17th Annual
Engineering
Project
Organization
Conference

Working Paper Proceedings

Understanding Community-Scale Energy Feedback: User Testing of a Mobile Application

Abigail Francisco; Georgia Tech, USA
John Taylor; Georgia Tech, USA

Proceedings Editors
Paul Chinowsky, University of Colorado Boulder and John Taylor, Georgia Tech

EPOC 2019 | VAIL, CO

UNDERSTANDING COMMUNITY-SCALE ENERGY FEEDBACK: USER TESTING OF A MOBILE APPLICATION

Abigail Francisco[1] and John E. Taylor[2]

ABSTRACT

Cities are increasingly adopting data-driven approaches to reduce greenhouse gas emissions and meet sustainability targets. As part of this effort, energy disclosure laws are becoming more prevalent, making publicly available vast new quantities of building-level energy data at urban scales. While existing research efforts have focused on the potential of this data to transform energy efficiency markets and investments in the real estate sector, little research has been dedicated to assessing this information's value to the general public. Given that achieving energy reductions in the built environment will require not only energy efficiency investments, but also greater awareness, engagement, and action from ordinary citizens, we study the potential of open urban energy data in providing citizen benefits. Using Georgia Tech's campus as a testbed, we transformed building-level electricity data into a novel energy feedback system for mobile devices. Using a user centered design approach, prospective users evaluated the system via thinking aloud sessions and user surveys. The user-driven design process informs how to design effective urban energy feedback displays and sheds light on citizens' reactions to and opinions of such data. This research is an integral step to further engagement and participation from the public to help achieve a sustainable, low-carbon, and citizen-valued energy future.

KEYWORDS

Energy feedback, urban energy efficiency, behaviour change, community energy systems.

INTRODUCTION

Cities around the globe are heavily investing in becoming 'smart'. World-wide investments in technology for smart city initiatives are expected to grow from more than $81 billion in 2018 to $158 billion in 2022 (Shirer and Da Rold 2018). While smart city definitions encompass broad variations, common across all perspectives is the aim to address an urban issue—whether it be energy, safety, health, mobility, or financial in nature—with an approach that is mediated through technology (Chourabi et al. 2011). Fostering citizen learning, participation, and benefit is an important element of smart city frameworks, and critiques have pointed out that this is the element most often glazed over, with greater emphasis put on technological progress

[1] PhD Student, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr., Atlanta, GA 30332, afrancisco8@gatech.edu

[2] Frederick Law Olmsted Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr., Atlanta, GA 30332, Phone +1-404-894-8021, jet@gatech.edu

and development in digitizing our cities. One prominent smart city paradigm area with a high potential to involve citizens is open data initiatives. Providing open data to citizens is envisioned to enable transparency of government operations, provide social and commercial value, and increase participatory governance (Attard et al. 2015).

Within the energy sector open data is an emerging and new resource, made available through building energy disclosure ordinances (Palmer and Walls 2015). Such laws have catalyzed transparency in building energy performance across cities, in the form of publicly available data. While researchers have documented the potential value of this data to private stakeholders such as building owners, investors, and utilities, little research attention has been drawn to the use of this data to empower and promote engagement from citizens (Kontokosta 2013). In this paper, we assess the value of this information from the perspective of citizens as data users. Building off of a previously developed energy feedback system (Francisco and Taylor 2018), which transforms this data into easily usable information, we perform user testing to assess the viability of this information in providing value to citizens.

BACKGROUND

OPEN URBAN ENERGY DATA AND THE ROLE OF CITIZENS

Public reporting of energy data through mandated building energy disclosure laws is driving a shift in the transparency of building energy production and consumption information across cities (ACEEE 2017), hereby referred to as *open urban energy data*. Researchers from economics domains envision have focused on how open urban energy data has the potential to transform energy efficiency markets by supporting building portfolio owners with performance management, guiding investor energy financing decisions, and increasing the value and marketability of commercial buildings (Palmer and Walls 2016). Noticeably, use cases and potential benefits of this data has focused on stakeholders interacting close to the real estate industry (Kontokosta 2013; Zullo et al. 2016). Little research has examined in detail the potential of citizens as data users in the context of open urban energy data. As one of the core tenets of open data is to provide use and benefit to the public, it is worthwhile to examine public understanding of this data and their interest in using this information to help decision making.

