Toward Improving Building User Energy Awareness

Yidan Zhang
Monash University
Melbourne, Australia
yidan.zhang@monash.edu

Arnaud Prouzeau
Monash University
Melbourne, Australia
arnaud.prouzeau@monash.edu

Hourieh Khalajzadeh
Monash University
Melbourne, Australia
hourieh.khalajzadeh@monash.edu

Sarah Goodwin
Monash University
Melbourne, Australia
sarah.goodwin@monash.edu

ABSTRACT

Raising awareness of users' energy consumption in non-residential buildings like offices or universities is an essential step toward a global decrease of energy use. A popular solution is to have a visual dashboard with general information about energy use on display to the public. While easy to implement, such solutions have been shown to not be very engaging for people and thus, mostly ignored. In this paper, we investigate the use of a mobile application as an alternative solution to a dashboard display, to increase energy awareness of building occupants. The application takes the form of a daily quiz about the building's energy consumption. We evaluate our solution in a field study in which we compare it to a dashboard display. Our results suggest that while both solutions increased energy awareness when used, and more generally the understanding of the building's energy behaviour, the mobile application was more engaging.

CCS CONCEPTS

• Human-centered computing → Ubiquitous and mobile computing design and evaluation methods; **• Software and its engineering** → *Interactive games.*

KEYWORDS

Energy Awareness, Mobile Application, Energy Dashboard

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1 INTRODUCTION

Increasing environmental and technical issues associated with current resource scarcity, such as energy shortage and increased greenhouse gas (GHG) emissions, have raised concerns about current energy consumption trends throughout the world [2]. Among all the sectors involved in energy consumption, buildings represent a considerable percentage of the energy usage. The building sector is responsible for over 40% of primary energy use and 40% of total GHG emissions in most countries[2]. In Australia, for instance, the energy consumption from the building sector accounts for 23% of the total GHG emissions and non-residential buildings cause 8-10% of the emissions [3, 8]. Nowadays many techniques are adopted to reduce energy usage in buildings including energy-efficient lighting, facilities and intelligent controls [20], yet to improve efficiency levels, it is necessary to involve occupants in the energy conservation. To be more engaged in saving energy, their energy awareness, i.e. to understand how energy is used in buildings, is required. To increase occupants' awareness of building energy usage, energy awareness feedback is usually involved. The main solution in non-residential buildings is to use a public display or website [6, 10]. However, there are issues with both approaches, in particular, they provide limited personal interaction and are not portable. Another solution, often used for residential energy feedback in particular, is a mobile application [16, 27]. In this paper, we explore the use of a mobile application to raise users' energy awareness in non-residential buildings and explore if it is more effective for raising the occupant's awareness of the building's energy use in comparison with a dashboard display.

2 RELATED WORK

Occupants' Energy Awareness in Commercial Buildings: Studies have found that occupants' energy awareness and associated behaviours greatly impact energy consumption in commercial buildings [12, 20]. People's lack of energy awareness could lead to a significant waste of energy in commercial buildings. According to Masoso and Grobler [20], over 50% of energy is used during non-working hours in commercial buildings because occupants are unconscious to save energy and fail to switch off equipment when leaving. These findings highlight the importance of raising occupants' energy awareness in commercial buildings. However, there are barriers and challenges to motivate occupants in commercial buildings that typically do not appear in household contexts. Occupants are less motivated to save energy since they do not need to pay the bill, and they feel less responsible for energy consumption because the non-residential building is usually a shared environment and individual energy usage remains indistinct [4, 11, 19].

Energy Awareness Feedback and Visualisation: We reviewed typical interface features of selected energy feedback examples that focus specifically on energy usage in commercial buildings. Most of them provide history comparison and real-time energy usage [18, 21, 25]. Charts are frequently used for historical comparison because they allow a quick overview of the data and trends over time [14, 22]. Normative comparison, which refers to comparing energy usage with similar groups of individuals such as friends or colleagues, is included in half of the selected feedback [5, 18, 21]. Especially, in the three feedback examples marketed for increasing energy awareness of normal users in commercial buildings (Lucid's Building Dashboard, Quality Attributes' GreenTouchScreen, and QA Graphics' EEED), where normative comparison is one of the primary features [18]. Novel visualisations, such as virtual objects, have recently been adopted for energy awareness feedback. For example, to represent energy usage using different health conditions of a virtual chicken and tree or the amount of fish in a digital aquarium [4, 7, 21].

