Energy Consumption Feedback Visualization for Increased Awareness

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Abstract

The objective of this thesis is to investigate how energy consumption can be translated into persuasive feedback visualizations, with the purpose of increasing awareness among consumers, and developing pro-environmental behavior. A part of this objective is also to investigate if and how the system can use ambient visualization to provoke pro-environmental behavior, as well as to lower consumption during peak-load hours. Finally, the aim is to evaluate the efficiency of the system by conducting experiments on actual households.

In this thesis, the characteristics and nature of eco-feedback systems, which have the purpose of changing consumers' behavior into pro-environmentalism through feedback, is briefly explained. Also, some of the related work that have, in one way or another, been influential to the work in this thesis, are highlighted.
In order to identify the requirements for an eco-feedback system in general, the relevant literature in the fields of HCI, and behavioral and environmental psychology have been analyzed. The requirements are then used in a design for a new eco-feedback system called enPower. The design is also influenced by the field of persuasive computing, and incorporates aspects from there, which makes the system more persuasive in exerting behavior change in its users. Also included in the design, is a physical, ambient consumption indication device, the Light Sphere.
Finally, the enPower eco-feedback system, along with the Light Sphere, is implemented in a high-fidelity prototype.

Two experiments, related to the objectives of the thesis, are conducted. The Ambient Eco-feedback experiment aims at cutting peak-levels by using a lamp (the Light Sphere) that gives feedback through ambient light. This experiment showed a decrease of 39% in the peak-load hour, and 25.7% decrease in the

overall consumption. However, there is reason to believe that the feedback was wrongfully perceived as real-time, which questions the validity of the result. The purpose of the second experiment was to investigate if the enPower web-app prototype could make a test-group aware of their electricity consumption with decreased consumption levels as result. A group of 9 households received daily consumption status reports, and had access to the eco-feedback web-app. Through the duration of the experiment a consumption decrease of 12.7% was detected compared to the same period in the preceding year (6.4% if bias corrected). The test-group's consumption during the experiment was also compared to a control group consisting of nearly 2,500 households. Here, the test-group used 7.0% less electricity than the control-group.

There are slight indications that feedback, both through ambient and attention demanding visualization, provokes pro-environmental behavior on Danish households from Funen by lowering peak-levels and generally decreasing the use of electricity. However, there is a need for additional experiments that account for the scientific pitfalls and statistical errors related to eco-feedback experiments.

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Chapter 1

Introduction

The world's population is growing with exponential pace and the need for energy resources is growing along with it. It is getting more and more difficult to supply the demand, especially when it is not constant throughout the day: The electricity usage during the peaking hours necessitate the use of expensive and unsustainable production methods, whereas the electricity produced by sustainable wind-mills during off-peak hours is not used and lost, since it cannot be stored. This is why focus is growing on how less energy can be consumed, in order to bring the demand down, and how the consumption can be moved from peak-hours to the rest of the day. The shift has led to initiatives to create awareness about energy consumption in the common population, and with the latest technological advancements in data collection and connectivity, it has further shifted towards digital visualization and feedback of the household's energy expenditure.

However, there is a problem in the way consumers receive feedback about their energy consumption. Currently, the consumer receives the total price of the previous month's, quarter's or year's energy consumption as feedback. Although online energy visualization tools have emerged in the recent years, where the consumers can look more closely at their consumption behaviors, they are not much different from their paper counterparts, printed on energy bills; The feedback is not translated and made understandable to the consumer and mostly consists of pie charts, and graphs that can be difficult for the common citizen to comprehend and relate to.

1.1 Problem Definition

With today's instant access to digital media that are online, capable of presenting rich graphics, and connect to social networks, it should be possible to engineer feedback visualizations that provide an engaging user experience and encourage action through awareness and reflection. These solutions can be integrated into homes, schools and institutions, and possibly lead to awareness and energy conservation as a result.

My objective in this thesis is to investigate how energy consumption data can be translated into useful, understandable feedback visualizations that increase the consumer's awareness, and develops pro-environmental behavior. The output of this investigation will be a web-app that engages the users through rich graphics, versatility, usability, and understandability.

Furthermore, I wish to investigate if the feedback system can increase awareness about peak-hours in a non-obtrusive, ambient way. The result of this investigation will be a physical, ambient consumption indication device, called the *Light Sphere*, along with the web-app.

Finally, I want to evaluate if the system results in peak-cutting and energy conservation by conducting two experiments. The ambient feedback experiment has the aim of cutting electricity peak levels by providing light and color feedback to a family. The second experiment aims at lowering the electricity consumption in a group of 10 households through the use of my eco-feedback web-app. During both experiments the consumptions of the households are studied for two weeks, while they receive eco-feedback. The consumption in the prior two weeks to each experiment is used as baseline. Furthermore, for the latter experiment, the consumption from the same two weeks in the previous year, as well as the consumption of a control group, will be used as comparison.

Conclusively, the baseline readings will be compared to the consumptions during the experiments, and the findings will be discussed.

1.2 Scope and Methodology

Due to the limited lifespan of the project, and the vast amount of studies, statistics, and research available about eco-feedback technologies, it is important to restrict the scope and set the focus of the thesis. Therefore, the thesis solely focuses on electricity as energy resource, even though most of the theories, designs and software can be applied to other energy resources. For sensing data from households, I make use of already established systems and databases from the utility company, and thereby omit the concern of data collection, and all the issues related to it. This means that the concern in matter is the interpretation and the visualization of the sensed data to the household.

The developed software is a prototype and is only tested to function during the evaluation. This means that some quality factors and requirements, that would normally be taken into consideration, when developing software for release, has been omitted. Such factors include, but are not limited to: adjusting consumption variation due to weather variations and time of year, considering heat warmers, weekends, and holidays. Still, the prototype will be of high fidelity, and the software architecture, as well as the written libraries and components, will be produced with future development and incorporation of the mentioned factors in mind.

Finally, the evaluation approach is simplified. The selection of test subjects does not consider demographic differences, such as occupation, income and geographic location of the household. Statistical error margins are neither accounted for, and is considered out of scope of this thesis. Still, the evaluations done in this project serve well as indicators of the efficiency and practicality of the ideas, as well as user testing of the software, and especially the user experience.

1.3 Organization of the Report

The rest of the report is structured into the following chapters:

Chapter 2 - Eco-Feedback Technologies

Chapter 3 - Related Work

Chapter 4 - Analysis

Chapter 5 - Design

Chapter 6 - Implementation of the Eco-feedback System

Chapter 7 - Evaluation and Results

Chapter 8 - Discussion

Chapter 9 - Conclusions

Appendix

Chapter 2

Eco-feedback Technologies

Researchers, in the fields of persuasive technology and human-computer interaction (HCI), have conducted studies and experiments in developing technology that senses energy consumption and feeds it back to the user in engaging and informative ways, which in turn increases awareness and promotes environmentally responsible behavior. These sensing and feedback systems are referred to as *eco-feedback technology* [Fro09].

Even though eco-feedback technology might seem as a subfield of persuasive technology [Fog02], it has been an examined and studied subject in the field of environmental, behavioral and social appliance psychology for more than 40 years [Fro09]. Therefore, a lot can be brought in from studies about human psychology, especially studies about pro-environmental behavior and behavior change.

Feedback can be considered as both low-level and high-level. If we take bowling as an example, the former is the feedback that is given to the player, when the bowling ball hits a number of the pins. In this case, the player can use the feedback to adjust his throw, as well as the speed and trajectory of the ball, in order to overturn more pins. The high-level feedback is given through the overall score of the game, where the player is able to compare performance to previous games, as well as other players.

Much in the same way, eco-feedback technologies rely on the hypothesis that people lack awareness about their behavioral impact on environmental issues, and that providing them with both low-level, and high-level feedback through technological solutions, will result in increased awareness, and thereby decreased consumption and pro-environmental behavior [Fro09].

2.1 Introducing the Eco-feedback Design Space

As already discussed, eco-feedback systems cross between numerous fields of science. Additionally, their design span over different physical platforms, visualization domains (e.g. from ambient colors to concrete numbers), etc. In other words, characterization of eco-feedback systems can be a challenge due to their heterogeneous nature. If so, how can prototypes, or existing designs be analyzed and compared to one another in a uniform way?

In his dissertation "Sensing and Feedback of Everyday Activities to Promote Environmental Behaviors" [Fro09], Jon E. Froehlich introduces an eco-feedback design space based on literature from multiple fields, including HCI, information visualization, environmental psychology and applied social psychology. The eight dimensions of the design space serve two main purposes "(1) to help in analyzing and critiquing existing designs and (2) to provide a process and foundation with which to approach building new designs, by understanding the tradeoffs of different points in the design space." [Fro09].

