., 2012; Gamberini et al., 2012; Kuznetsov & Paulos, 2010; Moere et al., 2011; Paay et al., 2013; Petersen et al., 2007; Petkov et al., 2011; Schwartz et al., 2013). Much of the energy consumption information people receive, such as monthly utility bills, is too general for

them to use to guide their energy related behavior (Erickson et al., 2012; Froehlich et al., 2012). Showing detailed energy consumption information can help households figure out what they can do to save energy.

Near real-time energy feedback. One way to provide richer information about energy consumption is to decrease the time interval between updates; for instance, a tool might show near real-time water consumption for an entire household rather than a monthly bill. Erickson et al. (2012) designed a persuasive system to show aggregated household water consumption every 4 hours and found it this helped family members better understand their household water consumption and reduce their consumption accordingly. Liu et al. (2013) used a similar strategy, showing room-level electricity consumption every 8 hours, to motivate college roommates to reduce electricity consumption.

Energy consumption at the individual level. Another common strategy for reducing energy consumption is to show aggregated usage data at the individual (Froehlich et al., 2012) or appliance level (Broms et al., 2010; Froehlich et al., 2012) to the entire household. A number of tools have collected and presented personal energy consumption data, making it easier for individual household members to understand their energy use (e.g., Arroyo et al., 2005; Froehlich et al., 2012; Kappel & Grechenig, 2009; Kuznetsov & Paulos, 2010; Petkov et al., 2012). For instance, Froehlich et al. (2012) designed an interface to show each family member his or her water usage. Not only did users have an improved understanding of how much water they were using, but they were also more successful at reducing their own consumption. Some interactive systems have collected and displayed the energy consumption of each household appliance (Broms et al., 2010; Froehlich et al., 2012), which helped people identify the sources

of consumption and reacted accordingly, e.g., unplugged heavy energy-consuming appliances when not at home.

One key concern about providing energy feedback at an individual level is that people may not want their energy-consumption patterns made visible to their entire household. Making individual energy consumption visible and identifiable to housemates can increase the stress of participating in energy conservation (Froehlich et al., 2012; Petkov et al., 2011; Thieme et al., 2012) and consequently discourage people from saving energy. For example, Thieme et al. (2012) found that housemates felt stressed when they consumed more energy than other household members, particularly when they failed to meet others' expectations. Displaying detailed energy consumption can also lead to tensions among household members. For example, some people blame their housemates for consuming more than their share of energy (Froehlich et al., 2012) and others may feel guilty even when they needed to consume energy (Thieme et al., 2012).

(Re)-engagement strategies

Once the users get used to having detailed energy feedback or figure out what a tool to promote sustainability does, they may forget about the system (Erickson et al., 2012) or lose interest in it (Emeakaroha et al., 2012). A second key design feature highlights the question of how to (re)-engage users in the system, with an emphasis on social motivation strategies.

Interruptions. Interruptions, such as notifications and reminders, are the main strategy to keep users engaged in tools to support sustainability. Erickson et al. (2012) found that notifications could (re)-engage families in a system if they had forgotten to use it (Erickson et al., 2012). Other forms of interruptions, such as push notifications (Emeakaroha et al., 2012; Erickson et al., 2012; Liu et al., 2013; Schwartz et al., 2013), SMS messages (Emeakaroha et al.,

2012), emails (Emeakaroha et al., 2012), and social media notifications (Emeakaroha et al., 2012) have been used to draw users' attention to the system. This is a particularly useful feature for persuasive sustainable designs that try to actively engage users, and there is evidence that repeated system notifications do not annoy users but instead help engage them (Gamberini et al., 2012).

One kind of interruption is to notify users about unusual energy events. As Petkov et al. (2011) argue, consistently engaging households with energy feedback may gradually tire them out. Notifying people only about peak times or unusual patterns of energy consumption is a promising strategy for tackling this problem (Froehlich et al., 2012). Peak energy consumption or unusual energy use patterns often draw people's attention (Broms et al., 2010), because those events can result in extra energy costs (Strengers, 2008). Families often use sustainability tools to make sure their energy consumption is "normal" (Broms et al., 2010; Filonik et al., 2013; Liu et al., 2013). The strategy of notifying users about special energy events is effective for re-engaging them with the system (Erickson et al., 2012), helping them reflect on the special events (Froehlich et al., 2012), and motivating them to take immediate actions to reduce energy use (Broms et al., 2010; Filonik et al., 2013; Liu et al., 2013).

Self-comparisons. Motivating individual household members to compare their own energy-saving goals and actual energy achievement is another effective way to engage people in saving energy. There are two common self-comparison strategies. One strategy helps users compare their current energy consumption with their previous consumption. This strategy helps making energy consumption identifiable to individual household members (Kuznetsov & Paulos, 2010; Petkov et al., 2011), increase their awareness that they are responsible for the energy consumption, and motivate them to reduce their individual energy usage (Petkov et al., 2011).

The other strategy presents household members with comparisons between their personal energy-saving goals and their actual energy-saving outcomes. This strategy encourages users to keep track of their goals and energy-saving activities. It is effective when individuals successfully achieve their goals but can lead to frustration when they do not (Shiraishi et al., 2009).

In sum, self-comparing energy consumption data is a promising strategy for persuading people to engage in sustainable energy behavior so long as they engage with the system and pay attention to the data. When considering self-determined goals and commitment, designers need to consider potential frustrations caused by failure to achieve goals. Frustrations can lead to a decrease in people's involvement in sustainable activities (Shiraishi et al., 2009).

Social comparisons. Comparing energy consumption with friends and families can also successfully engage people in energy-saving activities. Two common social comparison strategies are to compare a user's data with that of his/her friends (Marcus & Jean, 2009; Petkov et al., 2012; Petkov et al., 2011) and to compare all system users including family members (Erickson et al., 2012; Froehlich et al., 2012; Kuznetsov & Paulos, 2010; Liu et al., 2013; Thieme et al., 2012). Others have proposed comparing people to others who shared similar energy attitudes or energy usage patterns (Erickson et al., 2012; Petkov et al., 2012; Petkov et al., 2011). This can avoid unbalanced comparisons such as comparisons between sustainably-minded household members and ones who did not pay attention to energy conservation (Petkov et al., 2012).

However, social comparisons are two-folded. In a housemate or friend environment, those who use more energy often work harder to reduce their usage, while those who use less energy in comparison to others may gradually stop trying to reduce their energy because they

feel they are “winning” (Kim & Paulos, 2010). Another concern is that social comparisons can create stress (Petkov et al., 2011). Petkov et al. (2012) found out that some housemates did not like to be compared with others, because they felt stressed when others could figure out their energy behavior by comparing the consumption data. Thus, it is important to recognize that strategies like social comparison 1) may have negative as well as positive effects and 2) to design systems that avoid or reduce these negative side effects.

Social influence. Social influence as a design strategy is similar to social comparison but with an emphasis on energy-saving activities as opposed to energy consumption. People’s energy attitudes and behaviors are often shaped by others (Cialdini, 2005; Goldstein et al., 2008), including other family members (Håkansson & Sengers, 2013). Thus, some designers of persuasive systems for energy reduction have showed users what other family members are doing to save energy (Paay et al., 2013; Thieme et al., 2012) and their energy-saving achievements (Paay et al., 2013).

Unlike social comparison, making energy-saving activities available to the entire household may create a stress-free environment. This strategy makes it easier for others to recognize individual effort in energy conservation and has been shown to help shape individual energy behavior (Massung et al., 2013).

Competitions. Previous research also shows that competitions are an effective way to engage households in energy conservation (e.g., Gamberini et al., 2012; Gustafsson et al., 2009; Shiraishi et al., 2009), particularly at the outset (Gustafsson et al., 2009; Moere et al., 2011; Shiraishi et al., 2009; Thieme et al., 2012). For example, competitions can encourage families to try different strategies to reduce energy consumption (Gustafsson et al., 2009). However, competitions can only maintain users’ interest in the system for a short time (Massung et al.,

2013; Moere et al., 2011; Thieme et al., 2012). Competitions often require users' attention and consistent engagement with the system (Nakajima & Lehdonvirta, 2013; Shiraishi et al., 2009), thus they can tire users after a while, leading to lower motivation (Håkansson & Sengers, 2013).

Collaborations. Given that social comparisons and competitions may tire users over time (Håkansson & Sengers, 2013), collaborations have been proposed as a strategy for supporting and encouraging household energy-saving (e.g., Erickson et al., 2012; Petersen et al., 2007; Shiraishi et al., 2009; Thieme et al., 2012). Collaborating to save energy as a group draws people's attention to energy conservation (Shiraishi et al., 2009) and can effectively (re)-engage users with the system (Erickson et al., 2012). Erickson et al. (2012) found that families engaged in more energy-saving activities when they collaborated out of respect for other group members. Shiraishi et al. (2009) found out that household members considered it playful to work together against other households. Collaborations have thus been demonstrated to be a useful strategy for promoting household energy conservation (Erickson et al., 2012; Froehlich et al., 2012; Gustafsson et al., 2009; Marcus & Jean, 2009; Petersen et al., 2007; Shiraishi et al., 2009; Thieme et al., 2012).

Reflections and moving forward

In sum, the success of particular strategies to motivate energy conservation depends on people's feelings, attitudes, interpretations, and experiences of these strategies. Identifiable, personalized, and detailed energy data is a good way for individuals to learn and reflect on their energy behaviors, but it may create stress when energy-consumption is made visible to others, particularly in a domestic setting (Froehlich et al., 2012; Petkov et al., 2011; Thieme et al., 2012). Similarly, comparisons and competitions can draw people's attention to a sustainability tool and engage them with the system but can also demotivate people when they fail to achieve

energy-saving goals (Shiraishi et al., 2009). In social settings, comparisons with others may cause a boomerang effect, such that people who are saving more than others may become demotivated (Kim & Paulos, 2010). Comparisons among family members may cause stress when people do not enjoy comparisons (Petkov et al., 2011). Similarly, competing with others can also cause pressure and tensions between people (Petkov et al., 2011) and eventually tire people out (Håkansson & Sengers, 2013). These contradictory effects of strategies like social comparisons and competitions are related to how people may think, relate, and feel when they compare or compete with others. It is an open question how best to leverage tensions when motivating sustainability.

In contrast, previous research suggested that interruptions and collaborations are promising strategies to motivate energy conservation. Interruptions, particularly notifications about special energy events, elicit people's attention and motivate them to take immediate actions to reduce energy use (Broms et al., 2010; Filonik et al., 2013; Liu et al., 2013). Collaborations are seen as playful (Shiraishi et al., 2009) and engaging, particularly when people collaborate with family members (Erickson et al., 2012).

To move forward, it is important to recognize that any design strategy may have both positive and negative effects. It can motivate or demotivate energy-saving practices depending on a person's individual and social experiences of using energy. It is important to think about how to properly apply these design strategies by leveraging people's attitudes, feelings, interactions, communications, and experiences of energy consumption and conservation. In addition, it is important to examine how well strategies developed in family settings will work for households that consist of unrelated members.

Social Aspects of Energy Consumption

One major criticism about current tools to promote sustainability is the minimal focus on social aspects of energy consumption (Håkansson & Sengers, 2013). Energy-conserving practices and activities can be better motivated if we take a deeper and broader understanding in social aspects of energy consumption. In this section, I review current attempts to understand the interpersonal dynamics associated with shared energy management.

Fiske's relational models

People who share a household typically need to coordinate their interactions with others (Baldwin, 2015). Fiske (1991, 1992) provides a useful framework for thinking about the different forms these interactions might take. He proposed four basic relational models: *communal sharing*, *authority ranking*, *equality matching*, and *market pricing*. In the context of home energy use, communal sharing means that people can reach a consensus on energy use without specifying individual responsibility. In authority ranking, a leader of the household makes decisions on how to manage energy. In equality matching, each household member has an assigned responsibility for managing energy and shares equally in energy use. With market pricing, the amount of energy each member can use depends on how much he or she pays for its cost.

Based on Fiske's relational framework, Lickel et al. (2001) identified that families, because of their close bonds, were more likely to have communal sharing relationships that allowed them to reach consensus without specifying responsibility. In contrast, the interactions of unrelated members of a shared living environment are more likely to take the form of equality matching and/or market pricing. In particular, housemates might believe they should share equal responsibility for energy management because they share energy costs (Irwin et al., 2015).

Interpersonal conflicts may arise if household members disagree as to which of the four relational models applies to them (Fiske, 2004). For example, a conflict could occur when one housemate thinks he/she is in charge (authority ranking) when the rest of the household believes they are using equity matching or market pricing.

Much effort has been put into designing and evaluating sustainability tools for families who are closely bonded and share energy use without specifying energy responsibilities. Design strategies such as collaborations and notifications are effective for motivating families to save energy; however, those strategies may or may not work in households consisting of unrelated housemates, which may share different relation models. One of the primary contributions of this thesis is an evaluation of how well strategies for families can be applied to unrelated housemates.

Social aspects of energy consumption within households

The way people consume energy, their needs for using energy, and their intentions regarding energy use are intertwined with other members' decisions, behaviors, and habits (e.g., Chetty et al., 2010; Dillahunt et al., 2010; DiSalvo et al., 2010). Total household energy consumption is a function of each members' actions, decisions, and intentions, and household members often manage energy together (Håkansson & Sengers, 2013; Strengers, 2010; Woodruff et al., 2010). Individual choices about energy consumption may change other dynamics in the house, such as the relationship between the individual and other household members. In return, others' energy consumption may influence an individual's own energy-related decisions (Håkansson & Sengers, 2013; Schwartz et al., 2013).

Given that energy use in a shared environment is situated in both a personal and social context (DiSalvo et al., 2010), it is important to understand what energy management and

conservation mean to the people who are involved. How do they think they should be managing their energy use? How do they think others should be managing their own energy use?

In the past decade, researchers tried to answer these questions in a family context. They have found that individual family members are influenced by other family members' energy attitudes and behaviors (e.g., Erickson et al., 2012; Froehlich et al., 2012; Poortinga et al., 2003; Shiraishi et al., 2009; Thieme et al., 2012). For example, Strengers' (2011) study of 26 families found that family energy consumption and individual energy behaviors are affected by the relationships among family members (e.g., one family member might mentor others to reduce energy) (Strengers, 2011). More importantly, family members often work together to manage energy use (Håkansson & Sengers, 2013; Strengers, 2011). Other research suggests that collaborating with other family members to save energy can make a whole family more active in reducing energy use (e.g., Erickson et al., 2012; Froehlich et al., 2012; Nakajima & Lehdonvirta, 2013).

Energy-related conflicts

However, not every household member pays attention to others' energy needs, particularly in non-family households such as roommates or housemates (Irwin et al., 2015; Liu et al., 2013). Preliminary evidences show that making individual energy consumption identifiable and traceable to housemates can lead to feelings of guilt, getting blamed for consuming energy, and being required to pay a larger share of utilities (e.g., Chetty et al., 2010). In addition, it can be difficult to satisfy everyone's energy needs when housemates co-manage energy consumption instead of having a delegated energy manager like many families do (Liu et al., 2013). For example, housemates could repeatedly override each other's temperature settings

(Irwin et al., 2015; Riche et al., 2010) whereas families usually settle on a specific temperature after considering every members' needs (Irwin et al., 2015).

In summary, although conflicts are an important aspect of a household's energy routine (Irwin et al., 2015), we know little about them. In my dissertation, I aim to increase our understanding of housemates' personal and social experiences around energy management and the kinds of conflicts that arise. I also aim to design interactive technologies that apply these understandings and evaluate them with households comprised of unrelated housemates.

Sharing Energy Use in Hotels

As a starting point for investigating the personal and shared experiences of housemate's energy consumption, I conducted a preliminary study with hotel travelers who shared a hotel room with one or more roommates. I collected energy diaries from 13 travelers and conducted interviews with 20 hotel customers. From this data, I observed several interesting phenomena regarding energy sharing in hotel rooms. Some travelers reported attending to others' energy needs, which may lower energy usage. For example, they would not turn on lights at night because a roommate was asleep. However, accommodations could sometimes result in higher energy consumption, for example when people kept lights on in case their roommate(s) come back late in the evening.

Some travelers reported negotiating the use of electronics in their hotel room. They sometimes tried to achieve personal needs or comfort by speaking up about their energy needs (e.g., a desire to watch TV). However, this could lead to greater energy consumption.

The collective experiences of using energy reported by participants in my hotel study inspired me with some initial ideas for how to motivate energy conservation in households comprised of unrelated housemates. To those who are willing to attend to others' energy needs,

perhaps collaborative features will more successfully engage them in energy-saving activities. But for those who negotiate energy activities based on personal needs, personalized features might better engage them in energy conservation. In the next chapter, I design and evaluate an interactive system to answer those questions.

CHAPTER 3

ENERGYHOME: LEVERAGING HOUSEMATES DYNAMICS TO MOTIVATE ENERGY CONSERVATION

As discussed in Chapter 2, the success with which a tool can motivate household energy conservation is related to the structure and dynamics of a household. For example, providing energy feedback at the individual level helps household members recognize the causes of their energy consumption but can also cause stress and tension. In this chapter, I aim to understand and explain the success of common design strategies by applying successful interventions for families to households comprised of unrelated housemates. For example, if housemates' energy behaviors are independent of each other, encouraging individual energy conservation may be more successful than it is in families. Or, if a housemate is easily influenced by others' behaviors, inviting housemates to create a shared plan for energy use might be a successful approach. Or, perhaps, if housemates tend to rely on each other for getting things done, designing tools that enable housemates to help each other to save energy might be more successful that tools that target each housemate individually.

To examine these issues, I designed, deployed and evaluated an iOS application called EnergyHome that employs a number of design strategies to motivate individuals and sets of housemates to engage in energy-saving activities. Fourteen pairs of housemates from a large U.S. university used the app for one week. I interviewed each participant afterwards to understand: 1) how housemates used and interacted with each other using EnergyHome, and 2) whether and why housemates preferred to save energy by themselves or with others. I focus specifically on how social dynamics between housemates were related to the ways they used the tool.

In the remainder of this chapter, I first discuss the features of the EnergyHome app and the related literature that informed the design of these features. Then, I present the method and results of our user study. The study findings show that interpersonal relationships between housemates and their interactions with one another was related to how they choose to engage in energy-saving practices. I conclude by discussing strategies to encourage energy conservation that take housemate social dynamics into account.

EnergyHome Design

EnergyHome is an iPhone application that was designed to have the following four key features: individual challenges, group challenges, reminders, and sharing challenges. Each feature adapts motivation strategies from previous literature on family energy conservation reviewed in Chapter 2.

Individual challenges

The ability to set energy-saving goals and track these goals has been shown to have a positive influence on an individual family member's sustainable behavior (Abrahamse et al., 2005; Kappel & Grechenig, 2009; Nakajima & Lehdonvirta, 2013). Family members are more committed to energy conservation if they are appropriately motivated; individuals were more motivated to achieve goals when they had the ability to achieve those goals (Abrahamse et al., 2005). These self-determination goals are more effective in encouraging sustainable behavior than goals set by researchers or app developers (Abrahamse et al., 2005), because people can control goal content and difficulty, thus setting goals that meet their needs (Edwin et al., 2002).

Adapting the strategy of self-set goals, I designed a feature called my challenge (see Figure 1). Users can set their personal energy-saving goals or "challenges" and track them on their My Challenges page. An individual challenge can be a daily repeated action such as turning

off lights, a weekly action such as using cold water to do laundry, or an occasional action such as installing energy-efficient light bulbs. Actions were adapted from Mankoff et al. (2010) for a shared household environment.

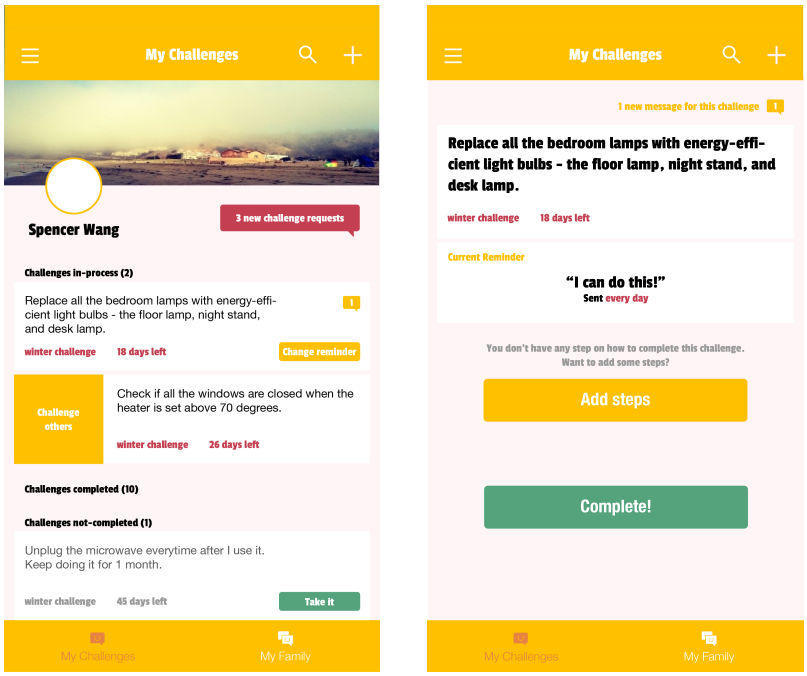

Figure 1. The My Challenge user interface with "track it" function at the bottom (left) and the individual challenge detailed user interface (right).