Mobile Applications for Energy Awareness: We also reviewed mobile applications targeting raising awareness of energy consumption. Most mobile applications we reviewed are game-based. Gamification is the process to apply elements of game design in non-game contexts [23]. It is frequently used and reported to be effective to motivate employees' engagement in workplaces [13, 23]. Almost all the mobile applications are reported to be effective on motivating energy saving behaviours. However, in contrast to extensive studies in domestic buildings [16, 26, 27], little research has focused on the investigation of energy awareness mobile applications in commercial building settings [5, 24]. This finding highlights the value of our research which presents a mobile application for energy awareness feedback in a non-residential building context.

3 MOTIVATION

We conducted a survey to collect energy awareness and expectations for the mobile application from 15 users in three different buildings on a large university campus. The three buildings were selected because public energy displays were currently adopted. Participants were contacted personally in the ground floor of target buildings and were asked to complete a 10-minute questionnaire with 30 multiple choice questions and 6 open-ended questions. The results of the survey shows that 93% of the participants were unaware of the energy consumption in their buildings. More than 50% of respondents had never noticed the energy display in the building. Out of those who noticed the dashboard, only 1 person reported knowing the energy consumption in the building. People also reported that the current display was too small and the energy information was hard to see and investigate. Out of the 15 responses, more than half of the participants believed that a mobile application would be quite useful to help users in the building to understand energy consumption. When inquiring occupants' preference, half of the participants preferred a mobile application when the other half preferred the public display.

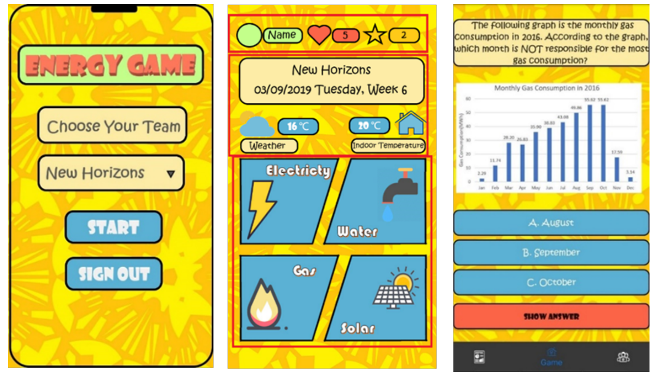

Figure 1: Screenshots of the mobile application interface

When asking building users if the mobile application should be developed as a game, 60% of the participants held a negative view for a game, while 40% of people were optimistic about a game-based mobile application.

4 PROTOTYPE

In accordance with the findings from prior work and our survey results, we sought to limit the gamification elements in the application and reach a middle ground between an informative application and a game. For this study, we designed the application for Android operating systems. Figure 1 shows the interface of the prototype mobile application.

Users need to verify their identifications and select a building. Then they can enter the building's home page where they can see their current lives and points and choose one of three different energy related utilities, electricity, water and gas (solar is currently unavailable), to gain knowledge about. After accessing the selected utility, there are various difficulty levels of quiz questions. Users must start from the easiest level and the proceeding level will be unlocked as each question is correctly answered. If the answer is correct, one point will be added to the user, also an explanation of the question and related energy consumption knowledge will be displayed on the screen.

We designed the quiz questions based on the results of the motivation survey and a data analysis of historical energy consumption of electricity, water and gas collected from the targeting building. Questions are multiple choice with three options. Since the application is used as an educational tool for increasing building users' energy awareness, we adopted Bloom's Cognitive Taxonomy [1] to classify educational learning objectives into levels of complexity and specifically, to identify difficulty levels of the quiz questions.

5 STUDY

To validate the design of our prototype we performed an exploratory study where we compared the mobile application to a simulation of a public display. The study was performed *in the wild*, meaning that participants were asked to use one of two solutions in their everyday life for 5 consecutive days. In the study, we wanted to assess the impact of the two solutions on *Energy Literacy* and *Energy Awareness*.

