”Will the Last One Out, Please Turn Off the Lights”

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“Will the Last One Out, Please Turn Off the Lights”:
Promoting Energy Awareness in Public Areas of Office Buildings

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Abstract. Most previous research in sustainable HCI has focused on electricity consumption in domestic environments or private office spaces. Here, we address use of lighting in public areas of office buildings with the goal of understanding and measuring how calm technologies can inspire positive engagement by promoting awareness and competition. We have conducted a 15-month study with the design, deployment, and assessment of two complementary ambient apparatus (one centralized, one distributed) in an office building occupied by ICT start-up companies. Our results show that calm technology can be effective under specific conditions, resulting in a significant reduction of average electricity consumption. We also discovered that in the absence of automatic controls, approximately 25% of lighting consumption occurred during off-work hours.

Keywords: Eco-feedback, Ambient display, Calm technology, Energy consumption awareness, Persuasive technology, Sustainable HCI, Human-Building Interaction, Office Building.

1 Introduction

Most research on energy consumption and lighting in office buildings has focused on the development of Building Management Systems (BMS) and energy efficient appliances, with focus on the use of electricity in the home [1, 4, 18, 23] or in private office spaces [5, 10, 14, 24]. In this paper, we address how awareness and competition can be harnessed to reduce consumption of lighting in shared public areas such as corridors and restrooms.

Collective control of lighting in shared public spaces requires occupants to shift from an individualistic selfish behavior, to a socially-conscious self-transcendent behavior that includes concern for the well-being of others [22]. Our goals in this research are to explore and understand how “calm” technologies can inspire such behavior, and to measure the impact of such technologies on occupants in terms of awareness and engagement. For this purpose, we have conducted a 15-month study involving three experimental conditions during which quantitative data have been recorded and compared to a baseline that covers the same period of the previous year. During this experiment, the occupants were not aware of the experiment.

A principal result is that a calm technology display can increase the awareness of electricity consumption in public areas, resulting in a significant reduction of average electricity consumption. We also discovered that during all the experiment, approximately 25% of lighting consumption occurred during off-work hours when the building was empty.

The article is organized as follows: we first review work from sustainable HCI as a background for persuasive technology and ambient awareness displays with particular attention to work on eco-feedback and design frameworks for the workplace. We then present the context of our study followed by a detailed description of the experimental process and the results. We close with a discussion of lessons learned and issues for future research.

2 Related work

Sustainable HCI builds on research from a variety of domains [4], including "Ambient awareness" systems and "Persuasive technology" [17]. Ambient awareness systems employ calm technology to make users aware of the impact of their behavior. Persuasive systems draw on cognitive theories such as the Transtheoretical Model of Change [20] and Fogg's Behavioral Model [9] to invent ways to persuade users to behave in a sustainable way. In practice, there is a large overlap between ambient awareness displays and persuasive systems as exemplified by eco-feedback solutions and eco-visualization.

Eco-feedback solutions have often built on theories from environmental psychology [11]. For example, Schwartz's values theory predicts that the activation of self-transcendent intrinsic values is more effective and sustainable than self-enhancement extrinsic values [11, 15, 22]. As Weinstein has demonstrated in a controlled experiment, intrinsic aspirations and generosity can be activated by exposure to nature [25]. Nature inspired eco-visualization combined with informative art [6, 8, 21] has been used in the "7000 oaks and counting" project as a way to increase conservation behavior in a campus institutional building. However, to the best of our knowledge, this system has not been evaluated formally [13].

While many investigators have proposed designs for eco-visualization technologies in the home [1, 18, 23], few have explored the workplace. Notable exceptions include the "watts in it for me?" study [10], the Watt-lite display, and the EcOffices project. Over a three day-long workshop with a total of 65 participants from 5 universities, the "watts in it for me?" study produced a design framework that structures the problem space into 5 themes: visualisation, incentives, engagement, leadership, communication, and openness. Using this framework, the authors designed a layout for a display. However, the design was not deployed or evaluated. The Watt-lite prototype was designed as a mediating object, projecting real time energy use on the floor to explore engagement and reflection with energy use [14]. The prototype was deployed four weeks in 8 factories. Preliminary results from that system show that social spaces are conducive for awareness. The EcOffices project has investigated the role of competition between workers for private office spaces [5].

Yun et al. [24] have demonstrated “an intelligent dashboard” that combines feedback on energy usage with online controls to remotely turn devices on and off and to set up automatic on/off controls at scheduled days and times. This system was evaluated with a 27 week-study with 4 groups of 20 participants (1 control group, and 3 groups provided with different levels of feedback and controls). Results showed that the addition of online controls improved savings. Unlike our study, this work was focused on office spaces, rather than public spaces in office buildings.

3 Context of the Study: A Real World Experimental Setting

3.1 The office building

This study was conducted in a three story 1200 m^2 building that serves as a living lab for research in smart object technologies, as well as a technology incubator and workplace for start-ups. The ground floor includes an open space with a cafeteria and a large entrance hall that provides access to 36 offices on the two upper floors. These upper floors have provided the arena for our experiments.