In the My Challenges page, there are three challenge sections. First, "challenges in-process" shows the energy-saving challenges currently being worked on. Once a user completes a challenge, he or she can click the "complete" button (Figure 1, left) and the challenge will be moved to the "challenges completed" section, which contains all completed challenges. This section is designed to create a sense of achievement by enabling users to see all competed challenges (Shiraishi et al., 2009). Viewing self-achievement can better engage users (He et al., 2012).

The "challenges not-completed" section stores uncompleted challenges. Each uncompleted challenge has a feature called "track it" that enables users to reactivate it. I did not

want to exclude the possibility that users might find uncompleted challenges interesting and want to return to them. Thus I designed this section and the "track it" function to allow them to get involved in previous challenges again.

To set up an individual challenge, a user would input the challenge content and set a deadline (Figure 1, right). For daily repeated individual challenges like turning off lights when not in use, the user needs to track his or her behavior until the deadline arrives. Then the user can report the challenge as completed by pressing the "complete" button. If the challenge is not reported as completed before the deadline, it will be moved automatically to the "challenges not-completed" section. For one-time challenges like installing an energy-efficient light bulb, a user can press the complete button once he or she installs the bulb.

I aimed to give users flexibility in setting up challenges and deadlines, because it is unlikely that they will stick to the same energy-saving goal for extensive periods of time (Poortinga et al., 2003). An energy-saving goal can fail to motivate a user if he or she has already achieved it (Poortinga et al., 2003). I designed a deadline feature for each individual challenge to give the challenge a limited life cycle and avoid tiring users. There were no pre-assigned individual challenges. It was up to each user to determine what challenges to set, since previous work has found self-set goals are more motivating than assigned ones (Abrahamse et al., 2005; McCally & Midden, 2002).

Group challenges

Previous research suggests that individual household energy behavior is influenced by those sharing a living space, such as family members (Erickson et al., 2012; Kappel & Grechenig, 2009; Nakajima & Lehdonvirta, 2013; Paay et al., 2013). People tend to be more committed to sustainable activities if their friends or family are also committed to them (Arroyo

et al., 2005; Petkov et al., 2012; Thieme et al., 2012). Household members also try to avoid causing utility costs to be higher than other members expect (Erickson et al., 2012; Nakajima & Lehdonvirta, 2013; Shiraishi et al., 2009).

In particular, saving energy as a group (e.g., a family or a community) is effective for encouraging individual sustainable behavior (Erickson et al., 2012; Liu et al., 2013; Massung et al., 2013; Nakajima & Lehdonvirta, 2013; Shiraishi et al., 2009). For example, Erickson et al. (2012) deployed a water conservation system that encouraged families to work on saving water as a team. People were more active in water conservation and visited the system more frequently when they were collaborating with other family members than when they worked alone. Similar influence was found in eco-island's study, in which family members participated together as a group to save energy (Nakajima & Lehdonvirta, 2013; Shiraishi et al., 2009). Thieme et al. (2012) further found that household members cared about having an identity as an energy-conscious person within their family.

Adapting the concept of family collaboration to the case of housemates, I designed a group challenges page (as seen in Figure 2) that includes group energy-saving challenges and the group's progress on each challenge. I called it "my family" in the application, using "family" broadly to include groups of friends, roommates, or housemates to potentially create greater affiliation and connection among group members.

On the group challenges page, users can see all members of the group (Figure 2). The circles on top represent each member's avatar. A single group challenge (Figure 2, right) has three elements: the challenge content, members' tasks for completing the challenge, and a deadline. Any member of the group can set up an energy-saving challenge for the group. He or she can decide the content of the challenge, assign tasks to each group member, and set the

deadline. For example, a group member can set a group challenge as “making sure the lights are off when leaving the house”, assign a task, “turning off the lights in the living room,” to one member and assign another task, “turning off the lights of kitchen and dining room,” to another group member. Similar to individual challenges, group challenges can be daily repeated actions such as turning off lights when leaving a room, weekly energy-saving actions such as using cold water to do laundry, or occasional energy-saving actions such as sealing cracks in the floor.

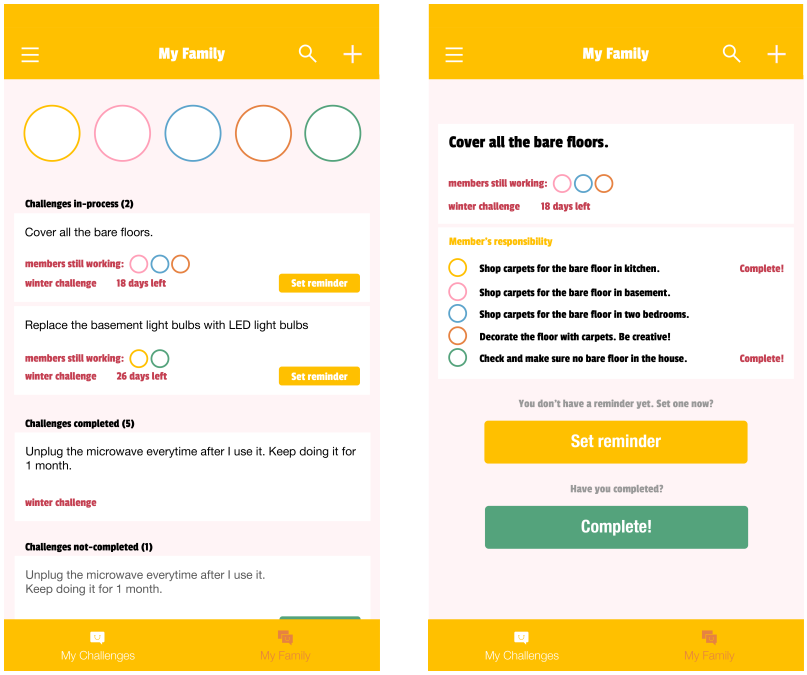

Figure 2. The Group Challenge user interface (left) and the group challenge detailed user interface (right).

Once a group challenge is created, it will appear on every group member’s “my family” page. No one can refuse his or her assigned task in the group challenge, and a group challenge cannot be completed unless every member of the group completes his or her task before the deadline. I examined whether housemates would be motivated by these group challenges or instead find them annoying. A group member’s task status is visible to the other members of the

group, in order to see if viewing other's commitment to an energy-saving task influenced team collaborations.

Similar to the "my challenges" page, the "group challenges" page also has three sections: challenges in-process, challenges completed, and not-completed challenges (Figure 2, left). The challenges in-process section shows current energy-saving goals. A distinct feature is that group members can view which group member is still working towards a group challenge. By showing group members' progress, I also wanted to make sure all group members were aware of each other's commitments to energy conservation. After everyone in a group completes his or her individual task, a group challenge is considered completed and it will be moved to the "challenges completed" section. As with the individual challenges, I aimed to let group members feel a sense of achievement by viewing this section. The last section is the "not-completed challenges", including overdue uncompleted group challenges. Different from an individual challenge, failure to complete a group challenge can be caused by one or more group members failing to complete his or her task.

Reminders

I also designed a reminder feature for both individual and group challenges. Personalized reminders have been shown to better support memory of daily routines (Stawarz et al., 2014). Inspired by this idea, I designed a reminder feature that allows users to customize the frequency and content of reminders for an energy-saving challenge. For example, a user can create a message such as "remember to turn off the kitchen light" and arrange for it to be sent every morning.

More importantly, providing social support for energy-saving practices is a successful motivation strategy in families (DiSalvo et al., 2010; Håkansson & Sengers, 2013; Strengers,

2011). Social support can appear in the form of reminders, so I added group reminders that allow other housemates to set a reminder message and frequency for an individual. I wanted to see if individuals would be motivated by receiving this kind of help from their housemates and to explore whether group reminders would be better than self-reminders for encouraging engagement in energy-saving activities.

Privacy concerns

Due to possible privacy concerns, I did not make energy-saving challenges (both individual and group) public in the current version. Individual challenges can be viewed and shared among friends. However, they cannot be viewed publicly. Group challenges can be viewed and edited only by group members. A group member's friend who is not in the group does not have the ability to view the group challenges of that member.

Technical specifications

EnergyHome was designed and developed based on the iOS 7 standards (iOS 7 standards, 2015). My collaborators and I used objective C to build the application, before Swift was released and then updated it to Swift 3.0 when it became available. EnergyHome is compatible with the latest iOS 10.

Methodology

To investigate the above research questions, I conducted a user study of 14 households of 28 housemates.

Participants

I recruited participants using Facebook, university email lists, flyers posted in dorms and on bulletin boards in local stores, and a university research recruiting system. Qualified

participants met the following criteria: First, they were currently living with a housemate in a shared suite in a dorm, an apartment, or a house.

Second, they participated in the study with their roommate or housemate so that I could look at use of both individual and collaborative features of EnergyHome. Third, each pair needed to be iPhone users and willing to install the application on their phones.

Seventy-five users responded to the study recruitment. I selected 14 households that met all of the above criteria, for a total of 28 participants (see Table 1). In those 14 households, each roommate or housemate had his or her own bedroom, I thus use "housemates" in the following sections to describe their household type.

Study procedure and analysis

First, participants were asked to interact with EnergyHome for 7 days. I helped them install the application on their iPhone. But I did not give them instructions about how to use the application. Instead, I let them explore how they wanted to use it.

After using EnergyHome for 7 days, participants were interviewed (see Appendix A for the interview protocol) about their experiences using the app and about their reasoning for using the app in particular ways. Each interview lasted from 45 minutes to an hour and each housemate was interviewed separately. I started by asking a set of general questions about how they used the app, whether they discussed the app with their housemate, and their general impressions of EnergyHome. I then asked a number of specific questions about their use of key design features (e.g., individual challenges, group challenges), what features they preferred for saving energy, the reasons why they chose those features, and what influenced their choices.

All interviews were audio recorded, transcribed, and coded iteratively using the constant comparative method of qualitative analysis (Glaser & Strauss, 1967). I first coded ten interviews

based on the research questions, and cleaned up the codes to generate new ones. Then, I used the new codes to recode first ten interviews and the rest of interviews, added emerging codes when necessary. Last, I organized the codes into emerging themes.

House Type	Housemates	Gender
Apartment	P1 P2	F F
Suite (each has a single room)	P3 P16	F F
Apartment	P4 P5	F F
Single house	P6 P7	M F
Suite (each has a single room)	P8 P9	F F
Apartment	P10 P11	M F
Single house	P12 P13	M M
Single house	P14 P15	F F
Apartment	P17 P18	M M
Suite (each has a single room)	P19 P22	F F
Suite (each has a single room)	P20 P21	F F
Apartment	P23 P24	F F
Suite (each has a single room)	P25 P26	F F
Suite (each has a single room)	P27 P28	F F

Table 1. Participant demographics.

Findings

I focused on housemates' experiences with EnergyHome and their evaluations of the app features. First, I describe participants' differing feature choices and interactions with EnergyHome. Second, I discuss how housemate dynamics may have played a role in the different ways the app was used.

General feedback

Participants had different preferences when interacting with EnergyHome. I found that 5 housemates favored individual challenges to save energy, while the rest preferred to engage in energy-saving practices with others. More than half of the participants (16 in total) appreciated the feature allowing them to receive energy-saving reminders from their housemates.

Individual vs. group challenges. A minority of respondents (5) favored using the app for individual rather than group challenges. For example, one interviewee stated that group collaboration was not necessary when both housemates paid attention to energy.

> *"We didn't use group challenges because both of us are concerned about energy consumption. So that's why we didn't do group things. We just did the individual (challenges)."* (P10, male, housemate with P11)

However, the majority of the users (23) found collaborating with housemates more engaging and motivating.

> *"...with roommates, all like your same age, and you're doing the same thing. You're all studying. Even though you are on different schedules, I think [group challenges are] especially useful."* (P20, female, housemate with P21)

> *"I just feel in general when you are working with someone else you feel like they relied on you so you're more likely to follow through something. But if it's just yourself, you get lazy. And then you don't do it because no one else is depending on you."* (P8, female, housemate with P9)

Reminders. A number of participants (16 in total) felt encouraged when they received reminders from their housemates, mainly because those reminders were drafted by their housemates. In particular, they found reminders helpful when they forgot to do energy-saving challenges.

> *"It's like when you have somebody encourage you to do something, there is a chance you are more likely to do it. It's a group effort. Because sometimes you do forget to set the reminders, so it's helpful like somebody who's reminding you."* (P14, female, housemate with P15)

In contrast, several participants (4 in total) mentioned that it was annoying to be reminded and that they wanted the feature turned off.

Housemate social dynamics

The general feedback above suggests that housemates had different assessments of the design features of EnergyHome. Some considered individual challenges more engaging, while the majority preferred group challenges. Some were annoyed by reminders from housemates, whereas others appreciated these reminders. In this section, I explore the role that the social dynamics between housemates might have played in these assessments of EnergyHome features.

I observed two different patterns when participants described how they interacted with their housemates using EnergyHome: complementary dynamics and symmetrical dynamics. A

complementary relationship refers to a pattern of interaction when one person is dominant and the other is quiet and respectful (Courtright et al., 1989; Rogers & Farace, 1973); a symmetrical relationship refers to a pattern of interaction in which both people are active in energy saving or both are quiet and respectful (Courtright et al., 1989; Rogers & Farace, 1973). If a housemate requested that his or her housemate turn off lights, and the housemate did as instructed; I consider this to be a case of complementary dynamics. If both housemates asked each other to turn off lights or they took turns doing so, and they did; I consider this to be a case of symmetrical dynamics. If neither housemate asked the other to turn off lights or they focused on turning off lights independently, I consider a different kind of symmetrical dynamics: both housemates are quiet or respectful.

These two types of social dynamics were associated with differences in housemates' interactions with the design features of EnergyHome and shaped their energy-saving experiences, summarized in Table 2 and described in detail below.

Complementary dynamics. I distinguished between two sub-types of complementary dynamics. *Leader-follower* refers to the social dynamics between an active housemate who gave directions and a passive housemate who was willing to follow those directions. When the housemate was not eager to follow, I term those dynamics to be *leader-reluctant follower*.

Leader-follower. Three pairs of housemates favored group challenges over individual challenges for the same reason: one member of the pair enjoyed creating group challenges and assigning the other one energy-saving tasks; the other member was inclined to do as assigned. All three leaders in this group considered themselves to be the only one in the household conscious about energy use, and they felt they could influence their housemates to save energy by using group challenges. For instance,

"The reason why I wanted to do [group challenges] with her, is because she's totally not eco-friendly. So it frustrates me." (P23, female, housemate with P24)

One of the features that leaders were excited about was the ability to assign housemates energy-saving tasks. They found it easier to engage their housemates via the app than by speaking in person,

"I think it would be easier to describe here [group challenges] rather than speak directly. Sometimes it is hard. You feel like you are your roommate's mom, telling them what to do." (P1, female, housemate with P2)

Types of social dynamics	**Sub-categories**	**Description**	**Design implications**
Complementary dynamics	Leader-Follower	One is active (leader); One follows as told (follower)	Group collaboration; Generate features required active inputs for leaders, e.g., customize reminders, and remove those features for followers
	Leader-Reluctant follower	One is active (leader); One follows reluctantly (reluctant follower)	Separate group collaboration; Provide individual features, e.g., energy-saving challenges generated by the system to reluctant followers
Symmetrical dynamics	Collaborator-Collaborator	Both are active and collaborative	Group collaboration; Add more social features; Encourage customize reminders;
	Conflict avoider-Conflict avoider	Both perform independently to avoid conflicts	Limit group collaboration; Provide more individual features, e.g., keeping track of daily actions
	Independent contributor-Independent contributor	Both are self-motivated and perform independently	Limit group collaboration; Provide more individual features, e.g., keeping track of daily actions

Table 2. Types of social dynamics and characteristics and design implications for each type.

Followers, on the other hand, preferred group challenges because they could depend on their housemates for guidance.

"I feel like if I get more suggestions from my roommate, I will be more willing to do that. Because my roommate told me to, I feel like I should at least try it. The group one is more definitely motivating. When you are just yourself, you have more freedom [to do it or not]." (P24, female, housemate with P23)

"Because my roommate told me to, I feel like I should at least try it. The group one is more definitely motivating." (P2, female, housemate with P1)

There was a difference between how leaders treated reminders from housemates and how followers reacted to such reminders. Being reminded often irritated leaders, for example,

"I got annoyed when I got [a reminder]." (P1, female, housemate with P2)

In contrast, all three followers considered it helpful when they received reminders from their housemate. One follower mentioned she would easily forget energy-saving challenges when she set reminders to herself. However, she felt the need to get challenges done when she was reminded.

"I also set an alarm to myself. But I got away with it. Then I was kind of like telling myself versus other people were telling me to do it. I felt like more responsible for doing it when my roommate told me to." (P2, female, housemate with P1)

Being reminded could also be a type of a peer support:

"I think [letting others set reminders] also reminds me of the weight loss app things too, just kind of like the support from the whole community." (P9, female, housemate with P8)

Leader-reluctant follower. I found only one pair of housemates with a different complementary dynamic. In this pair, one housemate (P13) was the leader, who used group challenges to push his housemate to reduce energy use. To P13, group challenges were a useful feature.

> *"Setting up how much saving you wanted to do, and like time, frequency at getting my roommate to use it, I thought that was really cool."* (P13, male, housemate with P12)

However, his housemate (P12), who was a reluctant follower, personally preferred individual challenges. He only did assigned energy-saving tasks as instructed but did not discuss group challenges.

Symmetrical dynamics. Different from complementary dynamics, symmetrical dynamics are more balanced interactions between housemates. I identified the following three types of symmetrical dynamics.

Collaborator-collaborator. This type of dynamic was most common in my study. I identified 8 out of 14 pairs of housemates as belonging to this type. Collaborators prefer to work on energy-saving challenges together with their housemates and like the idea of helping each other. For example, one participant explained group challenges were helpful because she could get support from housemate,

> *"I feel like with the individual you have to like self-motivate yourself to do it, and, so I feel like if there's someone else helping you and like making it fun to do it, it would be more helpful."* (P21, female, housemate with P20)

In particular, group challenges helped to keep collaborators on track of energy-saving activities.

"Group challenges kept us on track and we reminded each other to do that." (P15, female, housemate with P14)

"We noticed a lot that the lights are off a lot more. Like if the light's switched on in one of the rooms and no one's in there, someone's like, 'Oh, turn off the light, we have the challenge going.'" (P19, female, housemate with P22)

In contrast to pairs in which one leader created challenges and the other followed, collaborators often brainstormed group challenges as a group.

"We were thinking about what challenge we should try and set up. We set up one challenge to test it out. I think it was making sure we turn off the lights in our room every day when we left, and trying to conserve water also while showering, because we realized we don't always do that." (P7, male, housemate with P6)

Collaborators respected each other's opinions. When they did not create a group challenge together, one felt the need to get the other's consent before setting one up.

"We did it together. Because I need her approval before I set a challenge for both of us." (P20, female, housemate with P21)

To collaborators, their relationship with their housemate greatly influenced their participation in the group, and they were more committed to group challenges when they were closer with their housemate. For example,

"We yelled at each other to turn off lights. But if I was living with like strangers or like a random roommate, like we were random roommates, the first week I yelled at

her to turn off the lights. She would be like 'who is this freak and why do I have to live with her for the rest of the year?'" (P27, female, housemate with P28)

Another important feature of pairs with collaborator-collaborator dynamics is that members welcomed reminders set by their housemates. Similar to working in a group challenge, collaborators felt support from their housemate when being reminded, as the following participant explained,

"Rather than the app sending something to me, my friend (refers to her roommate) is sending it to me. That's more familiar and it's less annoying to me. It makes me feel like that person actually cares about my challenge, or cares about my living habits in general." (P4, female, housemate with P5)

Setting reminders to housemates and being reminded can be fun. For example, one collaborator engaged her housemate by tailoring the reminders to her housemate's interests.

"So we would like set [the reminders to] incentivize each other with food or something like that. That was just like as something funny." (P20, female, housemate with P21)

Receiving energy reminders from housemates also helped to build common ground about energy use. For example,

"Certain things, like turning off lights, I didn't think I needed a reminder for, but my roommate might think I did and she set that, I think that was really good." (P14, female, housemate with P15)

In sum, collaborators preferred group challenges because they genuinely supported and depended on each other. In particular, they were likely to be more committed to group challenges

if they were close to their housemate(s). To collaborators, being reminded shows housemates' care and support, helps to understand housemates' expectations about energy use, and can be helpful to deal with forgetfulness.

