Studying the Immediacy of Eco-Feedback Through Plug Level Consumption Information

Filipe Quintal, Mary Barreto, Fábio Luis, Vitor Baptista
Madeira Interactive Technologies Institute
University of Madeira
Polo Científico e Tecnológico da Madeira
9020-105 Funchal, Portugal
{firstname.lastname}@m-iti.org

Augusto Esteves
Centre for Interaction Design
Edinburgh Napier University
10 Colinton Rd, Edinburgh, United Kingdom, EH10 5DT
a.esteves@napier.ac.uk

***Abstract*— This work is focused on studying the immediacy of eco-feedback and the appropriation of these systems in households' daily life. This paper describes the development of Wattapp, a common two spots wall socket redesigned to display the current consumption using a set of LED lights, which change from green to red according to the consumption. The device was evaluated for fifteen days in the cafeteria/lounge of a research institute and a subset of six users were interviewed to assess how Wattapp was perceived. In general, users understood the feedback. In addition, our evaluation disclosed how such device could be used in the day-to-day lives, for example, comparing the consumption of electrical devices or used to remotely control appliances.**

Keywords*— Eco-feedback; Sustainability; User Interfaces; Prototyping.

I. Introduction

The increasing demand for energy and its negative impact on the environment is one of the main issues currently challenging researchers from different areas such as economics, engineering or social sciences. Although coal is still the main source of energy in the modern societies [1], the change for more sustainable sources is worldwide. However, to avoid the concretization of the Jevon paradox [2], this change should be followed by behavior change in consumers. Consumers will need to become more efficient and adapt to a changing paradigm where the availability of energy could vary according to factors such as battery state or photovoltaic production.

If we also consider the fact that the number of electronic devices in the modern household is increasing and small appliances account for 50% of the electricity consumed in a building, it is clear the end consumers will have an important role in the future of energy industry. This emergence of consumers as players in the energy field has been addressed in what came to be the eco-feedback research field [3], which we summarize as any hardware or software system or any technology-aided intervention that informs and/or educates individuals about their resource consumption with the goal of reducing it.

Eco-feedback is already an established field of research. Early work in this field was focused on informing consumers on their consumption using charts, comparisons, or simple numerical values. More recently, authors have studied how to include variables such as information on energy production or forecast of energy availability into the eco-feedback systems (e.g. [4]).

In this paper, we want to understand how electricity consumers react to Wattapp, an electricity socket that informs them on the amount of energy being consumed. In this study, we aimed at studying concepts such as the visibility and immediacy of feedback and appropriation/usage in the daily life of users.

II. Related Work

The development of Wattapp combines motivation from two related fields of research. The motivation for implementing an autonomous electricity socket emerged from household automation and energy sensing fields. The possible usage scenarios for Wattapp, and the scope of the problem we are addressing clearly belong to the eco-feedback field.

A. Household Automation

In recent years eco-feedback researchers have studied how automation can be used to reduce electricity consumption or the cost of electricity. Kobus et. al. [5] studied how automation could improve the usage of the washing machine to maximize self-consumption for photovoltaic installation owners or to reduce the cost of electricity. Fisher et al. describe a system that recommends better energy tariffs, which result in monetary savings for the end consumer [6]. Both these approaches presented promising results, yet they have as well limitations. Kobus work was limited to a single appliance and Fisher's study was focused on one decision point (the selection of the tariff). We argue that automation can ideally combine more appliances with other variables besides the cost of energy, such as its origin or availability. For this vision to work, there should be a way of making other household appliances "smart". We attempt to address this opportunity by placing computation and the decision making between the appliances and the electricity grid (in the socket).

978-3-901882-99-9 ©2017 IFIP

On the commercial side of the spectrum, products like the Phillips Hue[1] or the Amazon Echo & Alexa[2] have brought automation to the mainstream. Although automation is clearly gaining traction, researchers have found that communication with the user is still important for these systems to be perceived as accountable and trustworthy [7]. We plan to address this issue through Wattapp by providing consumption visibility to the electricity consumer.

B. *Plug-level feedback*

One of the most referred factors influencing the efficiency of eco-feedback is the immediacy and placement, authors have referred that it should be given as close to the point of decision as possible [8]. Therefore, researchers have explored including the feedback into the products consuming energy or close by (for example the NEST thermostat). The design of Wattapp is strongly motivated by the Power Aware Coord [9] and by the more recent work of Heller et al, where the authors built a prototype power plug that gives feedback on the energy being consumed [10]. Both these contributions also addressed the issue of the intangibility of electricity [11] by displaying the feedback in an artifact that is commonly used to consume electricity (an extension cord and an electricity socket), and which is the closest an electricity consumer gets to electricity itself. These approaches display real-time consumption, and although this technique can educate consumers about the consumption of individual appliances and allow the comparisons between devices, they are limited in their effectiveness. In certain situations, the consumption cannot be avoided, and in those scenarios, the plug-level feedback could be used to inform on other variables such as electricity price or origin, and these are opportunities we aim at testing during Wattapp evaluation.

