EnergyHome: Leveraging Housemate Dynamics to Motivate Energy Conservation

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ABSTRACT
We designed, implemented, and evaluated an iOS mobile application called EnergyHome to investigate how social interaction among housemates is related to their engagement in energy-saving practices. EnergyHome enables housemates to track personal energy-saving activities and to collaborate on saving energy together. Fourteen pairs of housemates used EnergyHome for a week. Afterwards, we interviewed each participant about their use of the app. All interviews were transcribed and analyzed using an iterative comparative approach. We identified two types of social dynamics in the way housemates used the app. In *complementary* dynamics, one housemate took the initiative to set energy-saving challenges and the other(s) followed. In *symmetrical* dynamics, housemates collectively set energy-saving challenges but no one tried to exert control. Based on these findings, we discuss design strategies to motivate energy conservation that take into account different social dynamics among housemates.

Author Keywords
Mobile design; user experience; housemates; household energy conservation; social dynamics.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Much attention has been given to motivate family energy conservation in sustainable HCI [41]. In the past decade, researchers and designers have examined various strategies to encourage families to reduce their energy footprint [e.g., 10,26,27,41]. One type of design intervention focuses on motivating individual family members to save energy. For example, families are more likely to engage in saving energy when they are given relevant feedback about their own consumption [1,12,29]. Personalized energy feedback is thought to be effective because individual family members tend to care more about energy information when it is directly related to them [34]. Moreover, customizing energy-saving goals to living conditions and personal schedules are considered to be a promising strategy for family energy conservation [20,22,24,36].

A second type of design intervention highlights social aspects of household energy consumption [e.g., 10,12,17,28,39]. Individual family members are influenced by other members' energy attitudes and behaviors [e.g., 10,12,35]. In addition, collaborating to reduce energy consumption can make a family collectively more active in reducing energy use [e.g., 10,12,18,35,38]. Considering social structure dynamics thus may increase the success of interventions to reduce energy usage.

The two aforementioned strategies are effective in families. In those environments, energy-related activities are shaped in part by family dynamics [15,40,44]. For example, research found that there is often a "*family leader"* who is in charge of managing energy use [40]. This person often pays attention to other family members' energy needs, and adjusts the energy settings (e.g., thermostat) accordingly. However, we do not know if these strategies will work in non-family households.

Statistics shows that more than 32% of American adults live with roommates or housemates [25]. Preliminary evidence suggests that these kinds of households manage energy differently than families do [7,8]. Instead of having a "family *leader*" in charge of energy management [42], housemates generally consider each other equally responsible for consuming and managing household energy [40]. For example, they can independently use any household appliances without attending to housemates' energy needs [19,40], whereas family members tend to be more mindful of others' energy needs [42].

In the current study, we explore whether the design strategies that have been successful with families are able to support energy conservation among housemates. For example, if housemates' energy behaviors are independent of each other, encouraging individual energy conservation may be more successful. In contrast, if a housemate is easily influenced by others' behaviors, inviting housemates to create a shared plan for energy use might be a more successful approach. If housemates tend to rely on each

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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.

We 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. We 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. We focus specifically on how social dynamics between housemates influenced how they used the tool.

In the remainder of this paper, we first discuss the features of the EnergyHome app and the related literature that informed the design of these features. Then, we present the method and results of our user study. Our findings show that interpersonal relationships between housemates and their interactions with one another were related to how they choose to engage in energy-saving practices. We conclude by discussing design strategies for persuasive mobile technologies that take housemate social dynamics into account.

ENERGYHOME DESIGN AND RELATED WORK

In order to investigate the influence of design strategies on housemates' energy behaviors, we designed an iPhone application called EnergyHome. This application is 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.

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 [1, 4, 17, 35, 42]. Family members are more committed to energy conservation if they are appropriately motivated; individuals were more motivated when they were confident they could accomplish energy-saving goals [1, 4, 35]. These self-determined goals are more effective in encouraging sustainable behavior than goals set by researchers or app developers [1,24], because people can control goal content and difficulty, thus setting goals that meet their needs [20].