The two upper floors are well suited for conducting comparative experiments: they are very similar in terms of number of offices, and their public areas are identical with each floor having two hallways, two restrooms, and one meeting room. Similarly, the location and number of lights and switches are identical, and both floors have excellent natural lighting conditions during daylight hours.

3.2 The occupants and the financial conditions

The offices are available to start-ups companies specialized in the development of Information and Technologies (ICT) with applications ranging from innovative cameras and sensors for medical applications, to novel solutions for networking and 3D graphics. The space is used by approximately 50 persons, including company founders, R&D engineers, hardware and software developers. Most occupants are highly qualified and work under tight time constraints. Rental conditions are based on the surface occupied with a rate per square meter that includes energy and water consumption. Thus, building occupants have no direct interest in reducing energy costs.

3.3 Data recording

The building is a perpetual sensing device, instrumented with a BMS platform that continuously measures electricity consumption, temperature, and human presence in all areas of the building. This system records 1200 data values every ten minutes, including readings from 50 electric meters, 8 water meters, and 47 environmental controllers installed in each office. Data is automatically recorded for research purposes in a secure server. For ethical reasons, we have limited our data records and analysis to the electricity consumption of the public area of the first and second floors, excluding all data related to private spaces and presence detection.

Although the building is well instrumented, lighting in both public and private areas of the upper floors is manually controlled with mechanical light switches. Actions on light switches cannot be directly detected, and the occupants are fully responsible for switching these lights on and off.

4 The Research Process

Our five-phase study covered 15 months, starting early March 2017 and ending mid-May 2018. The first two phases served as preliminary field studies to inform the design of our eco-feedback techniques deployed in the next 3 phases. During this period, the building was occupied by the same 17 start-ups with some minor turnover of employees. Occupants were not made aware of the nature of our study. In the following, we describe the phases in more detail along with their justification and implications for the next phase.

4.1 Phase 0: Initial field inquiry

Experimental conditions. The purpose of this phase was to collect occupants' view and attitude to energy savings related to both the workplace and their everyday life. Occupants were invited by email to fill in an online questionnaire. This questionnaire included 17 questions as well as entries for free expression, covering three topics: (1) Perception and control of comfort in the office as well as of lighting in the public areas of the building; (2) Usefulness and potential impact of real time visualization of the building consumption; and (3) Reward that would favor behavioral change.

The results. We received 19 answers (63% male, 37% female) of which 90% had worked in the building for more than 6 months[1]. The principal results were:

- 70% of the respondents use public transportation, bicycle or car-pooling.
- The majority (15 out of 19) has observed that the lights are on for no reason in the public areas, and 12 of them claimed that they generally turn them off when not used. Interestingly, two respondents commented: "*It would be highly appreciated that the building does not stay lit up H24, typically on week-ends when no-one is at work*". "*Corridors and cafeteria are always on.*" On the other hand, almost no one had any idea of the electricity consumption of the building.
- To the question "Would you be in favor of a device that displays energy consumption of the building in real time (e.g. screen in the entrance hall,

[1] As the invitation was performed via a mailing list managed by the owner of the building, we do not know the exact number of occupants who received our message.

smartphone App, etc.)?" 15 occupants supported this idea whereas 3 out of 19 stated that they did not appreciate it, as: "*a screen in the entrance hall would consume too much just to show the consumption of the building*". 12 of them (63%) thought that this would have a positive impact on their own behavior, but the impact would be very unlikely on the other occupants.

- Reducing the carbon footprint is the primary incentive to behavioral change of the respondents whereas monetary reward (i.e. reducing rental cost) received only 7 favorable votes. One respondent commented: "*I am opposed to rewarding people for an action that should be evident for all.*" In addition, socializing was not considered to be an effective reward as no one selected the option "organizing a party with the occupants of the building" and 10 out of 19 voted for "not at all" and "very unlikely".

Conclusions and implications for the next phase. The majority of the respondents showed clear concerns for sustainability. They observed that the lights are on uselessly, they felt responsible for turning the lights off in the public areas, they were not looking for monetary rewards, they tended to think that the "others are at-fault" [2], and that a screen display would be a waste just to show electricity consumption.

Our conclusions from Phase 0 were that the office environment of a technology incubator provides a challenging context for designing an apparatus that would encourage people to reduce lighting usage. Providing the occupants with real-time quantitative information is the obvious minimalist way to support awareness [10]. However, it was unclear whether typical visualization techniques were sufficient to promote curiosity and to maintain interest of busy people. Inspired by the principles of informative art [6, 8, 21], we hypothesized that "designing for the periphery" with the use of an additional layer of abstract expression to encourage moments of reflection, would be an appropriate option to address these issues. This became the focus for Phase 1.

4.2 Phase 1: Exposure to abstract representations

Design rationale and description. The goal of this phase was to collect occupants' reactions to abstract representations of quantitative data. Among the alternative forms of abstraction, particles have simple properties such as density, color, and size that can easily be used to display quantitative information. In addition, they can be animated in multiple ways to amplify the expression of a dynamic phenomenon.

