Tough Shift: Exploring the Complexities of Shifting Residential Electricity Use Through a Casual Mobile Game

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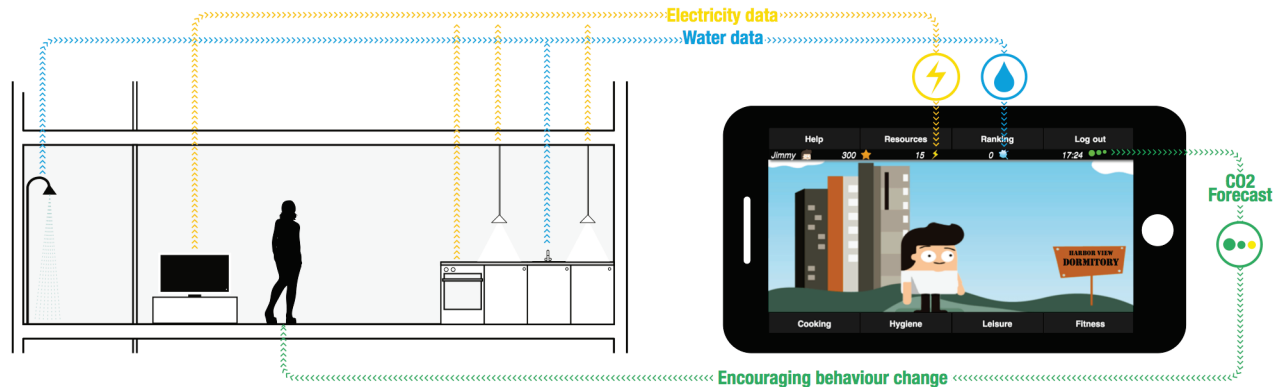mia.kruse@alexandra.dk

Figure 1: ShareBuddy is a casual, mobile game where players' real-world electricity and water use is tracked by sensors and compared to a baseline of their previous usage. When players shift their electricity use to better match forecasts of the best times to use electricity during the day, they are rewarded with resource points in the game, which they can use to play arcade mini-games.

ABSTRACT

Modern electrical grids are increasingly reliant on generation from renewable sources that can vary from hour to hour. This variability has led to the desire to shift the times of the day when electricity is consumed to better match generation. One way to achieve these shifts is by encouraging people to change their behavior at home. Leveraging prior research on encouraging reductions in residential energy use through game play, we introduce ShareBuddy: a casual mobile game intended to encourage players not only to reduce, but also to shift their electricity use. We conducted two field studies in a student dormitory and found that players did not shift their electricity use, because they were unwilling to change their schedules and found it easier to focus on reducing electricity use. Based on our findings, we discuss the implications for encouraging shifting, and also the challenges of integrating real-world resource use into a game.

Author Keywords

Games; serious games; casual games; energy; shifting; behavior change.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; K.8.0. General: Games.

INTRODUCTION

Renewable energy is providing an increasing share of the electricity in the modern grid [27], but the output from renewable sources typically varies throughout the day [10]. The implication is that there are better and worse times to consume electricity. Therefore, governments and utilities would like to "shift" electricity demand from the worse times to the better times of the day.

To achieve this shift in the timing of electricity use, it is necessary to motivate and encourage people to change the time when they perform the activities that consume electricity. A variety of techniques have been explored to encourage residential shifting: providing informational displays of grid CO_2 emissions [13, 31], introducing time of use pricing [28, 36], and using smart appliances that can be scheduled to run at certain times [14, 37]. However, each strategy has limitations: informational displays must find ways to get users to consult the display over the long-term, time of use pricing requires regulatory approval, and appliances must be replaced or upgraded to become smart.

On the related topic of encouraging people to *reduce* their electricity use, games and gamification [18] have shown promise as methods to encourage residential users to reduce their electricity use [1, 39], and ensure that users stay engaged with electricity feedback over time [9]. However, using game-based approaches to encourage shifting of electricity use has not yet been attempted.

To explore the feasibility of this approach to shifting, we developed ShareBuddy, a casual mobile game intended to motivate players to make real-world changes in resource use in order to do well in the game. ShareBuddy links the players' real-world electricity and water use to the game and offers opportunities for advancing in the game based on player's reductions and shifts in electricity use compared to a baseline of their resource use. To evaluate ShareBuddy's effectiveness in encouraging shifting, we conducted two field studies in a student dormitory equipped with several sensors in each apartment. We collected data on each resident's resource usage (hot and cold water volume, electricity use), game play data, questionnaire responses, and semi-structured interviews with both players and non-players. While the most frequent players gained some understanding of the shifting concept, players were largely unwilling to shift their electricity use, and those who did change their consumption tried to reduce rather than shift it.

RELATED WORK
This section describes the use of direct feedback and games as tools to assist behavior change to reduce consumption.

Providing feedback about resource use to help people reduce consumption has been used extensively by the energy efficiency community [16, 21, 22], and eco-feedback has been studied by many researchers in HCI [23, 42]. However, residential users still find it difficult to engage with these technologies [2, 41]. While feedback has been shown effective in reducing electricity use for some households, Houde et al. found that the effectiveness of feedback decreases over time [29]. Games provide the potential to make feedback more engaging so residential users will continue to consult the feedback over time [9].

