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Persuasive Lighting: The Influence of Feedback through Lighting on Energy Conservation Behavior

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ABSTRACT
Earlier research has investigated persuasive technology: Technology designed to influence human behavior or attitudes. The current research investigates lighting as persuasive technology. In an experimental study, participants could conserve energy while carrying out tasks and received feedback about their energy consumption in each task. We tested the effect of feedback through a lamp that gradually changed color dependent on energy consumption and compared these effects to more widely used factual feedback. Results indicated that feedback through lighting has stronger persuasive effects than factual feedback. Furthermore, factual feedback seemed more difficult to process than lighting feedback, because cognitive load interfered with processing factual feedback, but not with processing lighting feedback. Implications for theory and design of persuasive lighting, and (ambient) persuasive technology are discussed.

Keywords
Lighting feedback, factual feedback, interactive feedback, energy consumption behavior, ambient persuasive technology

INTRODUCTION
The threats of growing CO2-emissions and climate change effects and the exhaustion of natural resources have urged nations worldwide to seek for substantial reductions in energy consumption. Next to important technological solutions like more efficient systems and devices and the development of renewable energy sources, consumer behavior plays a crucial role in bringing down the level of energy consumption.

Influencing consumer behavior to promote energy conservation has become an important target of national and international policy efforts. Thereby, the question which instruments should be applied to promote energy conservation behavior has become highly relevant.

Recent reviews [e.g., 2, 15] have evaluated the effects of interventions to promote energy efficient behavior. In general, mass media public campaigns seem to lack precision in targeting and message concreteness to achieve behavioral change. By contrast, raising people's awareness of energy consumption by providing tailored feedback about their energy consumption (for example in kWh) can promote the achievement of behavioral change [see, e.g., 2, 15]. The results are mixed though. Weak linkages between specific actions and energy outcomes caused by low feedback frequencies (e.g. once per month) and insufficient specificity of the feedback (e.g. household in general vs. specific person or specific devices) are underlying these mixed findings.

Recently, technological solutions have created new opportunities to improve feedback efficacy by embedding feedback in user-system interactions. That is, energy use is in essence always the outcome of an interaction between a user and some energy-consuming device. Intervening in these specific interactions might improve the quality of feedback substantially. Some evidence supports this claim. McCalley and Midden [14] demonstrated in several studies that interactive forms of feedback could be effective in enhancing energy-efficient use of devices like washing machines. By adding an energy meter to the user interface of a washing machine they achieved 18% of energy conservation both in lab and field studies. Basically, their approach entailed giving factual feedback in terms of kWh consumed as a function of programming choices made by the user, like water temperature, spinning speed or the duration of the washing cycle.

However, in many day-to-day situations people might not be motivated or lack the cognitive capacity to consciously process relatively complex information [see e.g. 5]. Factual feedback (e.g., the numbers representing kWh consumption) might be that kind of relatively complex information. In the current research, we will investigate the persuasive effects of a form of feedback that is easier to process. We argue that (interactive) feedback using lighting is simpler to process than (interactive) factual feedback because it can directly express evaluative meaning whereas factual feedback still needs to be processed and evaluated by the user. For example, red lighting might be defined as meaning “high energy consumption”, which does not need to be evaluated further, whereas factual feedback that 120 kWh was used does. Also, feedback through (diffused) lighting can be perceived easily without focusing, in contrast to factual feedback. For example, (part of) the environment of the user can be used for lighting feedback, whereas the user needs to focus on factual feedback (e.g., in the form of numbers).

In addition, we argue that lighting has specific qualities that make it particularly suitable for providing user feedback. For example, lighting can be very cheap, is easy to install, lighting can be very energy friendly, lighting can be seen by other people present in a room as well (inducing social pressure as a persuasive mechanism), and lighting might have an emotional appeal or even direct emotional effects. Also, the low conspicuity of light and color changes sets lighting apart from other feedback mechanisms. Furthermore, lighting can be calm (in the sense of ‘calm computing’). Other feedback mechanisms often lack these characteristics. For example, feedback mechanisms like factual feedback or feedback that uses sound, smell, or tactile feedback cannot easily be calm in that sense. Therefore, we argue that lighting can be particularly suited as a persuasive agent.