Conflict avoider-conflict avoider. Although there is only one pair of housemates (P3 and P16) belonging to this type, it shows distinct features from the symmetrical dynamics of collaborators. Conflict avoiders preferred to save energy independently, in order to avoid potential conflicts with a housemate. Neither of the housemates (P3 or P16) collaborated on a group challenge; each worked only on individual challenges. Conflict avoider P16 admitted that she was not conscious about energy use and she did not consider it important in her life. Her housemate P3 was more enthusiastic about energy conservation but she did not feel right inviting P16 to a group challenge because she didn't want to interfere with her housemate's energy behavior.

> *"I feel like maybe it (refers to group challenges) crosses like a boundary that's a little difficult."* (P3, female, housemate with P16)

As a result, P3 preferred individual challenges. And she felt difficult to get her housemate into energy conservation.

> *"I'd prefer the individual one because I think it's I think it's sort of hard to convince your roommate to do that, because it's a sort of like a second family. Well for me like being in college but I don't think it's the same (as being in a family). And I wouldn't feel right imposing my roommate and telling them 'you have to do this'."* (P3, female, housemate with P16)

P16, on the other side, considered creating a group challenge on EnergyHome to be a passive-aggressive way of imposing on her housemate. She felt it was more appropriate to talk directly to P3 instead.

> *"I feel I'd probably just like mention it. Like, 'Oh, can you turn off the lights, or can you cover the bare floors,' instead of doing it in a passive-aggressive way (refers to creating a group challenge."* (P16, female, housemate with P3)

These two conflict avoiders tried to respect each other's energy behavior by avoiding group challenges and instead working on individual challenges.

Independent contributor-independent contributor. Similar to conflict avoiders, independent contributors preferred individual challenges because they did not see a need to work with others. However, they were self-motivated to conserve energy.

One pair of housemates (P10 and P11) belonged to this type. Both considered saving energy to be an individual responsibility and a personal life choice.

> *"Working alone is comfortable and I think it's my lifestyle. If I take a challenge, then I will do it by myself. And that's easier."* (P10, male, housemate with P11)

> *"When I was doing individual challenges, I was controlling the energy saving. It was good."* (P11, female, housemate with P10)

Another distinct feature of this pair of independent contributors is that both P10 and P11 preferred to set reminders by themselves. P10 felt that letting P11 set reminders interfered with his life and it affected his relationship with P11.

"I think it (refers to letting housemate set reminders) interferes personal habits. Yeah, I think it might impair my relationship with my roommate." (P10, male, housemate with P11)

P11 also preferred to set reminders by herself because she found it easier to keep things in mind.

"It will motivate me more, like I'm doing something, and I can keep it in my mind easily." (P11, female, housemate with P10)

Similar to conflict avoiders, independent contributors favored individual challenges. Considering energy conservation as an individual responsibility, they were more comfortable controlling challenge contents and reminders by themselves, rather than someone else.

Discussion: Social Dynamics in Design

This study suggests that people have different preferences for the design features of EnergyHome. Some housemates favored the idea of collaborating with others on group challenges, while others preferred to track their personal energy-saving challenges. Some people felt supported when their housemates sent challenge reminders, while others were annoyed when being reminded.

By analyzing the interviews, I found that whether housemates chose to participate in energy conservation individually or collaboratively was deeply influenced by two types of housemates dynamics. In complementary dynamics, housemates who do not want to initialize energy-saving activities follow those who want to take a more active role, although in some cases they may follow reluctantly. In symmetrical dynamics, housemates have similar interaction patterns when committing to energy-saving practices. When both are active and dependent on

each other, they enjoy working together. When both are independent or try to avoid conflicts, they tend to work alone.

To better motivate household energy conservation, I propose design strategies to understand and keep track of the interaction patterns between household members and the system features. Then, the system adjusts its features based on the identified interaction patterns. For example, a system can provide more collaborative features to housemates with leader-follower or collaborator-collaborator dynamics. Individual features can be highlighted to help conflict avoiders and independent contributors.

The distinction of complementary and symmetrical dynamics make me wonder how housemates with different social dynamics manage energy at home and whether they have a similar or different views about sharing energy use. In the next chapter, I aim to answer these questions by looking more deeply into what energy consumption and conservation mean to housemates and how they evaluate each other's energy activities.

CHAPTER 4

UNDERSTANDING THE SOCIAL ASPECTS OF HOUSEMATE ENERGY CONSUMPTION

In the previous chapter, I discussed how social dynamics could influence people's engagement in energy conservation by looking at housemates' use of specific types of features in my EnergyHome app, such as the use of individual vs. group challenges. In the housemate environment, whether people prefer to conserve energy independently or collaboratively is closely related to their interpersonal relationships and interactions with other housemates. This explains why successful motivation strategies for families such as tracking personal energy consumption and collaborating as a group to save energy may not always help non-family households save energy.

As discussed in Chapter 2, tensions, frustrations, and conflicts among housemates are social aspects of energy use that may play an important part in designing successful strategies for environmental sustainability. One common source of problems is failing to recognize household members' efforts in conserving energy or misinterpreting their energy activities (Nakajima & Lehdonvirta, 2013; Wilhite et al., 1996). However, it is unclear how those misunderstandings take place.

It is also common for families to focus on simple daily energy activities such as turning off lights to demonstrate their commitment to energy conservation (Strengers, 2011). Whether to keep the lights on or off is often used as a measure of sustainability. For example, Strengers (2011) found that people considered their neighbors wasteful if they left porch lights on all day. Unfortunately, ordinary households (who are not energy experts) often failed to map their energy

activities to cost (Schwartz et al., 2013). For example, they did not know which actions increased or decreased utility costs. Therefore, it remains unclear how people relate energy activities to utilities when they do not have a proficient understanding.

In this study I aimed to understand how people relate their personal energy behaviors and their housemates' energy behaviors to utility cost, and how they evaluate their roommates' energy behaviors. Building on previous work on social aspects of household energy consumption, I asked two research questions: 1) How do housemates understand their energy consumption in the home, and how does that understanding influence their personal energy behavior? 2) How do people evaluate their housemates' energy actions? What criteria do they use and why?

In the reminder of this chapter, I first present my research methods and findings on how people interpret energy conservation as well as how this interpretation affects their personal energy behaviors and their view of their housemates' energy habits. Second, I discuss two design opportunities for supporting energy conservation based on housemates' views and interpretation of each other's energy-consuming activities.

Methods

I conducted two studies to investigate housemates' understanding of energy consumption and their evaluations of others' energy activities. First, I conducted a survey (see Appendix B) with 104 participants who were currently living with others. Second, I interviewed 50 housemates to further investigate the reasons behind my survey results.

Study One: Survey

The goal of my survey was to get a general idea of what factors people consider important in terms of household energy consumption and to understand how they evaluate their

own energy behaviors in comparison with those of their housemates. I collected background information such as gender, age, and who was responsible for paying the household utility bill. I also asked questions about respondents' intentions to reduce energy use. Respondents then rated their own and their housemates' energy-saving actions in order to investigate how people compare themselves to their housemates.

In this survey, I also collected people's attitudes towards sustainability and their intended future energy-saving activities. Those data were not analyzed in this study which focuses on understanding housemates' assessments of each other's energy-saving activities.

Energy-saving actions. Participants were asked to report their frequency of performing 20 energy-saving actions (see Table 3) on a scale of 1-5 (1 = Rarely or Never, 5 = Almost Always/Always). Many of these actions were adapted from the StepGreen project (Mankoff et al., 2010). I also added additional actions from other sources, such as the EPA [2] and Energy.org [10]. I did not include actions that were unlikely to take place when living with housemates in a rental home (e.g., purchasing a programmable thermostat).

Participants. I recruited participants through social media sites (e.g., Facebook), email lists, flyers posted on bulletin boards in local business stores and university buildings, and a university research and recruiting system. Qualified participants (N=115) currently lived with at least one housemate in a shared physical space such as an apartment, dorm, or house. Approximately 90% of the participants (N=104) completed the entire survey.

All participants (N=104) were young adults aged 30 or less. About 29% of the participants were male and 71% of the participants were female. Approximately 80% were Americans. The rest were mainly from East Asian countries (e.g., China, Thailand, Philippine)

and Latin American countries (e.g., Mexico, Brazil, Costa Rica). Half of the participants reported being responsible for the household utility bill.

Optimize actions
Adjust the thermostat to below 68F (winter) above 70F (summer)
Leave thermostat's fan switch on "auto"
Wash only full loads of dishes
Keep the fresh food compartment 37F-40F, and 5F for the freezer section of your refrigerator
Wash laundry in cold water
Wash only full loads of laundry
Reduce actions
Wear a sweater rather than turn up the heat
Turn off lights in the shared common area (e.g., kitchen, living room) when no one needs them
Turn off lights in your room when you don't need them
Turn off lights in your room when you leave the room
Unplug electronics when not in use
Use the sleep or hibernate feature on computer
Turn off music when you are out of hearing distance
Air-dry your clothes
Only print out things you need
Reduce amount of meat in your diet
Take short showers (10 minutes or less)
Community actions
Buy locally farmed/produced products (within 200 miles)
Bring cloth bags to the market
Select ground shipping for online purchases

Table 3. Action types and 20 energy-saving actions.

Study procedure. In the surveys, I asked participants basic questions about their household energy use and demographic information (e.g., who was responsible for energy usage in the house). Then, I asked participants to rate their frequency of performing each energy-saving action on a 1-5 scale (1=*Rarely or Never*, 5=*Almost Always/Always*). Finally, I asked them to

rate the frequency of their housemates' energy-saving actions on the same scale. Adapted from Stepgreen environmental attitudes scale [17], I asked participants to rate how important the reasons to save energy are to them on a 1-5 Likert scale (1 = *Not at all Important*, 5 = *Extremely Important*). I then asked the participants how much they agreed or disagreed with the reasons people might not want to save energy on a scale from 1-5 (1 = *Disagree Strongly*, 5 = *Agree Strongly*).

Measures. Two researchers categorized the 20 energy-saving actions into three categories: *optimize*, *reduce*, and *community*. *Optimize* actions were occasional behaviors (e.g., weekly, monthly, or seasonally) aimed at making the most effective use of energy at home (e.g., setting the room temperature). *Reduce* actions were repeated actions that reduced daily or short-term energy use, such as turning off lights. *Community* actions were purchases and activities that had an impact on a community or required community participation, such as buying local products. There was reasonable agreement between the two researchers' categorizations (kappa = 0.79). Disagreements were resolved through discussion (see Table 1).

I then calculated the average self-reported frequency of performing actions in each of the three action categories and the average perceived frequency of housemates performing actions in each of the three action categories: *optimize* (self: Mean=2.53, SD=.84; housemates: Mean=2.50, SD=.93), *reduce* (self: Mean=3.37, SD=.61; housemates: Mean=3.09, SD=.90), and *community* (self: Mean=3.01, SD=.91; housemates: Mean=2.60, SD=1.13).

Gender was coded as a dichotomous variable, female=1 (71%) and male=0 (29%).

Number of housemates. I asked participants how many housemates they lived with, and I recoded their responses into the following binary measure: live with at most two housemates (47.2%) and live with three housemates or more (52.8%).

Responsibility for utility bills. I also asked participants whether or not they paid for their utilities using three response options: full responsibility (14.2%), partial responsibility (35.4%), and no responsibility (50.4%). I combined the full and partial responsibility category to create a binary responsibility measure (50% partial or full responsibility; 50% no responsibility).

Desire. In the surveys, I asked participants their environmental attitudes about saving energy. I used factor analysis to identify four types of environmental attitudes associated with desire to save or not save energy: *saving energy brings in personal benefits* (Cronbach's α=.62), *saving energy brings in benefits to others and society* (Cronbach's α=.86), *not saving energy because I cannot see personal benefits* (Cronbach's α=.63), *not saving energy because it takes personal effort to do so* (Cronbach's α=.72).

Survey results. First, I used a hierarchical linear regression analysis to investigate whether or not gender, responsibility for utilities, number of housemates, and desire were associated with participants' self-reported frequency of engaging in energy-saving actions. Second, I used a Mixed Model ANOVA to examine the differences between how participants evaluated their energy-saving actions and how they evaluated their housemates.

Individual energy saving behaviors. A hierarchical linear regression analysis was used to test the relationships among the predictor variables and the three types of energy-saving actions (*optimize*, *reduce*, and *community*).

First, demographic variables (gender, responsibility for paying utilities, number of housemates) were used to predict respondents' desire to save energy. Previous research showed gender and house sizes were related to energy use. Female participants reported being more active in saving energy than male participants (Stern et al., 1993). A bigger house size or a larger number of household members was related to higher energy consumption (Poortinga et al.,

2003). As a result, I used gender and number of housemates as the predictor variables. I also wanted to examine whether financial responsibility influenced people's desire of saving energy.

Second, I constructed the model in the following way. The first block included demographic variables (gender, responsibility for paying utilities, the number of housemates). The second block added the measure of participants' desire (not) to save energy.

Model 1. There were no significant effects of gender or number of roommates on participants' energy-saving behaviors, but financial responsibility was associated with greater engagement in energy-saving behaviors (F[3, 100]=2.56, β=.24, p=.05) (See Table 4). When people paid utilities, they were more engaged in energy-saving activities (M=3.06, SD=.50) than when they did not need to pay (M=2.77, SD=.57).

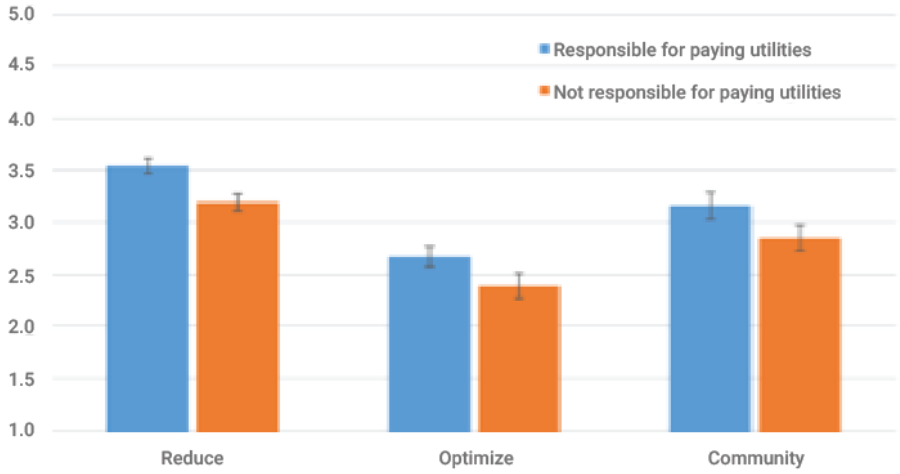

Figure 3. Mean rating of each category of energy-saving actions (on a scale of 1-5) for respondents who paid or did not pay for utilities (error bars represent stand errors of the mean).

As shown in Figure 3, participants reported a higher frequency of *reduce* actions than *optimize* and *community* actions. This suggests when individuals needed to pay utilities, they were more engaged in simple daily energy-reducing activities (e.g., turning off appliances when not in use) than *community* or *optimize* actions.

Model 2. When four factors of desire (not) to save energy were added to the model, there was not a significant effect of this measure on energy-saving behaviors (F[4,99]=1.43, p=.20, n.s.) (See Table 4). In contrast with a previous study (Abrahamse et al., 2005), this indicates housemates' interests in saving energy do not lead to a greater participation in energy conservation.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.82	.13		21.71	.00
	Female	-.05	.12	-.04	-.44	.66
	Age_22	-.11	.15	-.07	-.76	.45
	Rsp_Util	.26	.11	.24	2.39	.02
2	(Constant)	2.27	.40		5.63	.00
	Female	-.04	.13	-.03	-.29	.77
	Age_22	-.12	.15	-.08	-.82	.41
	Rsp_Util	.27	.11	.25	2.37	.02
	Benefits to others	.04	.07	.07	.60	.55
	Personal benefits	.04	.08	.06	.54	.59
	Cost personal effort	.08	.08	.13	1.12	.27
	No personal benefits	.03	.08	.03	.33	.74
a. Dependent Variable: self-reported energy-saving actions						

Table 4. Coefficients of Model 1 and Model 2.

In sum, the hierarchical linear regression analysis shows that housemates who need to pay utility cost demonstrate larger interests in saving energy. In particular, they frequently engage in daily simple energy-saving actions when having financial responsibilities. However, the models also showed people's environmental attitudes to save energy did not lead to a greater engagement in saving energy.

Evaluations of self vs. housemates' behaviors. I asked participants to identify who should be more responsible for consuming energy at home. The majority (61%) considered themselves

and their housemates equally responsible, 21% thought their housemates were more responsible, and 18% reported they consumed more than their housemates.

I conducted a 2 (perception conditions: how individuals perceive themselves vs. how they perceive their housemates) × 3 (energy-saving action types: *optimize* vs. *reduce* vs. *community*) Mixed Model ANOVA to understand how individuals evaluate their housemates' commitment to energy conservation and to determine whether there were differences between how individuals perceive their own energy-saving actions vs. those of their housemates.

The results suggest a significant difference ($F[1, 103]=53.23$, $p<.001$) between how individuals viewed themselves in terms of energy conservation and how they evaluated their housemates. Individuals rated themselves better in saving energy than their housemates.

Furthermore, a significant difference between how individuals perceive themselves in energy conservation and how they evaluate their housemates was found in *reduce* actions ($F[1,103]=11.42$, $p=.001$) and *community* actions ($F[1,103]=15.91$, $p<.001$) but not *optimize* activities ($F[1,103]=.08$, $p=.78$) (see Table 5).

Action types	**Evaluate self energy-saving actions**	**Evaluate housemates' energy-saving actions**
Reduce	3.37 (.61)	3.09 (.90)
Optimize	2.53 (.84)	2.51 (.93)
Community	3.01 (.91)	2.60 (1.13)

Table 5. Means and standard deviations for each category of energy-saving actions for respondents' evaluations of themselves in comparison with their housemates.

Survey study discussion. Similar to previous research findings (Abrahamse et al., 2005, Poortinga et al., 2003), the survey results indicated that housemates engaged more in energy conservation when they had financial responsibility for utility cost. Specifically, the results suggest they frequently take part in daily repeated actions such as turning off lights and unplugging appliances. However, it remains a question why people were more active in daily but

trivial energy-saving actions even though the saving is minimal. For example, a daily saving action such as unplugging appliances only saves up to $1 per year, while an optimize action like washing laundry in cold water can save $57 per year (Mankoff et al., 2010). Is it because they regarded daily repeated actions as having a large impact on saving utility cost? Or, did they only recognize daily actions to reduce energy cost but neglected other alternatives?

Similarly, I found that individuals considered themselves better in energy conservation, particularly in daily repeated actions (e.g., turn off lights when not in use) and actions impacting a community (e.g., buy local products). It is unclear why people only consider themselves more active in those two types of actions but not *optimize* (e.g., adjust the temperature to 68 degrees in winter). Is it because they were only aware of housemates' daily actions as opposed to other actions? Is it because they considered themselves better in reducing energy cost than their housemates by engaging more in *reduce* actions? Or, are there other reasons?

Study two: interviews

The surveys suggest that housemates strive to perform simple daily energy-saving actions, especially when they need to pay for utilities. They also considered themselves better at energy saving than their housemates. However, the survey study did not show why participants focused on simple energy-saving actions, which often have a minimal payoff in energy savings (e.g., turning off lights when not in use, which only saves about $10 per year, Mankoff et al., 2010), or why participants considered themselves better in reducing energy than their housemates. To address the those questions, I conducted follow-up interviews (see Appendix C).

Participants. Participants were young adults between 18 years old and 30 years old, who live with at least one housemate. Among the participants (N=50), the majority (N=43) lived in a shared apartment or a single-family house, while seven others lived in a fraternity or sorority

house with over 30 housemates. Of the 50 participants, 15 participants did not need to pay for utilities, either because they were included in their rent or because their parents were paying. Of the rest, 26 participants were directly responsible for paying their utilities including heat, water, electricity, and gas, while 9 only needed to pay the electricity cost.

I recruited participants using Facebook, university email lists, flyers posted on bulletin boards in local business stores, and a university research recruiting system. Qualified participants had to be currently living with at least one housemate in shared housing.

Interview procedure and analysis. I asked participants about their understanding, experiences, and evaluations regarding energy usage at home. In particular, I asked how they reduced energy costs, which household members paid attention to energy conservation, and who in the household had influence on energy consumption. I also asked participants about their experiences of managing energy use with their housemate(s). Each interview was 45 minutes to an hour.

Interviews were audio recorded, transcribed, and coded iteratively using the constant comparative method of qualitative analysis introduced by Glaser and Strauss (1967). I first coded ten interviews based on the research questions and cleaned up the codes to generate new ones. Then, I used the new codes to recode the first ten interviews and the rest of interviews, adding emerging codes as necessary. Last, I organized the codes into a set of emerging themes.