We explored three particle-based representations: a "heart-beat" display where particles are blown away from a central point, a "smoke-stack" which combines particles (the smoke) with a picture of the office building, and a "snow-fall" display whose particles fall from the top of the screen (see Fig.1). The smoke stack was rendered as augmenting an outside view of the building displayed with the surrounding mountains on a sunny day so that the occupants would be inspired to see their workplace as a collective space to be preserved.

Experimental conditions. The displays were presented on a large screen strategically located in the entrance hall adjacent to the cafeteria. The screen was visible from a distance to anyone passing through the hallway, as well as by people having lunch or taking coffee breaks. The occupants were not informed about the nature of the data represented, as the objective of this phase was to collect instantaneous reactions and personal emotional expressions. Occupants were invited to leave anonymous reactions to the displays on post-it notes.

Using a Wizard of Oz technique, the displays were selected serendipitously, with changes of color, size and density of the particles about six times per day. Comments on post-it notes were collected whenever the experimental condition had been modified. In addition, the wizard took notes about his own informal observations while discretely remaining in the area near the screen.

Fig. 1. The "heart-beat" (left). The "smoke-stack" (center). The snow-fall (right).

Qualitative analysis. We collected 50 post-it notes over the six-week duration of Phase 1: 24 notes for the snow-fall display, 22 for the heart-beat, and 4 for the smoke-stack. Overall, the reactions can be grouped into five themes:

- Technology denial and/or concerns for the environment (5 post-its). For example, "*a screen that is of no use*", "*a loss and waste of energy*", "*a screen saver*" and, associated to the smoke-stack, "*pollution!!!*"
- Science-inspired imagination, mainly from the magnetic field (9 notes), typically related to the heart-beat: "*a magnetic nucleus*", "*electrons orbiting an atom*", "*Newton*", "*a Tokamac (magnetic confinement)*", "*particles in a coil*".
- Nature-inspired imagination (9 notes) including animals ("*a jelly fish*"), plants ("*a dandelion*" and "*rose petals*"), or natural elements (mainly for the snow-fall" representation): "*snow*", "*rain*", "*cascades*" and the "*fountain of Versailles*".
- Culture and leisure-inspired imagination (7 notes), typically, food experience related to the heart-beat ("*a 3D pop-corn machine*", "*an apple dough-nut*"), cinema for the snow-fall ("*Star Wars*", "*The Big Blue*"), and travel for the smoke-stack: "*a cruise ship*", "*Costa cruise liners*", "*Tintin in Tibet*".
- Violent and destructive expressions, such as notes stating "*blood*" for the snow-fall display with fast falling large red particles.

In addition, 3 post-it notes, confirmed by the wizard's observations, indicate that occupants were influenced by an implicit culture of "IoT" and "experimental" ambience specific to the building. For example: "*A visual projection that depends on the number of persons in the building: the more people are present, the more dense is* *the visual*", or the "*animations evolve depending on the weather or the time of the day*". Interestingly, one post-it refers to the "*Roschach test*", a psychological test originally used to detect thought disorder by exposing subjects to specific inkblots, then used to identify a person's personality and emotional functioning. As for the wizard, he observed that "*people clap their hands hoping that the device will react*" or some of them "*look behind the screen to check the connections, trying to understand how the device works*".

Conclusions and implications for the next phase. The key lessons for the design of incentive ambient apparatus drawn from this phase were: (1) The concept of animated particles as an abstract layer of information encourages reflection and is sufficiently rich to express a variety of phenomena while making it easy for people to understand the mapping between the properties of the particles and the information to be represented; (2) Under some conditions, particles may evoke violence and destructive feelings; (3) Interactivity is expected; and (4) For the apparatus to support "Sustainability through Design" (StD) [16], it must also be "Sustainable by Design" (SbD).

The requirement for both StD and SbD has led us to investigate two alternative approaches (1) A unique exemplar of a centralized ambient interactive apparatus located at a strategic place, useful and attractive enough to help offset "*the waste of energy*" criticized by a number of occupants; (2) A distributed sustainable incentive solution that would not consume any energy and located where the action is, that is, in this context of use, at the light switch level. These have been explored in phases 2 and 4.

4.3 Phases 2 and 3: Central ambient display and friendly competition

Phases 2 and 3 concerned the effectiveness of a central ambient display suggesting a friendly competition for energy savings. We have adapted Bartram's design dimensions [1] as a systematic framework for structuring our design questions: What are the appropriate data and motivational strategies to support positive engagement and various forms of knowledge (i.e. awareness, analytical, operational)? What attentional effort and interactivity are required from the occupants? When and where is data consumed? Table 2 summarizes the justification of our design choices.

Table 1. Design questions and justification of the design choices for the ambient display.