Several serious games have been developed with the intent of reducing players' electricity consumption including: Power Explorer [1], Power House [39], EcoIsland [43], Energy Battle [24], Power Agent [26], Climate Race [40], Kukui Cup [7], Professor Tanda [11], Energy Life [4], and LEY! [34]. None of these games has considered shifting as a goal in their game design.

In particular, ShareBuddy builds upon two casual games with arcade elements. Bång et al. developed Power Explorer, a casual game designed to promote energy awareness in households [1]. Power Explorer teaches about the electricity consumption of home appliances through actual appliance use via real-time feedback. Players compete by controlling avatars in arcade games by actually turning appliances in the home on and off, with the goal of teaching individual appliances' electricity consumption. Because the games are controlled by appliance use, they can only be played while players are at home. Reeves et al. describe Power House, a casual game that tries to influence players to reduce their energy use [39]. Players follow an avatar around a virtual house, turning appliances on and off with mouse clicks according to what the avatar is trying to achieve. As more family members return to the virtual

home, it becomes increasingly hard to keep up until the family overloads the virtual house's electrical capacity. Power House encourages players to turn off appliances when not in use. The player's real-life electricity savings translate into upgrades of the in-game appliances in order to advance in the game. Results showed a reduction in player's real-world electricity usage during the game.

SHAREBUDDY: GAME DESIGN AND IMPLEMENTATION
ShareBuddy aims to encourage and support users to reduce and shift their resource consumption by providing appropriate feedback. One of the problems with motivating change through feedback is getting users to continue to consult this feedback. As such, we designed ShareBuddy as a casual game [45] structured around a daily "appointment" to provide a clear incentive to return to the game, that matches well with daily feedback data.

We describe the design requirements, the game rules and mechanics, integration of feedback, the feedback metrics used, and how ShareBuddy was implemented.

Design Requirements
Leveraging prior work and the survey by Gremaud [25], we identified five important characteristics used across these electricity games: 1) casual play, 2) arcade elements, 3) inclusion of resource data, 4) rewards that affect game play, and 5) game mechanics that encourage repeat play. ShareBuddy incorporates all five identified features, which no single game has done. In addition, to facilitate shifting (which no game has yet attempted), ShareBuddy must also incorporate forecast data to allow players to plan their activities to optimize electricity use.

Game Play and Mechanics
In ShareBuddy, players control an avatar in the game (the "buddy", see Figure 1), and earn mood points by directing their buddy to perform everyday residential activities. There are four categories of activities: cooking, hygiene, leisure, and fitness. Figure 1 (far right) shows the main page where players can select and move between different activities by pressing the navigation buttons on the screen. For example, in the hygiene category, players can choose from brushing their teeth, shaving, and showering. The mood points earned by performing these activities provide a way for players to track their progress, and enable competition among players [44, p. 255]. Players can also consult their game ranking (based on mood points) via a scoreboard.

In addition, each of the four activity categories has an associated thematic arcade mini-game: Whack-A-Mole (fitness), Thirsty Frog (hygiene), The Frying Pan (cooking), and the Broken Circuit Board (leisure). Whack-A-Mole is a simple mini-game that based on the popular Whac-A-Mole arcade game, where players must tap the moles to gain points before the moles disappear. In the Thirsty Frog mini-game, players earn points by moving a frog (normally placed at the bottom of the screen) to the left or to the right to catch falling rain drops. Figure 2a shows the third mini-
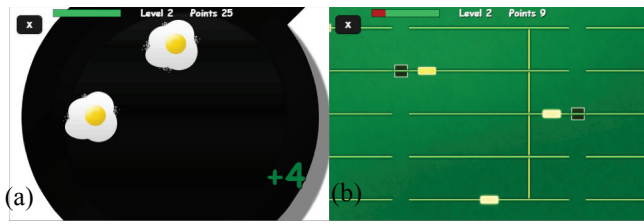
Figure 2: (a) The Frying Pan, (b) The Broken Circuit Board.

game, Frying Pan, in which players must let eggs fry up to 5 seconds to be perfectly cooked and tap of them to gain points for every second the egg has been on the pan and before getting burned. The last mini-game is the Broken Circuit Board (see Figure 2b) in which players must bridge the gaps for sparks that move from left to right to earn points. Players' score in the mini-game influences the number of mood points awarded for completing the activity. Moreover, players can only choose one activity from each category per day to: a) limit how long users can play every day and avoid becoming a burden as well as prevent over-involvement [1], and b) prevent users with more free time from increasing their score too much, which could discourage more casual players from competing.