Interview findings: personal energy use. As was the case with the survey respondents, interviewees reported paying more attention to energy-saving activities when they need to pay for utilities. All 35 participants who were directly responsible for utilities mentioned the main reason they were mindful about energy was to reduce its cost. As P31 described, his motivation to save energy was strictly cost-related rather than aimed at taking care of the environment,

"I guess if money were no object, I wouldn't really care one way or the other…I'm not really that into sustainability or anything I mean you know, it's that's pretty much it." (P31, male, lives in a single-family house)

The 15 participants who did not need to pay utilities showed less or no interest in reducing energy consumption. They explained that energy conservation was not their top concern unless they had to pay for it.

"I guess since we don't have to pay for [heat] we don't care as much, I guess, like what temperature the thermostat is set to." (P4, female, lives in an apartment)

However, if utility cost was their key concern when they had to pay for utilities, why would they expend most of their efforts on daily repeated actions like turning off lights or appliances that save relatively little energy? Why not focus on actions that could bring in a larger reduction in energy cost, such as adjusting the thermostat to above 70F in summer and below 68F in winter (saves up to $68 per year, Mankoff et al., 2010). The interviews suggest that people viewed small daily energy-saving actions as a way to reduce energy use, which is explained in the following section.

Reduce actions equal to lowering energy cost. The surveys show that people are more active in daily repeated actions when they are directly responsible for paying utilities. But the surveys did not answer why people hoped to reduce utility cost by engaging in these types of actions. The answer to this question becomes clearer in the interviews. All participants thought that actions like turning off lights and appliances, unplugging appliances, and using only appliances they need would reduce their energy costs.

All 50 participants thought keeping energy-consuming appliances or lights off when not in use was important for reducing energy cost. For example, one participant described how she tried to reduce energy cost by switching off lights and fans.

> *"If I'm leaving the house, I make sure that all the lights are switched off, all the fans, everything that at least I was using. I mean I can't be sure about my roommate's room or what's happening inside but my living room and my room, I make sure it's switched off because like I told you, I do care about the electricity bill because we are both trying to save on our bill."* (P30, female, lives in an apartment)

More than half of the participants mentioned unplugging appliances as a way to reduce energy cost.

> *"I unplug the microwave, the toaster, like phone chargers … my mom says that raises the bill you know, she's the most frugal petty person in the world, not petty just frugal so, I just follow in her footsteps. My roommates look at me weird though for the record."* (P9, male, lives in an apartment)

> *"We unplug the electronics and devices we are not using or when we are not there."* (P15, male, lives in a single-family house)

The interviews suggest that people emphasize reduce actions as ways to lower household utility bills. They put less effort into other energy-saving activities that could have greater impact, such as washing laundry with cold water (saves up to $56 per year, Mankoff et al., 2010). This may explain why roommates consider themselves more engaged in reduce actions when they are directly responsible for paying utilities, because they think they can relate those actions to reduced energy costs.

Reduce actions demonstrate environmental consciousness. Interviewees thought that engagement in reduce actions was evidence that they paid attention to energy conservation. For example, most participants (N=35) mentioned they tried not to be wasteful by switching lights off and unplugging appliances, like,

> *"Just being self-aware, like 'Did I leave the light upstairs?', and I check. Most of the times, I did not. But it's not always. I just make sure. Sometimes it is on, and I just turn it off because it doesn't need to be on."* (P15, male, lives in an apartment)

> *"I'm aware if things get left on. I really try not to… so actually earlier I was leaving the house with my boyfriend to come here, and he had left the light on in the living room, and as we were leaving I noticed it, so I went back in the house and shut it off. And so I'll try to do stuff like that."* (P42, female, lives in a single-family house)

It seems that engagement in daily repeated actions is the criteria used by the participants to evaluate energy behaviors. The more they engage in those daily energy-saving actions, the better they become in paying attention to energy issues.

Interview findings: evaluating housemates. Furthermore, I asked participants what they thought of their housemates' energy conservation. They told me three different scenarios when housemates were considered as heavier energy consumers: forgetfulness, quantity of household appliances; and longer stays at home.

Forgetfulness. Forgetting to turn off lights or household appliances was one common reason why participants thought their housemates consumed more energy than they did. A number of participants (N=32) mentioned this issue:

"I would say my roommate had a tendency to use more energy. He would not turn his lights off when he left, either. So yeah, he really had no regard of energy consumption." (P16, male, lives in a fraternity house)

"I would say my friend does [use more energy] because I feel like she leaves the light on pretty often and like even when she's not in the room, she leaves it on …my friend usually leaves her fairy lights on throughout the day. I'm not sure during the morning but definitely like when it starts getting dark the lights are on, I don't know what lights but the lights are on, and she's not in her room because I hear her coming back upstairs." (P21, female, lives in a single-family house)

Quantity matters. Several participants (N=12) mentioned that they believed their housemates contributed more to energy consumption, because these housemates used more appliances or used them for longer periods of time. For example, one participant observed,

"I think that one of my housemates watches a ton of TV, and takes really long showers, and always leaves the lights on. So I think she has the most impact on our energy use because she's just more reckless about it." (P12, female, lives in an apartment)

Some interviewees also saw their housemates' ownership of more personal devices as evidence that they did not pay attention to energy use:

"[my roommate] has a fish tank in his room. And it has frogs, tails, snails, and a bunch of animals in there. So I'm not exactly sure how much energy consumption it takes to have that fish tank consistently going. So when it comes with that, I'm not sure. He has a different energy need" (P15, male, lives in a single-family house)

"She's charging her laptop she probably uses the most energy for that as well, and she has to straighten her hair and blow dry everyday, so that's energy." (P34, female, lives in an apartment)

Longer stays at home. The third common criterion that participants used to evaluate their housemates' use of energy was how long they stayed at home. The longer housemates stayed at home, the more energy they were believed to consume. For example,

"I think him probably because he stays there more than I do. He spends more time there. I spend more time outside the house. So usually I end up getting back to the house like 10pm or in the evening. And I leave pretty early. So I guess he ends up using more of the energy." (P1, male, lives in a fraternity house)

"I'm out for most of the day and she's the one that comes home the earliest so just based on the duration of time, I think it's her." (P5, female, lives in an apartment)

Interview findings: comparisons between self and housemate. Participants considered their housemates to be less energy conscious than they were based on the three factors above (forgetting to turn off appliances, using more devices, and having longer stays at home). Engaging in reduce actions was an important criterion for evaluating housemates' energy activities. Housemates often failed to engage in those actions in the ways the interviewees expected. The majority of participants (40 out of 50) thought they were much better than their housemates in saving energy, because they were more active in, for example, keeping lights off,

"I'm probably the most conscious of it but I've never really said anything because it's just not worth my time … like our outside light is probably the one I would monitor the most, just because it's like right as I'm walking outside to go to class I notice the light

from the night before is still on. My house at home has a timer, so it doesn't really have that issue but here I'll notice that it's on during the day, so. I'll actively turn it off. But I think I wanna say I'm surprised that no one really cares about turning off lights and stuff." (P47, female, lives in an apartment)

Interviewees made one of two types of evaluations when assessing their own energy-related actions in comparison to those of their housemates: "I am environmentally conscious, but my housemates are not" or "we are all environmentally conscious, but I am more environmentally conscious than the others".

I am environmentally conscious, but my housemates are not. This was the most common evaluation of housemates' energy behaviors among the interviewees (32 participants). They reached this conclusion based on evidence that housemates did not turn off appliances or unnecessarily used a large amount of energy (e.g., electricity and water). For example, one participant described his roommate as mindless about energy conservation. Compared to his roommate, he was more environmentally conscious because he consistently engaged in daily repeated actions:

"He would also sleep with the light on. Not because he's afraid of dark, because he's like 21 years old college student. But he would be just watching TV in the bed with his light on, and just not turn it off… I try not to keep things plugged in if they don't need to. I turn off the lights when I leave most of the time. I unplug my AC and all that. I generally won't get cold, and I like being cold, so I don't use much heat. I would say I'm probably better than most, at least guys at my age. Well, guys at my house." (P16, male, lives in a fraternity house)

Similarly, one participant compared his frequency of turning off lights and the TV with his housemates and concluded that he was the only one who cares about energy.

> *"I think I'm probably the only one who pays any attention to water consumption and I pay somewhat attention to the electricity in terms of me turning off the lights when I come home and turning off the TV after I use it or when I just come home, which they clearly don't because I'm the one doing it."* (P34, female, lives in an apartment)

We are all environmentally conscious, but I am more environmentally conscious than the others. The other 8 interviewees believed everyone in the household was conscious about energy usage. They said their housemates were good at turning off appliances or lights in shared rooms. However, they felt they paid more attention to energy conservation in their own bedroom than their housemates did.

> *"I saw her bedroom light turned on, but she was not there. So I think I am maybe a little better turning off bedroom lights than her."* (P50, female, lives in an apartment)

Although 10 out of 50 interviewees considered themselves no better than housemates on energy conservation, about 80% of the interviewees believed their engagement in daily repeated actions demonstrated a better commitment to sustainability. They considered themselves better than housemates because they pay more attention to daily energy-saving actions as simple as turning lights off.

Discussion

Across both survey and interview components of this study, my participants indicated that engagement in simple daily energy actions ("reduce actions") such as unplugging appliances was an important criterion for reducing utility cost, demonstrating commitments to energy

conservation, and evaluating housemates' energy actions. When participants had to pay for their utilities, they reported taking more of these daily simple actions. Furthermore, most participants (40 out of 50 interviewees) considered themselves better at saving energy, because they took more of these reduce actions.

Participants' narrow focus on reduce actions may prevent them from recognizing alternative activities that might lead to greater reductions in energy use. Thus, I propose to shift the focus of apps to promote sustainability from encouraging frequent actions to learning quality energy-saving strategies to increase people's awareness of the most effective ways to save energy. Besides, I recommend acknowledging individual levels of involvement in daily actions and sharing personal environmental evaluations with housemates to help them reach a mutual understanding. Instead of focusing on collaboration, sustainability systems for housemates could better support negotiations between housemates, helping them meet each other's expectations by trading in energy-consuming activities.

In this chapter, I discussed housemates' understanding and evaluations of energy-saving activities, which may lead to misjudgments of housemates' energy behaviors. But how do these understandings and evaluations influence the energy experiences of housemates or change the dynamics among them? In the next chapter, I will take a closer look at housemate energy management and conflicts to answer this question.

CHAPTER 5

UNDERSTANDING HOUSEMATES ENERGY-RELATED CONFLICTS

In the previous chapter, I discussed how housemates perceived each other's energy activities through their evaluations of daily repeated actions. Their insufficient understanding of energy conservation and heavy focus on daily reduced actions as the evaluation criteria often lead to misinterpretations of housemates' energy-consuming activities. In this chapter, I will further investigate the social aspects of housemate energy consumption through the lens of conflicts.

As discussed in Chapter 2, while energy-related conflicts are common among housemates, little research has explored these conflicts and how they affect housemates' energy practices. Conflicts can arise when household members disagree about how they should manage energy and share responsibilities, and they may be especially common when housemates co-manage energy consumption instead of having a delegated energy manager (Liu et al., 2013).

It is unclear what causes conflicts, how housemates resolve or address these conflicts, or how conflicts affect energy consumption and people's experiences. This chapter aims to provide answers to the above questions and to explore motivation strategies for sustainability systems that will not cause unnecessary conflicts. Specifically, I ask the following research questions: 1) How do housemates manage and negotiate energy use? 2) Do housemates encounter conflicts while managing energy use together? If so, what are these conflicts and why do they occur? 3) How do housemates address these conflicts? and 4) How do conflicts influence household energy consumption and people's experiences of sharing energy use?

In the remainder of this chapter, I present the method and results of the interview study. I conclude with a discussion of how the findings can inform the design of persuasive technologies to support household energy conservation.

Methods

I conducted an interview (see Appendix D) study with 50 housemates to investigate their everyday energy activities in a shared living environment and related conflicts.

Participants consisted of 50 young adults (36 female) between 18 and 30 years old. Of these, 43 were undergraduates, 5 were graduate students, and 2 were visiting scholars at a large U.S. university. All lived with at least one roommate or housemate. The majority (N=43) lived in a shared apartment or a single-family house, while 7 lived in a fraternity or sorority house with over 30 housemates. Of the 50 participants, 15 did not pay for utilities, either because they were included in their rent or because their parents were paying, 26 were directly responsible for paying their utilities including heat, water, electricity, and gas, and 9 paid only for electricity. I recruited participants using Facebook, university email lists, flyers posted on bulletin boards in local businesses, and a university research recruiting system.

I used a semi-structured interview protocol with four parts. In part one, I asked warm up questions about their house and utilities. In part two I asked general questions about energy management. For example, I asked how they managed energy use with their housemates and how they and their housemates reached an agreement about how energy would be used. Part three focused on a particular energy experience. This part varied depending on how participants answered the previous questions. For example, I asked them to describe a time when they and their housemates had different needs for using energy and describe how they resolved these differences. I also asked them to describe a time when they successfully coordinated energy use

with their housemates. Part four consisted of wrap-up questions, such as whether they had any additional insights or experiences they would like to share. Each interview lasted 45 minutes to an hour.

Interviews were audio recorded, transcribed, and coded iteratively using the constant comparative method of qualitative analysis (Glaser & Strauss, 1967). I first coded ten interviews based on the research questions and cleaned up the codes to generate new ones. Then, I used the new codes to recode the first ten interviews and the rest of interviews, adding emerging codes as necessary. Last, I organized the codes into a set of emerging themes.

Findings

The analysis uncovered four general themes related to conflicts in energy use: personal comfort, monetary issues, public and private boundaries, and shared energy responsibilities. I elaborate on each of these themes in the sections below.

Personal comfort related conflicts

The interviews suggest that many energy-related conflicts take place when housemates have different preferred comfort levels for things such as household temperature. In addition, a housemate's energy use might reduce others' personal comfort, for example when he or she takes a long shower while others are waiting to use the bathroom.

Thermostat battles. The interviews show that it is common for housemates to get into thermostat setting battles due to differences in temperature preferences. More than half of the participants (N=30) mentioned they had disagreements with their housemates about heat settings such that everyone in the house repeatedly changed the thermostat to a temperature he or she preferred. They found these temperature battles annoying and frustrating but none of the interviewees mentioned discovering a successful strategy to address the problem. For example,

"I don't get cold very easily. But…once it started to get a little cold outside, then I would go home and the heat was turned up a little bit and I would start turning the heat down a little bit so I was in a bit of a war over the thermostat." (P31, male)

"…my roommate and I had a disagreement…she wanted when we left to turn down the heat a lot, but … you don't want to be freezing when you come into your house after being freezing all day. So I used to have an argument about that, because she would turn down the heat." (P5, female)

Long showers. Some interviewees also reported being annoyed by housemates who put their comfort above energy conservation. For example, some participants (N=20) found it annoying when their housemates occupied the shared bathroom for a long time. For example,

"There's always this disconnect where they take really long showers to get their fill of water whereas I only took showers to like get clean at home. That seems to be our biggest conflict. It bothers me like why are you taking a 30-minute shower?" (P6, female)

"If you wait [for the shower] too long, you might end up with cold water." (P16, male)

As you can see, independently pursuing personal comfort without considering others' comfort levels is a common factor contributing to energy-related conflicts.

Monetary-related energy conflicts

The interviewees reported that utility costs influenced how they used energy and that money sometimes led to energy-related conflicts. College housemates may have different opinions on how to balance personal energy needs and shared energy costs. Many of the energy-related conflicts reported by the interviewees were rooted in three concerns: *personal use of*

energy increases the entire household's utilities, *ownership of personal appliances*, and *unusual energy bills*.

Personal comfort increases entire household's utilities. Several interviewees reported that conflicts began when one housemate pursued personal comfort at the risk of increasing the entire household's energy cost. For example, eight participants specifically talked about the heat settings fights with their housemates during winter. They wanted to lower their utility bill by reducing the heat usage whereas their housemate(s) were only concerned with personal comfort.

> *"I heard the heater going on too, so I asked my friend like if she turned the heater on, and she was like 'yeah I'm really cold'. And then when she comes out of her room, I see her in like a t-shirt, and I tell her 'if you're cold, wear more'. But she's like 'oh no, but I want the heat on'. I didn't really understand her logic like we're all paying for the heat. And there's no need to turn the heat on now, because we can save that and turn it on more when it actually gets really cold."* (P21, female)

In some cases, energy conflicts even started when housemates were trying to reduce utility costs:

> *"One month, our utilities bill was incredibly high, because it was a very cold month and we'd kept the heat up. So our roommate had turned off the heat in the apartment and bought herself a space heater, and plugged it into her room, so that she still had the same temperature, but the bill was much lower for her and the rest of the house was very cold, which we were not happy about."* (P32, female)

Quantity of appliances matters. Interviewees also raised concerns when their housemates owned more personal appliances than they did. For example, several (N=7) mentioned being

unhappy when a housemate had a space heater or a personal air conditioning unit, because they felt these appliances used an unfair share of household energy cost.

> *"We think the bills are so expensive this month because a lot of girls got air conditioning units and that takes up so much energy. And it's kind of funny, like some people are really annoyed because obviously not all of us have AC units in our rooms, so some people are like 'Oh well you, like, are using up more electricity than me, whatever'."* (P10, female)

Unusual energy bills. The interviews show that unusually high energy costs may result in housemates accusing each other of consuming a significant amount of energy. Although it was unclear to the participants what factors contributed to an unexpectedly high utility bill, they assumed that their housemates were to blame.

> *"I don't know what he did to the power, but he probably left all the lights on. And nobody wanted to split that $400 power bill amongst three people. That would have been even more annoying. So yeah, we ended up having to fix it that way. It was just frustrating."* (P36, female)

In sum, the interviews show that direct responsibility for paying utilities impacts housemates' energy behaviors. Failures to balance personal comfort, ownership of appliances, and fair proportions of energy costs may result in friction.

Private boundaries and personal devices

Interviewees also mentioned that different understandings of what is personal and what is shared were also a source of conflicts with housemates. The interviewees considered energy-consumption activities that happened in their individual bedrooms to be private. If a housemate changed the status of personal appliances (e.g., a space heater) or lights inside their bedroom,

this could cause conflicts. There was also some blurring of lines concerning who could alter what appliances when those appliances were in a communal space. A few participants (N=7) mentioned feeling uncomfortable when their housemates used their personal devices in the shared space.

Energy consumption in bedrooms considered private. Most participants (N=40) agreed that they should not interfere with housemates' energy activities when these took place in the housemates' own bedrooms. It was up to individual housemates to manage energy in their bedroom, even when they left appliances unattended. For example, one participant explained,

> *"It's their room, I can't touch that [refers to turning off bedroom lights]."* (P25, female)

Even when the intent was to reduce energy use, violating private boundary could result in conflicts. For example, P12 considered her housemates unplugging her bedroom appliances as a way of blaming her for using more energy.

> *"I think they just unplugged it and realized that they unplugged it when I had it plugged in. So it wasn't really a communication it was like a signal I guess you would say."* (P5, female)

Personal devices in the shared space considered private. The interviews show that a few participants (N=7) were used to leaving personal energy appliances in communal spaces. They were not happy when their housemates used those items without asking their consent. For example,

> *"They would never listen to me, because I'd go and unplug their chargers [in the communal space]. And when they weren't using it, I'd be like stop doing this and unplug*

all the chargers from the wall. And then they would get annoyed, because they would not know." (P7, female)

In summary, interference with energy activities or appliances that interviewees considered personal could lead to conflicts. To some interviewees, going into a housemate's bedroom to turn off appliances or lights was a reasonable way to reduce energy. To others, it was a privacy violation. Some people considered personal appliances in a communal space to be free to use by anyone. Yet, others believed it was inappropriate to use them without the consent of the owner.

Shared energy responsibilities

Sometimes, different perceptions of shared energy responsibilities may cause unhappiness or conflicts among housemates. From the interviews, I identified energy-related conflicts associated with collective energy responsibilities, primarily in the form of forgetfulness, which might even lead to potential dangers.

Forgetfulness. All of the interviewees mentioned one or two incidences when they were blamed or blamed others for forgetting to turn off shared lights (e.g., kitchen lights). Repeatedly leaving shared lights on could be a frustrating situation because others need to take care of it. For example,

"I think there was a time [refers to when housemate was unhappy] when I was really tired so after cooking, I left the kitchen light on and so I forgot to turn it off." (P21, female)

Several participants (N=7) mentioned that they always needed to be responsible for shared energy use when their housemates forgot to do so. For example,

"I was so frustrated when a few nights ago, because we were getting ready for bed and I went and turned off the kitchen light, and then she went in there to do something and came out and it was on again. And I was like 'Are you kidding me? Like you know you're about to go to bed, why would you leave it on?'. Like I just think she doesn't think about it, whereas I do think about it." (P40, female)

Two participants (P7 and P33) also described times when a housemate forgot to turn off the oven overnight, which they saw as both wasteful and dangerous..

"This summer I lived with this roommate who would always leave the stove on overnight, leave the stove, the oven not the stove, and that made me really upset because it was dangerous and I didn't like it." (P7, female)

The frustrations because of shared responsibilities arise because some housemates felt they needed to take responsibility for tasks others have forgotten to do, and this required time and effort.

