GroupEnergyTable: An Interactive Tabletop for Energy Conservation

The GroupEnergyTable is an interactive tabletop that lets users explore shared electricity and transportation data, view energy tips, and set goals. A two-month study shows how the GroupEnergyTable can help decrease electricity use and change travel habits.

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Pervasive computing can help people reduce their energy consumption through increased awareness. Mobile devices are increasingly powerful and can sense and store significant amounts of energy-use data. Newer mobile phone models, containing accelerometers and GPS, can automatically sense motion and detect activities. Furthermore, ubiquitous computing sensors, such as home energy-monitoring sensors embedded in the environment, can gather large amounts of useful data.

Previous work illustrates the effectiveness of giving individuals feedback on mobile phones to encourage green behavior[1] and physical fitness.[2] (For more information on energy-use feedback methods and how they motivated our work, see the sidebar.)

However, providing feedback in a group setting can be more challenging. Mobile devices usually have small physical input and display spaces, so they're difficult to share among groups. Yet situations in which small groups consume shared energy resources are fairly common—for example, in a household or small office. People in groups share control of their environment, so they often have trouble determining their portion of the group's overall footprint. Being part of a group can also diffuse responsibility, making people less likely to take ownership of their usage. Changing group expectations is necessary for a sustained reduction in energy use.[3]

Setting shared goals and improving communication are important. Furthermore, group buy-in is essential to change energy allocations and encourage the group to take action. Ensuring that group members feel as though they're an equal partner in the decision-making process helps build consensus.[4] Also, involving them in the problem-solving process increases their commitment—and contributions—to the solution.[4]

Compared to mobile devices, digital tables provide a larger display for exploring and sharing sensed information in groups. Combining information from smaller individual devices with the larger form factor of interactive tables lets groups view collected data. Furthermore, the table form factor is well suited to consensus building because it provides equal access to information and shared data. Our GroupEnergyTable can support group exploration of home electricity and transportation data, encouraging users to reduce their resource consumption.

The GroupEnergyTable

We envision people using the GroupEnergyTable as an intervention measure during changes in their lives, such as when they move or buy a new appliance. The GroupEnergyTable uses detailed home electricity data (gathered from a home-energy monitoring system) and transportation

Published by the IEEE CS ■ 1536-1268/12/$31.00 © 2012 IEEE

Related Work in Energy-Use Feedback

There's mounting evidence that real-time feedback can effectively remind people to monitor their consumption and help them with their conservation efforts,[1] but not all methods of feedback are successful. Corinna Fisher surveyed 21 conservation feedback studies and identified best practices from the most successful ones.[2] This metastudy showed that improvements can range from 1.1 to 20 percent, but that the average improvement falls between 5 and 12 percent. Fisher found that all successful feedback projects had computerized, interactive energy feedback that let people explore their own data in their own way. The successful projects also had a detailed, appliance-specific breakdown of where the energy was being used.

For the GroupEnergyTable, we chose to focus on the effect of a one-time exploration of data. Monthly or bimonthly bills are the most common source of feedback today. Less frequently, people request home-energy audits to get more detail on their energy use.

One feedback approach is to provide *comparison points* that put the information in context. Normative comparisons compare users' consumption against others and can lead to a decrease in consumption for above-average users—but can increase consumption for below-average users.[3] We didn't use this approach, because the energy use of those participating in our GroupEnergyTable study was less than average. Another reason for not including normative comparisons is that people can be distrustful of the selection group and the reporting method.[4]

Historical comparisons have been positively received by consumers and are a common feature on many bills.[4] It seems valuable to give people a long-term view of their use. However, historical feedback seems likely to stimulate conservation only when use has risen.[2] We didn't include more than one month's historical information in our system because it wasn't available, but it would be valuable to include this information in the future.

Goals are another comparison point. Goal-setting theory and multiple experiments have shown that setting challenging goals can be effective,[5] and there's some evidence that this effect is even higher for groups than it is for individuals. Studies also show that a difficult goal is more effective than a small one.[6] Goals can be a valuable reference point, and providing goals in addition to feedback is more effective than feedback alone.[6]

In addition to providing information and setting goals, it's necessary to give people paths to achieve energy conservation.[1] Giving *actionable feedback*, such as specific energy-conservation tips or how-to guidelines, helps link opportunities to action.