Dimension	Design choice and justification
Data	Engineering measures aggregated at multiple temporal scales (current, hour, day, week) for supporting awareness of energy consumption, for provisioning actionable cues including self-monitoring.
Attentional effort	Ambient display for low attention demand, at-a-glance sense making supported by the histo-trees.
Interactivity	Passive interaction complemented with one single push-down action for accessing additional analytic knowledge on demand.

Motivation and engagement to sustainability	Nature-inspired histo-trees metaphor to activate intrinsic motivation. Friendly competition based on social comparison between the two floors to reinforce positive behavior. Goal setting capability using last year consumption as an intra-floor norm. Visual positive appeal of the histo-trees and tangible data provided by the cairns board.
Spatio-temporal context	Standalone always on apparatus as an integral part of the workplace at a strategic hot spot of the building (entrance hall and near the cafeteria).

Description. As shown in Fig.2, the ambient apparatus included:

- A large wall-mounted antiglare screen placed at a carefully identified location in the building so that the apparatus is easily visible to passing persons.
- A soft padding push-button and a Cairns board, both built for this experiment by the research team.
- A mini-PC connected to the BMS for data acquisition, aggregation and rendering, as well as for logging the press and release events that resulted from the users' actions on the push-button.

Fig. 2. The central ambient apparatus.

The computational system was completed with information printed on wooden panels: below the screen, the power of the apparatus (i.e. 170 watts) presented to inform occupants of energy consumption by the system; on the left hand side, the mapping used to translate raw electricity consumption into colored wooden discs (cairns board) with a radius inversely proportional to weekly consumption (an advanced computerized version of the same idea has been developed by Daniel et al. [3]). On the right end-side, the rules of the game "Challenge the switch" were displayed engraved in wood. The game presented each floor as a team represented by a color (yellow or blue). The winning team was the floor that used the least amount of electricity for each hour and each day.

The screen permanently displayed three types of information using three types of representation, chosen to communicate three different perspectives: utilitarian, nature-inspired, and symbolic:

- The Utilitarian representation provided a real time display of the *current consumption* of the two floors expressed in watts. The engineering measure used (i.e. watts) was intended for ICT occupants who, according to the results from Phase 0, had no idea of the electricity consumption of the building.
- The nature-inspired expression presented a record of the last 13-hours of consumption using *histo-trees*. A colored tree for the "winner of the hour" was displayed for each hour (from 8 am to 9 pm), along with a tree corresponding to the consumption during the previous night (i.e. the off duty hours from 9 pm to 8 am). The height and fullness of the trees were rendered in proportion to the virtue of the winning team. The branches of the trees swayed gently as if in a light breeze, creating a peaceful ambience. As the hours went by, the observers could get at-a-glance the overall trend of the day.
- Cumulative daily consumption for each team was rendered with tokens (*hebdo-tokens*), so that daily and weekly trends were visible.

A large push-button provided access to additional information about energy use: While the button remained pressed, a classic bar histogram was displayed so that the players could compare their electricity consumption with that of their competitors and possibly adjust their behavior for the next hours of the day. When the button was released, the screen returned to the histo-trees display. While the numerical histogram supported hourly-based comparison of performance for the current day, the cairns board was intended to support inter-team as well as intra-team comparisons on a weekly basis, using physicality as incentives to curiosity.

Experimental conditions. As in previous phase, the ambient display was installed at a socializing spot, in the entrance hall and near the cafeteria. The functioning of the ambient device as well as the rules of the game were presented at a convivial "think drink" social event organized in the cafeteria, the evening before the experiment started. Of the 20 attendees, 3 occupants of the building participated in the social event.

During the nine-week trial of this Phase 2, the electricity consumption of the public area of the two floors was collected as well as the time-stamped events resulting from the press and release actions on the push-button. The event log was intended to trace the occupants' interest and involvement over time. As occupants were not aware they were involved in an experiment, the use of a camera and microphone to record emotions and attitude was excluded. Every Monday morning, colored discs of the appropriate size were added to the cairns for each team.

Qualitative data analysis. We conducted 21 semi-structured interviews, two to four weeks after the end of this phase, during the Phase 3-no-feedback period. Participants were recruited serendipitously near the cafeteria or the entrance hall of the building. All interviews – 15 to 20 minutes each, were audio-recorded and analyzed using the design choices of Table 2 as coding themes. Table 3 provides some examples of the occupants' reaction structured according to these themes where texts in italic denote suggestions for improvement.

Overall, the design of the ambient apparatus was well received by the occupants. In particular, the association of the pure utilitarian engineering measures with the positive visual appeal of the nature-inspired histo-trees worked well. The low-cost interactivity was appropriate. The social framing drawn from the friendly competition worked well "*at the beginning*". Although three persons indicated that the device "*belonged to the landscape"* or has become *"part of the every day life*", although they kept "*glancing at it once or twice a day at coffee breaks and lunch time*", four participants observed a decline of interest as "*the days became similar*".

All interviewees asserted that they had not modified their behavior after the end of this phase, as they "*never turn the light switches on*" and they "*switch the lights off in the hallway* [not that of the others, though] if they believe that they are *"the last one leaving the building*". Four occupants suggested transferring the responsibility to automation with timers and presence sensors. Although some of the occupants have noticed that, since Phase2, "*the corridors are always off*", it was unclear, at this point of the study, whether the ambient apparatus had activated or reinforced positive behavior.