Methods of handling energy-related conflicts

In addition to asking interviewees about conflicts they encountered in their shared living environment and contributing factors to those conflicts, I also asked how they and their housemates managed any conflicts that arose. I probed what strategies they employed to solve conflicts, and what made those strategies successful or unsuccessful. For example, how could similar strategies end in either a successful resolution of a conflict or a failure to resolve the issue? Why did housemates decide to address some conflicts but not others?

I identified four common resolutions strategies: ignoring conflicts, staying silent, refusing to change, and collaborating. In the following sections, I discuss these successful and unsuccessful ways interviewees dealt with household energy conflicts.

Ignoring conflicts. Under some circumstances housemates were used to leaving the conflicts as they were. For example, interviewees suggested there was no need to resolve thermostat battles. In this case, neither the relationship with housemates or personal needs and values were seen as important enough for interviewees to engage in a negotiation to resolve the conflict. For example, participants simply changed the thermostat to their own preferred setting.

> *"In terms of managing [temperature], it's like if one person is home and nobody else is home, they just get free for all in what they want it, as it's kind of almost manage it by not managing it, if that makes sense. It's sort of a free for all of whoever sets it first until somebody else complains."* (P6, female)

Even though thermostat battles affected personal comfort and energy cost, the interviewees and their housemates did not care enough to solve the problem.

Staying silent. When interviewees valued their relationships with their housemates, they reported that they tended to keep quiet about energy conflicts rather than try to resolve them. They were less confrontational and did not voice their energy needs. Several participants (N=7) mentioned that they preferred to accommodate their housemates when a conflict occurred:

> *"Everybody gets along and everybody tries to accommodate to the best of their abilities…Just like I wouldn't want to be asked to like stop wearing gray shirts. You know, it's kind of the same concept."* (P37, male)

P48 explained a reason why she chose to accommodate to others' needs,

"Because we're too wimpy to actually call somebody out. I think if something really horrible happened, we would. But for the most part, we don't really wanna say anything to the person." (P48, female)

Unfortunately for P48, energy-related conflicts were unlikely to be resolved when she chose to accommodate.

"One of my roommates, I guess it's way colder than everybody else. She'll have her window just like completely open. It kind of drains the rest of the heat out of the apartment…but I guess most of us can kind of sympathizing enough with having our comfort violated, and we don't really want to violate her comfort also." (P48, female)

Refusing to change. On the opposite extreme, when interviewees cared more about their personal energy needs and values, they were reluctant to compromise with housemates. They were unlikely to resolve conflicts with housemates even when they talked to them about the issues. For example, P10 mentioned that her housemates were not happy about her keeping the fan running all day long, yet she did not care,

"I keep it running. Well, I don't have a window [in my bedroom]. If you want to take my room, take it, that's kind of what it is." (P10, female)

Some interviewees explained it was useless to negotiate with housemates who refused to change. For example,

"We can [negotiate with a roommate], but one of the things is that 90% of the time she does what she wants." (P17, female)

"It would just be pointless [to discuss the conflict with her]. She literally has like blinders on that. She's totally right in her situation and her life." (P39, female)

Without an effective negotiation, conflicts forced other housemates to adapt to some energy-consuming activities. For example,

"We mentioned it to her when she turned off the heat and bought herself a space heater. We kept telling her 'it's way too cold in this house, we need to turn up the heat', and she said 'that's nothing to do with the heat. It's just because it's cold outside and we have windows'. Every house has windows, but not every house is as cold as ours. So we talked to her a lot about that, but then after we got the space heaters the discussion sort of just ended right there." (P32, female)

According to P32, this strategy led to increased energy costs, since running four personal heaters turned out to be more expensive than running one central-controlled heating unit.

"[we said to her] 'We're going to go out and buy a space heater too. And then your … electricity bill is going to be high, and you're still paying that'. She didn't believe us. So we went out and each bought a space heater. The utilities bill came back the next month, and it was higher than before." (P32, female)

Worse still, a conflict might get heated when housemates refused to compromise.

"We both obviously have really different preferences. She's a very outspoken person. I feel like whenever we're talking, we're kind of starting an argument. And that gets a little frustrating, because I'm kind of hard-headed too. So it's like two hard-headed people talking and arguing, but never reaching a solution." (P21, female)

In sum, energy conflicts were unlikely to be resolved when interviewees valued personal needs and comfort more than their relationship with their housemates.

Collaborating: group discussions. In addition to unsuccessful strategies such as ignoring the problem, staying silent, or refusing to change, we also identified four successful strategies that housemates used to address conflicts: in-person conversations, group texting, apartment meetings, and outnumbering. Almost all the participants (43 out of 50) mentioned that they tried to communicate with their housemate(s) when they encountered energy-related conflicts. Some participants (N=15) preferred to discuss conflicts in person, some preferred to use messaging tools (e.g., GroupMe), and some arranged formal meetings.

In-person conversations. For 15 interviewees, discussing energy needs in person with their housemates was the best way to solve conflicts because it facilitated mutual understanding of the conflicts.

> *"In person [conversations], because I see them. And I feel better in person and it's easier than over text messages for sure, and also understanding."* (P7, female)

Interviewees reported that in-person conversations often resulted in satisfying outcomes.

> *"Well now since we've had that discussion, normally the lights are off everywhere … like the lights are all off in the kitchen, the living room, the hallway."* (P18, female)

Group texting. Some participants (N=18) chose to discuss conflicts via texting tools like GroupMe, Facebook messenger, iMessage, text, and emails. They saw this as a less threatening approach.

"In terms of managing the energy, when I try to talk to her, I text it to her, and I don't know if that's a generational thing or I think it's less confrontational. But, at the same time, I get my message across." (P12, female)

Apartment meetings. Several participants (N=7) mentioned that they held a apartment meeting to reach agreements on how to use energy, especially when conflicts had escalated. This was most common when many housemates were unhappy about an energy related issue.

"Three of us got the apartment meeting idea from living in an apartment abroad one semester. And it was very needed because lots of things [refers to energy management] were going wrong and many people were unhappy, so we had to make this into an official thing, so that people would take it seriously." (P25, female)

Outnumbering. A small number of interviewees (N=3) reported using a group consensus strategy to address energy conflicts. This strategy was often successful for resolving the issue to their satisfaction.

"Luckily there's an odd number of us with it being three, so we do some sort of democracy type thing where it's like the two against one paradigm, yeah." (P6, female)

"But nothing ever comes of it, especially like how many people want it, where it is or how many people want it changed. Then that determines, but normally I'm outnumbered. So it doesn't really matter." (P34, female)

The interviews suggest that it is easier to resolve energy-related conflicts when housemates communicate directly about the issues. In-person discussions are more direct and can make it easier to reach consensus, while texting is better for reaching everyone quickly and

reducing a sense of confrontation. Some households held apartment meetings to address more serious disagreements. And some people compromised to the majority of housemates' energy needs.

Discussion: Conflicts in Design

The interviews suggest that conflicts influence housemates' energy practices. Conflicts that lead to an increase of energy consumption may take place when housemates have different and conflicting personal comforts; when they have different ideas of balancing energy needs and costs; and when they have different perceptions of how to take care of the shared energy use. I also observed one type of conflict resulting in decreased energy consumption: violating another person's personal space (e.g., bedroom) to turn off heavy energy-consuming devices like space heaters.

The interviews also revealed four conflict management strategies that influenced the likelihood of resolving an issue. In most cases, the success of resolving an energy-related conflict depended on an effective discussion among housemates. Ignoring conflicts, staying silent, or refusing to accommodate other people's energy needs were less likely to resolve issues around energy use.

Based on the above findings, I suggest that motivation strategies could prevent energy-related conflicts by balancing personal comfort levels, concerns about energy cost, shared energy responsibilities, and public and private boundaries. I also propose that sustainability systems support conflict management by considering the following strategies: making personal adjustment options identifiable to reach a mutual understanding of shared energy responsibilities, and trading personal comforts and needs to support negotiations of energy use.

In the following chapter, I discuss a mobile application called EnergySense that is based on my proposed design strategies from Chapter 4 and Chapter 5 for supporting a conflict-free energy conservation environment. I also report the results of evaluating EnergySense with real users to see whether the suggested design proposals indeed motivate energy-saving activities without undesired conflicts.

CHAPTER 6

ENERGYSENSE: CREATING A CONFLICT-FREE ENERGY CONSERVATION ENVIRONMENT

As discussed in Chapter 2, effective motivation strategies to promote sustainability may lead to stress and tensions. In Chapter 4 and Chapter 5, I discussed social aspects of housemate energy consumption through the lens of tensions and conflicts and suggested three possible motivation strategies for avoiding conflicts: 1) helping housemates set the private and public boundaries of energy use, 2) making each housemate's energy adjustments identifiable, and 3) avoiding misinterpretations of shared energy responsibilities.

Based that work, I designed and evaluated a mobile application called EnergySense, which employs some of the suggested strategies to promote environmental sustainability without conflicts. In this chapter, I describe the features of EnergySense and examine whether EnergySense causes or reduces conflicts while motivating housemates to conserve energy. I conclude with a discussion of how the findings can inform the design strategies to create a conflict-free energy-saving experience.

EnergySense Design

I designed a mobile application called EnergySense that employs some of my suggested design strategies for motivating energy saving way also reducing the potential for conflicts. The application consists of two parts (see Figure 4): an iOS application with which users can interact and a wireless light switch that communicates with the iOS application and controls the light. Users do not directly interact with the wireless light switch.

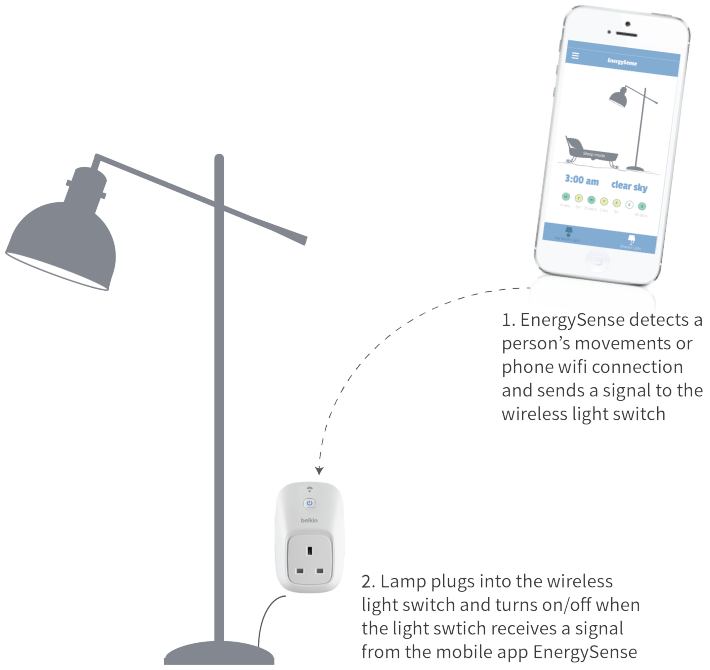

Figure 4. EnergySense overview.

Part I: EnergySense mobile application

The mobile application is designed to have the following two features: the bedroom light scenario and the shared light scenario.

The bedroom light scenario. My earlier studies showed that a blurring line of which space is considered personal and who can have access to the devices and appliances in that space often cause tensions among housemates. Some people thought housemates should not enter their bedroom to turn off devices, while others did not think it was a problem to turn off housemates' bedroom appliances when they forgot.

To address the above issue, EnergySense is designed to automatically control appliances in a personal space such as an individual bedroom. EnergySense can turn on and off a bedroom light based on an individual's sleeping status. When EnergySense knows a person is going to sleep, it turns off the bedroom light. When it senses a person is waking up in the dark, it turns on

the light. EnergySense will not turn on the bedroom light when a person is awake with plenty of natural sunlight in the bedroom, because there is no need for artificial light to illuminate the room.

Figure 5. EnergySense bedroom light interfaces: light off (left) and light on (right).

The lamp graphic represents the status of a bedroom light. If the bedroom light is off, the graphic stays grey with a white background (Figure 5, right). If the bedroom light is on, the graphic turns to orange (Figure 5, right). The sofa graphic, which is called "sleep mode", represents a person's sleeping status. If the person is awake, which means sleep mode is off, the graphic stays grey (Figure 5, left). If the person is asleep, the graphic turns to light green (Figure 5, left) to indicate the sleep mode is on and the person is asleep. A user needs to press the sleep mode button to indicate he or she is going to sleep, at which point EnergySense will switch off the bedroom light.

EnergySense detects a person's awake status based on his or her movements from the smartphone accelerometer and sound sensor. When the accelerometer values changes and the sound levels changes from low to high, EnergySense determines that the person is awake. Then,

the application will decide whether or not to turn on the bedroom light based on the time of a day and the current weather. It will turn on the bedroom light when it is dark outside, e.g., in the evening or a rainy day. But it will not trigger the bedroom light on when the person wakes up with plenty of sunlight, e.g., morning with a sunny sky.

In addition to automatic control over the bedroom light based on sleeping status, users can remotely switch the light on or off from EnergySense, even when they are not home. The purpose of this feature is to provide convenience to control to one's personal light, especially if has been left on by accident. For example, if an individual forgets the light when leaving the house, he or she can still switch it off remotely. To do so, users can tap on the lamp icon on the bedroom light scenario, to change the status of the actual bedroom light (Figure 5).

EnergySense also calculates and visualizes how long the light is kept on based on hours. On the interface of the bedroom light scenario, the green circles mean the light has been on for no more than an hour. The yellow circles means the light has been kept on for more than an hour. The white circles mean there is no time status for the light or no use of the light. The character inside each circle is the day of week (i.e., *M* is Monday, *T* is Tuesday, etc.). EnergySense also displays the current time and weather at the bottom.

I chose a sleeping scenario and control of a bedroom light as a test bed to evaluate the concept that a household sustainability application can avoid conflicts by setting personal and private boundaries. EnergySense's automatic control of a bedroom light is tied to an individual and can only be turned on and off based on the individual's sleeping status. His or her housemates do not have any control over the light. EnergySense also helps prevent an unattended bedroom light from being left on when not in use. Even when people forget, EnergySense automatically switches off the bedroom light after they go to sleep.

Shared light scenario. From the previous study on energy-related conflicts, I suggested that making energy adjustments identifiable and helping people better understand their housemates' energy needs could motivate energy conservation with fewer conflicts. To make energy adjustment identifiable, EnergySense allows each housemate to schedule the turn-off time of a shared light, such as one in the living room. Those schedules are made identifiable and visible to all housemates. Housemates can view each other's designated turn-off time for the shared light, to better understand each other's needs for using the light. For example, they can better understand how long others need to use a light in their communal space.

One common reason for household energy conflicts is that responsibilities for taking care of shared appliances and devices are ambiguous. From the energy conflicts study (Chapter 5), I found that people felt annoyed when their housemates left shared appliances such as the living room light on all evening. They believed they took good care of the shared space and assumed it was their housemates' responsibility to turn them off. They found it frustrating to see their housemates ignore their efforts spent turning off shared appliances and reducing electricity usage. To address this issue, EnergySense is designed to shoulder the burden of shared responsibility by automatically turning off a shared light. After housemates input their preferred turn-off times, EnergySense will turn off the light based on the latest time. For example, one housemate can schedule the turn-off time of a living room light as 12:00 AM midnight when she usually goes to sleep and another can set it to 1:00 AM when she usually comes home. In this case, the system will automatically turn off the light at 1:00 AM. The housemates no longer need to attend to the shared light or spend effort on turning it off; EnergySense will do it based on housemates' inputs and prevent it from staying on the entire day or night.

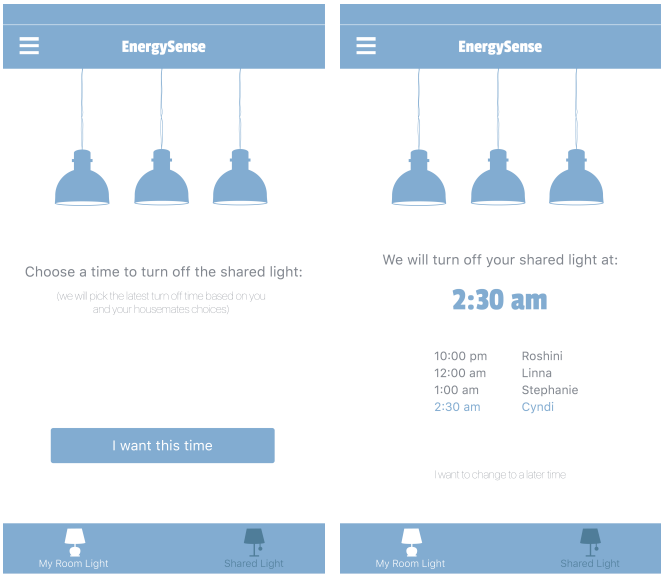

Figure 6. EnergySense shared light interfaces: the initial interface for new users (left) and the interface after housemates input their desired turn-off times (right).

Similar to the bedroom scenario, housemates have the freedom to remotely control the shared light. This can be particularly useful if the last person to leave the house forgets to turn off the shared light. If he or she later remembers, the light can be switched off remotely even if he or she is far from home. This feature also makes it easy for those who want to make sure the light is off when no one is using it. They can monitor the status of the light and press a button to turn off the shared light from EnergySense.

In the EnergySense application, the three-lamp graphic represents the status of a shared light. If the shared light is off, the graphic stays grey with a white background (Figure 6, left). If the light is on, the graphic turns to orange (Figure 6, right). The user can turn the light on or off by tapping the icon.

The left interface of Figure 6 shows the initial screen of the living-room light scenario. When a household member opens the living-room light screen and no one else in the house has set any particular time to turn off the light, EnergySense will ask the person to choose a time to turn off the living-room light. Figure 6 shows the screen when one or more household members

input their time choices. EnergySense automatically turns off the living-room light based on the latest selected time. The application displays every household member and his or her preferred turn-off time. Any household member can change the turn-off time to a later time by pressing the button “I want to change to a later time”.

I chose the control of a shared light based on housemates’ schedules to investigate how making energy adjustments and energy needs visible would impact housemates’ tensions. In particular, the shared light scenario is designed to see whether this strategy can reduce or prevent conflicts. EnergySense’s automatic control of the shared light is based on collective turn-off schedules. Everyone in the house can set a desired time to turn off the shared light. They can better understand how long the shared light is needed to be running based on the schedule. Since the system will automatically pick the latest time to turn it off, housemates do not need to worry about shared energy responsibility.

Part II: wireless light switch

The wireless light switch (Figure 4) controls the actual lights based on instructions sent from EnergySense mobile application. It is a separate artifact from the EnergySense mobile application. It receives signals from the mobile application via WiFi and controls the lights based on those signals. I chose Belkin Wemo switch to control the actual lights based on the safety specifications of Belkin (Product support, 2017) to ensure it is safe to install and configure in a household environment.

Technical specifications

The EnergySense mobile application was designed and developed based on the iOS 8 standards. I used Swift to build the application. It is compatible with the latest iOS 10.

Methods

To examine the design strategies suggested from the previous study on conflicts, I evaluated the smart application EnergySense with 19 housemates from seven households. The purpose of this evaluation was to investigate how the design of EnergySense influenced housemates' energy experiences and whether it could encourage energy conservation with fewer conflicts.

I recruited participants using Facebook groups, flyers posted in university buildings and on bulletin boards in local stores, and a university research and recruiting system. Qualified participants met the following criteria: First, they were living currently with at least one housemate in shared housing, e.g., an apartment, dorm, or house. Roommates who share the same bedroom are excluded for the purposes of establishing personal and public boundaries. Second, they participated in the study with the entire household, so I could investigate the use of both bedroom scenario and shared light scenario. Third, all housemates needed to be iPhone users and willing to install the application on their phones. Last, all housemates had an outlet in their individual bedrooms to control a personal light and an outlet in a common area to control a shared light, so that I could install the wireless light switches in both personal bedrooms and communal space.

Thirty-five users responded to the study recruitment. I selected seven households, for a total of 19 housemates, who met all of the above criteria. Each household consisted of at least two housemates living in a rental house or apartment, on-campus or off-campus, see detailed demographics information in Table 6.

During the study, I first visited participants at their house to install the EnergySense mobile application and configure the wireless light switches. Housemates each had a wireless

light switch installed in their bedrooms to control a lamp of their choosing, and the entire household had one installed in the living room. After the EnergySense mobile application and switches were installed, participants were asked to test whether they could remotely turn on or off the designated lights. I wanted to make sure everything worked and fixed any potential technical issues before they started to use the app.