III. THE WATTAPP

Wattapp was designed taking into consideration the body of work described above. Wattapp is a common two spots type F wall socket redesigned with two main goals (see figure 1). First, the capability of presenting information through a set of individually addressable LED's was added. Secondly, an Intel Edison™[3] microprocessor was incorporated into the inner shell of the socket. This way, the plug can measure the electricity passing through the sockets as well as controlling the visualization LED's. To assure the correct functioning of this package other items had also to be fitted, such as an: electricity transformer, custom build shield, ADC shield, relays and current sensors.

Overall, the Wattapp socket differs from a traditional socket in its capability to display information (through the LED's), process consumption data, control the state of the plug and by its connectivity (the Intel Edison™ used in the Wattapp supports Wifi communication). Coupled with the implementation of Wattapp there is a web server running a database and web service, which aggregates all the consumption associated with the socket. There are also web services capable of changing the ON/OFF state of the Wattapp, effectively blocking and allowing electricity through it. Wattapp samples electricity at 50Hz and at this stage, the system records two types of data. One is the continuous consumption, which can be identified as time-series data of the socket consumption over time. The second being the consumption events, which are abrupt changes in electricity consumption, resulting from a device being turned on or off. These consumption events are identified by a consumption value and a timestamp. Currently, Wattapp saves one consumption point per second and the consumption events in real time. It changes its color continuously from green to red by comparing the real-time consumption with a baseline for the device it is connected to. When a low consumption appliance is connected to it (e.g. a mobile phone charger) Wattap displays green, higher consumption appliances (e.g. kettle) will result in the color red being displayed. Appliances with different states (e.g. microwave) cycle through different colors in normal operation.

IV. EVALUATION

Wattapp was evaluated for approximately fifteen days in the cafeteria/lounge of a research institute (see figure 2). A coffee machine was connected to Wattapp. The duration of the study was set to fifteen days since we believe it was enough time for every employee or student to have a chance to try it. The rationale for selecting the coffee machine is supported by three main observations:

1. The coffee machine has several individuals and sequential "states" that range from low consumption (the illumination), medium (the water pump) to high (the thermostat).
2. The effect of the individual consumption is clearer if it is isolated in a single device.
3. This device is used throughout the whole day.

A. *Method*

Wattapp was left in the cafeteria for fifteen days, with a small note informing users of that space that they could use the appliances normally. After the 15th day, another note was placed next to the coffee machine with our contact, informing that we would like to hear peoples' impressions of Wattapp. Additionally, after this period we actively sought for regular users of the coffee machine. In total, we approached six individuals (4 female). Our interaction with users was composed of a questionnaire containing twenty-two questions: the first fifteen were meant to probe users' pro-environmentalism according to the New Environmental Paradigm (NEP) [12] scale; four questions focused on the interaction with Wattapp using a five-point scale (1-Strongly Disagree, 2-Mildly Disagree, 3-Unsure, 4-Mildly Agree, 5-Strongly Agree); and finally, users' demographic information was collected.

Afterwards, a semi-structured interview was performed to understand if the participants noticed Wattapp and if the information was clear and/or useful.

[1] http://www2.meethue.com

[2] https://www.amazon.com/dp/product/B00X4WHP5E

[3] https://software.intel.com/en-us/iot/hardware/edison

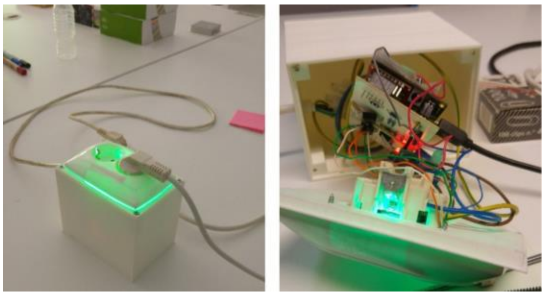

Fig. 1. Left: Display low consumption, Right: Wattapp inner components'

V. RESULTS

During the period of the study, the coffee machine was used 389 times, averaging 26 coffees per day and 1.10 per hour. The most active period was between and 9:00 and 10:00 with 35% of all usage. The period between 12:00 and 14:00 was also very active with 27% of all usage.

The remaining of this section summarizes the results from Wattapp's evaluation with 6 individuals. Firstly, we present the results from the questionnaires and subsequently the qualitative analysis of the semi-structured interviews.