The eight dimensions each engage a defined area of the overall design, and they all contain subspaces that deal with specific details of the dimension. In this paper, the design space will be the common vocabulary for examining the developed eco-feedback system, as well as discussing related works. Further information on the specifics of the design space can be found in [Fro09], and will not be discussed further here (the design space diagram is included in appendix B, figure B.1).

Chapter 3

Related Work

This chapter presents selected works that are state of the art, and/or significant in relation to this project in one way or another.

3.1 Opower

Opower is a fairly new startup company resided i SF, CA[1]. Their initial services consisted of eco-feedback visualizations that the utility companies sent out in letters to their customers. Since then, they have grown into a very big and successful company with a well-branded image of being environmentally responsible and aiming for sustainable design of eco-feedback technologies [Ber11]. Their technologies include social comparisons, grading, feedback via metaphors, self-comparison, apps, and webportals. They operate mainly in the US. Especially Opower's use of metaphors, and social ranking system (see figure 3.1) is interesting for this thesis.

[1] http://www.opower.com

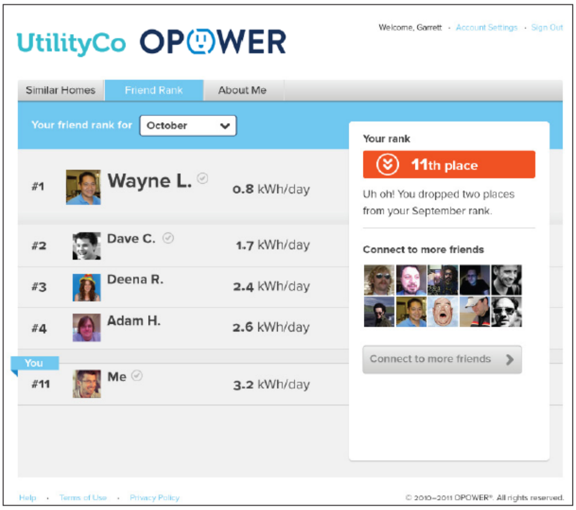


Figure 3.1: The social ranking system between friends in Opower.

3.2 Lucid Design

Like Opower, Lucid Design is also a startup company. It was a spin-off business of a study on dormitory eco-feedback [PSJ+07]. The technologies used in the study included kiosks and websites, as well as incentives and competition. The study showed impressive results, but its validity is doubtful, since a lot of incentives were given to the participants during the evaluation period, which might have influenced the results. Lucid Design has a major product called BuildingDashBoard, which serves as a total suite of energy management[2]. The parts of this product, that are directly related to enPower, is the eco-feedback visualizations that are embedded in the apps and the websites, that their product suite contain.
The study on dormitory eco-feedback is interesting, because it uses norm-activation to encourage pro-social and pro-environmental behavior (discussed in more detail in section 4.1.3).

[2] http://www.luciddesigngroup.com/

3.3 Nest

Also a fairly new startup company, Nest takes the eco-feedback with another approach, compared to the other products. Their main product is a circular thermostat that hangs on the wall. It is intelligent and learns how the residents use the thermostat, thereby making the heating expenditure more intelligent in the home. On their website, Nest go a long way with explaining, in metaphors, how their system works [3]. One of the interesting metaphors is how they explain peaking by the means of traffic rush hours on the roads, and how avoiding spending energy in the peaking hours makes the traffic jams go away.

The Nest thermostat is interesting for this thesis, because it is clever in the way it blends eco-feedback into the home, which is inspirational for the Light Sphere.

3.4 Peaking Study

The relatively old study, "A Behavioral Analysis of Peaking in Residential Electrical-energy Consumers" from 1976 by Robert Kohlenberg [KPP76], is interesting because of its use of a light bulb for shaving peak-loads. The study group had relays installed that sensed when the consumption of the homes increased over 90% and caused a lamp to be switched on. In addition to the lamp signal, incentives and information was also given, and the study concluded that peak savings could be as great as 50%. The ambient and non-obstructive nature of the lamp is the main inspiration behind the aforementioned Light Sphere, which will be described in detail later.

3.5 Ambient Orb

The company behind the Ambient Orb, Ambient Devices, provide consumers with "instant, effortless access to information – at a glance"[4]. The Ambient Devices product line includes different lamps and displays that approach specific areas, such as weather forecasts, stocks, and also recently, energy. The energy sphere is basically a spherical lamp, which it is capable of displaying information on peaking hours at a glance (through the color of the lamp). The idea for the product came from a manager from Southern California Edison that was looking

[3] http://www.nest.com/
[4] http://www.ambientdevices.com/about/about-the-company

for a clever way of providing eco-feedback to their customers. When he was made aware of the stock orb, he came up with the idea of reprogramming the sphere to give eco-feedback [Tho08].

This product is very similar to the Light Sphere that is presented in this thesis, however it is different in the way that it can only display information on peaking levels (at least at the current moment), and that it is not instructed from a central server, as the Light Sphere is. Controlling the lamp from a central server enables it to receive new functionality, such as live-feedback, once the technology is available at the utility company.

3.6 EMT Nordic WebTools

Lastly, there is the current eco-feedback installation provided to EnergiFyn customers, which is the tool that enPower relies on for data. EMT Nordic is a Danish company specialized in energy management technologies for utility and energy consultancy companies[5]. Their WebTools product line provides eco-feedback services to utility companies, which in turn make them available to their end-users. The product line consists of a web-site integration module, and apps for smartphones and tablets. The eco-feedback services are geared for energy-monitoring purposes, rather than motivational tools to encourage pro-environmental behavior. We use the eco-feedback design space for analyzing EMT WebTools in figure 3.2.

WebTools' data visualization has different user-changeable temporal groupings, which is hourly, daily, monthly, quarterly and yearly. It also compares the household's yearly energy expenditure with norm values. However, these comparisons do not take account for the size or type of the home. Via WebTools, users are also provided a feature, where they can manually enter custom measurements, which then will be visualized in a chart, along with the electricity, the water, and the heating meter (if available). Lastly, users are also provided with a alarm/notification feature that works over sms and email. WebTools does not engage peaking issues directly.

[5] http://www.emtnordic.com/

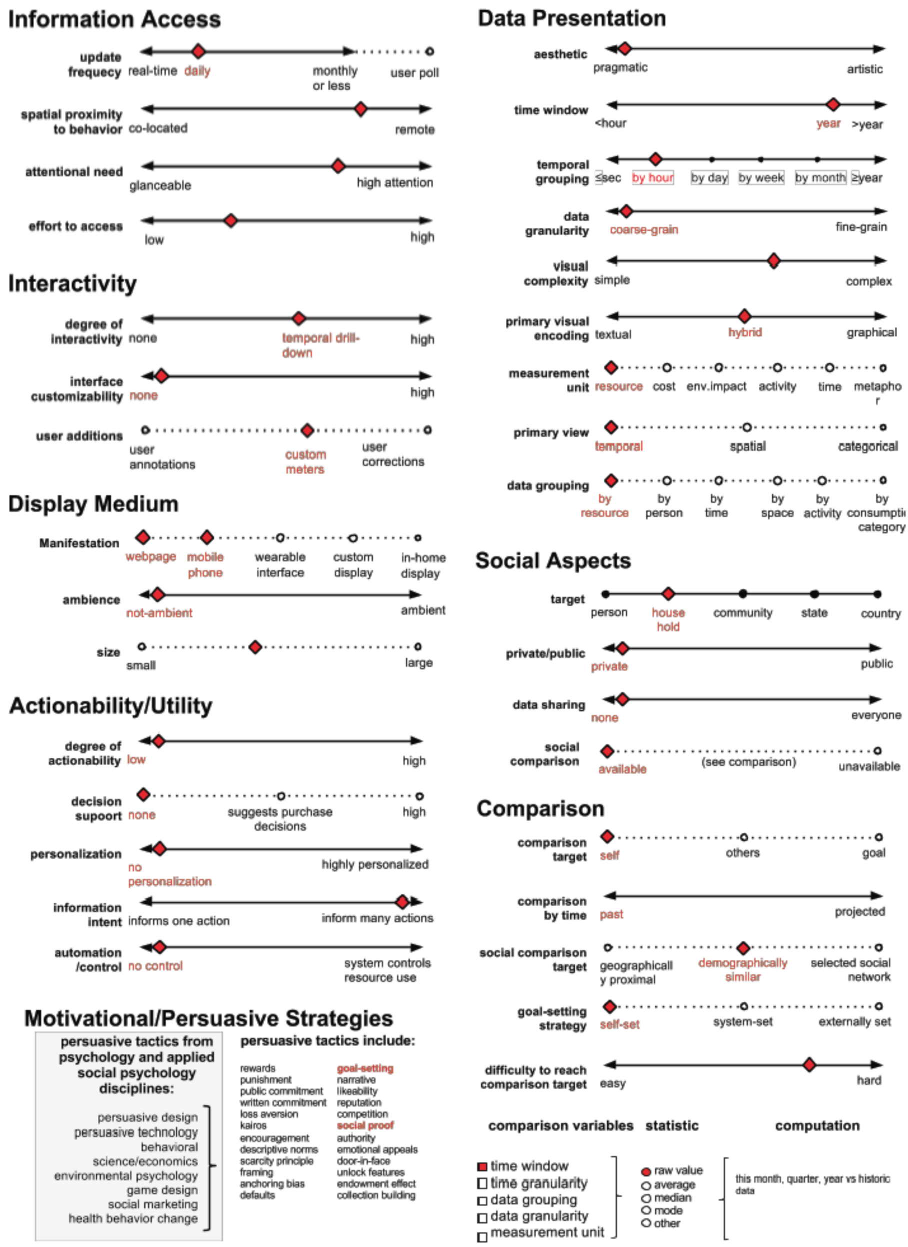


Figure 3.2: The eco-feedback design space applied on EMT WebTools.