Engaging in each of the activities costs a certain number of electricity or water resource points. At the beginning of each day, players are awarded a number of resource points based on their actual water and electricity use from the previous day compared to their baseline use (computed from a period before the game started). Since players' actual usage is compared to their baseline usage, they must shift or reduce their resource usage so that they can "share" resources with their buddy. Water use is calculated simply by computing the percentage difference between the number of liters of water actually used and the number of liters used during the baseline period. To account for both reduced electricity use and shifted electricity use, electricity points are actually computed as a comparison of baseline and actual CO_2 emissions. The emissions are computed by multiplying the number of kilowatt-hours consumed by the CO_2 intensity (g CO_2/kWh) of that hour based on the forecast. This calculation results in grams of CO_2 emitted for the baseline period and the previous day, which are compared as a percentage difference. Note that we use the CO_2 intensity forecast for the previous day when computing the baseline emissions, rather than a forecast from the time period that the baseline was averaged over. Using contemporaneous forecasts for the baseline would not make sense, as players had no access to the forecast, so they could not have taken any shifting actions as a result. Thus the baseline emissions calculation represents a prediction of how much the player would have emitted from electricity use for the previous day, based on their past pattern of use.

Each percentage point of CO_2 or water reduction is then converted into an electricity or water resource point. However, only 30 of each point type can be earned (corresponding to a 30% reduction) in order to discourage

players from taking radical and unsustainable actions to earn resource points. If players increase their water or electricity use, or if the sensor data is not available for their apartment, players are awarded a single point each of electricity and water, allowing them to perform at least two activities each day in the game.

These rules establish the following play cycle: players play the game each day, receive resource points based on their resource use from the previous day, and can choose one activity from each of the four categories (if they have sufficient resource points). To encourage regular play, ShareBuddy accommodates short play sessions at any time during the day. The player's 'turn' is then finished, and they can only view the scoreboard, feedback on their resource usage, or the forecast until the next turn starts.

To make a strong link between game play and real-world resource reduction and shifting, the rewards are the main source for player advancement to the next levels. To favor mobility, we optimized ShareBuddy for smartphones, although players can also use desktop computers or tablets.

Feedback in ShareBuddy

ShareBuddy provides a daily hour-by-hour forecast of CO_2 intensity to enable players to plan shifts in their electricity use based on a predicted forecast of the carbon intensity of the national electrical grid, expressed as grams of CO_2 emitted per kilowatt-hour for each of the next 24 hours, obtained from the Transmission System Operator (TSO). This carbon intensity is estimated based on the Danish grid's substantial renewable generation, as well as the predicted amount of imported and exported electricity from nearby grids, each with very different mixes of generation (solar, wind, nuclear, hydro, and fossil fuels). As this forecast is highly dynamic and changes from day to day, it must be communicated on a daily basis, taking into account that the better and worse hours can be different every day. Therefore, our first design decision regarding feedback was how to turn this list of 24 hourly intensity values into a visualization of the favorable versus unfavorable hours for electricity use. One method would be to set an absolute threshold for "greenness", and mark hours under the threshold as favorable, and hours above as unfavorable. Instead, we decided to make the forecast relative for each day: the forecast emission values for each day are sorted in increasing order. Using a relative forecast ensures that for almost every day there are some hours that are better than others, which provides players a target that they can attempt to shift towards. However, if the differences between the hourly emission rates are small, a relative forecast will exaggerate those differences. The final decision was to accept that this exaggeration might encourage players to shift even when the absolute difference between hours is small (rendering shifts ineffectual in reducing CO_2 emissions), since the goal of the game is to investigate whether players are willing to shift as a result of the game.
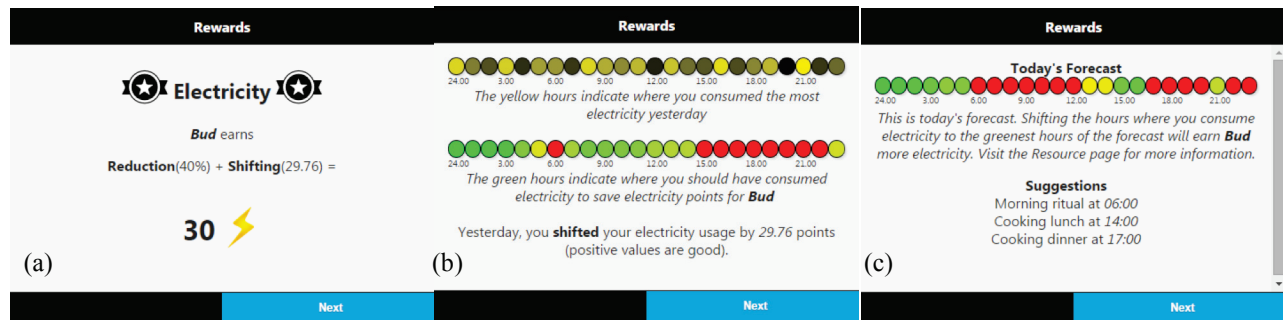
Figure 3: ShareBuddy's daily resource point rewarding process: (a) shows the electricity points being awarded, (b) compares the previous day's forecast with the player's electricity usage, (c) shows today's forecast and provides suggestions when to schedule everyday activities like cooking dinner. (Medal with star icon made by Freepik from www.flaticon.com, CC-BY-3.0.)