Importantly, the release of this data coincides with a growing interest from researchers and governments of the role of citizens with our future energy systems. A substantial body of research has called for a reconceptualization of ordinary citizens from passive energy consumers to active stakeholders and innovators in creating new and more sustainable energy systems (Bomberg and McEwen 2012; Schot et al. 2016). Citizen participation during energy project assessments and development is integral to see a project successfully come into fruition and integrate into a community—citizens increase the dissemination and adoption of energy technologies (Ornetzeder and Rohracher 2006), improve the acceptance of projects or technologies (Schot et al. 2016), help designers incorporate social and environmental contexts into a project (Seyfang et al. 2010), and enhance the design of the project or technology itself (Ornetzeder and Rohracher 2013). The many ways citizens can improve energy systems reflect the broad roles citizens could have in the future in relation to energy in their community.

Expanded citizen roles with energy systems in the future will undoubtedly be mediated by technologies and data. Open urban energy data has potential to be a resource to citizens, supporting education and decision making in these expanding roles. Integral to this effort is determining how to shape and present this data in a way that is meaningful and engaging to citizens.

Providing Open Urban Energy Feedback to Citizens

Few researchers have focused on the best ways to shape and communicate open urban energy data to citizens. Kontokosta and Tull (Kontokosta and Tull 2015) commented on how the current format of such data is most often provided in tabular spreadsheet format, making it cumbersome to analyze and relatively inaccessible to most potential users. To address this, they created an interactive web-based platform visualizing New York City's building energy benchmarking data, built primarily building portfolio owners and managers. While there has been a growing interest by governments in creating these platforms to improve accessibility and awareness of energy information (IMT 2015), how to design these systems for citizen engagement has scarcely been addressed by researchers. Research recently conducted by Francisco and Taylor (Francisco and Taylor 2018) proposed a design strategy for community-scale energy feedback systems, which are intended to incorporate open urban energy data. The proposed design elements are shown in Figure 1, and are described in detail in (Francisco and Taylor 2018).

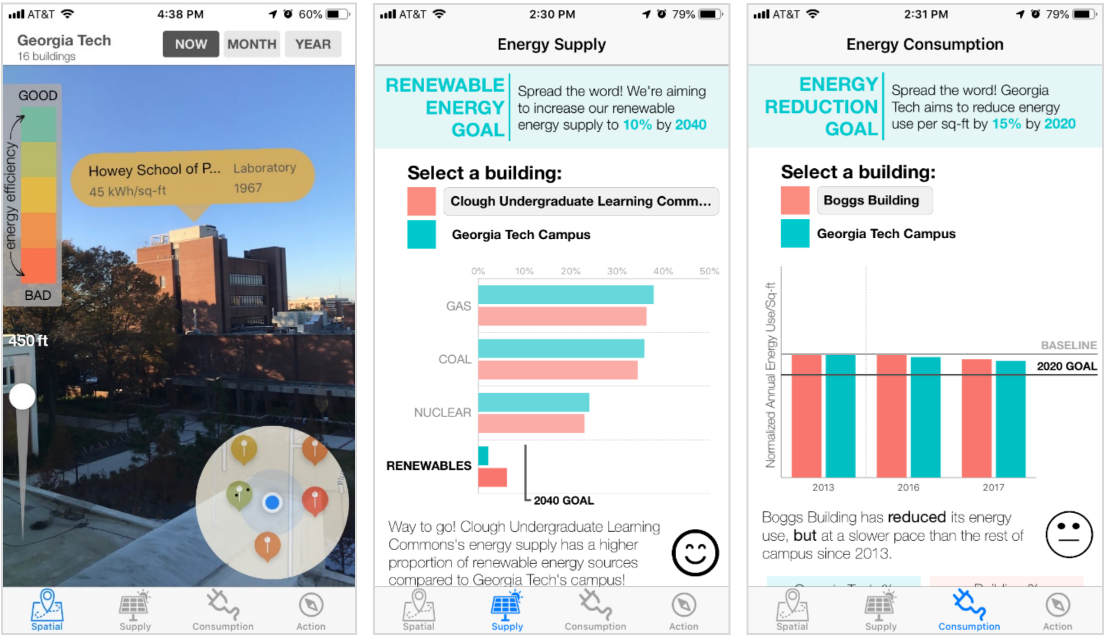

Figure 1. Community-scale Energy Feedback Application Screenshots of Spatial (left), Supply (middle), and Consumption (right) functionalities

Prior to the deployment this novel energy feedback system, it is critical to gather feedback from future users and ensure the system is appropriate for citizens as end-users. Literature has long drawn attention to importance of end user engagement during the design of technologies that humans will interact with (Peacock et al. 2017; Skjølsvold et al. 2017). User involvement during the design phase is important for technological acceptance, engagement, and effectiveness over the long term (Abras et al. 2004; Peacock et al. 2017). In addition, because open urban energy data is a relatively new and unfamiliar data stream, it is important to assess citizen interest in having access to this information.

