Team up with Eco-aware Everyday Things to Green your Workplace!

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***Abstract*—The lack of energy consumption awareness in public spaces is a fact. There, people do not receive energy consumption feedback nor do they pay a monthly invoice to electricity providers. Thus, there is practically a non-existent perception of energy waste; and hence, there is low motivation to reduce it. To tackle this problem we transform everyday shared electrical appliances which are placed in common spaces into collaborative eco-aware everyday things. These eco-appliances make people aware that they are not alone to save energy, but the everyday things can team up with them to achieve this task. Qualitative and quantitative results were gathered in three case studies performed with shared coffee machines at workplace. The objective was to assess the effectiveness of the proposed eco-aware design in terms of energy saving and the degree of affiliation between workers and the smart appliance to create a green-team relationship.**

***Keywords*-Eco-aware everyday things; Eco-feedback; Persuasive Technology; Teammates;**

I. Introduction

Methodologies for reducing the overall energy consumption are a hot research topic within the ubiquitous computing, HCI and IoT research fields [1], [2], [3], [4], [5]. To date, most of research has focused on saving energy at homes, where motivational approaches to increase awareness are centred at individual level. Nevertheless, still few procedures have targeted public or common areas, nor have they applied collective awareness approaches to tackle this major concern. The workplace is a very relevant case of study since our society spends at work more than half of the day, and this sector is now responsible for roughly the 10% of the overall energy demand [6].

According with [7], the energy consumed by work-appliances of collective use in offices represents more than 15% of the total and it is expected to rise above 20% in 2020. That report argues that this percentage could be reduced if workers increased their eco-awareness. However, they have usually remained left out of the understanding of device's power consumption and they are generally unconcerned about energy expenditure [8].
One of the reasons of such lack of energy awareness, both in sustainability and economic terms, is due to the intangible nature of electricity (i.e. they do not get feedback from appliances). In fact, there still exists a general misconception that energy wasting is only an issue of economical ground rather than an overall planet necessity [1].

The reviewed literature related with workplaces reveals that there are two strategies to cope with energy waste: On one side, a *complete technological approach*, like environment automation where machines are energy efficient and they take the sustainability oriented decisions by moving people aside of their intervention (e.g. device's auto-power down) [9], [10]. On the other side, a *human behavioural change approach*, where people bear the full responsibility of their decisions (e.g. switch off the devices when they are not in use) [11], [2].
Our proposal is aligned with both trends: It devises a *mixed approach* putting both Internet-connected devices (in this work, a smart coffee-maker which is an appliance of shared use) and workers on the same team to overcome the lack of energy consumption awareness. We propose that these shared appliances should motivate people to take more and better eco-actions. To this end, we embed intelligence within these devices in order to make them learn their daily usage pattern. The objective of this learning is twofold:

1) To predict their next-week usage in order to infer when it would be advisable (in energy terms) that the machine remains turned on or off as a function of the number of people that previously used it.
2) To make use of these predictions to interact persuasively with concerned users about the necessity of keeping the appliance on or, in contrast, switch it off over certain periods of time during the work-day.

Therefore, we aim to aware workers that they are not alone to save energy, but the surrounding everyday electrical appliances are ready to team up with them to accomplish this task.

This work contributes to the community by exploring whether the design of the eco-aware everyday objects is adequate to: *a)* help users to save energy; *b)* create a sense of interdependence between workers and the appliances in order to constitute a team relationship towards save energy; *c)* heed the advices that the eco-appliances give to workers to save energy.

The article is structured as follows: In next section,

the background of workplaces interventions is reviewed. Section III starts with a summary of the eco-aware everyday things' features followed by the definition of the research hypotheses. In Section IV the experimental procedure is explained while in Section V the qualitative and quantitative results are analysed. Finally, Section VI summarises the conclusions of this paper.

II. Background

The relationship between sustainability and ubiquitous computing is not new. Reviewing the literature [1], [2], [3], [4], [5] one can easily realise that most of this field research is centred in households. Unfortunately, their findings and outcomes are rarely tested in common spaces. In spite of this, there exists some references aiming to workplaces.

Siero et al. [12] introduced the concept of cooperative energy consumption feedback in organisations. They demonstrated that such feedback is most useful when is reported with other data to compete with (e.g. the energy saving of other group). Schwartz et al. [8] investigated the role of workers to save energy. They collected energy data from a group within a large organisation to conduct a series of participatory action research to spark reflection and discussions about energy wasting. Similarly, [11] describes how a qualitative research methodology, i.e. workshops in the public sector, was applied to investigate the perception that workers had about their energy use and how to change it through technology-led feedback. These three qualitative studies can be grouped within human behavioural change approaches to save energy. EnergyPULSE [13] was a pervasive system devised on the basis of [8]. The major difference with its base-line study was to create a technological system to support energy awareness in work environments.