Based on the related work and our own experience designing feedback visualizations [9], ShareBuddy provides players feedback on their resource usage in three ways: the daily resource point rewarding process (DRP), the Resource page, and the mini-forecast. The daily resource point rewarding process is the main method for providing feedback in the game. The DRP aims to reward players for reducing their real-life resource usage and for shifting. It takes place at the beginning of each daily turn, as shown in Figure 3, and informs players about how well they are doing at reducing and shifting their resource use, and helps them to plan their activities for the day. First, players are informed of how many electricity and water points they have been awarded, as a result of their resource use (Figure 3a). Second, players are shown how their electricity use from the previous day compares to the forecast for the previous day, providing feedback on when or if they have shifted (Figure 3b). This screen also shows the player's shifting metric from the previous day. Third, players are shown the forecast for the current day, and based on the forecast the game will suggest the best times for three standard resource intensive activities: the morning ritual, cooking lunch, and cooking dinner (Figure 3c).

The Resource page shows the same data as shown in the DRP, but it is available from the main game screen at any time (see Figure 1). Finally, the main game screen shows a "mini-forecast" with three colored circles, representing the current hour and the following two hours from the forecast (see upper right of game screen in Figure 1).

Resource Data Integration
ShareBuddy integrates resource data to enable comparisons by computing a *baseline* of the past resource usage of each player using the sensor data from the dormitory. A baseline is generated by averaging the electricity used by each player during each hour of an entire week (168 hours), from a period going back multiple weeks before the start of game play. We compute the baseline with a granularity of one hour because the essence of shifting is changing the *pattern* of electricity use throughout the day. As Johnson et al. [30] point out, using electricity baselines in a dormitory can be problematic when used to predict future usage, because players' routines can change and increasing or decreasing

trends of electricity use can make an average baseline misleading. To address these baseline issues due to changes in schedule, ShareBuddy generates a personalized baseline for each student apartment, and computes a separate baseline for each day of the week. This method ensures that the baseline will reflect players' schedules, for example if a player stays with their parents on weekends, then the weekend baseline for that player will be much lower than other players. Player's daily reduction in electricity use is then computed by taking the difference between the baseline and actual usage, divided by the baseline.

In addition, ShareBuddy tracks players' hot and cold water use. While water itself may not be in short supply in Denmark, water must be pumped, heated, and treated after use, all of which consume electricity, impacting electricity use. Players' hot and cold water use is combined and baselines are calculated in the same manner as electricity use described previously. The game does not promote any concept of shifting the time at which water is used. Apart from visualizing the forecast and displaying the "good" or "bad" hours to shift (see previous section), ShareBuddy also uses the forecast to compute the degree to which players shifted compared to their baseline. These metrics are discussed in detail in the next section.

Feedback Metrics
As described previously, electricity resource points are actually calculated based on reductions in CO_2 emissions, thereby accounting for both reductions and shifts in electricity use. However, since ShareBuddy was intended to explore encouraging shifting, we wanted a way to provide separate feedback on these two different methods, as shown in Figure 3a. Reduction feedback is easy to compute as just the percentage difference between the baseline and actual number of kilowatt-hours of electricity consumed. As we found no established methods for measuring the degree of shifting in prior work, developing it proved more challenging. The shifting metric should compare the hourly electricity usage to the forecast, since the desired outcome is for the times of highest consumption to match the times of lowest CO_2 intensity, and vice versa. In order to be a *shift*, there must be a change in the pattern of usage from past to current usage. Finally, the metric should capture

whether any shift taking place is towards or away from the desired pattern represented by the forecast.

Our shifting metric takes three arrays of values as input, each consisting of 24 hourly values: baseline electricity use, actual electricity use, and forecast CO_2 intensity. First, we normalize the values, so that the sum of the values of each array equals 100 units. This normalization is necessary, because we are concerned with the shape of the usage curve rather than the magnitude of the hourly values. Without normalization, a uniform reduction in usage compared to the baseline would be recorded as shifting, which we do not want. The forecast is also normalized to ensure that the magnitudes of the forecast values do not affect the shifting metric. Thus, we define the shifting metric as the sum of the differences between the hourly baseline values and the hourly actual usage values, each multiplied by the hourly forecast, as shown in Equation 1.

$$\sum_{i=1}^{24} B_i F_i - A_i F_i$$

Equation 1: The shifting metric defined, where B_i is the normalized baseline usage, F_i is the normalized CO_2 forecast, and A_i is the normalized actual usage, each for the ith hour.

This shifting metric meets our requirements: it tracks the shape of the usage curves rather than their magnitude, shows changes from the pattern of baseline use, and is positive when shifting towards the forecast has taken place and negative when shifting away from the forecast. The larger the shifting metric value, the more shifting has taken place. Unfortunately, the metric lacks an intuitive meaning that can be conveyed to users. For reduction, the metric is the percentage reduction from the baseline, which players can immediately understand, but the shifting metric does not have an equivalent interpretation. Both metrics are included as part of the DRP, as shown in Figure 3a.