To address these needs, we leverage open urban energy data, an emerging form of urban-scale energy data, to evaluate a community-scale energy feedback prototype. We integrate prospective users into the design process to gather feedback about the system and assess more broadly the potential of these data for use by the general public to support decision making. The approaches used to evaluate the feedback system and incorporate prospective users into the design process is described in the following section.

METHODS

First we begin with a brief description of the community-scale energy feedback system proposed by (Francisco and Taylor 2018). Following this description, the approach for the user testing is described. Georgia Institute of Technology's campus served as the testbed community which our platform was built on. The mobile-based application consisted of three functionalities, shown in Figure 1. The first functionality, the Spatial View, uses Augmented Reality (AR) technology to visualize building energy efficiency levels while a user walks through their community. The second functionality, the Supply View, displays a breakdown of the types of energy supplied to individual buildings and the campus, placed in the context of Georgia Tech campus' renewable energy goals. The third functionality, the Consumption View, alternatively focuses on individual building and campus energy consumption over time, placed in the context of Georgia Tech's energy reduction goals.

We employed a user centered approach to evaluate this system by exploring user reactions to and understanding of the system. We sought to examine not only if users could accurately interpret the energy feedback system, but also how interested people are in having access to this information in the first place. Through user testing, we sought to answer the following questions:

1. Do users accurately understand and interpret community-scale: (a) Augmented Reality feedback, (b) Energy Supply feedback, and (c) Energy Consumption feedback?
2. Do people want to seek out the information provided in community-scale energy feedback interfaces? Why or why not?

Drawing from user centered design best practices (Abras et al. 2004), this initial pilot study aimed to evaluate the three energy feedback features described above from the perspective of prospective users. A wide range of quantitative and qualitative methods have been employed to gather data on user perceptions and understanding of technologies. Qualitative methods are generally used to test products where the user needs are already well-defined. As community-scale energy feedback is a relatively novel concept to most people, the aim of our user testing was exploratory and prioritized collection of qualitative data.

To answer the research questions, 16 study participants were recruited to complete two activities: (1) a thinking aloud session, and (2) a survey questionnaire. Thinking aloud methods have been used for decades by researchers to diagnose usability issues and improve user interfaces (Nielsen 1994). The thinking aloud procedure involved a one-on-one session between a researcher and participant, where the participant was instructed to vocalize their thoughts out loud as they interacted with the interface. To prompt user interactions, they were provided with tasks to direct the user to test specific functionalities. While the participant completed each task, the mobile device's screen and microphone recording were turned on.

Immediately following the thinking aloud session, the participants completed a web-based survey questionnaire. The survey was divided into three parts. First, participants were asked questions to assess how accurately they interpreted each functionality (Table 1). The second part inquired more broadly about users' opinions on community-scale energy feedback. It captured users' desire to have access to this information, at what geographic scale, as well as motivations for wanting to seek out this information. A full list of questions and response types can be referred to in Table 2. The third part of the survey included demographic questions to learn more about respondents. While we expect that the primary users of this system would be people who are professionally or personally interested in local energy issues, we recruited people from a variety of backgrounds, from inexperienced to energy experts. This was done to gather a more holistic understanding of user interpretations. The user testing was approved through IRB protocol #H18398.

Table 1: Participant Interpretation of Energy Feedback Features (part 1 of survey)[3]

Question ID	Question	Question Type
AR1	If a building's icon is red, what do you think this indicates about the energy efficiency of the building?	Open-ended
AR2	If the button "Month" is selected, why do you think the color of some icons change?	Open-ended
S1	What do you think the happy face on the screen indicates?	Open-ended
S2	Based on the screenshot above, how much of the Georgia Tech campus energy supply comes from renewable energy sources?	Open-ended
S3	Based on the screenshot image above, has the Georgia Tech campus reached its renewable energy goals yet?	Open-ended
S4	Based on the screenshot image above, most of Georgia Tech's energy comes from what resource?	Open-ended
C1	What do you think the 'Baseline' label refers to?	Open-ended
C2	What building(s) do the red bars in the graph refer to?	Open-ended
C3	Based on the screenshot image above, has the Boggs building reduced its energy use at a faster or slower pace compared to the rest of the campus?	Open-ended

[3] Each of these questions were followed with a 5-point Likert scale question asking users to report how confident they were in their answer, which are not listed in the table for brevity.