Chapter 4

Analysis

The contents of this chapter is an analysis of the psychology behind pro-environmental behavior, an investigation of how people are motivated to change, and what motivational techniques there are available for fostering a change towards pro-environmentalism. The aim is to analyze the relevance and the appropriability of the models and techniques, as to create a set of requirements for eco-feedback systems in general.

The concepts discussed in [Fro09], sections 4.1, 4.2, and 4.3, are used as common thread for the requirement specification in this chapter.

4.1 Pro-environmental Behavior Models

There are numerous reasons for why people think and act environmentally responsible. The same is valid for why people fail to do so. In the field of environmental psychology there are various models and theories trying to explain the factors behind pro-environmental behavior. Each model has a specific approach towards behavior change, and with each follows simplifications and shortcomings. By using multiple models when analyzing the requirements for the system, these shortcomings are minimized. In this section, a relevant subset of these models will be analyzed and formulated into requirements for eco-feedback systems.

4.1.1 Attitude

One popular category in environmental psychology is *attitude models*, which, as the name implies, tries to foresee consumption behavior through an individual's attitude towards the environment. These models suggest that pro-environmental behavior can be achieved by informing and educating people about environmental issues [Fro09]. However, studies have shown that people do not necessarily behave environmentally responsible, even if they have a pro-environmental attitude. According to [SDA+99], the effect of attitude on behavior depends on context, amount of effort, expense, and inconvenience related to changing the desired behavior, and in addition to the knowledge of environmental issues, knowledge of appropriate actions are necessary for behavior change. Thus the following requirement can be formulated:

Requirement 1 The user should receive information and education about environmental issues when he/she is actively reviewing the household's energy expenditure. The system should deliver guidance to the user about how the environmental issues can be solved through pro-environmental actions.

4.1.2 Rational-Economic

This model assumes that people act to maximize rewards and to minimize costs. Transferred into environmental psychology this model suggests that people will adopt consumption behaviors that are financially advantageous. There is strong evidence supporting that price affects decision-making and behavior [Fro09].

Requirement 2 The system should clearly render visible the economical costs related to the user's electricity consumption. It should also visualize possible financial rewards related to conserving energy.

The model assumes that people understand what behavior or device is cost effective, and what actions are necessary for being rewarded, or for avoiding being punished. Requirement 1 fulfills this prerequisite.

4.1.3 Norm-activation

Norm-activation models assume the premise that moral, or personal norms are direct determinants of pro-social, and thereby pro-environmental behavior. Pro-environmental behavior is often considered pro-social, because it favors collectivism and the acknowledgment that one's behavior can affect other's and the future generations. For example, in the study on dormitory eco-feedback [PSJ+07], norm-activation is used to encourage pro-social, and pro-environmental behavior, by making the students aware of their collective effort through the use of kiosks.
According to [Sch77], pro-environmental behavior is simulated when a person is aware of the negative consequences of his behavior on others. Thus, norm-activated behavior is based on altruistic values, and personal morals. [SDA+99] elaborates on Schwartz' model with their value-belief-norm theory of environmentalism. Similar to basing behavior on altruism, the theory bases the same logic to curiosity, personal achievement, and wildlife.

Requirement 3 The eco-feedback system should encourage moral reflection. This could be about how environmental issues affect nature and wildlife. The user's conserving behavior should be rewarded with achievements and symbolic rewards.

4.2 Motivators for Behavior Change

Here, the drives and motivators for behavior change in general are analyzed.

4.2.1 Intrinsic and Extrinsic Motivation

People who are intrinsically motivated change their behavior because of a personal desire to excel, and the satisfaction related to it. They enjoy the achievement received through their changed behavior, as they are more excited and have more interest compared to those, who are externally motivated.

Requirement 4 The system should favor intrinsic motivation over extrinsic by encouraging education and self-improvement over rewards and punishment.

Extrinsically motivated people change their behavior because of external forces, such as fear of punishment, or bribe. The effect of these motivators often diminish soon after the external force is removed.

4.2.2 Sense of Control

Requirement 5 It should be emphasized, for the user, that he has an impact on consumption aspects, such as the next energy bill, amount of emitted CO2, exploitation of sustainable energy sources, etc.

If people are convinced that control is in the hand of external forces, such as the government, or god, they tend to be less motivated to show pro-environmental behavior. If they, on the other hand, feel that the locus of control relies with them, they are more likely to engage in pro-environmental behavior [HHT87]. Therefore, we want the user to feel in control, and to be aware of the impacts of his actions and behavior.

4.2.3 Dissonance and Emotions

According to [Fes62], when a person holds two beliefs that are inconsistent with each other, the person will be in a state of cognitive dissonance, and will be motivated to reduce the dissonant experience. In relation to eco-feedback systems, motivation towards behavior change can be ignited in users, who already have a pro-environmental mind-set, but do not behave pro-environmentally.
If the role of dissonance was to be described by an emotion, guilt would be the most suiting. However, other emotions, such as fear, sadness, pain, anger and regret, are also effective motivators. According to environmental psychologist, Paul Stern [Ste00], a person's predisposition towards feeling these emotions, in relation to eco-feedback, and thereby feeling motivated, or threatened to change behavior, depends on various factors, counting: 1) the person's notion in his vulnerability towards the threat, 2) consideration on the severity, 3) awareness of counter-actions to take to avoid the threat, and 4) conviction that the actions can be taken without additional costs.

Requirement 6 The system should create a feeling of guilt in the user, if the user performs poorly in regards of energy conservation. On the other hand, the system should create a feeling of satisfaction, if the user excels in energy conservation.

Despite the stated motivational outcome of using emotions, the effects of scare-tactics, in eco-feedback systems, is somewhat limited. In a review study from 2000, dubbed "Motivating home energy action: A handbook of what works", Shipworth found that scare tactics were substantially less effective than targeted, useful information [Shi00].

4.2.4 Desires

A person's behavior is guided by sixteen desires ([RH98]). Some of these are suited for eco-feedback systems, and could be effective motivators for pro-environmental behavior:

- Acceptance: the need for approval
- Curiosity: the need to learn
- Saving: the need to collect
- Status: the need for social standing/importance

The desires for acceptance and curiosity will already be handled by the system, in connection to the requirements formulated earlier. Therefore, we only address the desires of saving and status in the following requirement:

Requirement 7 The system should deliver collectibles to the user, if the user conserves energy. The degree of conservation, as well as the amount of collected collectibles should be shared with other users.

4.3 Pro-environmental Motivation Techniques

In the previous sections, we explored the psychology of pro-environmental behavior, and motivators for behavior change. Here, we go deeper in the *what* and the *how* of motivational techniques to use to change behavior towards pro-environmentalism.

4.3.1 Information

According to attitude models, in behavioral psychology, as discussed in 4.1.1, providing information and education is necessary to change a person's attitude, and thereby behavior. But simply providing information is not enough, and only results in marginal savings. The effect can be maximized by making the information understandable, attention-seeking, memorable, and delivered as close, in both time and place, to the target behavior, as possible [BS$^+$05].
Another technique, when giving information, is making use of *prompts*, where short, focused bits of information are given. The effect of prompting is limited, unless the information is delivered in the context of the behavior taking place.

Requirement 8 Information and education should be easy to understand, and easy to remember. Additionally, they should be delivered as prompts that are easy to spot, and given with high proximity to the behavior they concern.