Table 2. Verbatim as qualitative assessment of the ambient apparatus features.

Engineering measures
• Support for energy consumption awareness and understanding: "*There was the current consumption for each floor in watts. It was interesting. It was useful*." [P9, P13, P10] "*I saw that corridors consumed 3000 watts, this is enormous, just for corridors!*" [P5]. • Complementarity with the figurative representation: "*to clearly see the numbers behind the trees*" [P5]. "*I tried to understand how the trees were generated. As a result, I looked at the data and I understood what was meant. It's good to have visibility on data*." [P9]. • Missing measures for analytic knowledge: *"I would have liked to have a kind of a chart about a period that one could choose (week or month)…This is the kind of useful statistics depending on the weather conditions (sun, snow, rain)"* [P7]. • Missing measures for supporting the competition: *"It was difficult to assess which team was currently first within the current hour or within the current day. Thus, we did not know whether the situation was recoverable to win and make an effort to switch the lights off* [P17].

Attentional effort, at-a-glance sense making
"*I would take a look every time I went by*" [P5, P6, P9, P13,P12]. "*One could check the evolution based on colors* [of the trees] [P13].
Interactivity – Use of the push down button and analytic knowledge
Affordance and self-monitoring: "*There was a button, thus we felt compelled to press it to see what it did*" [P1, P23]. "*I pressed the button to check the tendency of the day at the building level*" [P7, P5].
Motivation and engagement to sustainability through the Histo-trees
• Positive visual appeal and appropriate mapping with numerical data: "*well done and fun*" [P3, P21, P17, P11. "*A good idea*" [P18-19-20]. "*This was good. I remember it. This means it left a mark*" [P12]. *I found this* [the trees] *rather nice, … a playful indication*" [P7]. "*The less electricity is used, higher is the tree, otherwise a tree would not have been chosen*" [P7, P10, P5]. • Potential for activating intrinsic motivation: " *I appreciated the ecological aspect*" [P10]. "*It evokes nature… In addition, they* [the trees] *moved*." [P13].
Motivation and engagement to sustainability: Friendly competition and social comparison
"Competing with the other floor has a nice feeling, *at the beginning*"[P7]. "*At the beginning, it* [the game] *was interesting for the competition aspect*" [P15]. "*We could also see which floor used the most energy*." [P13] or "*how we were doing*" [P15-P16]. "*Ah! We are first. Ah! We are good!"* [P6]. "*We are the best*" [P11].
Motivation and engagement to sustainability: Cairns tangible data and social comparison
"*This* [the cairns] *was to compare with the consumption last year. Thus, this was interesting*." [P13]. "*We have supposed that it was a physical version of histograms. We have compared with last year. We have consumed a lot less. Why*?" [P15, P16]. "*I think you added a ring at the end of every week to see the difference between the two floors*" [P5]. *Not noticed [P6]. Not understood [P11*]. *"I tried to move a disk to another pile but I did not know what I was doing. I was expected it to be computerized" [P8]."I did not understand right away*" [P9].
Spatio-temporal context
The location of the apparatus was appropriate except for 5 occupants who never go to the cafeteria: "*I noticed it from the distance, but when I come in, I go straight to my office*" or "*the device was not on our way so*, …". On the other hand, for the other occupants "*Typically, while coffee was getting ready, I went by the screen to check the situation*" or "*every lunch*" or "*coffee breaks*" [P10, P12, P13, P6].

4.4 Phase 4: Augmented sustainable light switches

Design rationale and description. The light switches of the building – white on white walls, are nearly invisible when illuminated with direct sunlight and very hard to see at dusk. There was obviously room for improving their perceivable affordance by turning them into gentle non-obtrusive reminders. Phase 4 sought to assess the effectiveness of drawing attention to the light switches. The hypothesis was that this approach should be more effective on reducing lighting reduction than that of Phase 2 as it is located where the action is. In addition, this approach is fully sustainable and easily reproducible.

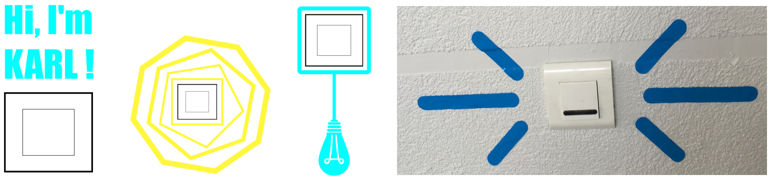

Fig. 3. Design options for light switch augmentation (from left to right): personification, waves propagating from the switch, hanging light bulb, glare of light.

Fig.3 shows several design options. The "glare of light" enhancement on the right was assessed as the most neutral and aesthetically appealing design by a number of our colleagues and was installed in the public areas accordingly.