Iterative Development and Implementation
Our design process of ShareBuddy moved back and forth between design, implementation, test, and evaluation. All design decisions were based on the related work and on the results and feedback from our diverse studies. ShareBuddy appeared to make a more direct link between real world resource usage and game play as well as overcome the issues from previous concepts. During this iterative process, we got feedback and suggestions on the functionality, vision, and goals of ShareBuddy to revise our prototypes. The current implementation of ShareBuddy is a cross-platform web application with a web service running the game logic. This implementation choice makes the game playable on any device with an HTML5-capable browser, such as smartphones, tablets, laptops, and desktops. As a web application, we avoided the complexity of submitting the game to the relevant app stores, enabling rapid iteration during both the development and field study periods.

System Architecture
The system architecture consists of a game client written in JavaScript running on the user's device, an online web service written in C# running the game logic on the server side, with a database storing user information and the game state. The client on the device provides the user interface and mini-games (see Figures 1 and 2), and it makes calls to the web service to retrieve information (e.g., scores) and to report the results of mini-game play. The client was optimized primarily for use on smartphones for our demographic, but it is also playable on desktop browsers. The web service requests the player's resource data and CO_2 forecast from internal REST services (including WattDepot [6] and Karibu [12]) via HTTP, and stores them in the database. Keeping the main game logic in the web service prevents certain types of cheating, such as selecting activities that the player cannot afford. The entire system was deployed on the Microsoft Azure web platform, enabling resources to be easily scaled as necessary.

USER STUDIES
We conducted two field studies, an eight-day pilot study followed by another over three weeks, to determine whether playing ShareBuddy has an impact on players' resource usage, and also gain a deeper understanding of how players behavior may have changed and why. In this section, we describe the setting for the field studies, the study design, and then the results from the pilot and second field studies.

Setting
We conducted our field studies in a dormitory populated exclusively with students attending different higher educational institutions in the surrounding area. Unlike many dormitories, each room has its own bathroom and kitchen. Designed as a "living laboratory" for research on sustainability and energy, the dorm has been equipped with more than 3,000 sensors, with 10 sensors in each apartment measuring electricity, water consumption, temperature, CO_2 level, and relative humidity. There are 159 apartments with room for more than 200 students. Some of the apartments are intended for two occupants and some single-person apartments actually have more than one resident. Students pay their electricity bill directly to the utility as well as periodically pay for water to the dorm administrators. Players were limited to shifting the electrical loads in their apartments, which included kitchen appliances and plug loads.

We purposefully [38] selected this dorm for several reasons. The availability of the sensor data from resource use in the dorm made it much easier to integrate the sensor data into ShareBuddy. Since the dorm is intended as a living lab, the residents are aware that studies take place in the dorm. We also hypothesized that students might have more flexible schedules compared to people with full-time jobs, making shifting more feasible.

Study Design

Inspired by a recent mixed approach [5], our study combines the quantitative data from an online questionnaire as well as game logs and sensors, with qualitative data from and semi-structured interviews [32] in order to triangulate [33] on the impact of ShareBuddy on players.

During the field studies, we gathered four types of data: a log of all actions taken by players in the game, hourly electricity and water data both from before and during the field studies, results from an online questionnaire provided to all players at the end of each study, and results from the semi-structured interviews with players and non-players. The questionnaire touched upon aspects about the game regarding enjoyment, difficulty, motivation, understanding of shifting (e.g., "on the forecast shown, which hours are best for electricity use?"), and behavior changes (e.g., "the game made me try to shift the time where I spent my electricity usage"). Most of the questionnaire consisted of statements on a 5-point Likert-type scale ranging from "strongly disagree" (represented as 1) to "strongly agree" (represented as 5). The semi-structured interviews were conducted as part of an overall project study of energy consumption and life at the dorm with specific questions about ShareBuddy, such as asking interviewees to explain the concept of shifting in their own words, and asking for examples of activities they had shifted (if any). All the collected empirical material has been translated to English.

To assess the impact of ShareBuddy quantitatively, ideally we would have randomly assigned participants to either an intervention group (playing ShareBuddy) or a control group (not playing ShareBuddy). However, because ShareBuddy had a noticeable presence in the dorm through recruiting posters and a kickoff event, and because players could win prizes, we felt it was not feasible to assign some residents to a control group that could not play. Therefore, we applied a quasi-experimental design approach with non-randomized group assignment [15]. Indeed, residents self-selected whether they were in the intervention or control group by whether or not they chose to play ShareBuddy. We decided against a within subjects design because of the variations in resource consumption commonly found in competitions [30]. To enable any resident to play ShareBuddy, we created user accounts for all residents in the dorm (linked to the resource usage data from the sensors in each apartment) based on a roster received from the management company that maintain the building.

Pilot Study

The pilot study of ShareBuddy was conducted over eight days in the fall of 2014. The study took place during a non-typical time in the dorm due to some external constraints. Because of problems with accessing historical resource data, we were limited to calculating the baseline resource use as an average of the two weeks just prior to the study. We also faced some external technical problems with our cloud database provider that affected reliability and performance. We offered gift cards to the top three highest scoring players worth approximately 50, 35, and 15 US dollars. After the study period finished, we asked players to fill an online questionnaire and interviewed players that received gift cards as prizes.