4.3.2 Goal-setting

A goal can be considered as "comparison between the present and the desired future situation" [VHVR89]. Goals affect behavior through four mechanisms: 1) they direct attention towards goal-attaining actions, 2) the have an energizing effect, 3) they encourage persistence, and 4) they have an indirect effect on behavior, since the individual seeks for information and guidance to reach the goal.
Furthermore, the relation between performance and the goal is affected by the degree of commitment to the goal. The commitment itself is affected by the significance for the user of reaching the goal, the belief in that the goal is reachable, and the received feedback as it helps to adjust and optimize the course to reach the goal.

Requirement 9 The user should be able to set a conservation goal of choice, for a desired duration.

Requirement 10 The system should deliver continuous feedback to the user on goal progress, and the degree of conservation compared to the goal.

4.3.3 Notifications

In a recent 2013 study on "The Power of Mobile Notifications to Increase Well-being Logging Behavior", researchers found that logging frequency could be improved by 63% through the use of notifications on mobile phones as reminders [BT13]. Notifications can be used in various scenarios of the eco-feedback design, such as informing about new available consumption data, alarming the users about attention-demanding events, or requesting the user to log which electric devices are being used at the moment, or what electricity-consuming behaviors are currently happening in the household.

Requirement 11 The system should be able to send out informative and attentional notifications to the users.

4.3.4 Comparison

Comparison can be against one self, or social. However, the effectiveness of comparison is doubtful, because having an interest in comparing one's performance does not automatically result in behavior change. Also, when comparing to oneself, at some point, performance plateau is reached, and comparison can actually result in negative performance. Another issue is the convergence effect, where efficient and inefficient users approximate their performance to each other's, meaning that efficient users perform less efficient.

The effects of convergence can be opposed by giving the person more to achieve, even if this person's performance is better than the comparison target. This could for example be some sort of grading, where the person's performance is plotted into a scale, and the previous, the current, and the next level of achievement is made visible to the user. This is how Opower tackles the effects of convergence.

Requirement 12 The system should grade the household in accordance to the household's energy conservation performance.

Requirement 13 The user should be able to post the household's performance to social networks.

Self-comparison is highly practiced in the area of personal informatics systems, where individuals collect data about behaviors in their lives, in order to quantify and track progress. Eventually, they reflect upon the results and take action to adjust their behavior to a desired state. The process goes through a stage-based model, starting with preparation, collection, integration, reflection, and finally, action [LDF10]. Each of these can either be user-driven, system-driven, or a combination of both. Our eco-feedback system must drive not only the preparation and collection state, but the integration stage as well, where "the information collected are prepared, combined, and transformed for the user to reflect on" [LDF10]. Thus, the user can easily reflect on his or her consumption behavior, and take action to adjust it towards pro-environmentalism.

Requirement 14 The eco-feedback system should function as a personal informatics system, and drive preparation, collection, and integration of data.

4.3.5 Incentives, Disincentives, Rewards and Penalties

In relation to behavior change, incentives and disincentives occur *before* the change takes place, whereas rewards and penalties are given as an effect of the change. Regulating electricity prices by differentiating between peak-load hours and off-peak hours is an incentive (or a disincentive, dependent on the consumer's point of view). Rewarding with achievement points, or moving the consumer up, or down in skill-levels, in a game-like environment, is examples of rewards and punishing. Studies have shown that even small rewards are enough to create a positive response in the user, and that the effect is greater the closer the reward is to the performed action [VS02].
Requirement 12 captures the essentials of a rewarding/punishment system. Incentives and disincentives, such as price regulations, is a task for the utility company, and will not be addressed in the eco-feedback system.

4.3.6 Feedback

It is a very well established belief in the field of psychology that feedback has a positive impact on performance [Bec78]. By examining over 25 studies and compilations about home energy consumption feedback, Fischer ([Fis08]) found that an average of 5-12 % conservation can be achieved through feedback. The degree of conservation was found to be closely related to frequency of feedback, proximity to the consumption, and whether or not the household was already an efficient consumer. Fischer reported that the most efficient eco-feedback interfaces provided the following: different time-resolutions, saving tips, comparisons, the ability to drill down in the consumption for a given time-slot, and delivering appliance-specific data.

Requirement 15 The user should be able to navigate between different time resolutions, including yearly, monthly, daily, and hourly views. Drill-down navigation between time resolutions should be made possible.

The *framing* of the feedback can itself be influential on behavior. For instance, people respond twice as strong to loss, as they do to gain [TKC81]. Also, people tend to make decisions based on initial estimates. They hang on to specific anchor-points of information, rather than doing a rational search and calculation of all available information [TKC81]. Thus, in eco-feedback, depending on how the initial feedback is presented, a bias can be created.

Requirement 16 The user's first encounter with the system should have an emphasis on the current amount of losses due to the practiced consumption behavior. The system should in general emphasize on potential loss over potential gain. This could be applicable to future projections, comparisons with historical data, etc.

4.4 Platform Considerations

The most desired scenario for the platform of the eco-feedback system's user interface would be to have it running on any kind of device with a screen. This is indeed the argument for making a web-app, and not a native application for e.g. Windows or iOS. The web is platform-independent, and accessible from almost anywhere, on any connected device. However, the required connectivity is also the weakness of web-based applications, but in our case, connectivity is already a requirement, due to the necessity of consumption data.

Requirement 17 The eco-feedback system's user interface must be based on web technologies, in order be platform independent.

However, even though creating a web-based application UI gives platform independence, it does not guarantee a good experience across platforms, specifically across different form factors; a user-friendly website, rendered on a 24" desktop screen, is not necessarily user-friendly on a 4" iPhone screen. Therefore, the application must be versatile, and responsive to the device and platform on which it is rendered.

Requirement 18 The user interface should be device- and platform-aware and have a responsive design that adjusts to the devices characteristics.

4.4.1 Ambient Platform

The idea of delivering information to the user in an ambient way is in accordance with Weiser's vision about ubiquitous computing [Wei91]. The users of ambient displays are passive in the way they obtain information from the display, and they do not interact with them as they would with computers. Instead, they *perceive* the displays, which "are aesthetically pleasing displays of information which sit on the periphery of a user's attention" [MDH+03]. Furthermore, people are more likely to act on subtle, but ambient available messages than on intermittent information reports that they are forced to focus on [Tho08] [BT13].

The reasons for why a more ambient, less attention-craving eco-feedback component is needed to accompany the web-app is three-fold: 1) to address the proximity-to-behavior requirements of such a system, 2) to create awareness of peak-load hours, and 3) to kindle the consumers' attention and invite them to investigate their consumption further.

In order for the eco-feedback design to have spatial proximity to the behavior, the most optimal solution would be to have an ambient indicator at each power outlet in the home, on which the consumer could get instant feedback on the electricity usage of the particular device, plugged into the outlet. However, the requirements for such a device would be very high and out of scope. A less demanding approach would be to add temporal proximity, by placing a device in a room where all the household's residents come and go. From there, one would be updated about the households current energy consumption by glancing at the ambient device. This could even happen subconsciously, and from the corner of one's eye.

Requirement 19 The system can advantageously include a physical component that can raise awareness of the household's current consumption through ambient information that is understandable through glaceability.

The ambient device also needs to visualize the dynamic of peak-hours and off-peak hours. This could perhaps be in conflict with the design of requirement 19, since the device would need to communicate multiple kinds information through glancebility. The system design should address this issue.

Requirement 20 The system's ambient indicator device should create awareness about when peak-hours occur, and when the off-peak hours are located in the 24 hours of the day. The information should be delivered in an ambient, glanceable manner.

Lastly, the ambient indicator should serve as a notification signaling device, much in the same way as the "new messages" indicator on an answering machine. The intention is to capture the consumer's attention, and lead him/her into using the web-app, in where the information that was glanced can be further investigated.

Requirement 21 The system's ambient device should have a notification state that can signal notifications, and persuade the residents to access the web-app.

Requirement 22 The system's ambient device should be able to deliver multiple types of information through ambience and glanceability.

In this chapter, we have identified the fundamental requirements for an eco-feedback system. In addition to the requirement analysis, a public survey was also conducted, in order to gain better understanding about people's existing knowledge about their own energy consumption. The findings of the survey are described in appendix A. These findings, as well as the requirements identified, are used in the design of the system.

The identified requirements are compared to the implemented version of en-Power, and the result can be seen in appendix D.

Chapter 5

Design

In the past chapters, we have examined the building blocks of eco-feedback systems, and gathered the requirements necessary to build the optimal eco-feedback system. In this chapter, the enPower eco-feedback system is designed. The designed system consists of 1) a responsive web-app that adjusts to the platform it is rendered on, and 2) a physical, ambient consumption indication device, the Light Sphere.