Experimental conditions. Reusing the concept of "yellow floor" and "blue floor", the light switches were enhanced with the corresponding colored stickers for each floor. The occupants were not informed that the experiment was still going on. In parallel, data about electricity consumption for each floor was recorded by the BMS.

5 Analysis of the data logged from phases 2, 3, and 4

Raw data logs provided by the BMS over the 27 weeks of phases 2, 3, and 4 were preprocessed to check data quality and to produce data in a format appropriate for the analysis. This process has resulted in individual data files per floor and per phase, giving hourly and daily consumption. In addition, times of push and release of the push-button allowed for the analysis of occupants' interaction with the apparatus.

The occupants actively used the push-button in the first 4 weeks of Phase 2. Engagement decreased as time passed, partly due to Christmas and New Year vacation, as well as a decline of interest as reported by some occupants (cf. Section 4.3). As shown in Fig.4, both for weekdays and weekends, the hourly consumptions average of the two floors were significantly lower in the three experimental conditions than for the base-line periods. In addition, these averages continued to decrease with time throughout Phases 2, 3, and 4. Interestingly, Floor 2, which was initially the highest consumer, became the most virtuous during the final phase. Meanwhile, weekend hourly consumption for the 1st floor overtook that of weekday. More generally, the chart of Fig. 4 also shows that the "weekend" columns denote higher consumption compared to workdays.

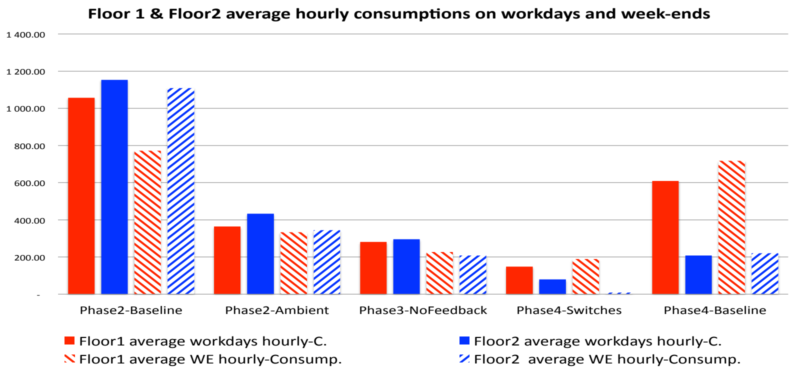

Fig. 4. Workdays VS weekends average hourly consumption for the 3 conditions and for the baselines used for phases 2 and 4 (i.e. the left-most and right-most group respectively).

The decrease of hourly consumption across the three phases is consistent with the increase of daylight between mid-November and mid-May: while in Phase 2 as well as for half of Phase 3, people arrive before sunrise and leave after sunset. This changed during the second half of Phase 3 and Phase 4 as the days grew longer.

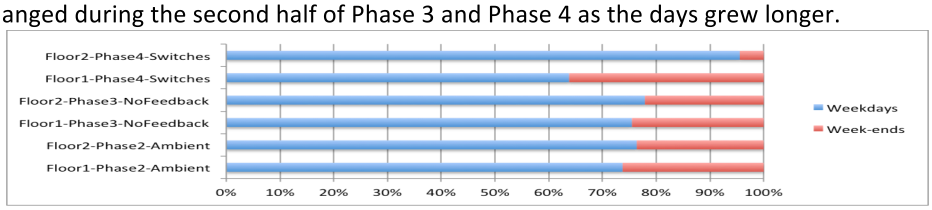

Fig. 5. Ratio (%) between workdays and weekends total consumption for the 3 conditions.

The seasonal effect can be alleviated using ratios as illustrated in Fig.5. We observe that weekend consumption was as much as 36% of the total consumption (cf. Floor 1, phase 4). Fig. 6 shows the distribution of consumption within workdays. Interestingly, off-work hours can represent up to 45% of workdays consumption (cf. Floor1, Phase 3). Going one step further, Fig. 7 shows in detail the number of times lights are left on in corridors and toilets during weekends and weekdays off-work hours. It shows that, for the 3 phases, the lights were left on in the corridors more often than in the toilets for Floor 1, whereas for Floor 2, this trend is reversed in Phase 4 where the corridors are generally switched off and the toilets become the main source of wasted consumption.

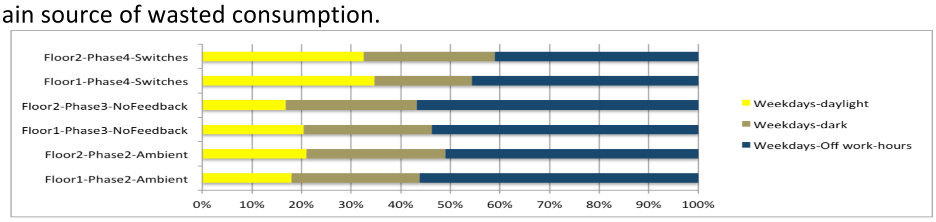

Fig. 6. Distribution of lighting consumption (%) within workdays.