Adapting the strategy of self-set goals, we designed a feature called *My Challenges* (see Figure 1). Users can set their personal energy-saving goals or "challenges" and track these challenges 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. [21] for a shared household environment.

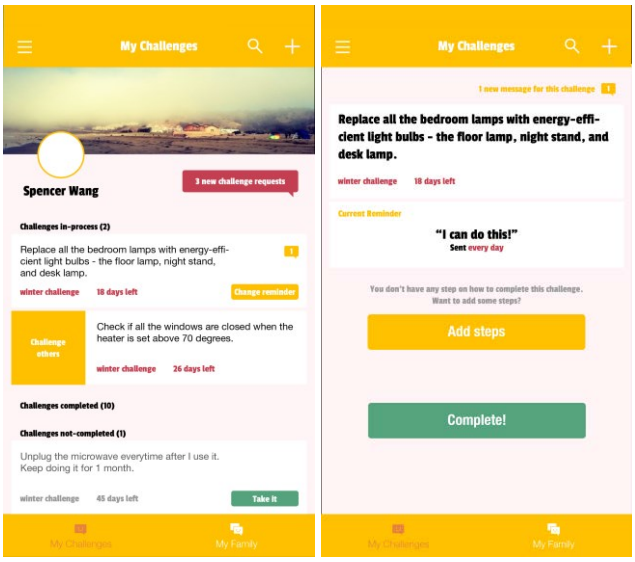

Figure 1. My Challenges user interface with "take it" function at the bottom (left); an individual challenge detailed user interface (right).

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, right) 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 [36]. Viewing self-achievement can better engage users [16].

The "challenges not-completed" section stores the uncompleted challenges. Each uncompleted challenge has a feature called "take it" that enables users to reactivate it. We did not want to exclude the possibility that users may find uncompleted challenges interesting and want to return to them. Thus we designed this section and the "take 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. To better facilitate setting up an individual challenge, we designed a few optional settings. For example, a user could choose to input necessary information or tools to accomplish the challenge, with whoever he or she wanted to share the

challenge, and customize the frequency and content of reminders for a particular challenge.

We aimed to give users flexibility in setting up challenges and deadlines, because it is unlikely that users will stick to the same energy-saving goal for extensive periods of time; [30]. An energy-saving goal can fail to motivate a user if he or she has already achieved it [30]. We designed a deadline feature for each individual challenge to give the challenge a limited life cycle and to avoid tiring our users. There are no pre-assigned individual challenges. It is up to each user to determine what challenges to set, since previous work has found self-set goals to be more motivating than assigned ones [1,24].

Group Challenges

Previous research suggests that individual household energy behavior is influenced by those sharing a living space, i.e., family members [10,17,26,27,33]. People tend to be more committed to sustainable activities if their friends or family are also committed to them [3,23,29,38]. Household members also try to avoid causing utility costs to be higher than other members expect [10,19,26,35].

In particular, saving energy as a group (e.g., a family or a community) is effective for encouraging individual sustainable behavior [10,19,23,35,38]. For example, Erickson et al. [10] 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 family members than when they worked alone [10]. Similar influence was found in eco-island's study, in which family members participated together as a group to save energy [26,35]. Thieme et al. [38] 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, we designed a *group challenges* page (Figure 2) that includes group energy-saving challenges and the group's progress on each challenge. We called it *My Family* in our application, using "family" broadly to include groups of friends, roommates, or housemates because it could potentially create more affiliations and connections 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.