Wokje Abrahamse's survey of 38 studies found that combinations of interventions more effectively reduce energy use than single approaches.[6]

We took notes from various successful projects and theoretical approaches, combined them with our desire to support group discussion, and decided on the following GroupEnergyTable design goals: encourage group collaboration, provide computerized and interactive feedback to encourage exploration, offer a personalized breakdown of current use at the category and appliance level, provide conservation how-to tips, and enable goal-setting and commitment.

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data (collected via mobile devices). The purpose is to provide groups with a better understanding of their current usage to help them identify wasted energy (see Figure 1). The system can help set group and individual conservation goals based on the benefits of potential actions.

The GroupEnergyTable comprises two components: the home energy view and the travel energy view. Both views let users explore their data, receive related tips, and set goals. The home energy view displays shared home electricity data, measured in kilowatt hours (kWh; see Figure 2). It breaks down information by appliance category—including home heating, hot water, cleaning, cooking, refrigeration, and small appliances. The travel energy view displays individual transportation trip data, measured in miles (see Figure 3). It breaks down data by mode of transport, such as car, carpool, bus, bike, walking, or other travel.

Viewing Data

Participants can view daily and weekly graphs of their consumption by touching icons located in the table's center that represent different categories. Touching the table's center icon will show overview graphs of all consumption from home or transport.

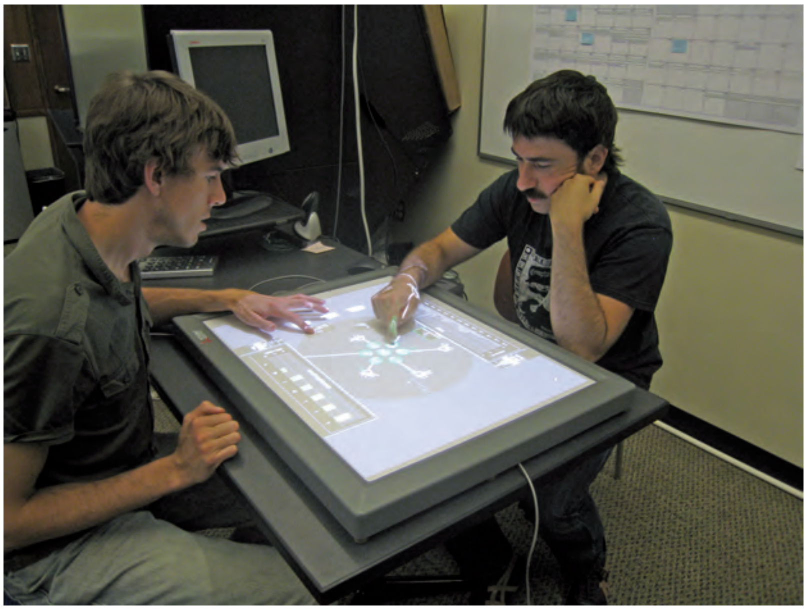

Figure 1. The GroupEnergyTable. It supports group exploration of home electricity and transportation data to encourage users to reduce their resource consumption.

One design goal was to accommodate viewing from multiple directions. Accordingly, the central shared visualization is orientated outward. Individual personal spaces are oriented toward a person and located directly in front of that person. When clicking on an icon, the requested data appears directly in front of the person who clicked on it. The travel energy view is based on individual data, and so clicking on an icon in that view shows that person's data, while a similar action in the home energy view would show shared data.

Conservation Tips

The GroupEnergyTable application suggests contextually relevant conservation tips related to specific categories (such as the "car" category). A group member can drag a particular tip (such as "keep your engine properly tuned") to one of three classification bins—"already do," "will do," or "no" (see Figure 3).

Dragging tips to a "will do" bin generates a list of tips to take home. We chose to use shared bins rather than individual buttons to make the tip selections visible to other users and more collaborative.

Setting Goals

The length of the line radiating from the icons represents the monthly consumption in kWh or miles. The lines end in a plug in the home energy view and a gas-pump handle or flower for the travel energy view, illustrating whether the category uses electricity or gas or has no emissions.

Goals are set by selecting this handle and dragging it to shorten the line. A dot shows the starting point (current use) so users can see how ambitious their goal is. Dragging the handle also shows how new goals will affect the overall carbon dioxide (CO_2) output per month, represented by the dark circle in the background. CO_2 is calculated based on the number of kWh or miles from the line lengths.