C4	Based on the screenshot image above has Georgia Tech reached its campus energy consumption goals yet?	Open-ended
Overall	As a whole, do you think this application offered: (A) Too much information, (B) Too little information, and (C) Just the right amount of information. • (*conditional follow-up for responses A or B*) Why? If you could add/remove one feature, what would it be?	Multiple Choice

Table 2: Participant Desire and Motivations for Seeking Out Community-Scale Energy Feedback (part 2 of survey)

Question ID	**Question**	**Question Type**
B1	In general, how interested are you in having access to a Community Energy Feedback System in the following locations: - Georgia Tech Campus. - The neighborhood or community I live in. - The city I live in.	5-point Likert Scale
B2	How often do you think you would seek out the information provided by a Community Energy Feedback System? (A) Daily (B) Weekly (C) Monthly (D) A few times (E) Once (F) Never (G) Only for specific occasions	Multiple Choice
B3	We are interested in why people would want to seek out information included in a Community Energy Feedback System. Below, please describe why you would want to have access to such a system. If you do not want to have access, please describe why.	Open-ended

RESULTS AND DISCUSSION

Thinking aloud and survey data was collected from December 2018 through January 2019. A total of 16 participants completed the user testing activities. As an important aspect of the developed application is that users are familiar with the community it represents, participants were required to identify as a member of the GT community. Participants' affiliation with the GT community consisted of being an undergraduate student (n=6), Master's student (n=4), PhD student (n=4), or staff member (n=2). About half (n=9) of the participants identified as female and the remaining participants identified as male. The survey also inquired about people's previous familiarity with AR technology and their previous involvement and interest in energy issues. These results are presented in Figures 4 and 5. In the following sections, the results pertaining to each of the research questions will be discussed.

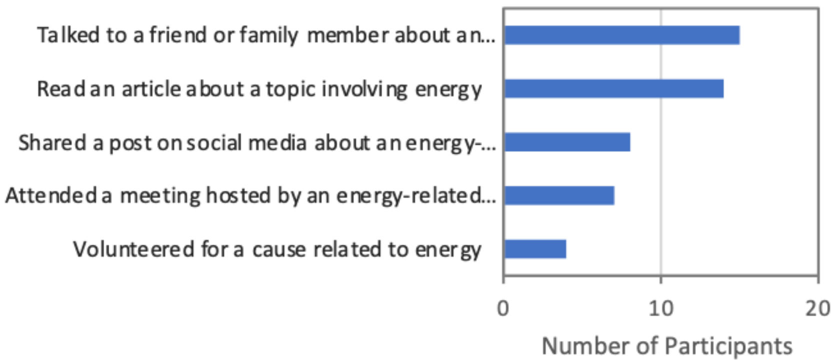

Figure 4: Results from the survey question, "Consider the following and check all that apply. In the last three months have you:"

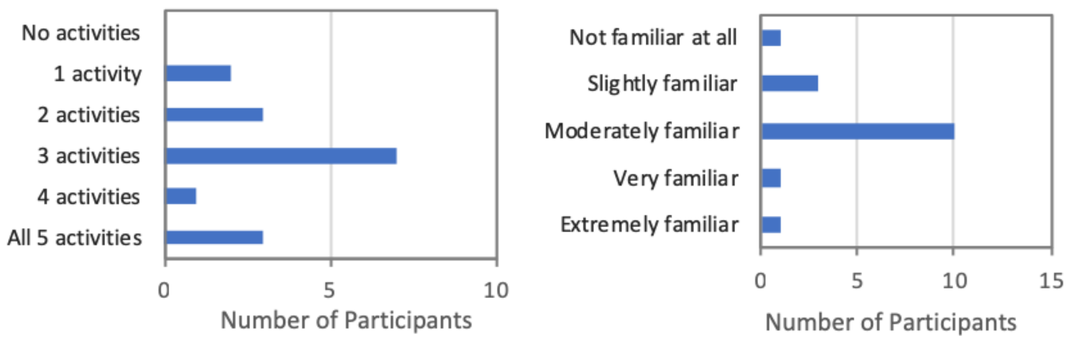

Figure 5: (left) Total number of activities each participant reported from Figure 4; (right) Results from the survey question, "Prior to this study, how familiar were you with Augmented Reality technology?"