Earlier research indicates that energy consumption feedback that does not consists of specific facts, but rather of lighting changes can influence consumer behavior [see 7, 23, 3, 9, 20, 18, see also 17]. For example, in the eighties of the previous century Becker and Seligman [6] investigated the effectiveness of a light that went on “in a highly visible part of the home” whenever the air conditioner was on, but the outside temperature was 20°C or lower. In homes that contained the signaling device, an average of 15% savings in energy consumption was found. More recently, a device called an energy orb was used that changed color dependent on the time-of-use tariff in operation. This type of information helped users save some energy [12] and the usefulness of the device was positively evaluated by users [20, 12].

The current research will investigate the effects of feedback through lighting on energy consumption and compare them to the effects of factual feedback. The feedback (lighting feedback and factual feedback) that we will investigate in this research will be of a highly interactive nature. Earlier research of lighting feedback has already employed feedback that contained elements of interactivity (e.g., in Becker & Seligman’s research [6]). For example, Becker and Seligman’s participants received feedback about their action, although not in direct response to those actions. In the current research, participants will receive feedback about consequences of an action in direct response to that action. More specifically, the current research will give users lighting feedback about their current energy consumption in a specific task, and this lighting feedback will change directly when they use more or less energy. Furthermore, the current research will investigate the assumption that lighting feedback is easier to process than factual feedback.

The Current Research

In the present study, we examine whether interactive feedback through lighting can stimulate energy conservation behavior. That is, we will use lighting color as feedback to indicate the absolute level of energy consumption (more green = lower energy consumption, vs. more red = higher energy consumption). We set up an experiment in which participants had the opportunity to conserve energy in a series of tasks and received feedback about their energy consumption during these tasks. We tested the effect of lighting feedback and compared these effects to more widely used factual feedback. More specifically, we compared the effects of lighting feedback using lighting color to indicate energy consumption, to the effects of factual feedback using a number to indicate energy consumption in Watts. When giving lighting feedback, low consumption was indicated by completely green lighting and high consumption by completely red lighting. So, people can quite easily understand whether a specific lighting (e.g. light-green) indicates high or low consumption. However, when factual feedback would consist of only one number (representing energy consumption in Watts), it would be a lot more difficult to know whether that number indicates high or low consumption. Therefore, when giving factual feedback, next to the number indicating the current energy consumption level, two additional numbers were presented indicating low and high consumption. Thereby the amount of information present in lighting feedback and factual feedback is comparable.

As argued above, we expect that feedback through lighting has stronger persuasive effects (leading to lower energy consumption) than factual feedback. In addition, we expected that lighting feedback would be easier to process. To test this, we manipulated cognitive load: Half of the participants performed an additional task. We expected that for participants processing *factual* feedback, performing this additional task would interfere with the persuasive effects of that feedback, leading to more energy consumption than without the additional task. At the same time, we expect that for participants processing *lighting* feedback, performing this additional task would not interfere with the persuasive effects of that feedback, leading to the same energy consumption as without the additional task. Also, we expected that for participants processing factual feedback, performing this additional task would lead to slower processing of that feedback, while for participants processing lighting feedback, performing this additional task would not lead to slower processing of that feedback.

METHOD

Participants and Design

Fifty-seven participants (39 men and 18 women) were randomly assigned to one of the four cells of a 2 (feedback type: lighting feedback versus factual feedback) x 2 (cognitive load: load vs. no load) experimental design. All participants were student at Eindhoven University of Technology, were recruited on campus to participate in a study on 'How to program a heating thermostat', and received € 5 for a participation of 30 minutes.

Procedure and Materials

Upon arrival, participants were seated in front of a computer. For all participants, a simulated programmable thermostat panel was presented on the computer screen (see Figure 1). This heating thermostat was modeled to look like a commercially available heating thermostat. It contained a virtual LCD display (with a background that was always green) on which all relevant information and clickable buttons were presented. For participants in the lighting feedback condition, a computer-controlled power-led lamp was positioned behind the participants' desk that reflected its lighting on the wall behind the desk (see Figure 2). For participants in the factual feedback condition, next to this thermostat panel we presented a number indicating the participant's energy consumption in Watts, and also two numbers indicating low and high consumption levels in Watts.

Figure 1 -- The simulated programmable thermostat panel

More specifically, for each of the ten scenarios (described below) we calculated a low consumption score in Watts (based on a setting of 17°C in relevant rooms) and a high consumption score in Watts (based on a setting of 26°C in all rooms). In the lighting feedback condition, these numbers were used to determine the lighting color. That is, when a participant's energy consumption caused by his or her setting of the thermostat were at the low consumption level or lower, the lamp was given a completely saturated green color, and when energy consumption was at the high level or higher, the lamp was given a completely saturated red color. When a participant's thermostat settings lead to an energy consumption in between the low level and the high level, the light the lamp emitted was set to a color between green (indicating low consumption) and white (indicating consumption of a medium level, halfway between low and high) or a color between white and red (indicating high consumption).