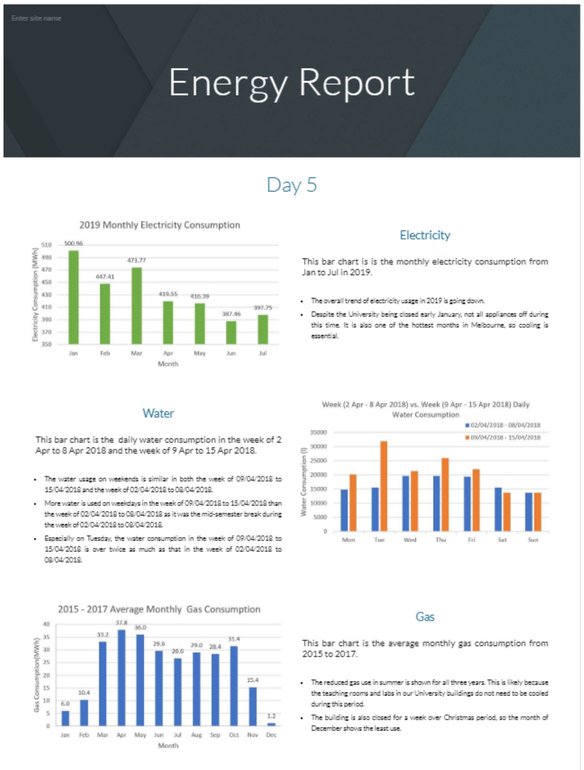

Figure 2: Screenshot of the energy website interface

To compare the mobile application and the dashboard display, the participants were divided into two groups: Mobile group and Dashboard group. Volunteers in the Mobile group played with our prototype mobile application using their own smartphones. While an online energy dashboard was provided for participants in the Dashboard group. The energy information on the online dashboard was the same as that in the mobile application and was updated daily (see Figure 2).

Participants: Nineteen volunteers participated in the user study. All the participants are building users from the selected university. The volunteers were recruited by a participant recruiting poster which was put on the wall of the targeting building a week before the study started. There were 9 Android users in the Mobile group and 10 non-Android users in the Dashboard group.

Procedure: The study was conducted for one week (5 weekdays) from Monday to Friday. On Friday before the study week, an information email introducing the whole process of the study and distinct participant IDs were sent to all participants. On the Monday of the study week, a link to the pre-questionnaire was sent to all the participants. A link to download the mobile application was also sent to the Mobile group, while a link to the online energy dashboard was sent to the Dashboard group. Participants were asked to fill in the pre-questionnaire before they started using the mobile application or investigating the energy report website. On Friday after the usage of mobile application or website for 5 days, a link to the post-questionnaire was sent to all participants to collect their understanding and awareness of energy consumption and their feedback about the intervention.

Measures: We measured participants' energy literacy, energy awareness, activities and feedback during the study. *Energy Literacy* – We measured energy literacy at the beginning and end of the study in the pre and post questionnaires. We took inspiration from the Energy Literacy test developed at Clarkson University [9] which has been used extensively in many studies [15, 17]. Due to the length and some questions being irrelevant to the topic we chose to adapt it to our context. The modified energy literacy test includes two sections: the cognitive section (12 multiple choice questions) and the self-awareness section (10 questions of rating in a 5-level Likert scale their awareness and attitudes towards energy conservation). We then compared participants' energy literacy before and after the study with the scores.

Energy Awareness – Similarly to energy literacy, we measured energy awareness before and after the study in the pre and post questionnaires. We asked participants to rate in a 5-level Likert scale their awareness of the building consumption of the three main types of energy: Electricity, Water, and Gas. We can then compare how energy awareness increased during the study in both conditions.

Participants' Activities – We recorded the Mobile group's logins per day and time spent on the game, which can be used to reflect participants' usage of the mobile application and help with the evaluation of users' commitment to the application. Users' responses to the quiz questions were recorded as well. This information can be used to calculate their correct rate which can indicate users' understanding of the energy consumption. The trends of the changes on correct rate from the first day to the last day can reflect users' transformation of energy awareness.

Feedback – For the Mobile group, 16 multiple-choice questions and 1 open-ended question were included in the post-study questionnaire to collect feedback for the mobile application. The questions asked users' frequency of usage, feedback of the application's usability, preferred features in the future and comments for improvement.