Implementation

We implemented the table software in Java using the DiamondSpin Toolkit,[5] and we used the Mitsubishi Electric DiamondTouch interactive touch table,[6] distributed by Circle Twelve. The DiamondTouch table is a top-projected tabletop surface. It has rows and columns of transmitters in the table's surface. When a person contacts the surface, the signal travels through the person's body and into a pad on his or her seat. This supports multiuser identifiable input.

People can touch the table icons to view data, and they can drag tips across the surface. Output is displayed on the table through a projector attached to the computer.

User Study

We performed a two-month combined in situ and laboratory study that explored shared interaction for understanding transportation and home energy use. We studied three homes, with two participants per home. The study comprised three sessions: installation, table usage, and sensor removal.

During the initial session, participants completed a background survey and were asked about their previous efforts to reduce energy use and their current understanding of their consumption patterns. We then installed The Energy Detective (TED) system (http://theenergydetective.com) and a monitoring laptop to track home electricity use, and we gave participants mobile phones so they could log travel events. For one month, we collected baseline home electricity and travel event data.

The second session took place in the lab. Participants were given a brief introduction to the DiamondTouch table and the use of the GroupEnergyTable. Participants used the home energy view first and then the travel energy view, both of which showed their collected data from the first month. We asked participants to explore the graphs of their data from month one, classify the tips listed under each category, and set new goals. After using each view, we asked them to complete a survey with their reactions to both the interface and their data. Finally, we interviewed them as a group.