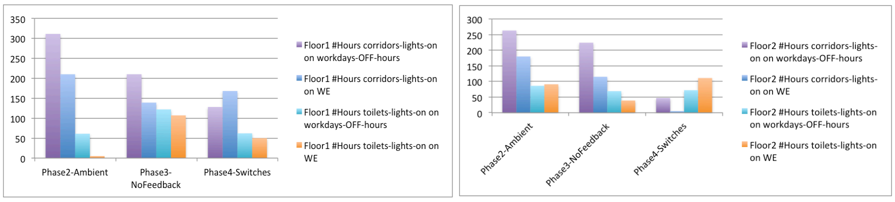

Fig. 7. Nb of hours lights are on uselessly in corridors &toilets - Floor1(left), Floor2 (right).

6 Discussion

Summary of the findings. The data logs reveal a significant decrease in electricity consumption compared to the same period over the previous year of the experiment. One possible explanation is the evolution of the general socio-political context with an increase of concerns for sustainability. However, we believe that our experiments may also have played a role.

Interestingly, the number of hours that the lights are left on uselessly, for both weekends and night-time off-hours, decreased steadily over the 27-week trial. This measurement indicates that the apparatus has served as a seed for more positive behavior, contradicting interview statements by occupants that the ambient display did not influence their attitude towards sustainable behavior. The decrease of consumption from phases 2 to 3 is consistent with Cialdini's influence principles according to which humans tend to invent reasons to justify their actions "after the fact" [2].

We also note that the augmented light switches appear to be more effective than the ambient display. This is likely to occur because the augmented light switches provide actionable reminders in context. In Fogg's terms, they acted as facilitators that increase ability, thus lowering the action line threshold [9]. This is particularly clear for the occupants of the second floor who were initially the highest consumers. However, for this floor, the toilets, which are not on the way when leaving the building, became the principal source of useless consumption.

Limitations and caveats. The order of the phase 2 and phase 4 trials may have affected the results in favor of the augmented light switch approach due to a possible increase in awareness. Nevertheless, the "augmented switch" idea is fully Sustainable-by-Design and so simple to implement that it provides a promising approach for future research.

The study was conducted in a relatively small building (36 offices) where it was not possible to control and identify the exact turnover of the employees. However, this limitation is counter-balanced by the real-world conditions of the experiment, as the occupants, who were unaware of their involvement in an experiment, were not tempted to act to please the researchers.

7 Conclusion

We have conducted a 15-month study on lighting consumption in the public spaces of a 36-office building occupied by ICT start-ups. This study included a 27 week-trial to assess the effectiveness of two complementary forms of ambient techniques (i.e. centralized VS distributed). Results appear to confirm previous work from environmental psychology or scattered in the literature related to eco-feedback technologies developed for the domestic environment. Unlike previous work on office workplaces, we have addressed consumption for lighting in shared public spaces of office buildings, and the 50 occupants of the trial were not aware they were involved in an experiment – i.e. they acted under no experimental constraint, were not given a task to perform, and where not generally observed when exposed to the two ambient apparatus.

The lessons and take-away messages from this study are three-fold:

(1) The "*distributed-augmented switch-where the action is*" approach works as an effective facilitator. It is fully sustainable-by-design (SbD), cheap to produce and easily deployable. On the other hand, it does not mirror the current lighting consumption.

(2) The "*centralized-friendly competition-ambient display*" approach is less SbD and more complex to deploy, but offers additional benefits provided that: (a) it is installed within a socializing space to favor engagement; (b) it supports glanceable sense-making to minimize attentional effort from busy people; (c) it combines engineering measures at multiple temporal scales (for provisioning actionable cues) with nature-based figurative aesthetic representations to activate intrinsic motivation and visual appeal; (d) it supports intra- and inter-social comparison as well as goal-setting to reinforce positive behavior; (e) it complements passive interaction with minimalist interaction techniques to access analytic knowledge on demand; (f) its behavior has to be consistent with that expected from the occupants (as one occupant remarked, "*I went by during Xmas vacation, and only one thing that was turned on was the screen. It breaks something!* ")

(3) Following Dourish's observation, scaling up the context should be considered as an important factor [7]. For example, in our case, maintenance, cleaning and supplies for the cafeteria and restrooms are provided by the local city government that owns the building. If these services are not sufficient, then as two occupants reported "*there is no point to make effort in conserving energy for these people* [the local government] *when there is no dish-soap.*"

In addition, informing people – in a non-obtrusive but effective way, that *they are the last one to leave* is clearly key as this feature serves not only reducing electricity consumption in the public spaces but security as well (e.g. turning the intrusion detector security on/off during off-work hours as this is the case in the building of our study). This remains for future study.