Households	**Participants**	**House Type**	**Location**	**Student Status**
101	P1	Apartment	Downtown	Master student
	P2			Master student
102	P3	Apartment	Between campus and downtown	Undergraduate student
	P4			Undergraduate student
	P5			Undergraduate student
	P6			Undergraduate student
103	P7	Apartment	On-campus	Undergraduate student
	P8			Undergraduate student
104	P9	Apartment	Downtown	Master student
	P10			Master student
105	P11	Apartment	Downtown	Master student
	P12			Undergraduate student
106	P13	Apartment	Airport area	Master student
	P14			Master student
107	P15	Single House	Between campus and downtown	Undergraduate student
	P16			Undergraduate student
	P17			Undergraduate student
	P18			Undergraduate student
	P19			Undergraduate student

Table 6. Participants' demographics information.

Second, participants were asked to use EnergySense for three weeks. I encouraged them to contact us for any technical issues regarding EnergySense or the wireless light switch. After they used the app for three weeks, participants were interviewed (see Appendix E for the interview protocol) about their experiences when using EnergySense, particularly how the app influenced their personal and social experiences of energy use. Each interview lasted from 45 minutes to an hour with each housemate interviewed separately. I asked a set of general questions about how they interacted with the app, whether they discussed the app with their housemate, and what they thought about EnergySense more generally. I then asked a number of specific questions about their use of key design features (e.g., bedroom light scenario, shared light scenario), what features supported them to manage or save energy, and whether they encountered conflicts while using the app and how.

Last, after the interviews, I visited the participants at their house again to uninstall the wireless light switch and EnergySense mobile application.

All interviews were audio recorded, transcribed, and coded iteratively using the constant comparative method of qualitative analysis introduced by Glaser and Strauss (1967). I first coded five interviews based on the research questions. Then, I generated a consistent format to clean up the codes. Third, I used the new codes to recode first five interviews and the rest of interviews, added emerging codes when necessary. Last, I used affinity diagram to organize the codes into emerging themes, and used the themes to answer the research questions.

Findings

EnergySense was designed to support energy conservation and avoid potential energy-related conflicts. In this study, I intended to examine whether EnergySense created tensions of saving energy or reduced conflicts of collective energy management among housemates, and

how. First, I discuss general feedback from the users. Second, I describe housemates' experiences with the design features that are intended to eliminate conflicts (i.e., public and private boundary setting, making housemates' adjustments identifiable, and taking care of shared responsibilities). Third, I describe how EnergySense enhanced the social experiences of a household's energy-saving practices.

General feedback

In general, participants were excited about EnergySense. For example, one participant especially valued the remote feature of EnergySense her,

> *"I thought it was really cool, because I always wanted to control the light before I came back home."* (P2, female, housemate with P1 in House 101)

Another participant was excited to try EnergySense because she expected it would motivate her to change her behavior:

> *"I was really intrigued and excited to use it (EnergySense)…I was expecting the app to change my behavior, in a sense that I was going to use energy less. But I wasn't quite sure how it was going to make me use energy less. But I was very aware. Hopefully it was going to change me, so I was excited to use the app."* (P11, female, housemate with P12 in House 105)

According to the participants, the use of EnergySense was easy and intuitive,

> *"It's relatively useful and like pretty easy to use. Just press a button on your phone and it opens and turns on the light, So, pretty useful."* (P18, housemates with P15, P16, P17, and P19 in House 107)

"I thought the part where you clicked on the light, and it was turned on, turned orange, and it was supposed to turn on. That was very intuitive." (P5, female, housemate with P3, P4, and P5 in House 102)

Over the three weeks, using EnergySense to control both the bedroom light and the shared light became a daily routine for participants. They used it to switch off the lights before they went to sleep. Thus convenience was a key reason why participants adopted EnergySense.

Some participants (N=10) wanted to adjust their energy behavior to the use of EnergySense when they were first introduced to it. Using EnergySense to control lights was novel, thus they were willing to change their energy behavior. Furthermore, they said that EnergySense made them feel good about engaging in energy-saving activities. As one participant explained, the greater convenience and good feeling associated with using the app to turn off her personal light at night engaged her in doing this action.

"I used to turn on and off the lights by hand. Now, I have to pause, 'No, I'm not supposed to do that. I need to get my phone'. It just changed my habit. And just turning it (refers to the bedroom light) off at light as I go to sleep, that has become a pretty good habit. I really enjoy doing that. It has become a good habit." (P14, female, housemate with P13 in House 106)

Another participant mentioned that she got used to checking EnergySense on her phone and used it to turn off the bedroom light when necessary.

"I would get up grab the phone, and I'd probably usually check emails first. And then go to the app and turn the light off." (P7, female, housemate with P8 in House 103)

Similarly, participants used EnergySense to engage in energy-saving activities in the shared space. For example, several participants mentioned they used EnergySense to turn off the shared light when leaving the house.

> *"I got used to it. It became like a habit to leave, open it (refers to EnergySense), and then just turn it (refers to the shared light) off." (P3, female, housemate with P4, P5, and P6 in House 102)*

> *"I kind of got into a habit of using my phone to turn off my house light (refers to the shared light) when I left." (P15, male, housemate with P16, P17, P18, and P19 in House 107)*

In sum, participants liked the experience of using EnergySense and welcomed EnergySense in their life. But why did they enjoy it? I explore this question in the next sections by first discussing housemates' experiences associated with each of the features designed to avoid conflicts and then describing how it enhanced their social experiences.

Conflict-free energy conservation

I asked participants whether any conflicts had arisen during their use of EnergySense. Surprisingly, none reported any energy-related conflicts. Instead, they described enjoyable experiences associated with the design features that were intended to eliminate conflicts.

Setting private boundaries by giving personal control to a bedroom light. First, all participants mentioned that they liked having personal control over their individual bedroom lights. They found it convenient to control the energy use in their personal space independent of their housemates. Over the course of the three week study, I found that all participants (N=19) adapted to the bedroom light feature of EnergySense. They liked being able to press a button to

control their personal light rather than switching it on or off manually, particularly at bedtime. For example, one participant mentioned that she intentionally left the bedroom light on at night *before* using EnergySense. But *with* the application, she now turned off her personal light before bed.

> *"I was telling her that the best feature of the app is now I can switch on and off the (bedroom) light without having to move, which is great for me. It's a laziness thing."* (P9, female, housemate with P10 in House 104)

EnergySense engaged participants in turning off the bedroom light, because 1) it was easy to do,

> *"Every night in my room before I go to bed for sure. Always. Because that's the one light I can control without getting out of bed."* (P13, male, housemate with P14 in House 106)

and 2) it saved them the effort of getting up from the bed to physically turn off the light.

> *"It's probably one of my favorite. It's when I'm about to go to sleep and I forgot to turn my light off. I don't have to walk up for it and turn it off. I could just like press the button. That's really convenient. That's probably when I use it the most."* (P17, male, housemate with P15, P16, P18, and P19 in House 107)

A second reason that participants liked having personal control of their bedroom lights is that they could attend to those lights without interrupting their current activities. For example, one participant used EnergySense to turn off the bedroom light while he was working in the communal space.

"P7 and I just worked here (refers to the living room), and we noticed the lights being on in our bedroom. We just opened the app and turned the lights off, and continued to work without disrupting our concentrations." (P8, male, housemate with P7 in House 103)

Another mentioned that he could continue to hang out with his friends without going into his bedroom to manually turning the light off.

"I was already downstairs, hanging out with my friends. I just wiped at my phone and turned that light off, instead of getting out from downstairs and walking up the stairs, turning off my light and then walking back down the stairs." (P15, male, housemate with P16, P17, P18, and P19 in House 107)

A third reason participants like having EnergySense to control their personal lights was that they could turn them off remotely if they left them on by accident. All participants (N=19) described one or more instances in which they forgot to turn off their bedroom light. EnergySense provided them a chance to switch it off when they remembered. For example.

"A lot of times I'm outside the door by the house and I remember to turn off my (bedroom) light." (P16, male, housemate with P15, P17, P18, and P19 in Housemate 107)

"Before when I was leaving, if I forgot to turn off something, I wouldn't have to come back to turn it off again. And now, I would just have to click it (refers to EnergySense)." (P4, female, housemate with P3, P5, and P6 in House 102)

Participants also mentioned that they could turn off their bedroom light remotely when they had more time.

"I was too much in a rush to turn off the lights myself, like actually walk up and turn it off, then I just did it when I was outside." (P16, male, housemate with P15, P17, P18, and P19 in Housemate 107)

In sum, participants liked how easy it was to control their personal light using EnergySense and many mentioned that it provided an opportunity for them to reduce undesirable energy usage.

Making energy adjustments identifiable. A key feature of EnergySense is that it allows housemates to set their own turn-off times for a shared light and then view one another's settings. This feature was intended to support mutual understanding of shared energy use; however, more than half of the participants (N=10) mentioned that they wanted to match their housemates' turn-off times. For example, one participant mentioned she altered her time to match her housemates' schedules,

"*Originally, I set it at 3 am because that is the latest I would ever be working. But I actually changed it to 12 am…Because I figured, everyone else was 12 or something. And I didn't want to be the only one*." (P4, female, housemate with P3, P5, and P6 in House 102)

Dealing with ambiguous shared energy responsibilities. In my energy conflicts study (Chapter 5), I found that these conflicts were often associated with people's responsibilities with respect to shared spaces. Some people were frustrated when they had to turn off a shared light, especially when housemates ignored their efforts. EnergySense was designed to avoid this type of conflict by introducing shared remote control.

From the user study, I found out that participants paid attention to the energy-saving activities in the shared space. All participants (N=19) regulated the shared light with EnergySense. They often used the app to check their living room light status and they did not report any frustration with EnergySense to take care of the living light when necessary. One participant mentioned that he would check the light's status even when he was traveling and turn it off when it was necessary.

> *"On the weekend when I am travelling in New York City, I check (EnergySense) to make sure the house light turned off."* (P15, male, housemate with P16, P17, P18, and P19 in House 107)

In addition to remote and collective control of the living room light, some participants (N=4) also mentioned positive experiences with the automatic function to turn off the shared light. For example, one participant mentioned that the auto function turned off the shared light when she left it by accident,

> *"Usually I would turn it off using the app before I leave the room. But last night I did not. It helps me catch my mistake when I forget to turn the light off."* (P14, female, housemate with P13 in House 106)

Although the automatic function was primarily designed to address ambiguity with respect to responsibilities for shared energy use, many times participants turned off the shared light using the remote control before the application did so automatically. It seems that they did not mind taking action to turn off the shared light as long as it was simple enough to do so. This suggests that a simple remote control for shared appliances can successfully engage housemates in energy conservation without causing conflicts.

I also found other unexpected influences on people's energy experiences - EnergySense enhanced the social experiences of energy conservation among housemates.

Fun and enjoyable energy experiences

The study suggests that EnergySense make housemates' energy experiences enjoyable and fun, particularly in the shared light scenario. I observed two interesting influences of EnergySense on people's social experiences of energy use. First, it strengthened the bonding of housemates. Second, participants found it exciting to introduce EnergySense to their friends.

Bonding housemates. The study suggests that EnergySense develops the interpersonal relationship of housemates, that housemates spend more time together by interacting with the shared light feature. Some housemates (N=6) liked to made decisions about the shared light and use the shared light function together, as a collective experience. As one participant mentioned, they often turned on and off the shared light when he was together with his housemates.

> *"When we used it, usually we were together. It would be like, 'oh, turn on the light' or me going from here (refers to the dining room) to there (refers to the living room) to turn on the light. Or when we were done with light, we would click on the light (to turn it off)."*
> (P8, male, housemate with P7 in House 103)

Playful. Some participants (N=6) considered it playful to use EnergySense with their housemates. The fun experience engages housemates in energy-saving activities. For example, one participant mentioned that she and her housemates competed to be the first person to turn off the shared light. Before EnergySense, they would keep the shared light on even no one was using it. With EnergySense, they all wanted to be the person who turned it off.

"We wanted to turn it off. We always wanted to be the person who turned it (refers to the shared light) off, after we finished doing something in the shared area… Sometimes, we feel lazy to turn it off. We feel lazy to be the person to turn it off. But with this app, we want to the person who turns it off." (P2, female, housemate with P1 in House 101)

In addition, some participants found it fun to trick their housemates by remotely turning on and off the shared light.

"But it was kind of fun, tricking people." (P4, female, housemate with P3, P5, and P6 in House 102)

"P11 was sitting out here (refers to the living room), watching TV. I turned the light on. P11 said 'Oh, my God'. Just stuff like that. We were fooling around. You don't really expect things to turn on. That was kind of funny." (P12, female, housemate with 11 in House 104)

Conversations on EnergySense. To other housemates (N=13), EnergySense brought them together, engaging them in conversation about the application and related energy experiences.

"It definitely strengthens the relationship, because we talked about the app and we both use it especially a shared area. We had discussions of when you have the (living room) light on or off, and both are responsible in the same way." (P13, female, housemate with P14 in House 106)

These participants liked to talk about the performance of EnergySense and how it affected their energy experiences. For example, one participant told his housemate how EnergySense positively influenced his daily life:

> *"'Oh, if I want to get something in the room', and I would like turn on the light and go in. I waited for the light to come on and so. You can ready your room before going in. It's nice that you don't have to walk into a dark room to find the light. So these are the kind of things we have been talking about."* (P8, housemate with P7 in House 103)

Sometimes, they exchanged ideas on how to use EnergySense and urged each other to try specific features.

> *"We talked about how it was working. You know, you try this, how does it work, and things like that."* (P9, female, housemate with 10 in House 104)

> *"We discussed it a couple of times. In general, it's mainly about the shared light… like when to turn it on and when to turn it off."* (P5, female, housemate with P3, P4, and P6 in House 102)

From the study, I found out that shared feature like collective control over an appliance engaged housemates in energy-saving activities. This suggests that features such as collective control over shared household appliances can help promote household energy conservation and increase bonds between household members.

Excited to introduce EnergySense to friends. A number of participants (N=15) also mentioned that they enjoyed introducing EnergySense to their friends and demonstrating how it worked.

"We liked to show people when they came over." (P3, female, housemate with P4, P5, and P6 in House 102)

"I cooked for four people one night and they were all here. And we were talking about the app and P14 said he could turn this (refers to the dining room light) off anytime without touching. We had friends over and it was pretty awesome introducing them what we were using." (P13, female, housemate with P14 in House 106)

Participants also mentioned that their friends were sometimes curious about the application, particularly the ability to control the lights remotely. For example, one participant mentioned that her friends were surprised about how easily she could remotely switch the light on and off.

"The girls were asking what I was doing, because they were really surprised (that I could turn on and off the living room light so easily). I think they just found it fun." (P11, female, housemate with P12 in House 105)

Although the participants did not mention why they enjoyed introducing EnergySense to their friends, it seems likely the participants were excited about the functions of the application and wanted to share their excitement.

Discussion

My evaluation of EnergySense suggests that the app makes energy conservation convenient, enjoyable, and social. Participants liked being able to control their bedroom lights remotely. When housemates shared control of a communal light using EnergySense, no conflicts were reported. Instead, EnergySense strengthened housemates' relationships.

To better engage housemates in energy-saving activities, I propose first to use simple and convenient strategies such as remote controls for household appliances, since people are willing

to take energy-saving actions when they are convenient. Second, I recommend that designers of systems to promote sustainability provide ways for people to take actions after the fact, for instance if they forget to turn off the light. This functionality can both reduce energy use and help avoid the kinds of household tensions reported in Chapter 5. Third, I suggest it can be more successful to shift the focus of sustainability apps away from comparing energy-saving outcomes to creating a meaning social experience around energy saving. For example, giving housemates equal and convenient control over shared household appliances may increase interpersonal bonds and engage them in saving energy at the same time.

CHAPTER 7

GENERAL DISCUSSION: DESIGN OPPORTUNITIES FOR TOOLS TO SUPPORT SUSTAINBILITY

This dissertation aims to understand personal and social experiences of household energy use and to explore design opportunities for tools to support sustainability. It includes a body of work examining housemates' energy choices and understanding their personal and shared energy practices as well as the design and evaluation of two interactive applications, EnergyHome and EnergySense, to encourage housemate energy conservation. My research suggests that housemates' energy consumption and conservation are deeply rooted in their social dynamics. It also elucidates housemates' standards for, and assessments of, energy-saving activities. Furthermore, it uncovers some of the causes of energy-related household conflicts.

Based on the key findings from the previous chapters, I suggest the following strategies for designing systems to support household sustainability: *considering social dynamics*, *establishing quality energy conservation*, *considering conflicts,* and *focusing on energy-saving experience*. I explain each of these recommendations in the following sections.

Considering Social Dynamics in Design

As discussed in Chapter 3, personal and social experiences of energy conservation are influenced by the social dynamics between housemates. For example, housemates with leader-follower or collaborator-collaborator dynamics like to save energy as a group, while conflict avoiders or independent contributors prefer to work alone. I argue that to be most effective, systems should be tailored to a household's social dynamics. One way to achieve this tailoring is

to first *observe and identify social dynamics* of people when they interact with the system, and then *adjust design features based on identified social dynamics*.

Observe and identify social dynamics

Chapter 3 suggests that people's engagements in energy-saving activities vary based on their interpersonal dynamics with others. Even though collaborations are often an effective strategy for motivating households to conserve energy, they may not always be the best choice. For example, it is unlikely that conflict avoiders or independent contributors would engage in energy-saving activities if a system only provided collaborative features. Thus, I suggest that tools to support energy conservation will need to observe, recognize, and learn users' social dynamics.

However, it can be tricky to identify types of social dynamics when a system is first introduced to users. Therefore, I propose 1) implementing both individual features (e.g., personal challenges) and social features (e.g., group challenges) in a system, and 2) having the system recognize users' patterns of activity using these features. For instance, a system could keep track of users' activities by learning from the system logs.

For example, with EnergyHome from Chapter 3, complementary dynamics might be inferred from behavior with the group challenges feature. If a user repeatedly creates group challenges, it may indicate they are potential leaders, because leaders like to take initiative in creating challenges. Correspondingly, other users could be deemed followers. If the follower regularly participated in group challenges, they could be considered cooperative; if they were initially active, but became less active overtime, they might be considered reluctant.

Adopt and change design features based on identified social dynamics

Unchanged motivation strategies can eventually demotivate users from saving energy (Purpura et al., 2011; Håkansson & Sengers, 2013). Similarly, people with different personalities react to different motivation strategies (Petkov et al., 2011). Beyond energy usage patterns and personalities, I suggest to personalize system features to individual users based on social dynamics after the system learns and determines social dynamics, e.g., encourage collaborations for leaders and followers or limit collaborations for those in symmetrical dynamics.

When a system identifies a leader-follower or a leader-reluctant follower dynamic, it could keep or motivate leaders and followers in collaborations, but separate reluctant followers if they are in a group with leaders. Instead, the system might encourage reluctant followers to participate in individual features, e.g., sending a system invite to work on an energy-saving action. In addition, the system could provide additional features for leaders, e.g., customize reminders to listeners, while simultaneously limiting or simplifying these features for followers, e.g., suggest other users' energy actions instead of asking them to create one.

When collaborator-collaborator dynamics are recognized, a system could keep collaborators in the group and add more social features to make collaboration fun and engaging. For example, it might notify a collaborator when it is his or her turn to set up a challenge. It could also provide peer-support features such as sending reminders to others.

When a system detects most of a person's activity is in individual challenges, this may mean the user is an independent contributor or conflict avoider. The collaboration features, such as group challenges, could be deemphasized and even replaced with individual features, such as keeping track of individual daily actions.

In sum, I argue that motivating domestic energy conservation can be more successful when applying appropriate design strategies based on types of social dynamics. Social dynamics of system users can be translated into their interaction patterns with design features. It would be valuable to have a system that could observe, learn, and identify the social dynamics of people based on their usage patterns and then adjust its design features to encourage or support energy conservation.

Establishing Quality Energy Conservation

As discussed in Chapter 4, people often take simple daily actions like turning lights off or unplugging appliances to reduce utility cost. This narrow focus on daily repeated actions suggests that people are not aware of other efficient ways to save energy.

From quantity to quality

Schwartz et al. (2013) found that households were able to learn and adjust their energy-consuming activities from an eco-feedback system. Similarly, as suggested in Chapter 4, broadening people's knowledge by presenting alternative energy-saving activities might lead to greater energy savings. Thus, I propose motivation strategies shift focus from encouraging frequency of taking actions (regardless of their actual energy savings) to promoting a deeper understanding of how much energy a particular action might save. Tools to promote sustainability could highlight more efficient energy-saving actions, e.g., setting the thermostat to 68F in winter rather than 70F. As a result, people might learn and adjust their energy saving strategies based on system suggestions.

In sum, enhancing people's knowledge of the relationships between actions and energy savings is one way to encourage them to be more sustainable. I argue that highlighting efficient saving strategies can further facilitate energy conservation.

Create meaningful interactions around energy conservation

As I showed in Chapter 4, individuals have standards for evaluating what activities they, and their housemates, should be doing to reduce energy use. I also found that people had different views about the best practices for reducing household utilities. When households failed to reach a mutual understanding about sustainability, they sometimes failed to conserve energy. Thus, I suggest that systems aim to build a mutual understanding of energy conservation within the household by acknowledging individual involvement (or lack thereof) in daily actions.