ShareBuddy 2 Field Study

While the pilot study demonstrated that the ShareBuddy game design could convince some residents to play and enjoy a game that integrated their resource use into the game, the results regarding shifting were disappointing. Most players did not understand the concept of shifting, no players indicated that they had tried to shift, and the average shifting metric for heavy players was almost identical to non-players (see details in the next section).

Based on the results of the pilot study, we revised ShareBuddy in several ways, resulting in "ShareBuddy 2" (SB2). SB2 was redesigned to emphasize the shifting concept and forecasts even further through: the addition of the mini-forecast, explicitly displaying the shifting metric to players, and integrating the forecast into the daily rewarding process (see Figure 3), none of which were present in the original ShareBuddy. We also made technical changes to improve stability and device compatibility. The baselines of resource use were calculated as an average of the 6 weeks prior to the competition. We also improved several aspects of the deployment of SB2 in the dormitory. This field study was conducted for 21 days, and timed to avoid vacation and exam periods. In addition to a prize for the highest score, we awarded a prize to the player who shifted the most, and a prize to a player selected at random with one chance for each day played. Each prize was a gift card worth approximately 35 US dollars.

STUDY RESULTS

We present the results from the two studies regarding the game play itself, the assessment of how ShareBuddy increased awareness, and the impact on resource use.

Pilot Study Results

A total of 32 residents played the game (18% of the 181 known residents at the time). We categorized players as heavy if they played at least half of the possible days (4), and the remaining players as light. There were 17 heavy players and 15 light players. Regarding the online questionnaire, we received 10 responses and interviewed two players after the study who ranked second and third highest in the game and received gift cards as prizes.

Based on the questionnaire responses, players perceived ShareBuddy as a fun game ($\mu = 3.8$, $\sigma = 0.6$) and would recommend the game to others ($\mu = 3.7$, $\sigma = 0.5$), despite the technical issues experienced during the competition described earlier. In addition, the respondents reported that incorporating resource usage into the game made it more fun ($\mu = 4.0$, $\sigma = 0.8$). Players were primarily motivated by winning prizes ($\mu = 4.5$, $\sigma = 0.7$), and competition with other players ($\mu = 3.9$, $\sigma = 0.9$), and neutral towards

resource reduction and playing the mini-games (both μ = 3.1, σ = 0.7 and 1.1).

Resource Awareness and Understanding

Similarly to the questionnaire respondents, participants from the interviews also highlighted the importance of the data integration feature. For instance, one interviewee said: "*I really liked the interaction with the real world, that what I did in the real world had an influence on the game. Usually, what you save disappears, but in this game you could actually use what you saved.*" However, only 40% of questionnaire respondents said that ShareBuddy made them aware of their resource usage. In a question comparing electricity usage to a forecast (as needed for shifting), only 30% of players could correctly determine if most of the usage matched the forecast.

Impact on Resource Usage

50% of questionnaire respondents indicated that the game had made them try to reduce their electricity use. And players' electricity use fell during the game period compared to the baseline by 27% for heavy players, and 26% for light players. However, the electricity use of non-players fell by 33%, more than either heavy or light players! It may be that non-players were more likely to be spending more of their time outside the dorm (because of exams or vacation), while players were more likely to be present at least part of the period, or they would not have been able to hear about and start playing the game. From this study, it is not possible to conclude that ShareBuddy encouraged players to reduce their electricity usage.

Regarding shifting, in the questionnaire, no respondent agreed that the game had made them attempt to shift (μ = 2.2, σ = 0.8). Indeed, in the interviews with two of the top scoring players, it was clear that shifting was not part of their strategy. One interviewee said, "*I didn't know how to shift. I didn't even know there was a Resource page... I first learned about it from the questionnaire.*" Apparently players found it possible to obtain high scores without even understanding the shifting concept. While the average shifting metric across the heavy players (-3) was not as bad as the values for light players (-22) and non-players (-25), given the data from the questionnaire and interviews, there is no way to conclude that players shifted as a result of ShareBuddy in the pilot study.

ShareBuddy 2 Field Study Results

There were a total of 30 players during the SB2 field study (16% of the 186 known residents), of which 15 had played before during the pilot study. As in the pilot study, we categorized players as heavy if they played for at least half of the possible days (11), and the rest as light players. There were 16 heavy players, and 14 light players. The light players were particularly light: of the total of 313 game days played, 92% were played by heavy players. There were 12 respondents to the questionnaire at the end of the competition, 5 of which had responded to the pilot study questionnaire. All the questionnaire respondents were heavy players, which is expected since the questionnaire was provided through the game and a post on the dorm's Facebook group. In addition, we interviewed 19 residents at the dorm, 11 women and 8 men aged 21–28, all of whom were students at institutions of higher education. Of those interviewed 6 were heavy players, 4 were light players, and 9 had not played the game at all.

As a casual game, SB2 play sessions continued to be short, with median length of 5 minutes for heavy players, and 2.5 minutes for light players. Questionnaire respondents found SB2 fun (μ = 3.6, σ = 0.7), but fewer would recommend the game to others (μ = 3.3, σ = 0.5). However, respondents did continue to find that incorporating resource use made the game more fun (μ = 4.2, σ = 0.6). The most important motivations for players remained winning prizes (μ = 4.3, σ = 0.6) and competition (μ = 4.2, σ = 0.9), and reducing resource use and playing the mini-games deemed unimportant (both μ = 3.1, σ = 1.2).