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References

1. Bartram, L.: Designing challenges and opportunities for eco-feedback in the home. Personal Visualization and Personal Visual Analytics July/August 2015, IEEE Computer Society, 52–62 (2015).
2. Cialdini, R.: Influence, The psychology of persuasion (1984).
3. Daniel, M., Rivière, G., Couture, N.: Designing an expandable illuminated ring to build an actuated ring chart. In: Proc. 12th intern. Conf. on Tangible, Embedded and Embodied Interactions (TEI'18), pp. 140-147, ACM, Stockholm, Sweden (2018).
4. DiSalvo, C., Sengers, P., Brynjarsdóttir, H.: Mapping the landscape of sustainable HCI. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems, CHI'10, pp. 1975–1984, ACM, Atlanta, Georgia (2010).
5. Decorme, R., Zarli, A., Trousse, B., Senach, B.: Improving energy awareness and use in office buildings: the ICT-enables ECOFFICES challenge. In: Proc. International conf. on Computing in Civiland Building, ICCCBE 2012, Moscow, Russia (2012).
6. DiSalvo, C., Boehner, K., Knouf, N., Sengers, P.: Nourishing the ground for sustainable HCI: considerations from ecologically engaged art. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems, CHI'09, pp. 385–394. ACM, Boston, Massachusetts (2009).
7. Dourish, P.: HCI and environmental sustainability: the politics of design and the design of politics. In: Proc. of the 8th conf. on Designing Interactive Systems DIS 2010, pp. 1–10. ACM, Aarhus, Denmark (2010).
8. Ferscha, A.: Informative art display metaphors. In: Proc. 4th International Conf. on Universal Access in HCI, UAHCI'07, pp. 82–92, Springer-Verlag Heidelberg, Beijing, China (2007).
9. Fogg, B.J.: A behavior model for persuasive design. In: Proc. 4th intern. conf. on Persuasive technology, Persuasive'09, ACM, Claremont, California (2009).
10. Foster, D., Lawson, S., Linehan, C., Wardman, J.: 'Watts in it for me': design implications for implementing effective energy interventions in organisations. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems CHI'12, pp. 2357–2366, ACM, Austin, Texas (2012).
11. Froehlich, J., Findlater, L., Landay, J.:The design of eco-feedback technology. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems CHI'10, ACM, Atlanta, Georgia, USA (2010).
12. Holmes, T., Blackmore, E., Hawkins, R.: The common cause handbook: a guide to values and frames, Public Interest Research Centre Ltd (2011).
13. Holmes, T.: Eco-visualization: combining art and technology to reduce energy comsumption. In: Creativity and Cognition Conference 2007, pp. 153-162, ACM, Washington DC, USA(2007)

14. Jönson, L., Broms, L., Katzeff, C.: Watt-Lite: energy statistics made tangible. In: Proc. DIS 2010, pp. 240-243, ACM, Aarhus, Denmark (2010).
15. Knowles, B.: Re-imagining persuasion: designing for self-transcendence. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems Extended Abstracts. CHI EA'13, pp. 2713–2718, ACM, Paris, France (2013).
16. Mankoff, J., Blevis, E., Borning, A., Friedman, B., Fussel, R., Hasbrouk, J. Woodruff, A., Sengers, P.: Environmental sustainability and interaction. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems Extended Abstracts. CHI EA'0, pp. 2121–2124, ACM, San José, California (2007).
17. Oinas-Kukkonen, H., Harjumaa: Persuasive systems design: key issues, process model, and system features. Communications of the Association for Information Systems, vol. 24, 485–500 (2009).
18. Pierce, J., Paulos, E.: Beyond energy monitors: interaction, energy, and emerging energy systems. In: Proc. of the SIGCHI conference on Human Factors in Computing Systems CHI'12, pp. 665–674, ACM, Austin, Texas (2012).
19. Processing home page, https://processing.org, last accessed 2018/06/11.
20. Prochaska, J., DiClemente, Norcross, J.: In search of how people change: application to addictive behaviors. American Psychologist, 47, 9, 1102-1114, (1992).
21. Redström, J., Skog, T., Hallnaäs, L.: Informative art: using amplified artwork as information displays. In: Proc. Designing Augmented Reality Environments, DARE 2000, pp. 103-114, ACM, Elsinore, Denmark (2000).
22. Schwartz, S.: Universals in the content and structure of values: theoretical advances and empirical tests in 20 countries. In: Advances in Experimental Social Psychology, 25, pp. 1–65 (1992).
23. Yang, R., Newman, M.W., Forlizzi, J.: Making sustainability sustainable: challenges in the design of eco-interaction technologies. In: Proc. the SIGCHI conference on Human Factors in Computing Systems, CHI'14, pp. 216–117, ACM, Toronto, Canada (2014).
24. Yun, R., Aziz, A., Scupelli, P., Lasternas, B., Zhang, C., Loftness, V.: Beyond eco-feedback:adding online manual and automated controls to promote workplace sustainability. In: Proc. the SIGCHI conference on Human Factors in Computing Systems, CHI'15, pp. 1989-1992, ACM, Seoul, South Korea (2015).
25. Weinstein, N., Przybylski, A., Ryan, R.: Can nature make us more caring? Effects of immersion in nature on intrinsic aspirations and generosity. Society for Personality and Social Psychology Bulletin, 35, 10, oct. 2009, 1315-1329 (2009).