6 RESULTS

In this section, we present the analysis of the result regarding the energy literacy, energy awareness, application usage and feedback. Of the 19 participants, 4 did not fill the post study questionnaire (3 Mobile and 1 Dashboard), therefore their results are not taken into consideration in the remainder of this section.

Energy Literacy: Figure 3 presents the percentage of correct answers for the Energy Literacy Test before and after the study in both conditions. We first compare the evolution of this percentage before and after the study. The Shapiro-Wilk normality test showed the difference followed a normal distribution. A paired t-test did not show any differences between the percentage before and after the study ($p = 0.75$).

Building Energy Awareness: Figure 4 shows the distribution of the answer to the Likert scale before and after the study, for the three types of energy in both conditions. We can clearly see that the awareness of the consumption of the three types of energy increased in both conditions.

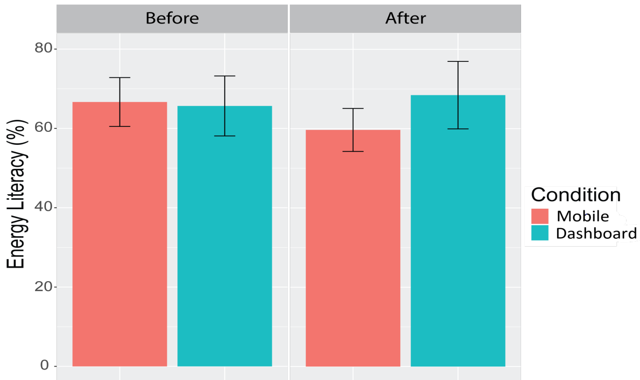

Figure 3: Percentage of correct answers for the Energy Literacy Test for Mobile and Dashboard conditions before and after the study. The error bars represent the standard error.

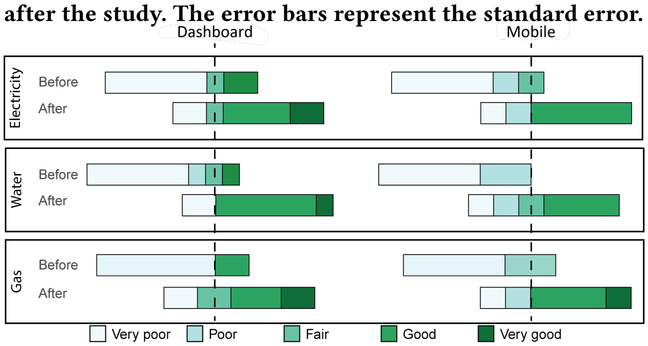

Figure 4: Distribution of the participants' answer to the Likert scale about energy awareness for the 3 types of energy (Electricity, Water, and Gas), for both conditions (Dashboard and Mobile) before and after the study.

Answers to Quiz Questions: Most of the users tried to answer all three questions of the day until they got them correct, while there was one participant only accessed the questions of electricity and water consumption and quit the game without knowing the correct answers. The average correct rate per day seems good as the correct rates of the first four days are at least 70%. The correctness dropped to 50% on Day 5, which is reasonable because questions on Day 5 were the hardest given the difficulties of questions increased with the study process.

Application Usage: There were 34 logins in total during the study. All the 9 app users logged into the application during the first two days of the 5-day study. However, 3 of the app users no longer logged in from Day 3. On Day 4, only 4 users played the game, while the number of active users went up to 6 on Day 5. There were 4 users logged into the application every day throughout the study period. The most popular login times were 10 am to 11 am and 11 pm to 12 am. Out of the 34 logins, 20 (59%) of them happened in non-working hours or during lunch time. The average time users spent on the application was around 2 minutes.

For the Dashboard group, 4 users reported visiting the website everyday, 3 users accessed the website for 3-4 days and 2 users visited for 1-2 days. For each day, 4 users spent 5-10 minutes on the website, 3 users reported spending less than 5 minutes and 2 users spent 10-15 minutes.

Feedback: All participants in the Mobile group responded that the application was easy to use, and they believe most people can learn to use this app quickly. Overall, 67% of the participants ranked the idea of this application as *very interesting* and the last 33% reported it as *moderately interesting*.

Users' feedback about the informativeness of the application and the difficulty of the questions in the game varies a lot, which may be caused by the different levels of their previous perceived knowledge about energy consumption.