Do users accurately understand and interpret community-scale: (a) Augmented Reality feedback, (b) Energy Supply feedback, and (c) Energy Consumption feedback?

Participants' ability to accurately interpret the interface was assessed through the thinking aloud procedure and the survey questions listed in Table 1. A summary of the number of participants who answered each accuracy question correctly and their associated confidence in their response is provided in Table 3.

Table 3: Count of participant confidence levels for each accuracy question assessing accuracy of interpretation.

Question ID	Number of Correct Responses	Very confident	Confident	Slightly confident	Not confident
AR1	15	14	2	0	0
AR2	15	5	8	2	1
S1	13	9	7	0	0
S2	16	13	2	1	0
S3	15	15	1	0	0
S4	15	14	2	0	0
C1	11	7	6	2	1
C2	16	15	1	0	0
C3	16	13	0	3	0
C4	15	15	0	1	0

Augmented Reality Feedback

In the Spatial view, participants were able to use the augmented reality feedback to identify a building's energy efficiency level with relative ease and accuracy. When asked in the survey, "*If a building's icon is red, what do you think this indicates about the energy efficiency of the building?*" (AR1), the vast majority of participants accurately interpreted the meaning of the color scale with high levels of confidence

(Table 4). This was also evident from the thinking aloud exercise, where participants were able to interpret the meaning behind the colors without difficulty or error. Furthermore, the double-coded numerical and color-coded efficiency representations also appeared effective; some participants focused initially on the colors to determine efficiency levels, while others were more inclined to focus on the numerical representations. By the end of the exercise, participants tended to use both. These findings reflect the results of other studies examining the impact of color-coded spatial views (Bonino et al. 2012; Francisco et al. 2018), where users reported color-coded information helped them understand energy use, and requested this information be presented in combination with numerical results.

Notably, the building characteristics integrated into the color-coded icon (e.g., year built, building type) stimulated comments from the participants as to why they thought a building had a certain efficiency level in relation to its listed characteristics, or how they were surprised by the results. For example, after visualizing a building with a green icon, one participant commented, "*that's interesting, oh and it was built in 1988 it appears, compared to this one that was built in 1967, so that's surprising. I would think that it would be less energy efficient since it's older, but it's not*". One of the advantages of augmented reality is it can integrate greater amounts of information into the visualization (Wu et al. 2013). In the Spatial view, this feature was able to integrate building characteristic data into the visualization, likely causing more engagement from users about building energy efficiency in relation to the listed characteristics.

One oversight by the participants in the Spatial view was highlighted by the survey question, "*if the button "Month" is selected, why do you think the color of some icons change?*" (AR2). While the vast majority (n=15) answered this question correctly, people were less confident in their response compared to the other survey accuracy questions. From the thinking aloud session, it was notable that most users failed to notice the time range buttons at the top of the screen. Thus, the lower confidence levels may be reflective of the minimal interaction participants had with these buttons during the tasks.

Energy Supply Feedback

In reference to the Energy Supply feature, participants were asked, "*What do you think the happy face on the screen indicates?*" (S1). While 13 respondents answered this question correctly, they were relatively less confident in their responses. From the thinking aloud session, participants expressed confusion about what level of building performance 'deserved' a smiling face. Moreover, it was not clear what emoticon options a building could potentially achieve. One participant summed up these concerns tellingly with, "*what is the smiley face scale*?". As energy feedback is expanded to the community scale, there are greater points of reference to compare building performance to (e.g., the community goals, average performance, state or national standards). This complicates what is considered 'good' and 'bad' performance, which is largely dependent on the application user and their concerns, and demonstrates a challenge for the design and deployment of future community scale energy feedback systems.

Questions S2, S3, and S4 were all answered with high rates of accuracy and confidence, indicating that participants were accurately able to identify from the bar graph Georgia Tech campus' current level of renewable energy production, renewable energy goal, and the energy resources the campus supply is composed of. An important main design issue in the Energy Supply page was determined through the thinking aloud activity, where most participants took a long time to notice the renewable energy goal listed at the top of the screen. Instead, their eyes and attention went immediately to reading and interpreting the graph on the center of the page.