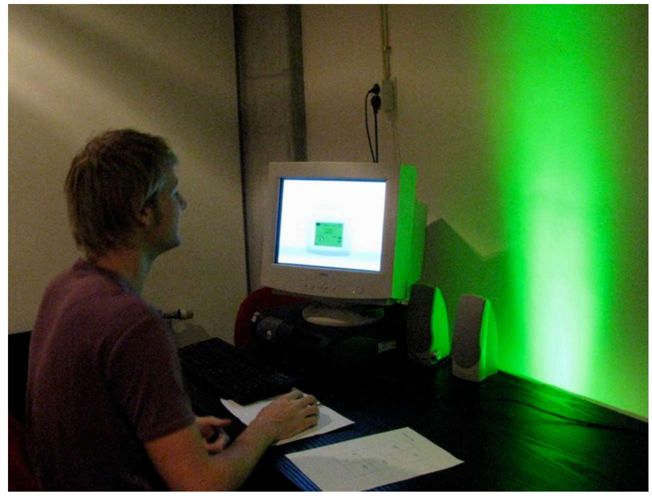

Figure 2 – Feedback through lighting on the wall behind the monitor

After general introductions, participants were asked to program the programmable thermostat in ten different tasks. Also, all participants were given two specific goals to strive for while programming the thermostat. First, they were instructed to strive for optimal comfort levels within each specific task. More specifically, they were asked to "program the programmable thermostat such that your house would be comfortable to live in."[1] Second, participants were instructed to use as little energy as possible. That is, they were told that heating your house costs energy (fuel) and diminishing the level of the temperature settings for specific rooms would lead to lower energy consumptions. We included the first goal to motivate participants to use energy (to heat the house to comfortable levels). Had we only included the second goal, all participants might have chosen to use as little energy as possible by simply not turning the heating on at all, and any feedback about energy consumption would have been irrelevant.

Next, the thermostat and the energy consumption feedback (factual or ambient) it provided were explained. In each task, participants were instructed to program the thermostat for a different scenario. For this, we used 10 different, short scenario descriptions (e.g., "It is evening and you are having a party at home tonight", "It is night and you are going to bed. It is -10°C outside", "On a Sunday afternoon you are at home and outside temperature is 18°C"). In each

[1] As in real-life programming of programmable heating thermostats, participants did not experience physical effects of changes (e.g., changes in heat) during the programming tasks. So, participants had to judge the comfort level corresponding to their settings of the thermostat based on earlier experiences and their current settings.

task, one of the ten scenarios was displayed above the programmable thermostat panel. Scenarios were drawn randomly from the set of ten and each scenario was used only once. Participants received feedback after each change of settings, until they pressed the "ready" button. For each task, we registered the energy consumption corresponding to the final setting, and the total amount of time a participant used for that task.

Participants in the cognitive load conditions performed an additional task while setting the thermostat. This task was comparable to cognitive load tasks used in earlier research (e.g., [22]). Participants heard numbers (one to thirty) read out aloud on headphones. As a manipulation check, we registered the number of correct responses (pressing the space bar after an odd number). Finally, participants were debriefed and thanked for their participation.

RESULTS

Averaged energy consumption scores (over the 10 tasks) were submitted to a 2 (feedback type: lighting feedback versus factual feedback) x 2 (cognitive load: load vs. no load) ANOVA. As expected, participants who had received feedback through lighting used a lower amount of energy on average on the tasks (M = 544 Watt, SD = 208) than participants who received factual feedback (M = 692 Watt, SD = 202), $F(1,53) = 7.16$, $p = .01$ (see Figure 3). This analysis did not indicate the expected interaction of Feedback Type X Cognitive Load, $F < 1$. Also, this analysis did not show a main effect of cognitive load, $F < 1$.