The reviewed works use informative feedback as the only tool to increase energy awareness, since it has a great potential to save energy [14]. Nevertheless, we consider that mere energy feedback in common areas is not enough neither to motivate workers, nor to eventually prompt a behaviour change. Likewise, we argue that technical solutions alone, like automation or domotics, will not be enough to create a sustainable environment. Therefore, we have devised a *mixed approach* where the Internet-connected appliances, i.e. eco-aware everyday objects, jointly collaborate with workers to reduce their energy consumption.

III. Eco-aware Everyday Things

Awareness about the energy consumption of collective appliances is negligible when compared with our own personal appliances [8]. Therefore, their saving potential is rather high. Analysing energy data from one of these shared appliances, a coffee-maker placed in our research laboratory, we found a wide variety of ways to use the device. That is, people applied different operating modes when preparing a hot-drink: some left the coffee-maker on *standby mode*, and others left the device switched-off after its utilisation. Such randomness, which could be extrapolated to any other electrical appliance of collective use, is noticeably correlated with energy waste as it was demonstrated in a previous authors work [15].

There exist several initiatives to increase the appliance's energy efficiency. For example, in EU there are some related to the coffee machines [10]. In that article Nipkow et al. [10] boost automation techniques to achieve energy efficiency. They argue that the best available technology, i.e. the most efficient coffee machines, are those provided with auto-power-down mode, better insulation of hot parts and low standby mode consumption. However, it has been proven that a better approach to save energy - when operating devices of shared use, it is to apply an intelligent and dynamic combination of the available operation modes [15]. The eco-aware everyday things are mainly designed on the basis of that intelligent approach. However they do not only rely on automation, but they also feature persuasive interaction with their users.

A. Teammates

Eco-aware everyday things raise energy awareness by making visible to humans their own energy waste. However, these 'things' are conceived to be more than mere energy consumption reporters. They could be considered as *eco-activists*, i.e. everyday things which actively aid people to take more sustainable decisions in common areas in order to save energy.

We are not the first to consider that humans and technology can and should work together, i.e. to be allies. Nass et al. [16] already investigated about team affiliation between humans and computers. They concluded that interdependence cues were pivotal to create a team relationship. Indeed, the subjects under interdependence conditions were found to be more cooperative and open to influence from the computer. This work borrows some of their findings to get a first step forward in the area of intelligent everyday objects. The first hypothesis of this research is the following:

> *If the eco-aware everyday things pursue the goal of reducing energy consumption and they actively team up with people to attain it, their potential users will exhibit greater encouragement and energy reduction will be a noticeable fact.*

B. Persuasive Device

Our society is getting increasingly influenced by everyday technological products. The concept of 'objects as mediators', also called 'persuasive technology' when using

pervasive computing [17], states that their designers have now the potential to change our opinions and behaviours through them [18]. Accordingly, the eco-aware devices are also conceived as mediators; they are designed to motivate behaviour changes towards increasing sustainability.

Fogg [17] asserted that people who perceive technology as an authority are more susceptible to persuasion by that technology. The authority principle discussed by Cialdini [19] states that people believe that they will be better off if they follow the lead of legitimate experts. The eco-aware objects have information that people do not have access to, e.g. energy consumption. So, the second hypothesis is as follows:

> *The users attribute a role of authority to eco-aware things and therefore users heed their advices to save energy.*

IV. Methodology

We have performed three case studies in three research laboratories (for the rest of the paper: S3Lab, ProtoLab and SmartLab) which were all related with the usage of an appliance of common use, a capsule based coffee-maker. The study was carried in real-life everyday contexts and it lasted one month. Three capsule-based coffee machines were augmented with pervasive technology to be able to collect and log energy data and to provide energy feedback to the corresponding users. Only one of these three devices featured the full distinctive of an eco-aware everyday thing. Therefore, we can define the research methodology as a comparative study.

The participants that took part in the study were 20 members of S3Lab, ProtoLab and SmartLab (8, 4 and 8 people respectively). Although the laboratories belong to the same institute, each has its own working-room. The three laboratories had a lounge-corner at the back of their working-room where the coffee-maker was located. Therefore, the three experimental conditions were isolated to prevent exposure from alternative conditions. The participants' age range was 20-40, they were all males and engineers in telecommunications or computer scientist. The three groups presented similar patterns of coffee intakes: around the noon and after the lunch.