Resource Awareness and Understanding

SB2 did seem to improve players' awareness of their resource usage, and understanding of shifting compared to the pilot study. Questionnaire respondents indicated that the game made them more aware of their resource use (μ = 3.9, σ = 1.1). There was also interest among residents who did not play the game, as four non-players who were interviewed stated that they were not interested in the game, but would like to be able to view their consumption data and the forecast information outside the game context.

Unlike participants from the pilot study, SB2 questionnaire respondents were much better at matching a visualization of electricity usage to a forecast (μ = 4.7, σ = 0.7), and all respondents were able to determine from a forecast which period was the best time to use electricity. In interviews, most participants (including light players and non-players) were able to articulate what the concept of shifting meant. However, one interviewee still confused reducing electricity use and shifting electricity use.

Impact on Resource Usage

SB2 attempted to impact players resource use in three ways: reducing electricity use, shifting electricity use, and reducing water use. 58% of questionnaire respondents indicated that the game made them try to reduce their electricity use. During the competition period all three categories of resident increased their electricity use compared to the baseline period (heavy players 3.1%, light players 7.7%, and non-players 6.7%). While heavy players electricity use did increase less on average, the difference is small and the standard deviation is large (σ = 29.5). In particular, some players did make a concerted effort to reduce, for example, the player with the highest score moved in with their significant other in the dorm for three days in the final week of play. However, in interviews no player was optimistic that they would maintain any changes in habit after the competition was over.

Shifting was even less popular with players. Questionnaire respondents indicated that the game did not make them shift ($\mu = 2.7$, $\sigma = 1.5$). The average shifting metrics for the three categories of players were small (heavy players = 32.3, light = 2.1, non-players = −14.6). While heavy players again showed better results than the light players and non-players, the questionnaire and interview results call into question any substantial shifting as a result of the game.

In interviews, players and non-players agreed that shifting was too difficult, and that many people have fixed schedules that prevent them from shifting. For example, one interviewee said that his work schedule prevents taking a late lunch, so he would be unwilling to eat a later dinner even if the forecast recommended it. Some interviewees suggested they could potentially be willing to shift if it fit into their other plans. Only two interviewees indicated that they had actually tried to shift their electricity use. For instance, the player with the highest score said "*Sometimes it showed that it would be a good time to cook dinner at 4, then I thought, I don't want to do that, and then I just didn't. Other times, maybe you had to wait until 8 o'clock and then I thought – Ok, I can do that... Sometimes!!*" Further, the player who won the shifting prize was unsure why she had won: "*I have just been lucky, I think*". She said she had cooked dinner three times during the green hours, but "*otherwise I think it has just fit in well with my daily rhythm.*" She also believed that leaving her apartment for two weekends might have helped as well, which is possible depending on when she left and her baseline usage pattern.

Overall, the SB2 field study continued to attract players, though with a little less enthusiasm compared to the pilot study, possibly due to the longer competition period. SB2 did seem to increase awareness and understanding of shifting among heavy players, but it appears that very few players actually tried to shift their electricity use, in part because of the lack of flexibility of their schedules.

DISCUSSION
Based on our two field studies of ShareBuddy, we identify and discuss three types of challenges of interest to designers and researchers working on motivating shifting and building games around resource usage data: the challenges of 1) shifting, 2) maintaining interest during sustained game play, and 3) designing games around resource usage. We also discuss new directions for this research.

The Challenges of Shifting
As shown in our field studies, motivating users to shift their electricity use is difficult. Shifting requires users to have an in-depth understanding and knowledge [28] of how electricity is generated, something that most people do not think about. It also requires users to consult a new information source: the forecast. Players in our pilot study found this challenging, as shown by this quote from the free response question in the questionnaire: "*I do not understand the shown picture. Which line is the player and which is the forecast? And what do you mean by forecast?*"

SB2 seemed to improve players understanding of shifting, and most interviewees (including energy-aware non-players) could articulate what shifting was. However, the interviewees did not see shifting as something that was compatible with their daily lives, except for two players who made it clear they had shifted a few times for the game and did not plan to continue to do so. Understanding shifting does not seem to be a gateway to actually shifting for our user population. In fact, shifting electricity use is fundamentally challenging because it requires people to change the pattern of their everyday lives, and make those changes dynamically based on a forecast. Our findings show that reducing electricity use is simpler than shifting because it is not time-dependent. For example, choosing to reduce electricity use by drying clothes on a rack rather than in a tumble dryer is a new habit that can be incorporated into daily routines. While drying on a rack takes more time, that fact can be incorporated into one's daily schedule on a permanent basis. In contrast, our studies show that trying to shift the use of a dryer to a "greener" hour is not something easily integrated into habits.

These challenges of shifting transcend the game-based method we have chosen to encourage shifting, and show the difficulties that will be faced by any behavior-focused shifting intervention. Combining information-based methods with automation of shifting through smart appliances and pricing incentives is one possible direction, though these still face challenges [8].