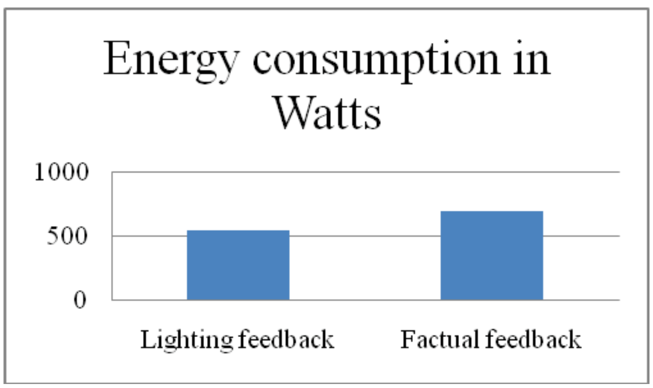

Figure 3 – Energy consumption by type of feedback

However, the manipulation check of the cognitive load task indicated that approximately half of the participants in the cognitive load conditions had not performed the load task in line with instructions (had pressed the space bar for less than 10% of odd numbers). Therefore, to assess whether the effect of feedback type on energy consumption was qualified by cognitive load (indicated by an interaction of feedback type x cognitive load), we submitted the average energy consumption scores of the remaining participants (14 in the load conditions, of whom 7 received lighting feedback and 7 received factual feedback, and 29 in the no load conditions, of whom 15 received lighting feedback and 14 received factual feedback) to an identical 2 (feedback type: lighting feedback versus factual feedback) x 2 (cognitive load: load vs. no load) ANOVA. This analysis showed results completely comparable to the previous one: a main effect of feedback type, $F(1, 39) = 4.63$, $p < .05$, but no interaction of feedback type and cognitive load nor a main effect of cognitive load, both F's < 1.

Finally, to assess whether lighting feedback would be easier to process, we analyzed the time it took these remaining participants to program the thermostat. This dependent variable was calculated by averaging the times they needed on each of the 10 tasks. This analysis showed the expected interaction of Feedback Type X Cognitive Load, $F(1,39) = 7.20$, $p = .011$ (see Figure 4). Further analyses indicated that participants who received factual feedback needed more time to program the thermostat under cognitive load (M = 55.0 seconds, SD = 15.1) than without cognitive load (M = 38.7 seconds, SD = 7.0), $F(1, 40) = 6.02$, p = .019, whereas this difference was not found for participants who received lighting feedback, $F<1$. In general, programming the thermostat using lighting feedback was faster (M = 39.3 seconds, SD = 8.0) than when using factual feedback (M = 44.1 seconds, SD = 12.7), $F(1,41) = 9.24$, $p < .01$.

Finally, we also explored the effect of cognitive load on energy consumption scores, but found no significant results of cognitive load, all F's<1.

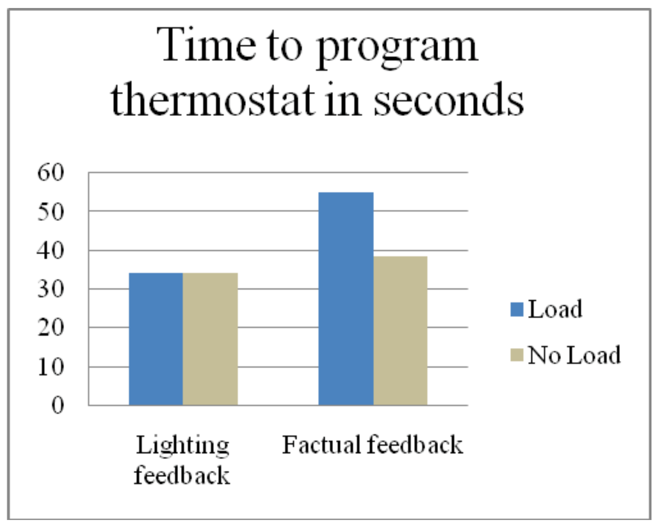

Figure 4 – Time to program thermostat by type of feedback and cognitive load

DISCUSSION

Results indicated that participants who received feedback through lighting used less energy in thermostat programming tasks than participants who received factual feedback. Thereby, the current research suggests that lighting feedback can have stronger persuasive effects than factual feedback (approximately 27%). Also, the current results suggest that for participants processing factual feedback, doing an additional task led to slower processing of that feedback. For participants processing lighting feedback, results suggest that adding cognitive load did not lead to slower processing. This finding fits our suggestion that lighting feedback is more easy to process and use in goal-striving processes than factual feedback.

In contrast to expectations, the current results did not show evidence for effects of cognitive load on energy consumption, or of different effects of cognitive load on energy consumption for participants who received lighting feedback compared to those who received factual feedback. An important reason for this might be that the setup of the current study may not have been ideal for finding such an effect because of the lack of time constraints when setting the thermostat. That is, because there were no time constraints, participants who received factual feedback and who performed an additional task, may have been able to use more time to set the thermostat (and did so, as indicated by the analysis of response times). It seems quite straightforward that these participants used this additional time to process the factual feedback. Thereby these participants may have processed the factual feedback well, even though they also had to spend processing capacity on the additional task. Future research might continue the investigation of whether cognitive load can increase energy consumption for factual feedback. Importantly, the current results indicate that setting time constraints might be important to find those effects.