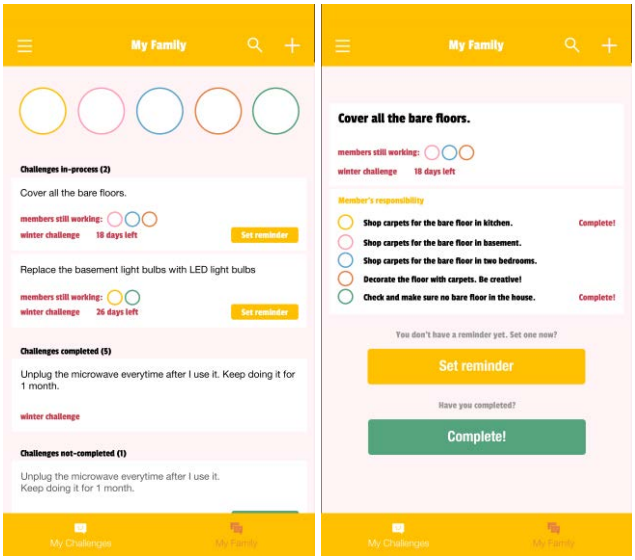

Figure 2. My Family group challenge user interface (left); a group challenge detailed user interface (right).

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. We 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 *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, we 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, we 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

We also designed a reminder feature for both individual and group challenges. Personalized reminders have been shown to better support memory of daily routines [37]. Inspired by this idea, we 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 to domestic members on energy-saving practices is a successful motivation strategy [9,15,44]. Social support can appear in the form of reminders, so we added group reminders that allow other housemates to set a reminder message and frequency for an individual. We wanted to see if individuals would be motivated by receiving this kind of help from their housemates' [15], and to explore whether group reminders would be better than self-reminders for encouraging engagement in energy-saving activities.

To set up an individual or a group reminder, a user could customize the content and frequency during or after creating a challenge.

Privacy Concerns

Due to possible privacy concerns, we 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 [2]. We 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 research questions described above, we conducted a user study of 14 households of 28 housemates. Housemates were non-family members living in the same house and having individual bedrooms.

Participants

We 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: 1) they were living currently with a housemate in a shared dorm, apartment, or house, 2) they participated in the study with their roommate or housemate so that we could look at use of both individual and collaborative features of EnergyHome, and 3) they were iPhone users and willing to install the application on their phones. It is worth noting that the "dorms" were actually suites arranged such that each household member had an individual bedroom.

Seventy-five users responded to the study recruitment. We 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 has his or her own bedroom, we thus use housemates in the following sections to describe the household type of our participants.

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

Table 1. Participant demographics.

Study Procedure and Analysis

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

After using EnergyHome for 7 days, participants were interviewed about their experiences using the app and why

they used it in particular ways. Each interview lasted from 45-60 minutes with each housemate interviewed separately. We 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. We 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 [14]. We first coded ten interviews based on the research questions and then cleaned up the codes to generate new ones. Next, we used the new codes to recode first ten interviews and the rest of interviews, added emerging codes when necessary. Last, we organized the codes into emerging themes.

FINDINGS

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

General Feedback

Participants had different preferences when interacting with EnergyHome. We 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 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, we explore the role that the social dynamics between housemates might have played in these assessments of EnergyHome features.

We 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 [6, 32]; a *symmetrical relationship* refers to a pattern of interaction in which both people are active or both are quiet and respectful [6, 32]. If a housemate requested that his or her housemate turn off lights, and the housemate did as instructed; we 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; we consider this to be a case of *symmetrical dynamics*. If housemates did not ask the other to turn off lights or they focused on turning off lights independently, we still consider that an example of *symmetrical dynamics,* albeit a different flavor, as both housemates are quiet or respectful.

These two types of social dynamics between housemates 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

We 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, we 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 housemate in the pair enjoyed creating group challenges and assigning the other one energy-saving tasks; the other housemate 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 leaders were excited about was the ability to assign housemates energy-saving tasks. They found it is 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)

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 annoyed 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. We found only one pair of housemates had a different complementary dynamic. In this pair, one housemate (P13) was the *leader*, who used group challenges to push his or her housemate to reduce energy use. To P13, group challenges is a nice idea.

"Setting up how much saving you wanted to do, and like time, frequency at getting my roommate to use it, I thought

Types of social dynamics	Sub-categories	Description	Design implications
Complementary dynamics	*Leader-Follower*	One is active (leader); One follows as told (follower)	Encourage group collaboration; Highlight active inputs for leaders, e.g., initiate a task, and highlight passive features for followers, e.g., accept a task
	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	Encourage 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.