5.1 Process and Method

The system design was built through an interplay between evolutionary design, and rapid prototyping, where design decisions were matured through feedbacks on mock-ups, and prototypes. A test group, consisting of 8 individuals was assembled, with the purpose of providing feedback through interviews, think-loud-testing, and heuristics. Two of the test-group participants have degrees in software engineering related fields.

5.2 Forced Limitations

If the project scope included data acquisition, and it was technically possible to communicate directly with the meters, an effort would have been made to poll data in real-time, which would open up for a lot of design possibilities. However, it is not the case; data is harvested from the utility company's self-service website[1], based on EMT WebTools, which our design has no influence on. Therefore, some of the characteristics of the system, including the update frequency, data granularity, and the like, are limited to the underlying EMT data provider.

5.3 Eco-feedback Design

In the design process, the eco-feedback design space was used to fine-tune and evaluate the trade-offs of different design approaches. Here, these design considerations are explained using the design space's dimensions, and sub-spaces. Some sub-spaces are omitted, some are added, while others are to be found in appendix B.

5.3.1 Update Frequency

The website, from which data is harvested, gathers data from the electricity meters roughly on a nightly basis. Thus, for our web-app the update frequency is **daily**. In a research from 1979, a group of households had a feedback card with the previous day's consumption placed into their mailbox, which resulted in 1-9% savings compared to households, who received their feedback monthly [BVT79]. This indicates that daily feedback should be sufficient to have a positive effect.
The Light Sphere's state is updated once every hour, even though the data is not realtime, but a calculated average, or a pre-defined dataset of the power-grid's peaking dynamics. In one state, it will signal a hue between red and green, where red is for the peak-load hours, and green is for the off-peak hours. In another state, it will use the same colors to signal the household's average usage for the present hour.

[1] The utility company, EnergiFyn, provides an EMT WebTools website to their customers through `http://forbrug.energifyn.dk`

5.3.2 Spatial Proximity to Behavior

A high level of spatial proximity to behavior will mean that the feedback system is resided everywhere, where the residents perform activities that require power. This could be a display placed in the kitchen, near the stove, fridge and oven, and another display in the living room, close to the entertainment devices, etc. However, the enPower web-app, being a website, does not dictate where the device, which it is rendered on, must be placed physically. It can be accessed in the living room, the bedroom, at work, or even on vacation.

5.3.3 Attentional Demand

This sub-space refers to the glanceability of the system's display, e.g. if it is easy to glance and understand the feedback, or if it requires high attention.
For the web-app, we want as low a attentional demand, as possible, without compromising on the information extent. Therefore, different chart styles was prototyped and examined with the test group. For most of the views, except the 24-hour view, the bar chart delivers the least attentional demand, and the least clutter, because it allows easy plotting of additional guidelines, such as running average, and baseline for efficient users.
However, for the 24-hour view the bar chart is not optimal. The continuity of the data is not respected, and is broken. For example, imagine a household, where the residents' main electricity consumption spans from 10 AM, when they awake, and until 2 AM, where they go to sleep. The bar chart will not be able to capture the cyclic continuity of the household's consumption habits, and by result the chart will be hard to understand through glancing. So, what are the alternatives for visualizing cyclical data? In his comprehensive blog-post "Visualizing Cyclical Time - Hours of Day Charts"[2], Doug McCune answers the problem by using *circular* charts of different types.
Therefore, several circular chart prototypes were created iteratively and refined for the 24-hour view. The final design uses a so-called rose chart, which resembles a bar chart, where the start and the end has been brought together. Still, understanding all the information provided in a chart will require some attention, thus the attentional demand is somewhat glanceable.

The Light Sphere, on the other hand, has a very low attentional demand and is highly glanceable. Its color-coded signal values will be visible through the corner of the eye.

[2]Website - accessed July 2013: `http://dougmccune.com/blog/2011/04/21/visualizing-cyclical-time-hour-of-day-charts/`

5.3.4 Aesthetic

The aesthetics of the data representation refers to the degree of abstraction and artistic representation in the visualizations, in contrast to pragmatic visualizations. The design of enPower's charts first and foremost aims at being pragmatic and exact. However, the gradient color-codings of the charts, and the red, green and yellow rings in the circular menu, as described in section 5.5 on page 51, adds an artistic flair to the aesthetics. For example, the goal progress view shows all-green bars if the consumption is below the goal limit, or all-red bars if it is not. The artistic traits can be taken even further by letting the web-app's theme be influenced by the household's current performance. For example, the general color palette can go from green through yellow to red. Here, the user will instantly be aware of the household's performance, even though no specifics are given. In the same manner, the home screen displays an associative photograph of nature and wildlife, if the household's consumption is descending (figure 5.1 B). If the consumption is increasing, dark, alarming photos of industrial smokestacks will be shown (figure 5.1 A).

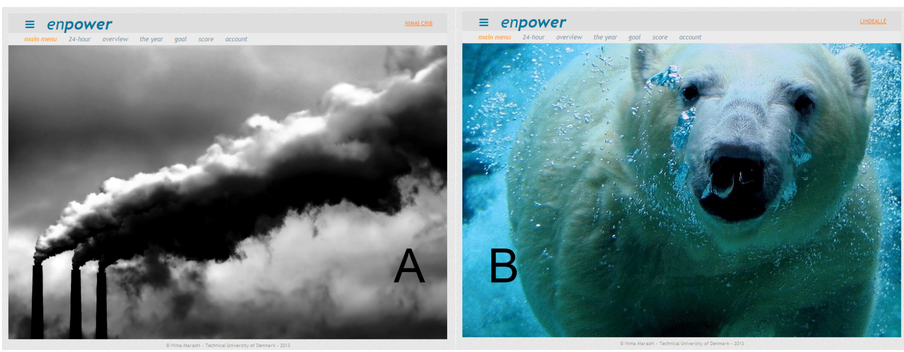


Figure 5.1: A) Smoke, pollution, smog and generally dystopic photos are shown, if the household's performance is increasing.
B) The home page depicts wildlife because the household's performance is declining. The photo is randomly selected among a list of encouraging nature and wildlife photos.

The Light Sphere is highly artistic in its visualization. E.g., if it is in the state, where it displays the general load on the power-grid, and the present hour is one of the peak-hours, it will light red. The residents will immediately know the meaning of the signal. However, they will not know the exact values, nor will they be able to see the previous or next values.

5.3.5 Time Window

Users can browse through their consumption via three different views, which each uses a specific time window.

The most course grain is the year view, which shows months of a selected year. Here, a particular month can be compared to the other months of the year, and the year's total consumption is compared to the previous year. It would also be useful if the consumption of a month could be compared to the consumption of the same month for previous years. In fact, the current system at EnergiFyn has this functionality, where a yearly bar chart shows three bars for each month, one for the current year, and two for previous years. However, this design adds a lot of clutter and attentional demand to the visualization.

On the other end of the scale is the 24-hour view, and finally, there is an "overview" that shows the daily consumption throughout the last 14 days, in a bar chart.

The Light Sphere's time window is the present hour.

5.3.6 Visual Complexity

Of course, the less unnecessary complexity in the visualization and the general visual design, the better. This is especially important on smaller screens, such as smartphones. Therefore, the layout, as well as the amount of information, varies depending on device type and display size (see figure 5.2).

5.3.7 Primary Visual Encoding

In order to keep the attentional demand down, and avoid visual complexity, the visualizations in the web-app try to minimize the need for textual information by the use of color coding, performance indication arrows, and comparison guidelines. However, textual information is sometimes to prefer over visuals, because of understandability. Thus, the results is a mixture of textual and visual encoding, but primary focus on the latter.

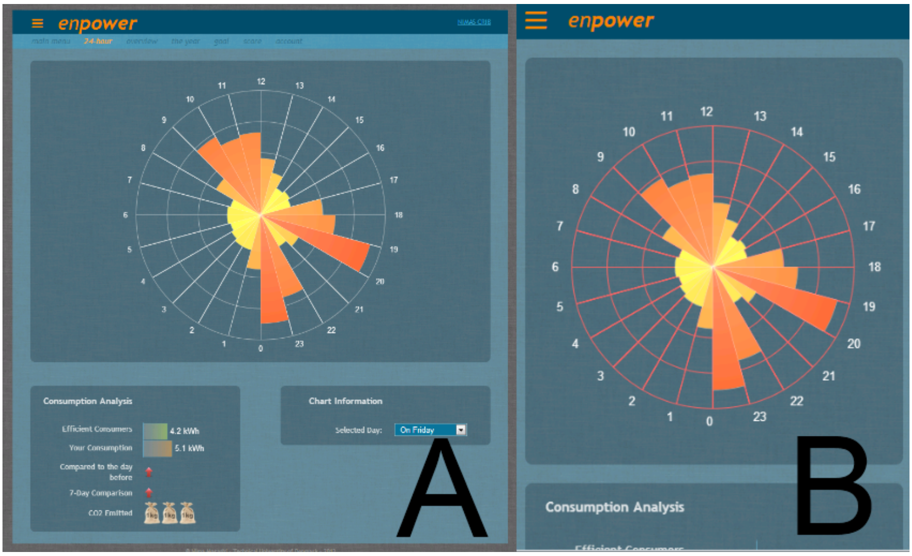


Figure 5.2: A) The visual design for a desktop-sized screen. The primary focus is on the visualization, but there is enough space to show additional information on the screen.
B) The visual design optimized for smaller (mobile) screens. Here, the upper navigation menubar is stripped, and margins are adjusted to fill use the entire screen real estate. The layout of the information boxes is changed from horizontally side-by-side, to a vertical scroll screen, below the gap.