The procedure was divided in 3 parts: *1)* The pre-trial survey (we obtain the participants' agreement to collect their energy data); *2)* The development of the field studies; *3)* The post-trial questionnaire and a semi structured interview.

1: In the first round of interviews, personal information from the participants was collected, i.e. age, genre, laboratory, etc.; the pre-trial survey was focused on getting people's perception about their energy consumption at work.

2: In the second phase of the pilot the three coffee-makers where augmented with Internet connection to send to a remote database their energy consumption data. This phase lasted as long as the whole experiment, i.e. 4 weeks.

On the 1st week, the three coffee machines were left without changes, i.e. we did not apply any intervention beyond collecting data.

On the 2nd week, a public Twitter profile was created for each coffee-maker (@S3LabCoffee, @ProtoLabCoffee, @SmartLaCoffee). In this condition, the three coffee machines were able to publish their everyday energy consumption, both effective and wasted (see Figure 1). The idea behind making them 'social' was to let people follow their laboratory's performance by seeing their daily published energy consumption in `Wh` on Twitter. All the subjects implied in the case studies were notified about this new feature. Twitter was selected as communication channel, because according to the interviewees, it was their most used social network and they in general pointed that it was easy to reach all the members of a group with just one 'tweet'. Indeed, several researchers on the field of IoT [20], [21] argued that it is a suitable platform to pave the bridge between people and things to communicate with each other, as well as we did in one of our early works [22]

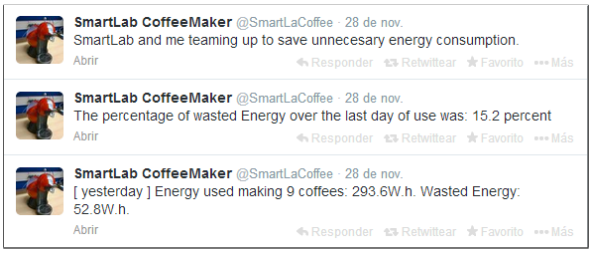

Figure 1. Set of tweets sent by the SmartLab coffee-maker.

On the 3rd and 4th week, the devices under study were augmented with different eco-feedback technologies. The interactive designs, which can be appreciated in Figure 2, are slightly described next. Deeper details and their design rationale can be found in [23].

Figure 2a shows a web interface developed for the S3Lab group. It plots the same data that is published in its Twitter account. To reach this site, the coffee-maker tweets everyday the website's url, and a QR-code linking to it was also placed on the appliance's top. This interactive visualisation allowed participants to compare the energy consumption with the historical recorded one.

In ProtoLab, we installed a physical display close to the coffee-maker as shown in Figure 2b. The idea behind this metaphor was to motivate people to not reach the energy wasted the previous day.

The SmartLab's coffee-maker was the only appliance that featured the traits of an eco-aware everyday thing.

On the one side, it provided visual feedback, through an ambient light arch - top of Figure 2c, about the energy that was being wasted due to absent mindedness. On the other side, the coffee-maker collaborated by giving advices to users about its appropriate usage to avoid wasting energy. To this aim it displayed subtle advices (bottom of Figure 2c).

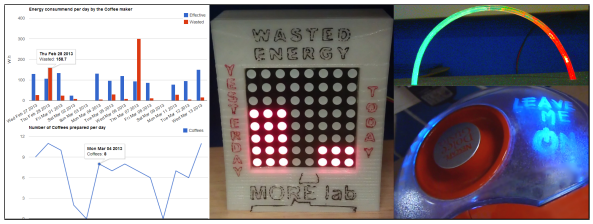

Figure 2. *a)* Dashboard showing the wasted and effective energy in S3Lab; *b)* The physical display allows to compare the current wasted energy with the previous day; *c)* The light arch shows the increase of the wasted energy, while the coffee-maker prevent people with subtle advices about how to behave efficiently.

3: When the intervention concluded, we did a post-trial semi-structured interview with participants. The main objective was test our hypotheses. The post-interview was divided in two parts: In the first part we recorded the participant's open answers. The latter part was a self-report of eighteen items that interviewees had to fill in a 5-point Likert scale. It was structured in four blocks to record the participant's insights about their affiliation and interdependence with the coffee-machine, the role of authority that they attributed to the device, and finally three items devoted to extract the participant's acceptance around the inclusion of the smart-device in their work routine. Most of the items were based on the scale used by Nass et al. [16][1]
Assuming that there were certain similarities among the three groups (number of people, background, schedules of coffee intakes), Pearson chi-square analysis was used to assess the statistical significance between the answers of the group that interacted with the eco-aware coffee-maker and the groups which did not.