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. We identified the following three types of symmetrical dynamics:

Collaborator-Collaborator. This type of dynamics is most common in our study. We identified 8 out of 14 pairs of housemates belong to this type. *Collaborators* prefer to work on energy-saving challenges with their housemates. In particular, they are engaged in doing energy-saving activities with others; collaborators like the idea of supporting 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)

Rather than one leader creating challenges and the other person following through, collaborators often brainstormed and came up with 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)

Furthermore, 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 housemate greatly influenced their participations in the group. Collaborators are more committed to group challenges when they are close 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 *collaborator-collaborator* is that they 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 a common ground of 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 are likely to be more committed to group challenges if they are close to their housemate(s). Being reminded shows housemates' care and support, helps to understand housemates' expectation of energy use, and is often 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 other symmetrical dynamics. Different from collaborators, *conflict avoiders* preferred to independently save energy to avoid potential conflicts with a housemate. Neither of the housemates (P3 or P16) collaborated on a group challenge, but only worked 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. However, she did not feel right to invite P16 to a group challenge, because she was concerned about interfering 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 as a passive-aggressive manner to impose her housemate on energy-saving activities. She felt 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 they felt more comfortable to work on individual challenges.

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

One pair of housemates (P10 and P11) belongs to this type. Both of them considered saving energy as 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 independent contributors is that both P10 and P11 preferred to set reminders by themselves. P10 considered letting P11 to set reminders interfered his life and 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)

And P11 preferred to set reminders by herself because it was 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 to control challenge contents and reminders by themselves, rather than someone else.

DISCUSSION

We designed our EnergyHome application to incorporate factors that have been shown to motivate energy saving in family settings. We deployed EnergyHome with pairs of housemates for a one week period and then interviewed them about their experiences. Our findings suggest that how housemates used EnergyHome, especially whether they chose to participate in energy conservation individually or collaboratively, was deeply influenced by the social dynamics of their home.

Previous research highlighted the "one size cannot fit all" approach in persuading household energy-saving practices, which means persuasive technology should alter its features based on people's usage patterns [31, 37]. Our work suggests that we should tailor technology based on housemate dynamics. In particular, we identified two types of social dynamics that are especially relevant to energy consumption - *complementary* and *symmetrical* dynamics.

In *complementary dynamics*, housemates who do not want to initialize energy-saving activities tend to listen to those who speak out. This suggests, for example, this type of housemates may favor collaborating to energy conservation when one can initiate energy-saving tasks and the other follows. We suggest collaborative features for leader-follower type of dynamics. For example, let one housemate to create an energy-saving challenge and assign energy tasks to other housemates.

However, we also observed one case of a reluctant follower. This suggests that when a follower stops supporting an ongoing challenge that technology should shift towards individual strategies for that person instead. For example, it could be helpful to remove the "assigning energy-saving tasks" feature and highlight individual energy-saving features.

In *symmetrical dynamics*, housemates have similar interaction patterns when committing to energy-saving practices. When both housemates are active and dependent on each other, they *enjoy* working together. In this case, providing collaborative features or encouraging peer support may lead to a more delightful energy-saving experience. For example, we can facilitate housemate collaboration to save energy by sending customized reminders to each other.

On the other hand, we suggest to limit or even remove features that encourage collaborations to those who try to avoid conflicts or prefer to work alone. This indicates that providing detailed steps to keep track of personal energy activities may lead to a better outcome in encouraging energy conservation for certain individuals.

Limitations. We did not log users' activities on the app due to privacy concerns. Our main source of data came from interviews and when participants showed us their app usage during the interview process.

However, our key focus is not how participants used EnergyHome but how and why the design features influenced their energy-saving experiences. Thus, readers should keep the limitations in mind, but also be open to a broader understanding of how design influences non-family members' energy conservation.