5.3.8 Measurement Unit

The primary measurement unit, in which the system displays electricity consumption, is in kilo-watt-hours. Very early in the design process, a prototype was developed that provided simple feedback in the form of sentences, such as "Yesterday's consumption was 26%, or 1.6 kWh lower than the day before". The purpose of the prototype was to test the ability of the web-app to use responsive web design, and it was therefore sent out to the test-group. In addition to testing out the responsive design, the testers were also asked to give feedback on the sentences. Half of them responded that they had a hard time grasping the size and weight of a kilo-watt-hour, and that they were missing either something to compare against, or being informed of the price of the consumption.
Later in the design process, the sentences were replaced with visualizations along with information widgets that also showed the total expense related to the consumption for the time window, as well as the estimated CO2 emission for the

consumption. Still, the CO2-emissions are hard to relate to for normal people, since they do not have emission examples or metaphors to compare with. One design strategy was to visualize the expense with money bills, and CO2 with 1, 50, or 100 kg sacks, both accompanying the raw numbers. Another strategy was to use a car's CO2 emission as metaphor.

5.3.9 Degree of Interactivity

Interaction between the user and the system happen through the user interface, emails, notifications, and the Light Sphere.

The user interface design supports the following inputs and actions:

- The user can provide the system with account information as well as information on the household, such as type of house, size of house, number of children (small and big) and number of adults. The provided information will be used in various scenarios. For example, when receiving an email from the system, the user is greeted with the recorded name for the household, and the information about the household will significantly affect calculation for how much the household spends more or less than average and efficient households.
- The system "talks" to the user through a panda avatar, with an animated speech-box (see section 5.4 on Persuasive Design).
- Hover on UI elements reveal explanation tooltips.
- Hover on visualization chart elements highlights a specific chart area and reveals the consumption in alternate measurement units.
- The user can navigate back in and forth in time on the year and the 24-hour view, using navigation controls.
- In the 14-days overview, and in the goal progress view, clicking on a day in the visualization chart brings up the 24-hour view of that day. In the 24-hour view, there is a link that takes the user back to the original view.
- In the 24-hour view clicking on an hour in the visualization chart opens up the dialog with in-depth analysis.
- The energy advice dialog (see figure 5.7 on page 38) lets the user browse through a catalog of energy saving tips.

- In the goal view, when a new saving goal is being set, the user interacts with a knob that animates a bar, which corresponds to the percentage decrease in consumption (see figure 5.10 on page 44).

Notifications are events that either require the user's attention, or events that might interest the user. For example, one of the design ideas describe a feature, where the household can receive alarms when the consumption exceeds a certain threshold (see section B.0.7 on page 96). Here, the user will receive a notification about the event. An example of an interesting but not attention-demanding event is when the system receives consumption data for the day before. Notifications are delivered to the user over email, push-notifications on the smartphone, and over the Light Sphere.

5.3.10 Interface Customizability

In addition to customizing account settings, and changing details about the household, the current design allows the users to change the web-app's theme by choosing from a pre-defined list of themes. Since theming is supported natively by the website, it is straightforward to create new designs, e.g. to differentiate between utility companies, or energy resources.

An addition to the customizability would be to have a favorites section on the home page, where each feedback visualization could be added in a miniature widget form.

If the household has a Light Sphere installed, the residents can customize settings, such as quiet hours, where the Light Sphere will not light up, as well as switch between feedback modes, including peaking hours and the hour's average for the last series of days. In the final design, the configuration can be made directly from the account page. Currently it is done from the administration page by the administrator.

5.3.11 User Additions

When examining visualizations and receiving feedback about the household's consumption for a given time window, the user tries to identify the cause behind the particularities in the consumption. In my own experience, it can be a difficult task to pair a consumption spike with a particular behavior at a certain moment in the past.

The system could aid the user in this task by offering a *usage tagging* feature, where the user would be polled about which electricity-consuming tasks the residents of the household are doing at the moment. The polling could happen at each site visit, or it could be started by a notification on the smartphone. The tagging could be done via an auto-complete textbox, in which different electric devices could be searched for. Each tagged device would be accompanied with information about usage patterns, e.g. "typical for this hour", "daily", "sporadically", or "randomly". Then, during feedback examination, the user would have usage tags on the corresponding time and consumption value on the visualization. In addition, the system would be trained in the household's consumption habits and provide suggestions to the user, both during usage tagging, and during examination.

5.3.12 Target/Audience

Although, one of the residents of the household will perform the sign-up procedure, the intended target users are *all* the residents of the household. By design, the app is able to run simultaneously with multiple sessions across devices and platforms.
The current prototype design sends daily status reports to the users by email. Therefore, only the person who owns the email-account will receive these reports. The support of multiple targets would have been better, if notifications were sent as push notifications to the users' smartphones, but this would require a native app for each smartphone platform. Alternatively, multiple email recipients can be set up.
The web-app can also target multiple users, if it is viewed on a web-capable TV-set, or on a dedicated feedback kiosk. This case is especially useful for work-places, schools, and dorms, as seen in [PSJ+07].

Finally, the Light Sphere is targeted towards all the residents of the household, and it supports multi-targeted notifications through light signals. This is explained in more depth in section 5.3.15.

5.3.13 Data Sharing and Social Comparison

Three features were considered for social data sharing:

1. **Highscore Table**
   This feature is simply a list of the top-ten households, who have saved the

most electricity since sign-up, and it was particularly designed with the two-week evaluation in mind (see chapter 7 for more on the evaluation of the system).

2. **Sharing over existing social media sites**
In this scenario, the user can attach social media accounts to his enPower account, and through there share the household's performance in saving energy. The shared content is then simply a screen capture of a desired visualization from enPower, along with a descriptive text generated by enPower, or entered by the user, as in figure 5.3.

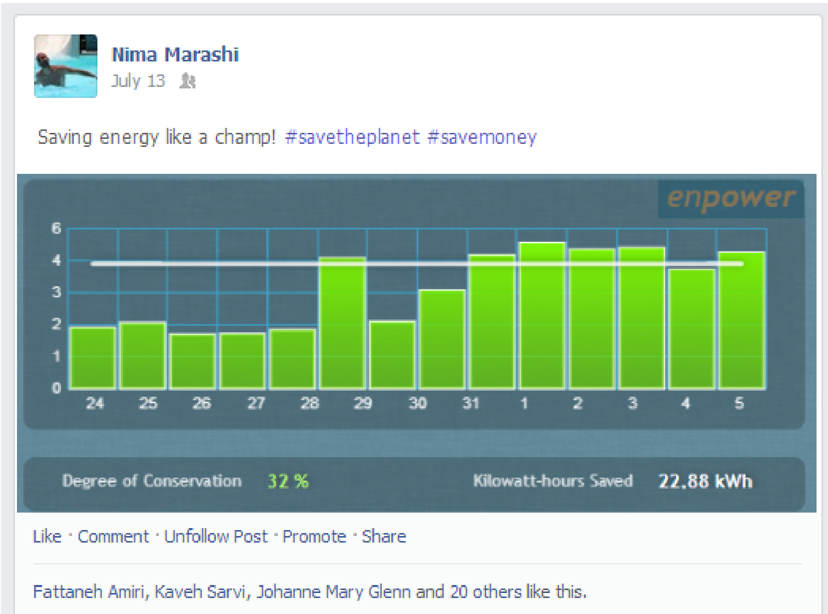


Figure 5.3: Social sharing of consumption data through existing social networking channels.