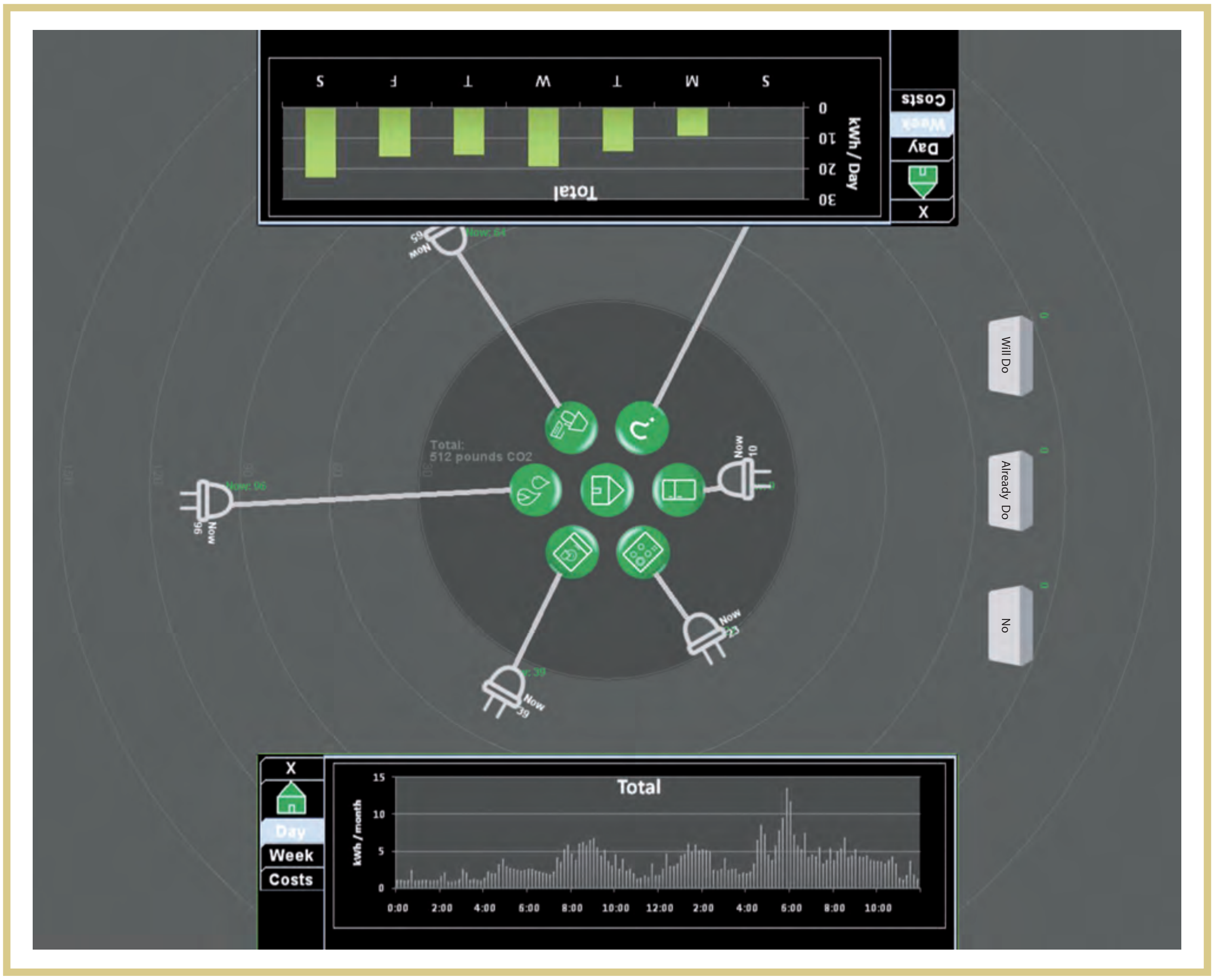

Figure 2. The GroupEnergyTable's home energy view. It displays data for the day and week, measured in kilowatt hours (kWh).

During the next month, we continued to collect home and travel data. In the final session, we removed the sensors and surveyed and interviewed the participants.

Participants

Our participants were three couples living in the Seattle area, all interested in reducing their carbon footprint. *Household 101* lived in a 1,500 to 2,000 square-foot two-story house built in 2001, with natural gas home and water heating. *Household 102* lived in a 1,000 to 1,500 square-foot one-story house built in 1925, with electric heat and hot water. *Household 103* rented a 1,000 square-foot 1960s apartment with electric home and water heating. Participants of the first two households had their own cars, while household 103 shared a vehicle. Gas mileage ranged from 21 to 30 miles per gallon.

Five participants wanted to reduce their energy consumption to improve the state of the environment. Those same five said that personal cost savings were also an important factor in choosing to reduce consumption. All six participants shared a concern for the well-being of future generations, while only one participant said that status among peers and friends was a reason for reducing consumption.

Home Data Collection

We monitored home electricity use with the TED system, installed in each home's circuit breaker box to detect real-time energy use. We used the TED API and a Perl application to log the data to a laptop every second. We used Clearwire Internet devices and, in one case, the participants' own Internet for continuous remote monitoring.

We measured three kinds of electricity data:

- 10-minute totals over the course of a day,
- daily totals over the course of a week, and