Energy Consumption Feedback

In reference to the Energy Consumption feature, participants were asked, "*What do you think the 'Baseline' label refers to?*" (C1). Compared to the rest of the accuracy questions, this question had the lowest correct response rate, and one of the lowest confidence rates. While most of the participants (n=11) understood that the 'baseline' represents a reference point to compare a building's current energy efficiency to, only 6 participants reported that the baseline referred to a building's performance in the year 2013. From the thinking aloud session, most participants (n=9) had noticeable trouble interpreting the meaning of the 'baseline' and '2020 goal' horizontal lines on the Energy Consumption page. While most participants were eventually able to correctly interpret the graph, they commented that they were initially confused because on the previous Energy Supply page, a building achieves the goal when its bar exceeds the '2040 goal' line. Conversely, the way the Energy Consumption graph was designed, the farther the bars are below the goal line, the better a building is performing relative to the goal. This created confusion when the conceptual model for interpreting the graph was reversed between the Energy Supply and Consumption features (i.e., wanting to go below instead of above the goal line).

Questions C2, C3, and C4 were answered with high rates of accuracy and confidence, showing that by the time of the survey users were able to accurately and confidently interpret from the bar graph what the red bars refer to, a building's level of energy reduction compared to the campus, and the energy reduction goal. With regards to C4, which inquired, "*Based on the screenshot image above has Georgia Tech reached its campus energy consumption goals yet?*" it is important to note that while users answered this question correctly and confidently, many had trouble interpreting the graph when they were initially encountered it, as described in the previous paragraph. This demonstrates the effectiveness of the thinking aloud activity combined with the survey in helping understand the users learning process and difficulties.

Overall Application Feedback

Judging the application as a whole, 75% of survey respondents (n=12) reported the application provided 'just the right amount of information'. The remaining participants (n=4) indicated it provided 'too little information'. No respondents felt the application provided 'too much information'. In a follow-up question where participants who selected 'too little' or 'too much' information were asked what they would like to add to or remove from the application, two themes emerged. First, two commented they would like to see the information in the Spatial feature better integrated with the information in the Energy Supply and Consumption feature. As one participant explained, "*The Spatial Tab tracks energy efficiency, but that information is not available for easy searching. Conversely, the supply and consumption tabs do not offer an interesting spatial visual for their respective metrics*". This parallels the findings in Bonino et. al (Bonino et al. 2012), where users reported they preferred color-coded feedback combined with more technical/numerical feedback. In this case, users preferred the color-coded spatial feedback combined with the numerical charts. This could potentially be accomplished by allowing the user to transition to the Energy Supply or Consumption graphs by clicking on a building icon in the Augmented Reality feature.

The second theme focused on wanting more detailed information about retrofits or sustainability features implemented for each building. Participants reported they wanted this information to understand better *why* a building may be performing poorly or efficiently. This points to a challenge with whole building data and energy feedback engagement; whole building data may not provide enough detail to engage users, as it does little to indicate why a building achieved a certain level of efficiency. It could also drive skepticism if there is not additional information to provide context for the reported efficiency levels. Providing detailed building retrofit information, particularly at larger scales, is a challenge as it is difficult to collect, standardize, and maintain the reporting of this information. Thus, in the design and deployment of future community energy feedback systems, a major unanswered question is how to provide enough context to users so that they trust the information, while also limiting the information scope so that it is feasible to maintain and ensure the accuracy of the feedback information.

Do people want to seek out the information provided in community-scale energy feedback interfaces? Why or why not?

Participant openness and desire to seek out the information provided in a community-scale energy feedback interface was assessed by the questions listed in Table 2. For the open-ended question, "*We are interested in why people would want to seek out information included in a Community Energy Feedback System. Below, please describe why you would want to have access to such a system. If you do not want to have access, please describe why*" (B3), several trends emerged. These trends were aggregated and sorted into three categories: (a) individual motivations, (b) motivations in relation to their peers, or (c) motivations in relation to their institutions (Table 3). In Table 3, specific motivations and the number of participants who mentioned each motivation is grouped by each category. The total number of participants who had at least one comment in a category is specified in the first column. The most frequent motivations were related to the 'individual' category, and are comprised of motivations driven by personal interest, values, or financial reasons. Motivations belonging to the second group were less frequent, and involved commentary in relation to their peers or community. Comments falling under the last category were least common, but covered a wide range of concepts related to government or institutional structures. For example, one participant commented that access to community energy feedback, "*would make me want to use the data to lobby for policy changes or programs that could help expand energy efficiency upgrades at a community level…I think the visualization is most helpful for outside my home and thinking at a neighborhood, campus, or city level*".

Table 3: Summary of participant open-ended responses to why they would or would not want to have access to a community-scale energy feedback interface.