Also, some participants in the study suggested the visualisation and the ways of presenting knowledge about energy consumption should be improved. They reported that text and statistical figures was sometimes boring, which made them unwilling to read explanations thoroughly and gain further knowledge from the application.

When asked a question about features that could potentially be included in the app, 67% of the users were interested in the team competition and 50% thought communication between different buildings was appealing.

In addition, as shown from the application usage, mobile application users reduced during the intervention. In this case, notifications could be used in the application to nudge users about returning to participating in the quiz game.

7 CONCLUSIONS AND FUTURE WORK

In this paper, we designed an energy awareness mobile application based on findings from previous work and requirements that we collected from surveys at a university campus. We conducted a comparison of the mobile application and a dashboard display via a user study at the same university campus. The results show that both solutions are effective on improving occupants' energy awareness, while they did not show a difference in energy literacy. The game mechanism in the application were appreciated by participants and make it more engaging.

A limitation of our study is the low numbers of participants, especially in the Android group as a few of those who started did not complete the study. Recruiting high numbers of participants and maintaining their interest throughout the study is a common risk with 'in the wild' studies (i.e. longer term studies in the natural working environment). Whilst the time of our study can be considered as long for a controlled experiment, it can also be considered short for an 'in the wild' study, especially for intrepreting a change in awareness (i.e. only 5 days). The length of study could explain the low impact of both conditions on Energy Literacy, as people received a limited number of questions and data. However, we found the results and feedback from this preliminary research positive. In future work, we will look to improve the mobile application based on the feedback and implement a longer term study to evaluate the application with a larger set of participants, to be able to generalise the findings in more detail.

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REFERENCES

[1] Lorin W. Anderson, David R. Krathwohl, Peter W. Airasian, Kathleen A. Cruikshank, Richard E. Mayer, Paul R. Pintrich, James Raths, and Merlin C. Wittrock.