DESIGN IMPLICATIONS

Based on the types of social dynamics identified from the study (see Table 2), we propose the following two design considerations for mobile solutions to engage domestic household members in energy-saving activities: *recognize social dynamics of domestic household members*, and *adjust design features based on identified social dynamics*.

Recognize social dynamics of domestic household members. Previous research highlights collaborations is a promising strategy to promote family energy conservation [e.g., 9,10,18,26,33]. However, we found that collaborations was not always the best choice for housemates to save energy. For example, it is unlikely that conflict avoiders would engage in a collaborative-only system. Thus, we suggest that persuasive mobile systems recognize users' social dynamics and categorize them accordingly.

However, it can be tricky to identify types of social dynamics when a smart system is first introduced to users. We suggest the following design strategies to identify types of social dynamics. Instead of determining which strategy best works to motivate domestic household members, we 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' activity patterns of the design features. For instance, a system can keep track of users' frequent activities by learning from the system logs.

Taking EnergyHome as an example to identify *complementary* dynamics, when certain users repeatedly create group challenges, it indicates they are potential leaders, because leaders like to take initiatives in creating challenges. Correspondingly, other users would be deemed followers. If the follower regularly participated in group challenges, they would be considered *cooperative;* if they were initially active, but became less active overtime, they would be considered *reluctant*.

Adjust design features based on identified social dynamics. Although consistent group collaborations [e.g., 10,19,23,35, 38,44] and social support [e.g., 9,15,44] have been found successful to promote family energy-saving behavior, our findings suggest *unchanged* social strategies may not always keep housemates stayed motivated. Housemates' energy-saving practices are deeply rooted in their interpersonal dynamics. Different households with different social dynamics will require different solutions.

Thus, we propose the persuasive mobile system to personalize its features to individual users based on social dynamics after it learns and determines those dynamics, e.g., encourage collaborations for leaders and followers or limit collaborations for those in symmetrical dynamics.

When a mobile system learns a *leader-follower* or a *leader-reluctant follower* dynamics, it can keep or motivate leaders and followers in collaborations, but separate reluctant followers if they are in a group with leaders. Instead, the system encourages reluctant followers to participate in individual features, e.g., sending a system invite to work on an energy-saving action. In addition, the mobile system can provide features that require leaders' inputs, e.g., customize reminders to listeners, while 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 is recognized, a mobile system can keep collaborators on the group and add more social features to make collaboration fun and engaging. For example, it can notify a collaborator when it is his or her turn to set up a challenge. It can also keep track of a collaborator's favorite reminders received from others.

When a mobile system detects most of a user's activity logs in individual challenges, this probably means the user is an independent contributor or conflict avoider. The collaboration features, such as group challenges, can be emphasized less, even replaced with more individual features, such as keeping track of individual daily actions.

To motivate domestic household energy conservation, we propose to understand patterns of household members' activities and interactions with the mobile system features, to identify their preferences. Then, we suggest the ability to personalize design features to individual users based on social dynamics. To better engage users living under different social dynamics, design features can appear and disappear. For instance, the system can provide more social features to *leader-follower* or *collaborator-collaborator*, while those features can fade away from *conflict avoiders* and *independent contributors*.

CONCLUSIONS AND FUTURE DIRECTIONS

In order to examine whether successful design strategies for individuals and families would be suitable for housemates with a flat structure [40], we designed, deployed, and evaluated EnergyHome. By introducing a distinction between symmetrical and complementary dynamics, we were able to explain differences in how housemates used EnergyHome. Specifically we found that symmetrical and complementary dynamics could be further divided into five distinct interaction types, each with different patterns of application use and different design implications. For example, while collaborators found working with others helpful to save energy, as they supported and relied on each

other, conflict avoiders and independent contributors preferred individual challenges as they did not find group challenges motivating.

Our findings suggest that persuasive mobile technology can benefit from taking social dynamics into account to promote user engagement in energy conservation. Our findings also open a design space for applications that learn from and adapt not only to patterns of use with the system itself but also for applications that learn from and adapt to the interaction patterns between users.

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