A. Questionnaire

The questionnaires confirmed that Wattapp was not intrusive, nor was it seen as hazardous. User answers averaged 1.5 and 1.6 to the questions: "Wattapp was in the way of me getting coffee"; and "Wattapp made using the coffee maker dangerous", respectively. In addition, we were able to assess users' pro-environmentalism. Users average answers of the NEP placed them in the "New social paradigm" (avg=3.98) part of the scale, which implies that our participants are in average pro-environment individuals. We also investigated if using Wattapp made our participants more aware of the different stages of the process of making coffee, with users answering to the question "*The process of making coffee has different stages*" with an average of 3.5 (using the same 5 point scale presented before).

B. Interviews

The interviews were transcribed and analyzed using the thematic analysis proposed by [13]. Two researchers performed the analysis independently and agreed with the themes explained below.

1) Visibility and feedback

The coffee machine was clearly visible, and all participants noticed Wattapp connected in the lounge of the workspace: "*I definitely noticed it was there*" P1 and "*Yep I saw it… always on with a green light*" P6. Regarding the feedback itself, most participants understood the association between the colors and the consumption as P1 referred: "*The first thing that I notice is that there is obviously a relationship between the different colors displayed by the power socket and the energy consumption*" P1. Yet other participants did not notice these relations: "*I think I was too focused on the machine and taking my coffee, (…) I did not notice it*" P5. Or did not agree with how the feedback was displayed: "*I think the color red (…) raises your attention about a problem or about something in the machine that is not working properly (…) I would use orange instead*" P2.

Lastly, one participant referred that the feedback displayed by Wattapp allowed him to visualize the different states of the coffee: "*I can understand … see the different stages that the coffee machine is doing during the procedure of coffee making, like getting the coffee (…) warming up the water, using the coffee …*" P1.

2) Trigger for behavior change

It was also important to assess if the feedback displayed by Wattapp could motivate or eventually trigger any change in the way our participants use energy. A recurrent observation made by our participants was that the real-time feedback followed their behavior, and that way there was no time to alter that decision, as it was referred by P4 and P3 *"(…) when it became red what could I do? Not use it?*" P4, "*I think it is cute but when you are using energy there is no other option*" P3.

Other participants mentioned that a historical feedback mechanism would have helped them plan their future utilization of the coffee machine: "*What I can do is reduce the times that I use the machine if I know the accumulated energy consumption*" P1. The next sub-section explores further how these features would help our participants.

3) Appropriation in daily life

Our qualitative analysis explored how users hypothesized using Wattapp in their daily lives. In general, participants referred that such device would be useful, however, some features had to be added to fit into their routines: "*I would definitely use … this kind of information in my electrical devices (…) in an accumulative manner (…)*" P1, "*control remotely (…) relevant for the fridge, the door...to let you know you are opening it too much and wasting energy*" P3. Most participants referred as well that additional concrete (numerical) information would have been valuable, as P5 mentioned: "*Some numbers (…) or something similar to what you have in your car to show how fast you go*".

In addition, participants suggested other features that could be added to Wattap. For example the display of the energy source in the plug (if it is renewable), comparisons with other electricity consumers, information about the impact in the environment, or even use the plug to automate actions in the household as P2 and P3 mentioned: "*detect if it was overusing energy… and it would place the device in standby mode or something in those lines*" P2, "*it could tell people about the energy type and when it was cheaper to use one or other devices*" P3. Participants also referred the information could be better contextualized in a scenario with more plugs.

VI. DISCUSSION

Wattapp was perceived as safe and not intrusive (as a wall socket should be), the raw amount of times the coffee machine was used further validates this observation. In general, the feedback was well understood, having a drastic change in the color helped our participants gain attention, which is in line with the observation in [14] about how radical feedback can raise consumer's attention. However, the decision of displaying real-time feedback cornered our users when using the coffee machine. Having Wattapp colors change in real time helped contextualize the consumption since consumers could relate it to their current actions similar to what was observed by [9]. Nonetheless, this modality of feedback could have been extended to support the decision making for future actions.

Furthermore, the appropriation in the day to day routine is a challenge for any eco-feedback device [15], our participants' suggestions reinforce literature recommendations such as using historical data, social comparisons [16], presenting the impact on the environment [17] or the energy origin [18]. During the interviews, one participant clearly stated that Wattapp visualization revealed the different stages of making coffee, similarly to [19] observation and with the results from the questionnaire. We argue that this type of feedback could be useful to inform on an appliance state or correct functioning. However, as it is only visible at the point of a decision it is not an effective tool to change the current behavior.

Altogether Wattapp is a working prototype of a system that fits in the state of the art eco-feedback research. We extended [20] work with a device that was used for fifteen days straight. The presented study disclosed that the color-coding could be used to uncover individual consumption, which in a first stage simply informs consumers. However, our participant's observations suggested other approaches that could be implemented with Wattapp that are in line with the work of [6], [7] on household automation or tariff selection. This way our study discloses that there is the opportunity to implement automation in individual electricity sockets and that a simple color code can be used to convey information in the socket itself. The current implementation of Wattapp was valuable as a probe to explore scenarios regarding feedback and automation, yet, to extend work on eco-feedback regarding behavior change other approaches rather than just displaying current electricity consumption must be explored, and our study was not successful in accomplishing that.