Learning each other's expectations. First, I propose sustainability systems support housemates' sharing of their views about sustainability. For example, each housemate might express what he or she thinks are the best ways to reduce utility costs. Similarly, systems should allow housemates to share their views about what actions they consider wasteful. By sharing their definitions of sustainable and wasteful actions, housemates can learn and understand what others expect.

Making daily repeated actions obvious. Sharing sustainable criteria may not be enough for building mutual understanding, however, because housemates might understand each other's expectations but not be aware of each other's energy saving activities (e.g., they not see their housemates turn the lights off). I thus suggest making daily repeated actions visible to all household members. For example, the system could report a housemate's daily repeated actions to another, such as 'Hi Danielle! Olivia just switched off the kitchen light'. In return, the system can also collect Danielle's response to Olivia's action and report back to Olivia (e.g., 'Thanks, Olivia. You are awesome!').

Systems to promote sustainability could also keep track and present housemates' other "invisible" but impactful energy-saving activities. For example, the system might track a

housemate's online purchase activity and report it to other housemates, e.g., 'You know, Dan did not purchase online this month. He made your household greener'. In this way, the technology not only broadens people's understanding of energy-saving practices by showing alternatives, but it also makes others' actions visible: housemates can learn from Dan's energy-saving action and at the same time it can inform their interpretations of Dan's energy activities.

In sum, I suggest that system design focus on creating meaningful interaction around energy conservation among household members. This strategy may bring more success in energy conservation by helping housemates to reach mutual understanding of energy practices.

Considering Conflicts in Design

As discussed in Chapter 5, unbalanced personal comforts, ambiguous shared energy responsibilities, and violation of personal space are common causes of conflict. I recommend that designers of sustainability technology consider ways to avoid conflicts.

Preventing energy-related conflicts

One way that sustainability tools might prevent energy-related conflicts is by dealing with the common causes to conflicts, e.g., housemates' personal comforts and ambiguous shared energy responsibilities.

Expressing "fatigue" based on energy consumption. I propose that sustainability tools include a way to express "fatigue" or the depletion of resources, to engage people in energy conservation. An appliance, device, light, faucet, or other source of energy might demonstrate weariness when it has been turned on for an extensive of time.

Consider, for example, the thermostat battles discussed in Chapter 5. Housemates frequently reported engaging in these battles; however, continuously adjusting a thermostat can lead to increased energy use. Suppose a smart thermostat expressed "*I'm tired of being adjusted*

multiple times", and gave suggestions to housemates for reducing energy use, such as, "*I can adjust myself to maximize your comfort and energy cost*". Likewise, a shower system might say "*I'm tired now. Would you mind finishing soon?*" when a person occupies the shower for an extended length of time. Expressions of metaphorical fatigue of this sort may help shift housemates' focus from their personal comfort to the "fatigue" of a smart system. It could also convey others' needs and comfort levels in an interesting way, potentially motivating housemates to reflect on how they might balance their personal comfort levels with those of others.

Furthermore, expressing "fatigue" may help reduce conflicts due to shared responsibilities. For example, a smart light might say "*I've been on all night... Would you turn me off?*" when a housemate is passing by, to motivate the person to turn it off. In this way, turning the light off might be seen as helping the system rather than making up for another housemate's forgetfulness. Plus, this expression could also encourage someone who generally forgets to turn off the lights to do so, thus reducing the burden on other housemates.

Establishing the concept of boundaries. Another common type of household energy conflict stems from violations of private boundaries, e.g., turning off a housemate's personal device (Chapter 5). To prevent these sorts of conflicts, I recommend that tools for promoting energy conservation provide a means for housemates to establish personal boundaries and automatically regulate energy use within these boundaries. For example, a smart system can suggest a list of spaces and ask housemates to specify who can alter devices or appliances in those spaces. A smart system might only allow individuals to control their bedroom appliances, but give everyone access to the control of shared appliances. If an area is marked as private

space, the system would help regulate the energy use when no one is there, for example by turning off a personal space heater when it is not in use.

By focusing on establishing a common understanding of private and public boundaries among household members, as well as by providing automatic energy regulation in private spaces as an alternative to boundary violation, systems may be able to promote household energy conservation with fewer conflicts.

Supporting conflict management

Second, I suggest sustainability systems can benefit from including support for conflict management. The intention is not to create technology that can directly solve energy conflicts but rather to support successful conflict resolution strategies. Two ways this might be done are by *making energy adjustment identifiable* and by *trading in energy needs*.

Making energy adjustment identifiable. A system might track and display each household member's energy activities. For example, it could display which housemate turned on or off a shared light, or who turned up or down the heat. This may affect household energy use in two ways. First, making the last person who *turns on* a shared device identifiable might lead him/her to take personal responsibility for turning the device off. Second, identifying the person who *turns off* a shared device might facilitate a better understanding of the way energy-related responsibilities are shared among housemates. For people who are willing to work on resolving energy conflicts with housemates, tracking and displaying each member's energy adjustments provide a basis for understanding why the conflict occurred.

Collaboration isn't always the key: trading in energy needs. As discussed in Chapter 5, housemates have different expectations with respect to personal comfort, cost, and energy needs. One common conflict takes place when one housemate consumes energy based on personal

needs while others consider it a waste of energy. To balance conflicts due to comfort and need, I suggest that sustainability technology can support trading one energy activity for another. Imaging the following scenario: Sarah considers turning lights off important for lowering energy costs while her housemate Veronica feels safer having the lights on. A persuasive system might encourage Sarah to trade her long shower for Veronica's running lights in order to balance their comfort and understanding of energy conservation.

Another example of trading would be a smart system that encourages housemates to develop a rule for taking care of shared energy use, like who should take care of living room lights. For example, if Jackie always turns off shared lights in the living room and kitchen, while Ashley sometimes forgets, Jackie may feel like she always needs to take care of Ashley's tasks and become upset that Ashley is not doing her fair share of the work. If a smart system could suggest that Jackie and Ashley come up with a plan to take care of shared energy use, and then consistently remind Ashley to take care of her assigned actions, friction may be avoided.

Focusing on Energy-Saving Experiences

In the past decade, much emphasis has been placed on the outcomes of energy conservation, e.g., how much energy has been reduced, how frequently people engage in energy-saving activities, whether people change their behavior. Motivation strategies are primarily designed to encourage people to reduce their energy consumption, and typically draws people's attention to energy-saving outcomes. One common strategy is to show aggregated energy consumption data at the individual level (Froehlich et al., 2012) or the appliance level (Broms et al., 2010; Froehlich et al., 2012), which focuses on evaluating people's performance based on whether energy use has been reduced or how much has been reduced.

As discussed earlier, solely focusing on energy-saving outcomes, like how much has been saved, may cause tensions among people (Froehlich et al., 2012). In contrast, crafting a convenient and playful energy-saving experience might engage people in energy conservation without conflicts. As demonstrated in the EnergySense study (Chapter 6), housemates are willing to adopt new sustainable energy practices when the energy-saving experience is convenient and enjoyable. This suggests design strategies should focus on energy-saving processes in addition to outcomes.

The findings of Chapter 6 suggest that people are more committed to energy-saving activities when they enjoy the process. Housemates enjoyed the process of controlling the shared light remotely. Besides having meaningful conservations, housemates competed to be the one who turned off the shared light. Instead of problem-solving approach, such as drawing people's attention to the amount of energy consumption, a system should focus on creating and constructing a plausible experience of saving energy. But how? This research suggests the following three ways: *creating a playful experience*, *making energy-saving easy and convenient*, and *providing repairing options*.

Creating a playful energy-saving experience

Chapter 6 suggests that fun and playful energy-saving experiences can bond people together. For example, housemates competed to be the first to turn off the living room light. They enjoyed sharing control over the light. The collective experience of controlling the shared light triggered meaningful conversations about energy conservation. This suggests we might better motivate sustainability by creating playful experiences with collective or collaborative features. For example, a system might make a strange sound when the setting of a shared appliance has been overridden. This sound might make energy adjustment identifiable to others,

help people understand each other's energy needs, and bring people together to discuss energy issues.

Providing convenient ways to save energy

When people can easily control their devices and appliances, they tend to be more committed to energy-saving activities (Chapter 6). With EnergySense (Chapter 6), for example, people recalled leaving their personal light on intentionally, to avoid the trouble of walking up to the physical light switch. While they were using EnergySense, they preferred to turn it off when not in use because it was easy to do so. Thus, a simple feature like as a remote control can engage individual housemates in energy-saving activities and increase their desire to adopt energy-saving actions.

Providing repair options

Sometimes people forget about energy use when they have other priorities (Chapter 6). It is likely that people would leave lights on when they are running an errand or in a rush leaving home. In those cases, it is difficult for them to turn off the lights because they are already away from home. In the EnergySense study, housemates were excited about remotely controlling the lights when they were not at home. This is particularly useful when people forget about their personal lights, because failure to turn off lights could cause tensions and conflicts of housemates. This suggests that it is necessary to provide chances to housemates to fix unnecessary energy use, e.g., remote controls for personal appliances.

CHAPTER 8

CONCLUSION AND FUTURE DIRECTIONS

This dissertation investigates housemates' personal and social experiences of energy consumption and conservation and explores design opportunities for motivating energy conservation. Based on a careful review of successful motivation strategies for families, I first designed and evaluated a mobile application called EnergyHome (Chapter 3) that was intended to help unrelated housemates save energy. My evaluation of EnergyHome revealed that housemates' participation in energy-saving activities is deeply rooted in their household dynamics. For example, housemates with leader-follower dynamics prefer to work in groups to save energy, while conflict avoiders choose to work independently.

To further understand the social aspects of housemate energy use, I examined people's evaluations of housemates' energy behaviors (Chapter 4). I found that housemates considered engagement in simple daily actions, such as turning off lights, to be a key factor in reducing energy cost, a sign of commitment to energy conservation, and an important criterion for evaluating their housemates' energy behaviors. Because of this narrow focus on simple daily actions, housemates tended to believe that they were more sustainable than others, neglect alternative ways to save energy, and misjudge others' energy behavior.

Chapter 5 investigated housemates' energy experiences through the lens of conflicts. I identified four key factors that led to conflicts (conflicting personal comforts, concerns about energy use and cost, private vs. public boundaries, and vague shared energy responsibilities) and four strategies households used to manage these conflicts (ignoring them, staying silent, refusing to change, and collaborating on solving the problem).

In Chapter 6, I presented the EnergySense mobile application, which employed many of the proposed design strategies from Chapter 4 and Chapter 5. My field evaluation of Energy sense showed that it successfully created a fun and enjoyable energy-saving experience for housemates, strengthening their relationship, without creating conflicts.

Based on the findings of all my studies, I lay out a set of design recommendations in Chapter 7. First, I recommend considering social dynamics in system design and creating systems that can observe, learn, and adapt to the ways a household uses a sustainability tool. Second, I argue that sustainability systems include ways of showing users information about the quality of specific energy-saving actions, thereby promoting a mutual understanding of energy use among members of a household. Third, I suggest taking conflicts into consideration, for example by setting private and public boundaries or allowing housemates to trade energy needs. Finally, I suggest that sustainability tools focus on crafting an enjoyable energy-saving experience by making it playful, convenient, and easy to repair human mistakes (e.g., forget to turn off lights).

There are several limitations of this work, which point to areas for future research. First, I tested my research questions and applications with a narrow subset of potential users. EnergyHome (Chapter 3) and EnergySense (Chapter 6) were built as iOS applications and my evaluations of these apps only recruited current iPhone users. In addition, most of my participants were college students; it is unclear whether household dynamics and conflicts would be in other types of households, especially housemates who work and pay for their living expenses. Furthermore, the study participants were all self-selected and likely to be interested in the research topic or use of technology; it is unclear how people who are less interested in these

topics would engage with the tools. Thus, future research is needed to explore the concepts from my work in a more technologically and demographically diverse population.

Second, most of my studies have used qualitative research method with relatively small groups of users, such as interviews with 50 participants (Chapter 5). Whether the findings and design strategies could be generalized to a larger population is unclear. Some quantitative studies such as larger scale surveys would be useful to triangulate my findings.

Third, some of my proposed design strategies have not yet been evaluated with real users. More designs and evaluations are needed to understand the influence of these proposed design strategies on energy conservation and people's experiences. Another opportunity for future work is to evaluate my proposed design strategies of this dissertation in other types of households or groups of people, such as families and activity groups, to gain a better understanding of how social aspects of energy use influence people's preferences and choices of energy conservation.

In sum, this dissertation has argued that housemate dynamics, people's assessments of each other's energy behaviors, and undesired conflicts deeply influence the user experience of energy consumption and people's participations in energy-saving activities. With tool designs and evaluations, this dissertation has further demonstrated that sustainability tools can benefit from considering household social dynamics and conflicts, and by crafting a quality and enjoyable energy-saving experience.

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APPENDIX A

ENERGYHOME INTERVIEW PROTOCOL

Thank you for participating in our study. We appreciate your time and efforts. Our research attempts to explore and to understand the role of mobile designs in household energy conservation. In particular, we try to evaluate a mobile application design and we try to understand how you think about the mobile design in the following aspects: 1) whether or not such mobile design motivates you to save energy; 2) whether or not such mobile design make you aware of energy conservation; and 3) your experience of interacting with the mobile application.

The reason why you are here is because you've responded in the survey that you are willing to participate in this follow-up interview. The goal of this interview is to help us better understand your experience of the app and possible influences of app. And we really want to hear your thinking and thoughts on those things that helps us to understand the experience of using our design. It will take you 30 minutes or less.

We want to audio record this interview. You indicated in the informed consent that you are / are not willing to be audio recorded.

(If the participate is willing to be audio recorded) We will audio record the interview. All the audio files are for research analysis only and all the files are kept confidentially in our principle investigator's computer. No third party could get access to the data except our research group. We won't put your name, email, or any other personal information in any publication. But we will use your quotes, I mean your words and sentences from the interview as an evidence to support our research findings in the publications. If you are uncomfortable with the record, we will not use it. However, although every reasonable effort has been taken, confidentiality during the actual Internet communication procedures cannot be guaranteed.

(If the participate is not willing to be audio recorded) We are not going to audio record since you indicated in the informed consent.

We also want to let you know that you can leave the interview at any time if you want to.

General feedback

In general, how often do you use the mobile app in a given day? And how long do you usually stay on the app in a given day?

(Note: this question is used to get the participant to think about the application)

How do you think the app in general? Anything you like or dislike?

Are you interested in installing such app in your phone?

Are you interested in continuing to use this app?

Have you ever discussed the mobile site with your roommates? What did you talk about?

Do you find yourself more conscious about using energy at home this week? Why?

Are you motivated to save energy at home, e.g., use less electricity, after playing with the mobile app?

What did you do to save energy?
What caused that change?
Which features(s) or functions of the app do you find motivating for saving energy?

Scenario: imagining that today is a just a typical day in your life, can you show me how you use the application? Walk me through the process and think aloud.

(Note: Part 1 and Part 2 are probe questions, ask when it is appropriate)

Part 1: Challenges
[Design features]
How do you think about challenges in the app? Do you like this feature?

> How do you think about creating a challenge? What go through your mind when you are creating a challenge?
> How do you think about sending a challenge to your roommate(s)?
> After challenging your roommate(s), what did you think you roommates would do?
> After challenging your roommate(s), do you care about their responses?
> Is the challenge easy for you to complete?

How do you think about the family challenge feature?

> How do you think about creating a family challenge?
> What do you think about assigning responsibility to each roommate?
> Is family challenge easy to do?

Have you ever challenged by someone else in the app?

> When you were challenged by someone else, what did you do?
> How do you feel about being challenged?

What did you feel when you completed a challenge?

> Did you ever think about or click the “complete” button when you haven’t finished the challenge?
> Did you ever do that?

Anything confusing in the app, the UI, the navigation, or wording?

[Comparison]
Which one do you think is more interesting, seeing how well you are doing or seeing how well you and your roommate are doing? Why?

Which one do you think you would value more, your individual accomplishment or family challenge accomplishment? (In this app, think about completing challenges as an accomplishment.)

Which one is more interesting to you, individual challenge or family challenge?

[Influences]
Which one is more motivating to you, challenging yourself or challenging your roommates? Or neither of them.

Which one makes you more aware of energy consumption, working on individual challenges or working on family challenges with your roommates?

Part 2: Reminders
How do you think about the feature of helping others to set reminder? Do you think it makes sense?

> Has someone helped to set a reminder for you?
> If so, how did you feel? Do you like it?

If you were the designer, how would you do to help others to stay on and finish an energy-conserving challenge?

Does “setting a reminder for others” make you more aware of the energy consumption at home? Do you think you will be more conscious about using energy?

Anything confusing in the app, the UI, the navigation, or wording?

Wrap-up
Do you find it useful (or effective) to save energy by using this application?

> If yes, can you give an example?
> If no, how can we improve it?

Do you have any other thing you want to tell me?

APPENDIX B

ENERGY BEHAVIOR SURVEY

Roommates and Energy

Default Question Block

Thank you for participating in our study. We appreciate your time and efforts. Our research attempts to explore and to understand your perspectives, attitudes and behaviors of energy consumption at home. Also, we want to understand how you think your roommate(s) consume energy.

This survey is part of our study. The goal of this survey is to help us better understand your current thoughts, attitudes, and belief of energy conservation, as well as your roommate(s)'. It will take you approximately 30 minutes to complete.

All the survey data are for research analysis only and all the files are kept confidentially in our principle investigator's computer. No third party could get access to the data except our research group. We won't put your name, email, or any other personal information in any publication. However, although every reasonable effort has been taken, confidentiality during the actual Internet communication procedures cannot be guaranteed.

Before starting the survey, please take a look at the statement of informed consent. It sets your rights as a person who is participating this study.

Informed Consent

You are invited to take part in a user research study of **perspectives, attitudes, daily behaviors of household energy consumption**. We are asking you to take part because you answered one of the recruitment methods we utilized to recruit participants for this study. Please read this form carefully and ask any questions you may have before agreeing to take part in the study.

What the study is about: The purpose of this study is to learn about your attitudes, feelings, and behaviors of household energy consumption in the following aspects: first, we want to know your attitudes and perspectives towards home energy use when you are sharing with roommates; and second, we want to know how you evaluate your roommate's energy behaviors.

You must be 18 years old or over and speak fluent English to participate.

What we will ask you to do: If you agree to be in this study, you will be asked to participate in **a 30-minute online survey.**

Risks and benefits: We do not anticipate any risks to you participating in this study other than those encountered in day-to-day life. Although every reasonable effort has been taken, confidentiality during the actual Internet communication procedures cannot be guaranteed. Also, data may exist on backups or server logs beyond the time frame of the research study.

Incentives: 1 course credit, from SONA.

Taking part is voluntary: Taking part in this study is completely voluntary. You may skip any questions that you do not want to answer. If you decide not to take part, it will not affect your current or future relationship with Cornell University. If you decide to take part, you are free to withdraw at any time. You can drop out the study at any time if you uncomfortable of answering any question of the survey.

Your answers will be confidential. The records of this study will be kept private. In any sort of report we make public we will not include any information that will make it possible to identify you. Research records will be kept in a locked file; only the researchers of our research team will have access to the records.

If you have questions: The researcher of this study is Xiying Wang, with oversight from Professor Susan R. Fussell. Please ask any questions you have now. If you have questions later, please contact our Principal Investigator, Xiying Wang at xw282@cornell.edu or 812-369-9568. You can reach Prof. Fussell at sfussell@cornell.edu or 607-255-1581. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) at 607-255-5138 or access their website at http://www.irb.cornell.edu. You may also report your concerns or complaints anonymously through Ethicspoint or by calling toll free at 1-866-293-3077. Ethicspoint is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured.

Statement of Consent: I have read the above information, and have received answers to any questions I asked. I consent to take part in the study. Please put your initials here

Part 1: Household, Leisure Behaviors

Are you currently living in an apartment / dorm / house with roommate(s)?

- O Yes
- O No
- O You are living in other type of house (please specify)

Are you responsible for paying your household utility bill?

- O Yes, 100% responsible
- O Yes, but a portion of the bill
- O No, not at all

Who / who else is responsible for the utility bill?

How often do you take the following actions when you are at home? Please rate on a 1-5 scale. If it is not applicable, click N/A.