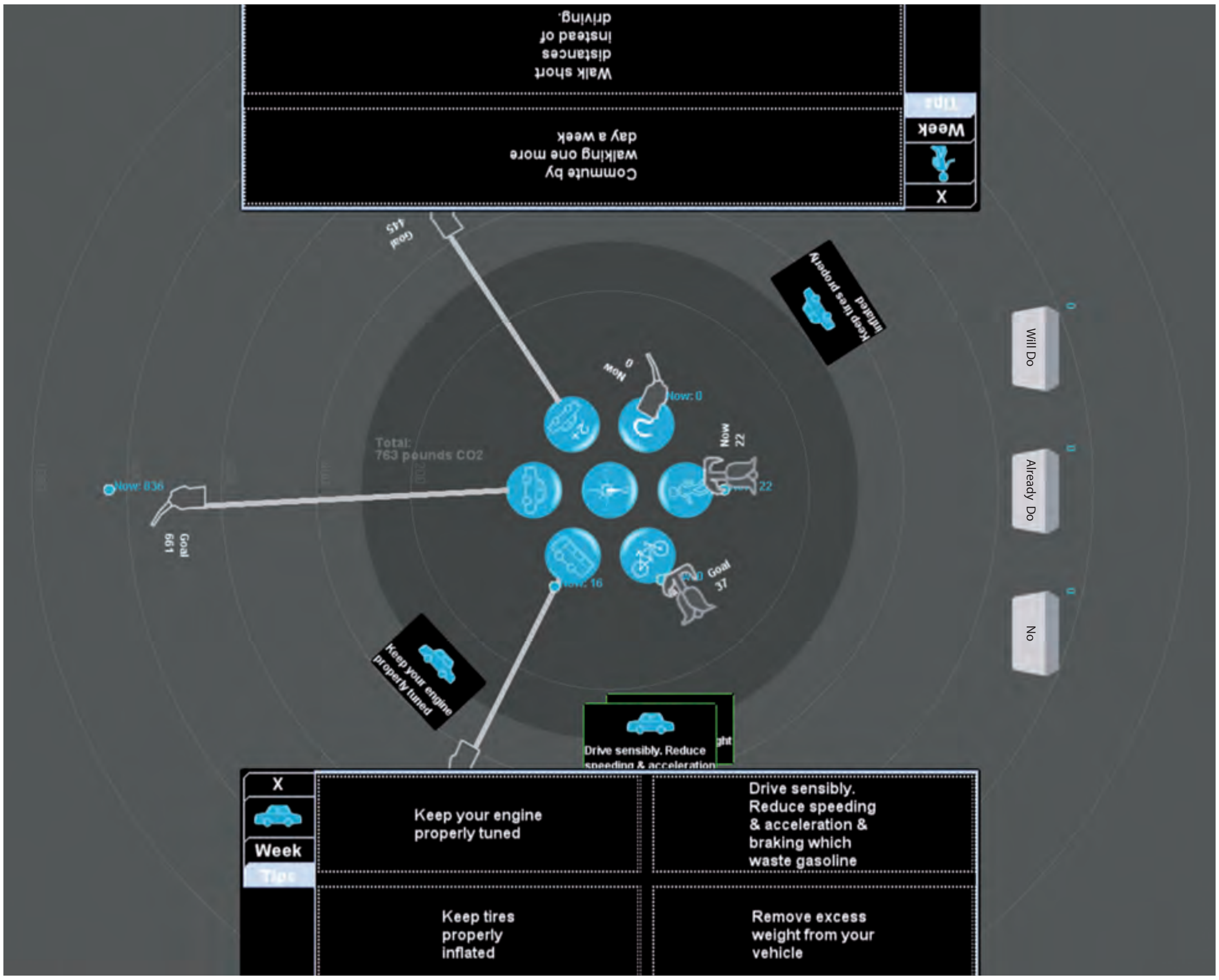

Figure 3. The GroupEnergyTable's travel energy view, which presents related conservation tips. The transportation data is measured in miles.

- activities broken down by appliance type.

We determined the appliance breakdown using the difference in power draws between clearly differentiable appliances. Many large devices, such as dishwashers and hot water heaters, have different power draws. We performed a calibration test to determine the power use of each major appliance in the home, including the microwave, stove, oven, toaster, refrigerator, hot water heater, electric lawnmower, dishwasher, clothes washer, clothes dryer, hair dryer, and iron. When there's a power change, we detect an event and determine the likely appliance within a given threshold.

We focused on detecting large loads (more than 300 watts), which are more significant consumers of home energy. Very small appliances, such as light bulbs and light fixtures, were difficult to detect accurately because their power usage was less than the noise floor for large loads such as ranges, dishwashers, and water heaters. Some appliances, such as dishwashers and clothes washers, have multiple states, so they can be more challenging to detect. We couldn't accurately detect multiple events, such as someone starting the microwave and toaster in quick succession, or quick events that lasted only a couple of seconds.

In households 102 and 103, we have "high" confidence that the system correctly detected events 81 and 84 percent of the time, respectively, and we have at least "moderate" confidence in the detection for 92 and 99 percent of events, respectively. In household 101, 64 percent of the detected events were of low confidence. The differences are likely because of the different electrical appliances in the various homes. Household 101 didn't have many of the high-confidence appliances such as an electric hot water heater, dehumidifier, electric range, or electric oven. We confirmed the weekly and daily home energy information presented in the home energy view using billing information and meter readings.

Transportation Data Collection

The participants manually monitored their transportation use. We used Cingular 2125 smartphones running Windows Mobile 5, and the MyExperience Toolkit[7] triggered surveys when people took a trip. The phone detected trips by looking at the GSM towers within the phone's range. When the visible towers changed, the phone detected a trip. When the towers stopped changing, the phone presented the survey. A participant could also pull up a survey manually if the automatic trip detection failed.

The survey presented three questions via a text interface:

1. What was your mode of travel?
2. What was your destination?
3. How many miles did you travel?

The answers were multiple-choice, such as car, bus, bike, or walk, and home, work, or other?

All participants reported reliably logging their trips, although sometimes they would log them at the end of a series of errands or at the end of the day. Multiple sets of participants mentioned that participating in the study in pairs made it easier to follow through, because they'd remind each other to complete the surveys.

Results

Harold Wilhite and Rich Ling postulated that "feedback" leads to "increased awareness or knowledge, which leads to changes in energy use behavior," thus leading to a "decrease in consumption."[8] Using this theory and based on the GroupEnergyTable's design goals, we evaluated the table's ability to perform the following functions.