VII. Conclusions

Wattapp can be simply described as a computer embedded in a wall socket, in that sense we acknowledge that our field of expertise might limit the usages we envision for the system. Therefore, Wattapp is currently an open source project at Instructables.com[4].

Fig. 2. Wattap as it was deployed next to the coffee machine, in this particular case the consumption is very low.

[4]http://www.instructables.com/id/Create-a-Plug-to-Monitor-Power-Consumption-With-In/

References

[1] International Energy Outlook 2016. US Energy Information Administration, 2016.

[2] S. Sorrell, "Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency," Energy Policy, vol. 37, no. 4, pp. 1456–1469, 2009.

[3] J. Froehlich, L. Findlater, and J. Landay, "The design of eco-feedback technology," in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, NY, USA, 2010, pp. 1999–2008.

[4] W. Simm et al., "Tiree Energy Pulse: Exploring Renewable Energy Forecasts on the Edge of the Grid," in Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, New York, NY, USA, 2015, pp. 1965–1974.

[5] C. B. A. Kobus, E. A. M. Klaassen, R. Mugge, and J. P. L. Schoormans, "A real-life assessment on the effect of smart appliances for shifting households' electricity demand," Appl. Energy, vol. 147, pp. 335–343, Jun. 2015.

[6] J. E. Fischer et al., "Recommending Energy Tariffs and Load Shifting Based on Smart Household Usage Profiling," presented atIUI, 2013, pp. 383–394.

[7] T. A. Rodden, J. E. Fischer, N. Pantidi, K. Bachour, and S. Moran, "At home with agents: exploring attitudes towards future smart energy infrastructures," in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, NY, USA, 2013, pp. 1173–1182.

[8] C. Fischer, "Feedback on household electricity consumption: a tool for saving energy?," Energy Effic., vol. 1, no. 1, pp. 79–104, Feb. 2008.

[9] A. Gustafsson and M. Gyllenswärd, "The power-aware cord: energy awareness through ambient information display," in CHI '05 Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA, 2005, pp. 1423–1426.

[10] F. Heller and J. Borchers, "Physical Prototyping of an On-outlet Power-consumption Display," interactions, vol. 19, no. 1, pp. 14–17, Jan. 2012.

[11] J. Pierce and E. Paulos, "Materializing energy," in Proceedings of the 8th ACM Conference on Designing Interactive Systems, New York, NY, USA, 2010, pp. 113–122.

[12] R. E. Dunlap, K. D. Van Liere, A. G. Mertig, and R. E. Jones, "New trends in measuring environmental attitudes: measuring endorsement of the new ecological paradigm: a revised NEP scale," J. Soc. Issues, vol. 56, no. 3, pp. 425–442, 2000.

[13] V. Braun and V. Clarke, "Using thematic analysis in psychology," Qual. Res. Psychol., vol. 3, no. 2, pp. 77–101, Jan. 2006.

[14] S. O'Neill and S. Nicholson-Cole, "'Fear Won't Do It' Promoting Positive Engagement With Climate Change Through Visual and Iconic Representations," Sci. Commun., vol. 30, no. 3, pp. 355–379, Mar. 2009.

[15] G. Wallenborn, M. Orsini, and J. Vanhaverbeke, "Household appropriation of electricity monitors," Int. J. Consum. Stud., vol. 35, no. 2, pp. 146–152, Mar. 2011.

[16] D. Foster, S. Lawson, M. Blythe, and P. Cairns, "Wattsup?: motivating reductions in domestic energy consumption using social networks," in Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, New York, NY, USA, 2010, pp. 178–187.

[17] "7000 oaks and counting, by Tiffany Holmes," Change as Art. .

[18] J. Pierce and E. Paulos, "The local energy indicator: designing for wind and solar energy systems in the home," in Proceedings of the Designing Interactive Systems Conference, New York, NY, USA, 2012, pp. 631–634.

[19] L. Broms, C. Katzeff, M. B\aang, \AAsa Nyblom, S. I. Hjelm, and K. Ehrnberger, "Coffee maker patterns and the design of energy feedback artefacts," in Proceedings of the 8th ACM Conference on Designing Interactive Systems, New York, NY, USA, 2010, pp. 93–102.

[20] F. Heller, K. Tsoleridis, and J. Borchers, "Counter Entropy: Visualizing Power Consumption in an Energy+ House," in CHI '13 Extended Abstracts on Human Factors in Computing Systems, New York, NY, USA, 2013, pp. 2363–2366.