2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives.* Longman, New York.
[2] Umberto Berardi. 2017. A cross-country comparison of the building energy consumptions and their trends. *Resources, Conservation and Recycling* 123 (2017), 230 – 241. https://doi.org/10.1016/j.resconrec.2016.03.014
[3] Wahidul K Biswas. 2014. Carbon footprint and embodied energy consumption assessment of building construction works in Western Australia. *International Journal of Sustainable Built Environment* 3, 2 (2014), 179–186.
[4] Christine Boomsma, Julie Goodhew, Sabine Pahl, and Rory V Jones. 2016. The feasibility of saving energy in challenging organisational contexts: Testing energy visualisation in a social services office in the United Kingdom. *Energy Research & Social Science* 15 (2016), 58–74.
[5] Dirk Börner, Jeroen Storm, Marco Kalz, and Marcus Specht. 2012. Energy awareness displays: motivating conservation at the workplace through feedback. *International Journal of Mobile Learning and Organisation* 6, 3-4 (2012), 189–203.
[6] Amanda R Carrico and Manuel Riemer. 2011. Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education. *Journal of environmental psychology* 31, 1 (2011), 1–13.
[7] Hung-Ming Chen, Chun-Wei Lin, Shang-Hsien Hsieh, Hsuan-Fu Chao, Chuin-Shan Chen, Ruei-Shiue Shiu, Shiang-Ru Ye, and Yu-Chang Deng. 2012. Persuasive feedback model for inducing energy conservation behaviors of building users based on interaction with a virtual object. *Energy and Buildings* 45 (2012), 106–115.
[8] Daniel Daly, Paul Cooper, and Zhenjun Ma. 2014. Understanding the risks and uncertainties introduced by common assumptions in energy simulations for Australian commercial buildings. *Energy and Buildings* 75 (2014), 382–393.
[9] Jan DeWaters, Basil Qaqish, Mary Graham, and Susan Powers. 2013. Designing an energy literacy questionnaire for middle and high school youth. *The Journal of Environmental Education* 44, 1 (2013), 56–78.
[10] Graham N Dixon, Mary Beth Deline, Katherine McComas, Lauren Chambliss, and Michael Hoffmann. 2015. Using comparative feedback to influence workplace energy conservation: A case study of a university campaign. *Environment and Behavior* 47, 6 (2015), 667–693.
[11] Paul C Endrejat, Florian E Klonek, and Simone Kauffeld. 2015. A psychology perspective of energy consumption in organisations: The value of participatory interventions. *Indoor and Built Environment* 24, 7 (2015), 937–949.
[12] Mehreen S Gul and Sandhya Patidar. 2015. Understanding the energy consumption and occupancy of a multi-purpose academic building. *Energy and Buildings* 87 (2015), 155–165.
[13] Juho Hamari. 2017. Do badges increase user activity? A field experiment on the effects of gamification. *Computers in human behavior* 71 (2017), 469–478.
[14] Rishee K Jain, John E Taylor, and Gabriel Peschiera. 2012. Assessing eco-feedback interface usage and design to drive energy efficiency in buildings. *Energy and buildings* 48 (2012), 8–17.
[15] Mageswary Karpudewan, Jamunah Ponniah, and Ahmad Nurulazam Md Zain. 2016. Project-based learning: An approach to promote energy literacy among secondary school students. *The Asia-Pacific Education Researcher* 25, 2 (2016), 229–237.
[16] Jesper Kjeldskov, Mikael B Skov, Jeni Paay, and Rahuvaran Pathmanathan. 2012. Using mobile phones to support sustainability: a field study of residential electricity consumption. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2347–2356.
[17] Lung-Sheng Lee, Yi-Fang Lee, James W Altschuld, and Ying-Ju Pan. 2015. Energy literacy: Evaluating knowledge, affect, and behavior of students in Taiwan. *Energy Policy* 76 (2015), 98–106.
[18] David Lehrer and Janani Vasudev. 2011. Visualizing Energy Information in Commercial Buildings: A Study of Tools, Expert Users, and Building Occupants. *UC Berkeley: Center for the Built Environment* (2011). https://escholarship.org/uc/item/6vp5m5m3
[19] Clare Littleford, Tim J Ryley, and Steven K Firth. 2014. Context, control and the spillover of energy use behaviours between office and home settings. *Journal of Environmental Psychology* 40 (2014), 157–166.
[20] Okatoseng Tsametse Masoso and Louis Johannes Grobler. 2010. The dark side of occupants' behaviour on building energy use. *Energy and buildings* 42, 2 (2010), 173–177.
[21] Brian Orland, Nilam Ram, Dean Lang, Kevin Houser, Nate Kling, and Michael Coccia. 2014. Saving energy in an office environment: A serious game intervention. *Energy and Buildings* 74 (2014), 43–52.
[22] Arnaud Prouzeau, M.B. Dharshini, Manivannan Balasubramaniam, Joshua Henry, Ngoc Hoang, and Tim Dwyer. 2018. Visual Analytics for Energy Monitoring in the Context of Building Management. In *2018 International Symposium on Big Data Visual and Immersive Analytics (BDVA)*. 1–9.
[23] Umar Ruhi. 2015. Level Up Your Strategy: Towards a Descriptive Framework for Meaningful Enterprise Gamification. *Technology Innovation Management Review* 5 (08/2015 2015), 5–16. https://doi.org/10.22215/timreview/918
[24] Jonathan Simon, Marco Jahn, and Amro Al-Akkad. 2012. Saving energy at work: the design of a pervasive game for office spaces. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*. 1–4.
[25] Alexa Spence, Murray Goulden, Caroline Leygue, Nick Banks, Ben Bedwell, Mike Jewell, Rayoung Yang, and Eamonn Ferguson. 2018. Digital energy visualizations in the workplace: the e-Genie tool. *Building Research & Information* 46, 3 (2018), 272–283.
[26] Markus Weiss, Claire-Michelle Loock, Thorsten Staake, Friedemann Mattern, and Elgar Fleisch. 2010. Evaluating mobile phones as energy consumption feedback devices. In *International Conference on Mobile and Ubiquitous Systems: Computing, Networking, and Services*. Springer, 63–77.
[27] Devon Wemyss, Roberta Castri, Vanessa De Luca, Francesca Cellina, Vivian Frick, Evelyn Lobsiger-Kägi, Christian Hertach, Tobias Kuhen, Vicente Carabias, et al. 2016. Keeping up with the joneses: examining community-level collaborative and competitive game mechanics to enhance household electricity-saving behaviour. In *Proceedings of the 4th European Conference on Behaviour and Energy Efficiency*. 1–17.