The Challenges of Maintaining Interest Over Time
The main goal of game-based approaches is to build a system that can make an activity more enjoyable and fun [35] in non-gaming contexts to improve the user motivation and engagement [18, 19]. For a game such as ShareBuddy, the goal is for players to understand shifting and further change their habits and practices, and for those changes to persist after players stop playing the game, rather than only focusing on the "fun factor" [35]. When users play the game, they should be able to understand how the rules of the game relate to shifting and reduction over time providing them with a positive experience. This goal creates challenges for game designers, because the game should reward consistently maintained changes (such as reduced or shifted resource use), as we do through the mood point system in ShareBuddy. But this accumulated point system makes it difficult for other players to "catch up" to the top players, especially for less frequent players, reducing the motivation from competition. One way to address this issue is to break the competition into smaller rounds, so that players who might not be able to win the entire competition could still try to win some rounds, as done in the Kukui Cup energy challenge [9]. In our field studies, the top players could win prizes.

However, for players who are primarily motivated by competition with others, and have no strong interest in changing their resource usage, games may simply not be an

effective way of encouraging changes. An overemphasis on extrinsic motivators like competition could be detrimental to user's intrinsic motivation [17]. Designers should account for the potential dangers of over-engagement and consider implementing features that may prevent it [35]. In some cases, designers should decide whether or not gaming is the most beneficial approach for a specific target group.

The Challenges of Integrating Resource Usage Data
Resource usage data is sensitive, for example, it can be used to infer the employment status of residents [3]. Therefore, it is important that games incorporating resource usage data use some sort of authentication to ensure that only the residents of a home are able to view their resource usage data. Authentication makes the "onboarding" experience for a casual game more difficult, because players must be provided their username and password through some secure out-of-band method. For our studies, the credentials were printed and either handed to players at a kickoff event, or placed in their mailbox. Another possible solution would be to use a common sign-on system (as is common in many schools and companies) to authenticate users, as long as the mapping of accounts to homes is known in advance.

Collecting real-world resource data also introduces problems for games like ShareBuddy, as the data can often be missing, delayed, or inaccurate. While the game system must be robust in handling these situations (e.g., not crashing), unlike other applications for the sensor data, these "expected" data problems must be integrated into game play. For example, when resource data is unavailable for an apartment, how should a casual game like ShareBuddy handle the daily resource rewarding process? In our case, we decided to provide a default reward of 1 point when data was unavailable for any reason, thereby allowing a player to at least play one mini-game during that day. Any game using resource data will need to decide how to handle these kinds of data errors. Overall, our study shows the importance and the positive effects of integrating real resource data into a game to facilitate the understanding of shifting and reducing electricity use.

Limitations and New Directions
In our user studies, we faced some limitations in how much players could shift based on the infrastructure of the small apartments in the dormitory. The activities with the most shifting potential were interactive, such as: cooking, watching TV, or playing on game consoles, and players were understandably reluctant to change the schedule of those activities. However, ShareBuddy could also be tested in single-family homes, which usually have more options for non-interactive shifting, such as: electric heating and cooling, dishwashing, and clothes washing and drying. While dorm residents were motivated by competition with other residents, homeowners might be more interested in competing with their own past performance, rather than other homeowners. As more homes incorporate renewable energy generation (e.g., photovoltaic panels), ShareBuddy

might be used as a tool to help those homes shift their electricity use to better match personal electricity generation.

Two problems became clear from our work: players will focus on reduction over shifting if given the choice, and the comparison to a baseline (as discussed by Johnson et al. [30]) makes game play and data analysis more complicated. A solution to these problems would be a game where players are rewarded based solely on how well they can match their electricity usage to a forecast, thereby focusing only on shifting without any comparison to past usage.

When discussing the concept of shifting with players in interviews, four people indicated that shifting was too hard because it would interfere with their existing schedule. One way to address this concern would be to adopt an approach that focuses on understanding the everyday practices of residents [20] to develop technological interventions. These practices are often tightly interrelated, as exemplified by a player who expressed that he felt he could not eat a later dinner because his lunchtime was fixed by his job schedule, and was thereby *non-negotiable* [20, 42]. Rather than focusing on individual behaviors, interventions could support the planning and coordination of everyday practices by integrating a daily planner so players could see how the forecast could fit into their practices over the day. Planning could also be extended beyond a single day to facilitate shifting tasks across days.

CONCLUSION
We have presented ShareBuddy, a casual, mobile game designed to encourage players to reduce and shift their electricity use to better match the needs of the electrical grid by incorporating forecasts of grid CO_2 intensity into the game. Through two user studies in a student dormitory, we found that while players enjoyed the game and it led to increased understanding of the shifting concept, it did not lead to significant shifting of electricity use. We discovered that convincing players to shift was more difficult than getting them to reduce consumption, due to the added complexity of the dynamic forecast combined with their existing daily schedules.

Although addressing the challenges presented in this paper might require a considerable investment due to the infrastructure needed to collect resource data, designers and developers must consider them when developing sustainable interventions that combine games with eco-feedback technologies.

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