3. **Integrated social network**
Here, enPower integrates the same traits as a social media network, where users can follow other users, comment on events and like each other's accomplishments. To exemplify, imagine two households, The Smiths and the Fords. Through enPower, the Smiths send out a request to follow the Fords, which the Fords accept. The Smiths can now access the Fords social profile page, which visually and textually summarizes the Fords' performance. The Smiths have their own social news page, in which the followed households' consumption performance events are digested. These events include reaching a goal, logging in for a number of days in a row,

using less energy in the recently completed month, compared to the year before, etc. (see figure 5.4).

Figure 5.4: An example of how the news feed of an integrated social media engine could look like.

5.3.14 Manifestation and Size of Display Medium

The physical manifestation of the web-app is on computers (desktop/laptop), and on mobile devices (smartphone/tablet). Additionally, the manifestation can happen on any device with a web-browser, e.g. smart-TVs, and TVs connected to game consoles. Various demonstrations of the web-app running on different displays can be seen in figure 5.5.

The Light Sphere itself can be considered as a display medium, on which feedback is manifested on (see figure 5.6). It has approximately the same dimensions

Figure 5.5: A) The web-app's log-in/sign-up page manifested on a 47" TV-screen, using a the built-in browser of a Sony Playstation 3 game console. B) Goal progress view on a 47" TV. C)The year view manifested on the display of a smartphone running the Android OS. D) The web-app's year view manifested on a iPad Mini tablet, and a notebook screen.

as a bowling ball.

5.3.15 Ambience

The system's ambience comes to display through the Light Sphere (see figure 5.6).

The design idea of the ambient display is that it can be configured via the web-app, where each household can switch between *average consumption mode* and *peak-load mode*. Users can also configure *quiet hours*, which is the hours that the Light Sphere is not lit up, as well as adjust the brightness of the light, and turn notification signals on or off.

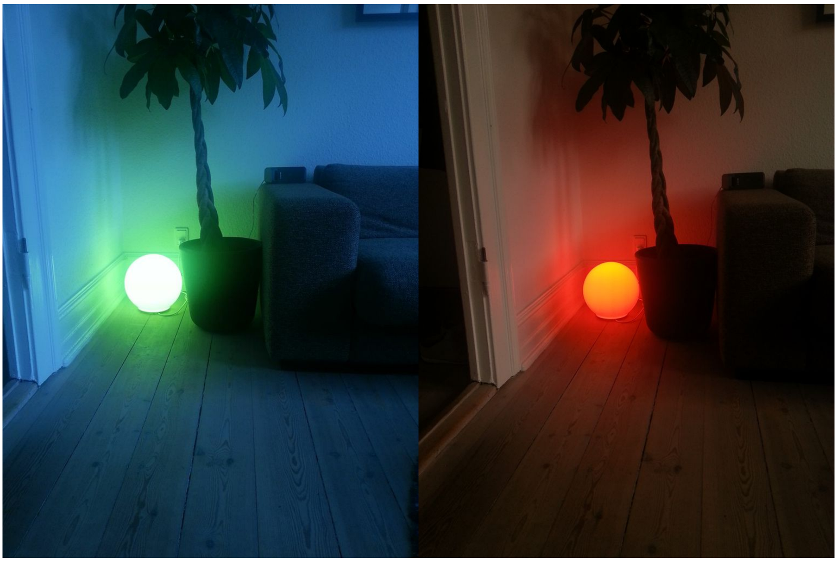


Figure 5.6: The Light Sphere in "average consumption mode", displaying a gradient between green and red, which respectively means low and high consumption in the present hour, based on the average of historic data for the hour.

The average consumption mode is based on a special time window, called "Averages" in the 24-hour view in the web-app, which visualizes each hour by the means of the previous 14 days' average. For example, when a household's consumption peak between 9-10 AM, the Light Sphere will emit a red light in that specific timespan (as can be seen on the right in figure 5.6), and if the average consumption between 10-11 AM is one of the lowest in the 24-hour cycle, it will switch to a green hue (as depicted on the left in figure 5.6). Consumptions in between highest and lowest averages will be emitted with colors in a gradient between red and green, e.g. yellow and orange. The peak-load mode is very similar to the average consumption mode, except that it uses general, nation-wide averages, instead of household-specific data.

The Light Sphere communicates two types of notifications to the user: attention-notifications and, and information-notifications. The former is signaled through a sequence of 5 rapid flashes of pink light, which is repeated every 15 minutes, until the user visits the web-app. Information-notifications are signaled through a sequence of 3 smooth fade-in and fade-out of blue light, and is repeated once every two-hours. In both cases, the notifications temporarily interrupt the normal state of the Light Sphere (average consumption mode, or peak-load mode) for a few seconds, until the notification sequence ends, and the Light Sphere is returned to the previous state.

5.3.16 Decision Support

The energy advice dialog (see figure 5.7) provides a catalog of saving tips and advices for the user to browse through. It is displayed in the scenario, where

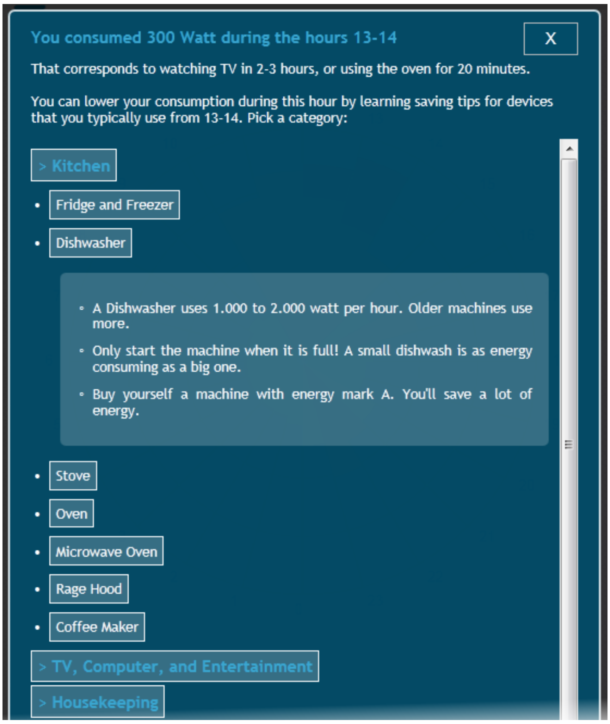


Figure 5.7: This modal dialog, containing metaphors and energy saving tips, is displayed when the user clicks on a particular hour's consumption, in the 24-hour view.

the user drills all the way down through the visualizations, until the hourly consumption is reached (it can also be viewed through a menu item in the main menu). The catalog is, however, not targeted or personalized, since it has no knowledge of what devices the household used during the hour that is being examined.

5.3.17 Comparison-Target

Households using enPower can compare their consumption to reference values of typical consumption of similar households, and efficient consumption of similar households. The typical consumption is a computed value based on calculations from a danish report on a demographic analysis on electricity consumption in Denmark [GH05]:

- The normal usage for detached houses:

$$apartment_{normal} = 530kWh + m3 \cdot 12kWh + numberOfResidents \cdot 690kWh \quad (5.1)$$

- The normal usage for apartments:

$$detached_{normal} = 340kWh + m3 \cdot 11kWh + numberOfResidents \cdot 350kWh \quad (5.2)$$

- Reduced electricity usage for every small child:

$$detached_{reductionPerSmallChild} = -158kWh \quad (5.3)$$

$$apartment_{reductionPerSmallChild} = -76kWh \quad (5.4)$$

- Increased energy for every other child:

$$detached_{increasePerChild} = 179kWh \quad (5.5)$$

$$apartment_{increasePerChild} = 117kWh \quad (5.6)$$

A similar equation is not available for efficient consumers, because, after all, an efficient level of consumption is subjective. It is, of course, natural to make the assumption that the level is to be found somewhere below a normal consumption, but still this value can be anything from 0 to normal minus 1 kWh. So, how can we specify an acceptable value for an efficient consumption? The report mentioned above states that if a family uses 40-50% of what the average households consume in electricity, then there is little or no further savings to be made. This implies that the most efficient users must be the ones using the half of what average households use. However, the report explains that efficient single-person houses cannot obtain as big savings as houses with multiple residents, since their electricity expense per appliance (such as freezer, fridge, TV, etc) is higher than in multi-person houses. Finally, consumers in detached houses generally use more electricity than consumers in apartments, why they should be able to save a higher amount of electricity. This chain of reasoning was put together into a set of rules to candidate for the calculation of efficient usage per household:

- The most efficient consumption possible in single-person apartments is 80% of the normal usage.
- The most efficient consumption possible in single-person detached houses is 70% of the normal usage.
- The most efficient consumption in multi-resident apartments is 60% of the normal usage in apartments
- The most efficient consumption in multi-resident detached houses is 50% of the normal usage in detached houses.

For evaluation of the rule-set, three of the participating households in the test-group was presented with the user interface that contained the comparisons. All three had higher consumption than the assumed values for efficient consumers.