V. Results and Analysis

The pre-trial survey confirmed that interviewees were not concerned with energy expenditure in their workplace and that they lacked of motivation to reduce it. Indeed, four in five felt confident when saying that the use that they do with appliances in the workplace is energetically inappropriate. 74% asserted to be much more aware about energy consumption in their homes than in their workplace. The remaining 26% said to be equally concerned in both spaces. Most of them attributed economic reasons. For example Martin stated: *"That [the energy waste issue at work] does not directly affect to me. Is a sharing thing and in public spaces I lose track of responsibility*" or Jim argued: *"I am not motivated to reduce energy since the action of one guy is diluted if the group does not take joint actions to tackle it"*.

However, there was a general agreement that in case of being aware of energy waste in real time, their perception of energy waste would increase. Moreover, they asserted that the more informed they were, the better their actions towards energy efficiency would be.

The summary from the post-trial questionnaire reveals that 65% of participants declared to have followed the interactions from the coffee-makers, while 76% asserted that they had reflected with work-colleagues about the energy updates. 4 in 6 of S3Lab's members, which was the laboratory with the worst response to the intervention, confessed to not have paid much attention to the experiment.
Interestingly, 73% of subjects attributed energy reductions to the coffee maker and 82% of them said that the information reported increased their motivation.

The most promising finding was that in only two weeks receiving eco-feedback, 56% of the participants stated to have changed their way of using the coffee maker. More important for us was to find that within such percentage, almost 80% belonged to the SmartLab, i.e. the laboratory of the eco-aware appliance.

During the interview John pointed: *"Now I wait until the message appears after preparing a coffee"*; Mike exhibited his awareness when stated: *"I quickly switch it off [the coffee-maker] to not to see the amount of wasted energy increased"* while Anthony asserted: *"If I see around and I find somebody that is about to prepare a coffee after me, I leave the device on."*

Regarding the Likert questionnaire for the first hypothesis (5 out of 18 responses), with an alpha value of 0.0005 we got a statistical difference between the answers of the group that interacted with the eco-aware coffee-maker regarding the other two (χ^2=17.5201 with df=2, p=0.0001569). We also contrasted the results for the second hypothesis (4/18 responses) with an alpha value of 0.02. The Pearson test also backed that the two groups answered differently (χ^2=9.0013 with df=2, p=0.0111). With this simple analysis and with such a small population ($N < 20$) we can not state that our hypotheses are completely met. However, the results reveal that the group under the eco-aware condition attributed more interdependence cues to the coffee-maker and showed to be more open to the influence of such eco-aware thing.

Besides qualitative results, we can also get conclusions to strength the hypotheses from the quantitative side.
The total energy consumed by a capsule-based coffee-maker

[1]The whole questionnaire in its Spanish version is available on http://tiny.cc/xrasbx

can be broken down in three different states depending of the device operation: *(1) Warming* a phase to ready the pressure engine whenever the device is switched on; *(2) Standby* the energy consumed whilst the device is on without being used; *(3) Working* the device is preparing a hot drink.

Warming and *Standby* are two states where the coffee maker is leaking energy, so both are tagged as Non-effective energy. The remaining state, i.e. *Working*, is tagged as Effective energy.

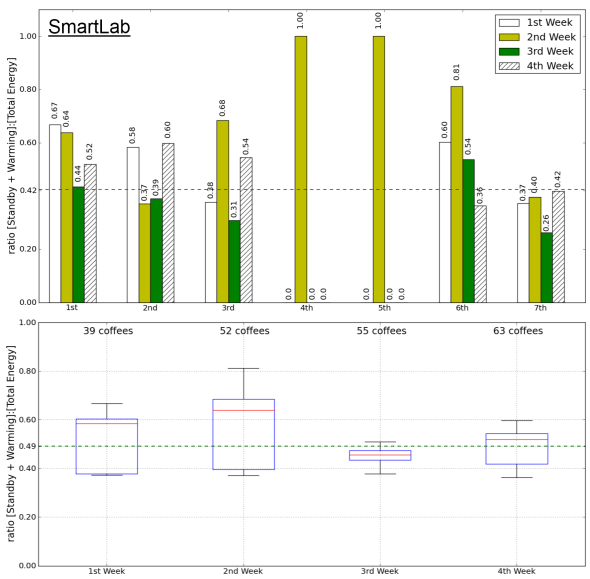

Figure 3. *a)* The ratio of non-effective energy to the total along the days of the week (1st plot-bar corresponds to Wednesday); *b)* A side-by-side box-plot to compare the distribution of the ratio of non-effective energy for each of the 4 weeks.