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Adjust the thermostat to below 68 F (winter) above 70 F (summer)	O	O	O	O	O	O
Leave thermostat's fan switch on "auto"	O	O	O	O	O	O
Wash only full loads of dishes	O	O	O	O	O	O
Keep the fresh food compartment 37F-40F, and 5F for the freezer section of your refrigerator	O	O	O	O	O	O
Wash laundry in cold water	O	O	O	O	O	O
Wash only full loads of laundry	O	O	O	O	O	O
Wear a sweater rather than turn up the heat	O	O	O	O	O	O

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Turn off lights in the shared common area (e.g., kitchen, living room) when no one needs them	O	O	O	O	O	O
Turn off lights in your room when you don't need them	O	O	O	O	O	O
Turn off lights in your room when you leave the room	O	O	O	O	O	O

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Unplug electronics when not in use	O	O	O	O	O	O
Use the sleep or hibernate feature on computer	O	O	O	O	O	O
Turn off music when you are out of hearing distance	O	O	O	O	O	O
Air-dry your clothes	O	O	O	O	O	O
Only print out things you need	O	O	O	O	O	O
Reduce amount of meat in your diet	O	O	O	O	O	O
Take short showers (10 minutes or less)	O	O	O	O	O	O
Buy locally farmed/produced products (within 200 miles)	O	O	O	O	O	O
Bring cloth bags to the market	O	O	O	O	O	O
Select ground shipping for online purchases	O	O	O	O	O	O

In the next six months, do you plan to take the following actions more often, less often, or about the same as you do today?

	N/A	Much less often (1)	Somewhat less often (2)	About the same (3)	Somewhat more often (4)	A lot more often (5)
Adjust the thermostat to below 68 F (winter) above 70 F (summer)	O	O	O	O	O	O
Leave thermostat's fan switch on "auto"	O	O	O	O	O	O
Wash only full loads of dishes	O	O	O	O	O	O
Keep the fresh food compartment 37F-40F, and 5F for the freezer section of your refrigerator	O	O	O	O	O	O
Wash laundry in cold water	O	O	O	O	O	O
Wash only full loads of laundry	O	O	O	O	O	O
Wear a sweater rather than turn up the heat	O	O	O	O	O	O

	N/A	Much less often (1)	Somewhat less often (2)	About the same (3)	Somewhat more often (4)	A lot more often (5)
Turn off lights in the shared common area (e.g., kitchen, living room) when no one needs them	O	O	O	O	O	O
Turn off lights in your room when you don't need them	O	O	O	O	O	O
Turn off lights in your room when you leave the room	O	O	O	O	O	O

	N/A	Much less often (1)	Somewhat less often (2)	About the same (3)	Somewhat more often (4)	A lot more often (5)
Unplug electronics when not in use	O	O	O	O	O	O
Use the sleep or hibernate feature on computer	O	O	O	O	O	O
Turn off music when you are out of hearing distance	O	O	O	O	O	O
Air-dry your clothes	O	O	O	O	O	O
Only print out things you need	O	O	O	O	O	O
Reduce amount of meat in your diet	O	O	O	O	O	O
Take short showers (10 minutes or less)	O	O	O	O	O	O
Buy locally farmed/produced products (within 200 miles)	O	O	O	O	O	O
Bring cloth bags to the market	O	O	O	O	O	O
Select ground shipping for online purchases	O	O	O	O	O	O

Are there any other things you are using to help to reduce your energy consumption at home? If so, please describe here.

In the following question, you are going to evaluate your roommate's energy behaviors at home. If you are not sure about your roommate's behavior, please click N/A.

How often do your roommate(s) take the following actions at home?

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Adjust the thermostat to below 68 F (winter) above 70 F (summer)	O	O	O	O	O	O
Leave thermostat’s fan switch on “auto”	O	O	O	O	O	O
Wash only full loads of dishes	O	O	O	O	O	O

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Keep the fresh food compartment 37F-40F, and 5F for the freezer section of your refrigerator	O	O	O	O	O	O
Wash laundry in cold water	O	O	O	O	O	O
Wash only full loads of laundry	O	O	O	O	O	O
Wear a sweater rather than turn up the heat	O	O	O	O	O	O
Turn off lights in the shared common area (e.g., kitchen, living room) when no one needs them	O	O	O	O	O	O
Turn off lights in your room when you don't need them	O	O	O	O	O	O
Turn off lights in your room when you leave the room	O	O	O	O	O	O

	N/A	Rarely or Never (1)	Occasionally (2)	About half the time (3)	Frequently (4)	Almost Always/Always (5)
Unplug electronics when not in use	O	O	O	O	O	O
Use the sleep or hibernate feature on computer	O	O	O	O	O	O
Turn off music when you are out of hearing distance	O	O	O	O	O	O
Air-dry your clothes	O	O	O	O	O	O
Only print out things you need	O	O	O	O	O	O
Reduce amount of meat in your diet	O	O	O	O	O	O
Take short showers (10 minutes or less)	O	O	O	O	O	O
Buy locally farmed/produced products (within 200 miles)	O	O	O	O	O	O
Bring cloth bags to the market	O	O	O	O	O	O
Select ground shipping for online purchases	O	O	O	O	O	O

If you and your roommate have a disagreement on energy use when you are at home, e.g., you want to turn up the thermostat to 72 degrees in the winter while your roommate wants 65, what would you do?

Who do you think should be more responsible for energy use in your house?

- ○ Yourself
- ○ Your roommate(s)
- ○ Guests
- ○ Your roommate(s) and yourself are equally responsible
- ○ Other (please specify) _____

Why do you think this person (or these people) should be more responsible for energy use in your house?

_____

Part 2: Personal Attitudes and Thoughts about Energy Conservation

People choose to reduce energy consumption for a variety of reasons. Please indicate how important the following reasons for reducing energy consumption are to you.

	Not at all Important	Somewhat Important	Important	Very Important	Extremely Important
Concern for the state of the environment	○	○	○	○	○
Status among roommates, friends or family	○	○	○	○	○
Personal cost savings	○	○	○	○	○
Cost savings for an employer or other person	○	○	○	○	○
Concern for the well-being of future generations	○	○	○	○	○
It is the right thing to do	○	○	○	○	○
Save energy with my peers, roommates, friends or family	○	○	○	○	○

Are there any other reasons are important for you to reduce energy consumption? If so, please specify here.

_____

Similarly, people choose not to reduce energy consumption for a variety of reasons. Please indicate how much you agree or disagree with the following reasons that people might not want to reduce energy consumption.

	Disagree Strongly	Disagree Somewhat	Neither Agree nor Disagree	Agree Somewhat	Agree Strongly

Energy problems cannot be solved by individual people's actions	○	○	○	○	○
Changes to my lifestyle are too inconvenient	○	○	○	○	○
Changes to my lifestyle would be too expensive	○	○	○	○	○
The cost savings are not large enough	○	○	○	○	○
Energy problem will be solved by scientists	○	○	○	○	○
The positive benefits of energy conservation will not occur in my own lifetime	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Part 3: Demographics

Number of roommate(s) you have (if you are living by yourself, please enter N/A):

Please describe your relationship to your roommate(s)

Do you want to reduce your household energy consumption?

○ Yes
○ No

How much was the utility bill for the whole house last month, roughly?

How much was your shared part of the utility bill?

Your age:

- ○ 18 - 21
- ○ 22 - 25
- ○ 26 - 29
- ○ 30 or above

Gender:

- ○ Male
- ○ Female
- ○ Other
- ○ Rather not say

Nationality:

Your position in Cornell University

- ○ Undergraduate
- ○ Master student
- ○ Ph.D. student
- ○ Post-doc
- ○ Other (please specify)

Ethnicity (select as many as apply)

- ☐ Caucasian/White
- ☐ African American/African descent
- ☐ Asian/Pacific Islander
- ☐ Native American
- ☐ Hispanic
- ☐ Other (describe)

Native language

- ☐ English
- ☐ Other (describe)

Questions? Contact Xiying at xw282@cornell.edu

APPENDIX C

ENERGY TENSIONS AND MISUNDERSTANDING INTERVIEW PROTOCOL

Welcome participant

Thank you for participating in our study. We want to learn how you and your roommates manage energy at home. In particular, we want to know if you and your roommates have different energy behaviors and how you coordinate the energy use. We really want to hear your thoughts on those things which help us to understand your household energy use. It will take you approximately 45 minutes.

We want to audio record this interview.

All the audio files are for research analysis only and all the files are kept confidentially in our principle investigator's computer. No third party could get access to the data except our research group. We won't put your name, email, or any other personal information in any publication. But we will use what you say in the interview, we mean your words and sentences from the interview as an evidence to support our research findings in the publications. If you are uncomfortable with the record, we will not use it. However, we also want to let you know that although every reasonable effort has been taken, confidentiality during the actual Internet communication procedures cannot be guaranteed.

We also want to let you know that you can leave the interview at any time if you want to.

Informed consent

(The interviewer will walk through the informed consent, and ask the participant to sign the form. The interviewer will give a copy of the form to the participant. The interviewer also asks for consent to audio record the interview.)

Interview Questions

1. Breaking the ice

Tell me about the place you are currently living in. What type of house is it (e.g., an apartment condo, a house, a campus dorm, etc.)? How many housemates do you have?

Tell me about your house monthly utility bill. Who is responsible for paying the utility bill?

(If all housemates share the utility bill)

How do you and your housemates coordinate to pay the utility bill?

How do you and your housemates get along? How often do you and your housemates interact?

How do you and your housemates manage energy use at home?

Who do you think have a larger influence on your household energy use?

What made you think that?

In your opinion, what other factors impact your household energy use?

What utility do you share with your housemates?

Tell me the last time when you had a disagreement with your housemates when using utility at home?

What was it about? What happened?
How did you want to use it? What's your housemates' opinion?

How did you coordinate the use with your housemates?
What worked and what didn't?

2. A particular event

Tell me a specific time when you and your housemates have different needs for using utility (e.g., adjust the heater to a different degree in the winter). What happened?

When did that happen?
What did you do? What did your housemates do?
How did you and your housemates work it out at the end?

How about now? Do you and your housemates still have different needs for x (the above energy use mentioned by the participant)?

(If YES)

When was the last time you and your housemates encountered such situation?
What was it about? What happened?
What did you do? What did you housemates do?
How did it work out at the end?
What worked? What didn't? What made you think that?
What would you do if similar thing happens?
What do you think you can do to coordinate the energy use?
In your opinion, what can be done to make it better?
What do you wish could have done to coordinate better?

(If NO)

How did you and your housemates manage to coordinate x (the above energy use mentioned by the participant)?
What worked? What made you think it worked?
What did you do to coordinate x? What did your housemates do?
Tell me how you and your housemates treat x (the above energy use mentioned by the participant) now.

Tell me a specific time when you and your housemates managed to coordinate energy use at home. What energy use are you referring to? What was it about?

How did you and your housemates work it out? What happened?
What do you think was important for you and your housemates to work it out?

Tell me a specific time when your housemates were not satisfied with the way you were using energy. What was it about?

What did you use?
How did you use it?
How did you find out that your housemates were not satisfied?
At the end, how did it work out?

Tell me a specific time when you were not satisfied with the way your housemates were using energy. What made you unsatisfied?

What did your housemates use? How did they use it?
What did you do?
At the end, how did it work out?

3. Wrap-up
Do you consider yourself paying attention to energy-saving at home? What made you think that?

Do you consider your housemates paying attention to save energy at home? What made you think that?

Do you have other things you want to tell me?

Do you have any questions?

Do you have any feedback or suggestions to this study?

Thank you
Thank you for participating in our study. We really appreciate your time. Feel free to contact me if you have any question regarding this study. My email address is xw282@cornell.edu.

Have a nice day.

APPENDIX D

ENERGY-RELATED CONFLICTS INTERVIEW PROTOCOL

(Script)

Welcome participant

Thank you for participating in our study. We want to learn how you and your roommates manage energy at home. In particular, we want to know if you and your roommates have different energy behaviors and how you coordinate the energy use. We really want to hear your thoughts on those things which help us to understand your household energy use. It will take you approximately 45 minutes.

We want to audio record this interview.

All the audio files are for research analysis only and all the files are kept confidentially in our principle investigator's computer. No third party could get access to the data except our research group. We won't put your name, email, or any other personal information in any publication. But we will use what you say in the interview, we mean your words and sentences from the interview as an evidence to support our research findings in the publications. If you are uncomfortable with the record, we will not use it. However, we also want to let you know that although every reasonable effort has been taken, confidentiality during the actual Internet communication procedures cannot be guaranteed.

We also want to let you know that you can leave the interview at any time if you want to.

Informed consent

(The interviewer will walk through the informed consent, and ask the participant to sign the form. And the interviewer will give a copy of the informed consent to the participant.)

Can we audio record the interview?

(Waiting for participant's consent to the audio record)

(Interview questions)

1. Breaking the ice

Tell me about the place you are currently living in. What type of house is it (e.g., an apartment condo, a house, a campus dorm, etc.)? How many housemates do you have?

Tell me about your house monthly utility bill. Who is responsible for paying the utility bill?

(If all housemates share the utility bill)

How do you and your housemates coordinate to pay the utility bill?

How do you and your housemates get along? How often do you and your housemates interact?

How do you and your roommates/housemates usually communicate house stuffs?

How do you and your housemates manage energy use at home?

How did you and your housemates use energy yesterday?

How do you and your housemates come up with an agreement on using energy?

Who do you think have a larger influence on your household energy use?

What made you think that?

In your opinion, what other factors impact your household energy use?

What utility do you share with your housemates?

Can you describe your room to me? How many electronics do you have?

Are you aware of the electronics in your roommate's/housemate's room?

Can you describe those to me?

Tell me the last time when you had a disagreement with your housemates when using utility at home?

What was it about? What happened?
How did you want to use it? What's your housemates' opinion?
How did you coordinate the use with your housemates?
What worked and what didn't?

(Weekday vs. weekend)
Tell me how you used energy (e.g., electricity, water) with your roommates/housemates in the morning today.

How do you usually manage energy with your roommates/housemates in the evening?
How about last night when you were all back home?

Tell me how you managed energy with your roommates/housemates last weekend, in the morning?

How about at noon?
How about evening?

2. A particular event
* Topics to prompt them to talk: **playing music loud, light usage at night, room temperature**

Tell me a specific time when you and your housemates have different needs for using utility (e.g., adjust the heater to a different degree in the winter). What happened?

When did that happen?
What did you do? What did your housemates do?
How did you and your housemates work it out at the end?

How about now? Do you and your housemates still have different needs for x (the above energy use mentioned by the participant)?

(If YES)
When was the last time you and your housemates encountered such situation?
What was it about? What happened?
What did you do? What did you housemates do?
How did it work out at the end?
What worked? What didn't? What made you think that?
What would you do if similar thing happens?
What do you think you can do to coordinate the energy use?
In your opinion, what can be done to make it better?
What do you wish could have done to coordinate better?

(If NO)
How did you and your housemates manage to coordinate x (the above energy use mentioned by the participant)?
What worked? What made you think it worked?

What did you do to coordinate x? What did your housemates do?
Tell me how you and your housemates treat x (the above energy use mentioned by the participant) now.

Tell me a specific time when you and your housemates managed to coordinate energy use at home. What energy use are you referring to? What was it about?

How did you and your housemates work it out? What happened?
What do you think was important for you and your housemates to work it out?
Tell me a specific time when your housemates did not like the way you were using energy. What was it about?
What did you use?
How did you use it?
How did you find out that your housemates were not satisfied?
At the end, how did it work out?

Tell me a specific time when you did not like the way your housemates were using energy. What made you unsatisfied?

What did your housemates use? How did they use it?
What did you do?
At the end, how did it work out?

3. Alternatives
(New space vs. old space)
How long have you been living in the current apartment/house/condo?

What made you move to a new place?

Do you have any moving plan in the next year?

Do you plan to live alone or stay with roommates?

If staying with roommates, how do you decide whom to live with?

What made you decide?

(Light in the evening)
Tell me about a specific time when you woke up in the evening. What did you do?

Was lighting essential for you while you woke up? Why or why not?
Do you care to come home in the dark if you happen to come home in the evening?
Why or why not?
What do you usually do to prevent coming home with a completely darkness?

4. Wrap-up
Do you consider yourself paying attention to energy-saving at home? What made you think that?

Do you consider your housemates paying attention to save energy at home? What made you think that?

Do you have other things you want to tell me?

Do you have any questions?

Do you have any feedback or suggestions to this study?

Can you ask your roommate/housemate to participate in the interview? Can I have his/her NetID for contact purpose? (Note: ask if their roommates/housemates can also participate in the study)

(Script)

Thank you

Thank you for participating in our study. We really appreciate your time. Feel free to contact me if you have any question regarding this study. My email address is xw282@cornell.edu. Have a nice day.

APPENDIX E

ENERGYSENSE INTERVIEW PROTOCOL

1. User experience of EnergySense *(General feedback)*

Tell me about EnergySense. What do you think about the mobile application in general?

What worked well for you?
What didn't?

How do you find EnergySense fit into your life?

Are you interested in continuing to use this app?

(If Yes)
What made you want to continue?
Can you imagine yourself using this in the future?

(If No)
What made you stop?
Have you ever discussed the mobile app with your housemates? What did you talk about?

(Expectations)
Tell me your expectation of EnergySense when it was first introduced to you.

Do you think EnergySense facilitate the way you use energy?

(If Yes)
Can you give me an example?

(If No)
Why not?

Did EnergySense control the light the way you expected?

(If Yes)
What met your expectation?

(If No)
Can you tell me what happened?

Anything strange took place?

Anything out of your expectation?

What did not meet your expectation?

What did you expect in that situation?

(Use)
How did you use EnergySense in the past 3 weeks? Can you show me how?

(Follow up)
What did you use the app for?
When did you mostly use the app (e.g., before sleep, after wake up)?
How often did you check on the app?
How long did you usually stay on the app in a given day?
Did you keep it running in the background?

How did you use the bedroom light feature of EnergySense?

How did you and your housemates use the shared light feature of EnergySense?

(Follow up)
Was it convenient for you to turn off the shared light?
What do you think of this feature?
Have you ever set a time to turn off the shared light?

(If Yes)
What do you think of this feature?

(If No)
Why not?

(Impacts)
How did you find EnergySense influence your household energy use?

How did you find EnergySense influence your energy behaviors?

How did you find EnergySense influence your housemates' energy behaviors?

Do you find yourself pay more attention to energy use at home after using the app?
(Follow up)
Can you give me an example?
What made you think that?
Do you find yourself motivated to save energy at home?

(Follow up)
What did you do to save energy?
What caused that change?
Which features(s) or functions of the app encouraged you?

2. House basics
Tell me about the place you are currently living in. What type of house is it (e.g., an apartment condo, a house, a campus dorm, etc.)? How many housemates do you have?

(Utility)
Tell me about your house monthly utility bill. Who takes care of the utility bill?

(If all housemates share the utility bill)
How do you and your housemates coordinate to pay the utility bill?

Do you read the bill every month?

(If Yes)
What made you do that?

(If No)

Why not?

How do you and your housemates get alone?

Where do you usually hang out?
Tell me last time when you and your housemates hung out. Where, and what activities?

How do you and your housemates manage appliances or electronics in the shared areas such as kitchen and the living room?

(AC/Heater)
Can you control the air conditioner or heater in your bedroom?

(If No)
Who sets the temperature for the entire house?
How do you and your roommate decide what is the best temperature for everyone in the house?

(Communication)
How do you and your roommates usually communicate house related stuffs (or chores)?

How do you and your housemates manage energy use at home?

How did you and your housemates use energy yesterday?

How do you and your housemates come up with an agreement on using energy?

(Weekday vs. weekend)
Tell me how you used energy (e.g., electricity, water) with your roommates in the morning today.

How do you usually manage energy with your roommates in the evening?
How about last night when you were all back home?

Tell me how you managed energy with your roommates/housemates last weekend, in the morning?

How about at noon?
How about evening?

(Conflict)
Have you ever got into conflicts of using energy with your roommates?

(If Yes)
Can you tell me more about it?
How do you think the conflict influences your way of using energy?
How do you think the conflict influences your roommates' energy uses?
How do you think the conflict influences your utilities bill?

(If No)
How do you manage to use energy so well with your roommates?

(Impact)
Who do you think have a larger impact on your household energy use?

What made you think that?

3. Use of light

Tell me how you manage lights in your room in a typical day.

Was there a time when you slept with lights on?

(If Yes)
Can you tell me more about that?
What happened?
What made you sleep with lights on?

(If No)
What made you always turn off lights before going to bed?

Tell me how you used lights in your room last night.

Tell me how you and your housemates use the lights in the shared areas.

(Follow up)
Who usually takes care of the lights?
Is there a delegated person responsible for taking care of those lights?
Who is responsible for turning on/off the lights in the shared areas?

Tell me a typical day of using the lights in the shared space. How did you and your roommates manage the lights?

Was there a time when you and your housemates slept with lights on in the shared areas?

(If Yes)
Can you tell me more about that?
What made you sleep with lights on in the shared areas?

(If No)
How do you and your housemates manage to turn off lights?
Do you have any strategy of how to take care of the lights?

Tell me how you and your housemates used lights in the shared areas last night.

(Follow up)
Was the light on when you got back?
If not, who turned the lights on?
When you went to bed, were all the lights off in the shared space?
If not, what left on?
How about this morning, any lights on?
Did you know who took care of the lights in the shared space?

4. Wrap-up
Do you consider yourself paying attention to energy-saving at home? What made you think that?

Do you consider your housemates paying attention to save energy at home? What made you think that?

Do you have other things you want to tell me?

Do you have any questions?

Do you have any feedback or suggestions to this study?

Thank you