Category	Motivation	Count
Individual (n=12)	Financial- to save money or inform purchasing/renting decisions	8
	Curiosity - to stay informed or have fun	7
	Values- care for the environment or their community	3
Peers (n=7)	Learn about how their building is performing compared to others	5
	Learn about community buy-in to energy goals	1
	Promote peer learning about energy use	1
Institutional (n=4)	Hold cities/institutions accountable to goals and lobby for better practices	2
	Learn about energy related programs in their area	1
	Support neighborhood energy organizations with targeting efforts	1
	Support energy efficient businesses	1

The variety in these open-ended response indicate a wide range of ways people reflected that community energy feedback could affect their engagement with their energy systems. The diversity of comments align with previous work examining the diverse roles citizens can have when engaging with our energy systems (Schot et al. 2016). This has implications for future experimental work on community energy feedback; the diversity of citizen roles in energy systems and broad scale of community energy feedback behaviors widens the potential possible variables measured to assess behavior change. While these results are from a fairly small sample size and reflect the notions of a college-educated and energy-aware population, they are an encouraging first step in terms of the range of possible outcomes of community energy feedback. A prominent challenge for future research, however, is determining how to measure these various potential effects.

A few participants commented on why they would not want access to or use a community energy feedback system. One participant expressed they do not think they would check out this type of feedback system unless there was a stimulus that prompted them to be curious about building energy use (e.g., the building looked new and/or efficient, when buying a home). In addition, another respondent expressed that they felt that public reporting of residential data would be an invasion of privacy, and they would not be supportive of open access to this type of data.

When asked how often they would use such a system (B2), 5 participants responded ‘weekly’, 7 responded ‘monthly’, and the remaining 4 reported ‘a few times’ (‘daily’, ‘once’, and ‘never’ received zero votes). Participants were also asked to specify how interested they were is having access to community energy feedback spanning different geographic regions (B1). All locations, including the Georgia Tech campus, neighborhood they live in, and city they lived, received overwhelmingly positive responses (Table 4). Previous community-scale energy feedback studies have been confined to the neighborhood scale (Gupta et al. 2017), while the campus scale (e.g., universities, workplace campuses) and city scale has yet to be created or investigated by research. This pilot validation indicates citizen interest may exist in scales beyond their individual neighborhoods and provides support for the development of campus and city-scale energy feedback. From a data availability and privacy perspective, whole building data at the campus and city-scale is more readily available due to open data requirements (Zullo et al. 2016), and may be more feasible to implement compared to neighborhood-level feedback.

Table 4: Results from the survey question on what geographic scale the respondent is interested in having access to community-scale energy feedback

Location	Extremely interested	Somewhat interested	Neutral	Somewhat uninterested	Extremely uninterested
Georgia Tech Campus	7	9	0	0	0
Neighborhood or community I live in	10	4	1	1	0
City I live in	8	7	1	0	0

CONCLUSIONS

As cities invest in technologies to solve urban issues and become 'smart', vast quantities of open data will be produced and made available for public use. For this data to provide utility, particularly to citizens, it is important for this data to be shaped in a way that is accessible, engaging, and actionable. The objective of this study was to evaluate a novel community-scale energy feedback system, which aims to engage citizens with energy use and production in their community. We involved prospective users to assess how accurately they interpreted the feedback system and gauge how interested they are in having access to community-scale energy feedback. First, the results identified specific strategies to improve the design of system. In addition, the findings showed that while the augmented reality features were easiest for users to understand, users still valued the graphical information and preferred an integrated approach for visualizing both the spatial and graphical information. Regarding participant desire to have access to such a system, the survey results indicated there was high interest among most participants, for a wide variety of reasons. These findings also highlight challenges for future work in the area of community-scale energy feedback, primarily involving how to promote engagement and trust in such systems. Overall, this study presents the first user evaluation of community-scale energy feedback systems. As open data becomes a prevalent potential resource in the era of smart cities, technologies can be used to improve the accessibility of this information for citizen benefit. This study presents a critical step examining technologies' role in engaging the public to help achieve a sustainable, low-carbon, and people-oriented energy future.

REFERENCES

Abras, C., Maloney-krichmar, D., and Preece, J. (2004). *User Centered Design. Encyclopedia of Human-Computer Interaction*, Thousand Oaks: Sage Publications.

ACEEE. (2017). "Local Government Energy Efficiency Goals." <http://database.aceee.org/city/local-government-energy-efficiency-goals> (Jul. 30, 2017).