The top of Figure 3 shows the breakdown of the proportion of non-effective energy consumption to the total in SmartLab on each of the four weeks. The dashed horizontal line represents the monthly-mean which is 42%. As can be observed, giving feedback using Twitter did not lead to a significant change in the device usage on the 2nd week. In fact, the wasted energy increased and somebody forgot the device on during the whole weekend (days 4th and 5th). Nevertheless, transforming the coffee-maker into an eco-aware everyday thing in the 3rd week, the proportion of non-effective energy consumption was considerably reduced. In the last week, despite the usage was less efficient than the 3rd week, the energy efficiency was better when compared with the first two weeks.

The bottom of Figure 3 illustrates a side-by-side box-plot to analyse in depth a presumably increase of energy awareness of SmartLab members during the weeks of interaction with the eco-aware device. The plot shows the spread of the Non-effective energy wasted in the SmartLab along each of the weeks that the trial lasted. The horizontal shaded line denotes the median of the month. It can be appreciated that the 3rd and 4th weeks the distribution of Non-effective energy ratios changed with respect to the previous ones, i.e. the energy wasted decreased and the dispersion of the data was concentrated near their median which means a uniform usage of the appliance.

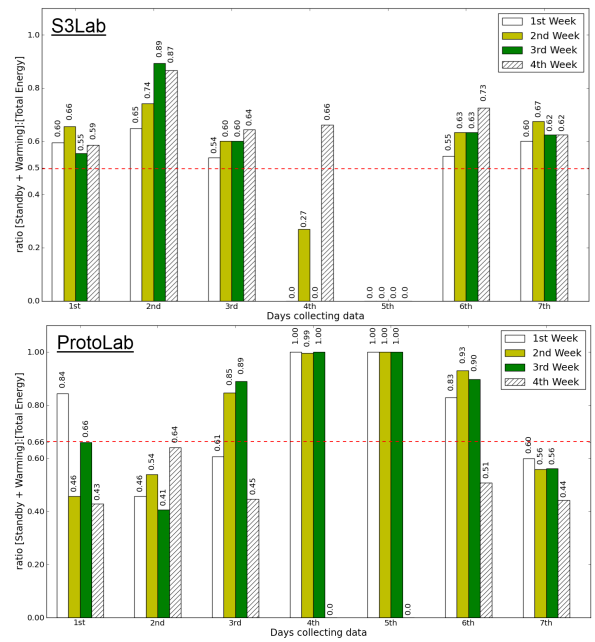

Figure 4. Ratio of non-effective energy consumed to the total from Wednesday (1st bar) to Tuesday during 4 weeks in *a)* ProtoLab (Top); *b)* S3Lab (Bottom)

Analysing the S3Lab data (see top of Figure 4) we found no cues of changes in device usage (mean up to 50%). The non-effective energy was kept uniform even during the two weeks under the eco-feedback condition. These results on the 3rd and 4th weeks could be attributed to the time period elapsed between the action of using the device and the feedback provided by the dashboard.

ProtoLab data is showed on the bottom of Figure 4. This laboratory presented the highest ratio of non-effective energy, 66%. We attribute such energy waste to the workers' absentmindedness of leaving the device uselessly switched on in three out of four weekends. The introduction of Twitter in the 2nd week and the physical display in the 3rd, did not lead to a significant change of device usage. However, the 4th week was much more efficient in energy terms than previous ones. We reckon that this presumable increment of energy efficiency could be attributed to the effectiveness of the physical display installed in this laboratory.

VI. Conclusions

This work has presented the basis of an approach to save energy in common areas through eco-aware everyday things. To back it, three capsule-based coffee machines placed in three different research laboratories have been augmented. Each of them displayed different means of eco-feedback to the group. Only one of them featured the distinctive of an eco-aware everyday thing.

The reviewed field-study has yield promising results for further research; we reckon that the eco-aware appliance has contributed to make workers become more energy consumption aware than they were at the beginning of the experiment. The group that jointly collaborated with the 'eco-aware coffee maker' was found to be the most efficient in energy terms. Likewise, this group attributed interdependence cues to the device and showed to be more open to influence from the advices of such eco-aware thing. Therefore, this work has evaluated a set of first evidences about how people and eco-aware things can perform a joint action to reduce energy consumption in common spaces as green-teammates.

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