Support Interaction and Engagement

Four of the six participants referred to the interface as "fun" or "like a game." Participant 102B said it was "a lot more fun than sitting around for an hour and a half looking at a computer screen," and participant 101B said it was "easy to use."

Half of the participants also liked the data presentation—especially for the tips. The table's physical nature and the need to classify the tips made the participants feel more committed to the action than if they'd just read the tips on a website. Participant 102A liked that you had to "make goals or make choices and take the tips and [do] something with them." Participant 102B felt that because "you have to actually move [the tip] into the bin, you have already taken the first step [in making a change]."

Encourage Collaboration and Consensus

Having participants collaborate around the table helped them come to a consensus regarding energy tips. Five of the six participants liked the shared interface and ability to explore the data collectively.

According to participant 103B, "it really did make us talk more, especially since we were sitting across from one another." Participant 101A liked that the table encouraged cooperation: "We could look at our shared info and make decisions together when it was house stuff, but we could make individual decisions for the transportation. When it's a computer, it can feel a little too much like only one person is driving." Participants thus appreciated the collaborative aspects, but two of them also liked having control over their own area and actions. Participant 103A said, "I liked having the ability to have and control my own view of the statistics."

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Increase Understanding

Before the study, participants correctly identified their top energy uses in their homes 55 percent of the time. After using the home energy view, this increased to approximately 77 percent. Also, almost all of the participants reported learning something new about their home energy use. For example, one household didn't know that the hot water heater required so much energy, and two households expected the refrigerator to consume more electricity than it did. Members of household 101 were surprised by how much electricity they used late at night, but they figured out it was because they start the dishwasher and dryer just before they go to bed. Three participants said the system made it easy to identify where the most energy was consumed so that they could better determine what changes to make. As participant 102B said, "It's interesting to finally get to [see] where you get the most bang for your buck, like the water heater."

All participants identified the car as their major cause of CO_2 use for local transportation. Only one participant (101A) mentioned learning something about transportation: "I thought of my commute as being short because it's only like 5 miles, but it doesn't take much for the miles to add up. It [my CO_2 use] is a lot higher than I expected it to be."

Half of the participants liked that the data and tips were categorized and broken down into various areas. According to participant 101B, the table was "easy to use [and had] good categorization of power usage profiles [and] good tips per

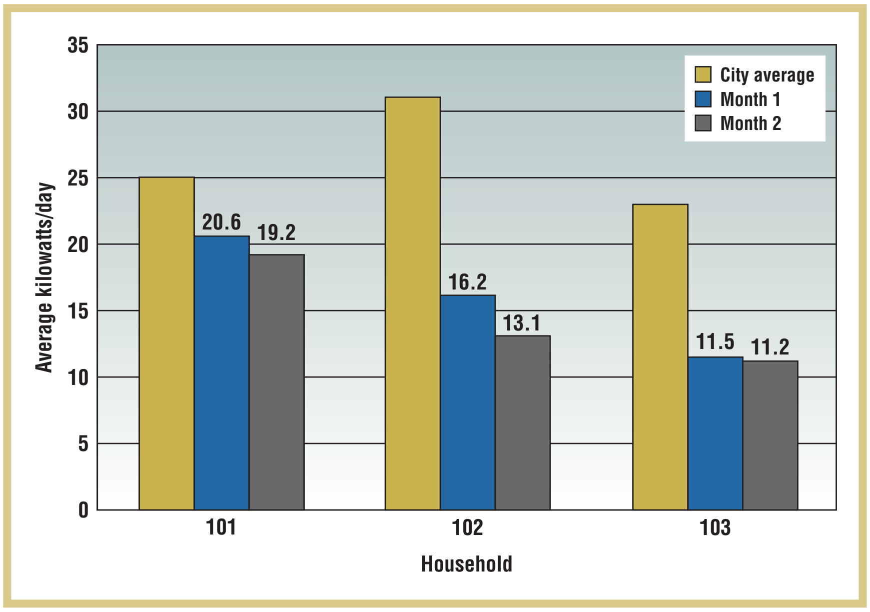

Figure 4. Home electricity consumption. All participants decreased their electricity use after using the GroupEnergyTable. Households 101 and 102 had significant drops.