Another possibility is that cognitive load could exert an effect on energy consumption even without time constraints, especially in a goal-setting paradigm, since it leaves less cognitive capacity for considering the various goals (i.e., 'comfort' and 'energy saving'). Cognitive load might make people forget secondary goals ('energy saving' would often be considered secondary), or process additional cues (e.g., light feedback) in a more peripheral rather than central way. Interestingly, both paths would have implications for the most optimal design of feedback cues, and future research could investigate both pathways.

Future research might also investigate using other forms of cognitive load. That is, because the current cognitive load task contained numerical elements (as participants had to identify odd numbers in a spoken list of numbers), it could have interfered especially with processing the factual feedback because that also consisted of numbers (indicating energy consumption). Therefore, cognitive load may not have been equal in both cognitive load conditions. That said, we argue that the numbers in the current load task were only of secondary importance, as the main task participants had to do was to identify specific element in an array of elements (and these could just as easily have been arrays of letters, in which participants would have to identify consonants). In line with this argument, theories that account for effects of information processing demands generally do not identify different effects of processing demands caused by different types of information (for an overview, see [16]). So, these theories would not predict fundamentally different mental load effects of a cognitive load task that consisted of a more numerical load task versus another type of load task. Likewise, cognitive load theory [21] indicates that limitations of human cognitive processing become especially pronounced when dealing with complex tasks [4]. Based on cognitive load theory, we argue that adding an additional task (our load task, which indeed contained numbers) could have revealed limitations of cognitive processing also in the lighting feedback condition, *independent of the specific nature of that additional task*. In other words, because our load task added to the complexity of the overall task participants in the lighting feedback conditions had to perform, it therefore could have revealed limitations of cognitive processing. And indeed results did not indicated these limitations (in terms of slower processing) in lighting feedback conditions, but only revealed these limitations (slower processing) in factual feedback conditions. Still, future research replicating the current findings with different cognitive load tasks would certainly strengthen the evidence for our argument that lighting feedback is easier to process and use in goal-striving processes than factual feedback.

Furthermore, future research could also investigate which other differences between lighting feedback and factual feedback may underlie the stronger persuasive effects of lighting feedback in addition to the higher ease of processing of lighting feedback that the current research suggests. For instance, lighting feedback might be more conspicuous, have specific physiological consequences, or may have stronger emotional or moral effects.

Overall, the current research indicates that diffuse lighting can be used successfully as persuasive technology. These technologies can be incorporated into everyday life in many forms to change different types of behavior or attitudes. For example, the data about energy consumption provided by smart meters might be used to deliver interactive lighting feedback in the living room. The current research suggests that such an application could successfully influence energy consumption behavior, even when users do not spend cognitive attention to this lighting feedback. The current research indicates that lighting can have a particular aptitude as a medium for persuasive communications. Next to being very cheap, or easy to install (and other fitting characteristics, as discussed in the Introduction), the current research suggests that persuasive lighting can have stronger persuasive effects than other forms of persuasion (i.e., factual persuasion), especially under (day-to-day) circumstances of high cognitive load.

In addition, we argue that lighting has specific qualities that make it particularly suitable for providing user feedback. For example, lighting can be very cheap, is easy to install, lighting can be very energy friendly, lighting can be seen by other people present in a room as well (inducing social pressure as a persuasive mechanism), and lighting might have an emotional appeal or even direct emotional effects.

Also, the low conspicuity of light and color changes sets lighting apart from other feedback mechanisms. Furthermore, lighting can be calm (in the sense of 'calm computing'). Other feedback mechanisms often lack these characteristics. For example, feedback mechanisms like factual feedback or feedback that uses sound, smell, or tactile feedback cannot easily be calm in that sense. Therefore, we argue that lighting can be particularly suited as a persuasive agent.

In general, persuasive technologies are generic technologies which are "intentionally designed to change a person's attitude or behavior or both" [7, see also, 12]. Based on current results, we argue that lighting in various modalities can serve as Ambient Persuasive Technology [see also 6, 8, 10, 11, 19]. We propose that Ambient Persuasive Technologies are generic technologies that are intentionally designed to change a person's attitude or behavior or both, that can be integrated unobtrusively into the environment and exert an influence on people without the need for their focal attention. The current research suggests that ambient persuasive technology can have important advantages over more focal persuasive technologies without losing its persuasive potential.

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