Attard, J., Orlandi, F., Scerri, S., and Auer, S. (2015). "A systematic review of open government data initiatives." *Government Information Quarterly*, Elsevier Inc., 32(4), 399–418.

Bomberg, E., and McEwen, N. (2012). "Mobilizing community energy." *Energy Policy*, Elsevier, 51, 435–444.

Bonino, D., Corno, F., and De Russis, L. (2012). "Home energy consumption feedback: A user survey." *Energy and Buildings*, Elsevier B.V., 47, 383–393.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Pardo, T. A., and Scholl, H. J. (2011). "Understanding smart cities: An integrative framework." *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2289–2297.

Francisco, A., and Taylor, J. E. (2018). "Designing community-scale energy feedback." *Proceedings of the 10th International Conference on Applied Energy*.

Francisco, A., Truong, H., Khosrowpour, A., Taylor, J. E., and Mohammadi, N. (2018). "Occupant perceptions of building information model-based energy visualizations in eco-feedback systems." *Applied Energy*, Elsevier, 221(December 2017), 220–228.

Gupta, R., Barnfield, L., and Gregg, M. (2017). "Exploring innovative community and household energy feedback approaches." *Building Research and Information*, Taylor & Francis, 0(0), 1–16.

IMT. (2015). "Chicago's Large Buildings Could Save $184 Million Annually." *Institute for Market Transformation*, <https://www.imt.org/boosting-energy-efficiency-in-chicagos-large-buildings-could-save-up-to-184/>.

Kontokosta, C. E. (2013). "Energy disclosure, market behavior, and the building data ecosystem." *Annals of the New York Academy of Sciences*, 1295(1), 34–43.

Kontokosta, C. E., and Tull, C. (2015). "EnergyViz: Web-Based Eco-Visualization of Urban Energy Use from Building Benchmarking Data." *Proceedings of the International Conference on Computing in Civil and Building Engineering*, (March), 1405–1412.

Nielsen, J. (1994). "Estimating the number of subjects needed for a thinking aloud test." *International Journal of Human - Computer Studies*.

Ornetzeder, M., and Rohracher, H. (2006). "User-led innovations and participation processes: Lessons from sustainable energy technologies." *Energy Policy*, 34(2 SPEC. ISS.), 138–150.

Ornetzeder, M., and Rohracher, H. (2013). "Of solar collectors, wind power, and car sharing: Comparing and understanding successful cases of grassroots innovations." *Global Environmental Change*, Elsevier Ltd, 23(5), 856–867.

Palmer, K., and Walls, M. (2015). *Can Benchmarking and Disclosure Laws Provide Incentives for Energy Efficiency Improvements in Buildings ?*

Palmer, K., and Walls, M. (2016). "Using information to close the energy efficiency gap: a review of benchmarking and disclosure ordinances." *Energy Efficiency*, Energy Efficiency, 1–19.

Peacock, A. D., Chaney, J., Goldbach, K., Walker, G., Tuohy, P., Santonja, S., Todoli, D., and Owens, E. H. (2017). "Co-designing the next generation of home energy management systems with lead-users." *Applied Ergonomics*, Elsevier Ltd, 60, 194–206.

Schot, J., Kanger, L., and Verbong, G. (2016). "The roles of users in shaping transitions to new energy systems." *Nature Energy*, 1(5), 16054.

Seyfang, G., Haxeltine, A., Hargreaves, T., and Longhurst, N. (2010). "Energy and communities in transition - towards a new research agenda on agency and civil society in sustaianbility transitions." *CSERGE working paper EDM, No. 10-13*, (January).

Shirer, M., and Da Rold, S. (2018). "IDC Forecasts Smart Cities Spending to Reach $158 Billion in 2022, with Singapore, Tokyo, and New York City Among Top Spenders." *International Data Corporation*.

Skjølsvold, T. M., Jørgensen, S., and Ryghaug, M. (2017). "Users, design and the role of feedback technologies in the Norwegian energy transition: An empirical study and some radical challenges." *Energy Research and Social Science*, Elsevier Ltd, 25, 1–8.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., and Liang, J. C. (2013). "Current status, opportunities and challenges of augmented reality in education." *Computers and Education*, Elsevier Ltd, 62, 41–49.

Zullo, L., Resources, N., Council, D., Antonoff, J., and Amberli, Y. (2016). "Putting Building Energy Benchmarking Data into Action." *ACEEE Summer Study on Energy Efficiency in Buildings*, 1–12.