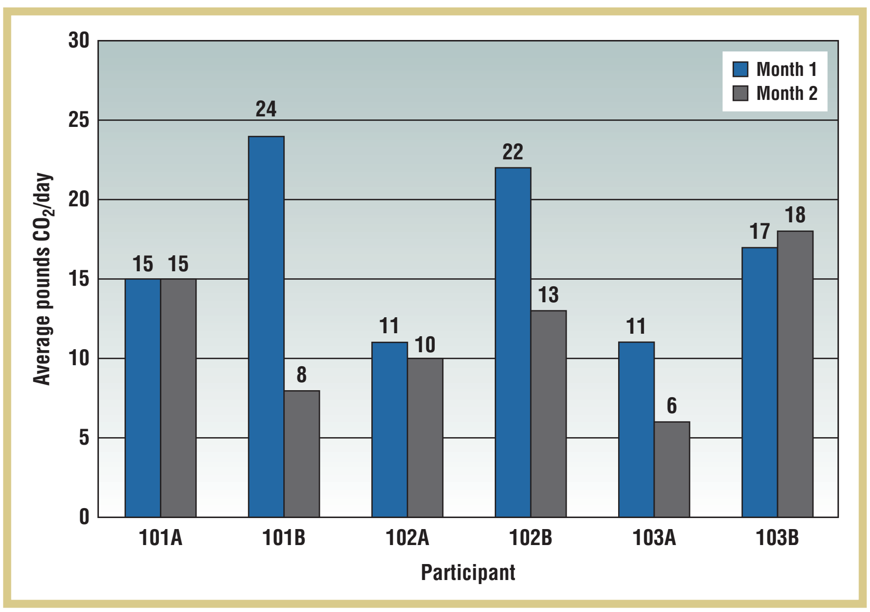

Figure 5. Transportation consumption of CO_2. Five out of six participants reduced their CO_2 production.

category." A couple of participants also mentioned liking the center circle's representation of the overall CO_2 output.

Encourage Actions and Change Behaviors

Although it's difficult to show long-term behavior change in a study as short as two months, many of the participants reported changes in their actions during the study's second month. In household 101, the participants mentioned being more conscious of not leaving things on when they left the room. For instance, they reported making an effort to turn off fans or lights when leaving. Household 102 made significant efforts: they turned down their hot water heater's temperature and adjusted the setting on their fridge. They also made an effort to line-dry more clothes. Household 103 reported being more conscious of their energy use, reducing their hot water use and unplugging electronic devices when not in use.

Participant 101A reported biking and walking more in the second month when going short distances, and participant 101B tried taking the bus to work instead of driving. Participant 102A committed to biking more, and both 102A and 102B tried to walk when they could but were thwarted by time constraints or the need to carry heavy equipment. Participants in household 103 continued to carpool to work. Participant 103A said she tried to walk more for local trips, while participant 103B said he actually increased his driving time during this period because of a few weekend trips he took when he wasn't busy.

Decrease Home Electricity Consumption

All participant households (101, 102, and 103) reduced their electricity use—by 7, 20, and 3 percent, respectively (see Figure 4). Households 101 and 102 had statistically significant drops ($p < 0.01$). All participants were already well below the city average for their home type, making it even more challenging for them to improve. (We determined this using the Seattle Public Utilities/Seattle City Light Home Resource Profile at https://websafe.kemainc.com/websitescl/login.asp.) None of the participants had air conditioning or used their heat during the study, and average temperatures were 64 and 67 degrees F in month one and two, respectively.

Decrease Transportation Consumption

Figure 5 shows the average CO_2 production from transportation over the study's two months. Travel is highly variable and dependent on external factors, so comparison is difficult. However, a decrease in driving activities and an increase in walking or biking decreased the CO_2 output for five of the six participants.

The GroupEnergyTable successfully reached its goal of decreasing home electricity and transportation consumption. The 3 to 20 percent reduction in home energy use was comparable with other feedback studies, which have shown a 5 to 12 percent reduction,[9] and there were no obvious external factors, such as weather, that might cause this change in consumption. Participants mentioned making changes because of the information from the travel energy view, but because transportation is strongly influenced by external factors, it's difficult to say for certain that the travel energy view was the cause.

In general, the participants tended to prefer the GroupEnergyTable's home energy view, because they felt that having more data and tips made it more valuable. Almost all participants reported learning something new about their home energy use. Although these participants were already well below the Seattle consumption averages for their home types, they still learned something about their use and were willing to try additional actions.

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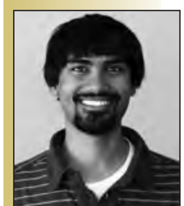

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