The representative for household 1 was very surprised by their high consumption, which was well over the calculated value for average households. Household 2, with a consumption-level about average and living in a detached house, questioned the reliability of the system, and said "there has got to be an error somewhere. I'm never home and it's not realistic that some people use the half of what I use", referring to the number for efficient consumers. Participant 3, also living in a detached house with a consumption of 75% of normal households, said: "We have energy saving lights everywhere, and we never cook, so I don't think it is realistic to say that we can save much more". Interestingly, none of the inquired participants commented on other than the immediate consumption-target, e.g. participant 1 and 3 only noticed the level of average consumers, whereas the participant 2 only commented on their consumption compared to efficient consumers.

The received feedback was not satisfactory. If the users perceive the calculations as unrealistic, they will assign negative feelings towards the system (see section 5.4.2 on page 48 about Psychological Cues), which can impact the ability to persuade a behavior change. Therefore, the rule-set was simplified, and based on the official recommendations given by the Danish energy government agency, which recommends a consumption of 1,000 kWh per person, per year, though 1,500 kWh, if you are living alone [3].

[3]Source: Energistyrelsen, July 2013: `http://www.ens.dk/forbruger/el/dit-elforbrug`

The results of these comparison targets can be seen in figure 5.9 on page 43, in the Consumption Analysis box in the lower left. In addition, the level of effective consumption is plotted into the chart (the green line in the chart).

Households can also compare their consumption to their own historic data, and to a self-set goal. These comparison targets are explained in the next two sections, respectively.

5.3.18 Comparison by Time

Comparison to the household's own historic data is possible through the 24-hour view, and the year view. Most often, these types of comparisons (comparison by time) are delivered by plotting historic data into the same chart as the primary data, which both has its advantages and disadvantages. The biggest advantage is the ability to compare each time slot, to its corresponding historic counterpart, side by side. However, the actual comparison must be made by the user through a mental process of grasping which visual elements represent what, how they compare to each other, and finally whether the comparison result is positive, neutral, or negative. Furthermore, these kinds of comparisons add to the visual complexity, and raise the attentional demand. We can use the monthly view of EMT WebTools, as can be seen on figure 5.8, as an example. The amount of information is great, and a lot of observations can be made

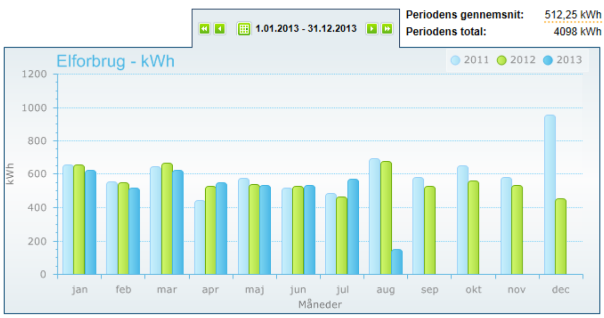


Figure 5.8: The current EMT WebTools solution at EnergiFyn provides in-chart comparison in their month view. The amount of information available for comparison analysis is high, but so is the visual complexity and the effort needed from the user.

from the visualization, e.g. that the particular household consumed over 100 kWh more electricity in July 2013, compared to July 2012. Yet, seen in the perspective of a stage-based model of a personal informatics system [LDF10], the integration stage is left on the shoulders of the user:

1. Determine and remember the color that represents the months of 2012 in the chart by using the legend.
2. Do the same for 2013.
3. Localize the month of July on the chart, and match the color of 2012 to one of the three bars.
4. Repeat the last step for 2013.
5. Hover over the bar for July 2012 and read the exact value in the tooltip that comes to display.
6. Repeat for the bar representing July 2013.
7. Compare the two values (571 kWh to 466 kWh).
8. Reach to the conclusion: More energy was consumed in July 2013 than in July 2011.
9. Reflect on why this is the case.

The process is tiresome, and the effort required to reach to the conclusion is huge compared to if the information was already processed and readily available to the user. Of course, the importance of how well the visual design conveys the information is crucial. If only values for two years were plotted, instead of three, and if the color-coding clearly emphasized the current year's data over the previous year's, the cognitive integration of data would be easier. However, this stage can be entirely removed, so the user can focus on reflection and taking action.

EnPower is designed to handle the integration of data for comparisons by providing a number of *reflection points* by design, and displaying them for the user to reflect on (see figure 5.9). Thus, if we want to compare July 2013 to July 2012, we have to go through the steps below:

1. Localize the month of July on the chart.
2. Hover the cursor over the month's bar, and read the text in front of "Compared to last year"
3. Reach to the conclusion: More energy was consumed in July 2013 than in July 2011.

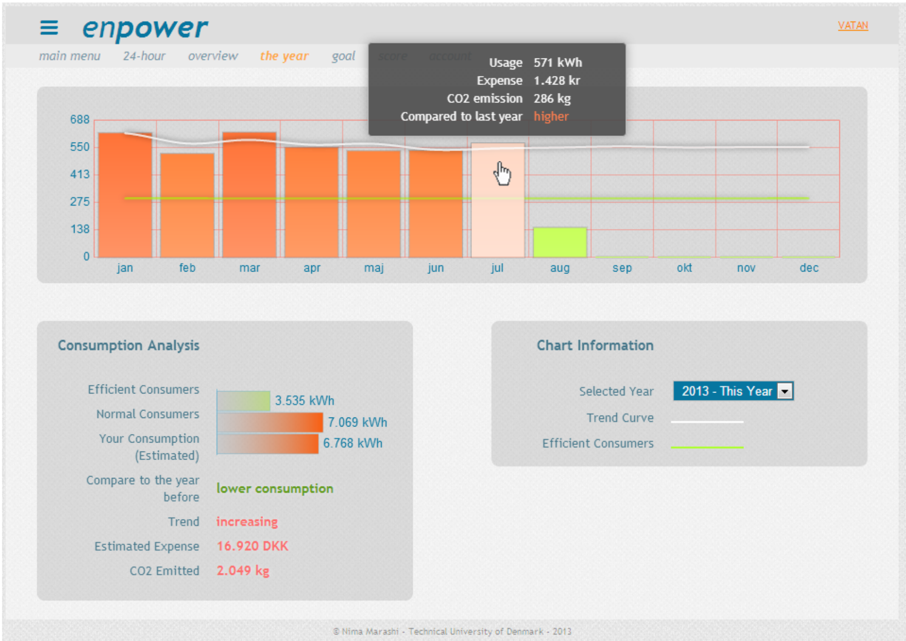


Figure 5.9: The year view.

4. Reflect on why this is the case.

The design philosophy of reflections points is used in various scenarios. For example, in the year view the total consumption of the year is compared to the year before ("Compared to the year before", lower left in figure 5.9).

Furthermore, comparison by time is present in the system design through *trend analysis*. For each time slot in the time window (the year view and the overview), a running average value is calculated by taking a number of preceding time slots into consideration. The resulting values are plotted into the chart along with the primary values (the white "Trend Curve" in figure 5.9). The trend analysis is finally summarized in a reflection point, which states if the general consumption trend is increasing or decreasing ("Trend" in the lower-left box, figure 5.9).

5.3.19 Goal-Setting Strategy

The dedicated goal view has three life cycle states. Before a goal is set, it displays controls and guidance for *goal-setting*. Once a goal is set the view shows *goal* *progress*, and when the goal's deadline has been reached, the goal view shows *goal summary*.

In the initial state, the user is guided through the goal-setting process, as can be seen on figure 5.10. The panda avatar (explained in section 5.4) is used for persuasion and guidance of the user. The goal-setting strategy is user-set, but the system persuades the user to set an ambitious goal. For example, the panda makes a direct comparison between the household and efficient households, and displays the losses associated to the higher consumption. If the household's consumption is lower than efficient households, the comparison result is not displayed.

Figure 5.10: The goal view in goal-setting mode. On the left, the panda uses motivational techniques, in order to persuade the user to set a high consumption reduction goal. The goal-setting widget on the right uses social dynamics through the button-text, which engages the user to make a promise. The widget calculates potential rewards related to setting the goal, which fulfills requirement 2.

The goal progress view is displayed to the user, once a goal has been set. This state emphasizes on the household's performance with respect to the goal. If the performance is better or on par with the goal, the visualization chart is all in green, and so is the reflection points. If the performance is poor, compared to the goal, the chart and the reflection points are displayed in red. The progress view contains a chart that depicts each day's consumption. Also, the desired maximum level of consumption, with respect to the goal, is plotted as a flat, white line. In addition to the chart, the view has one grouping for goal progress information, and another for specifics of the goal contract. The progress information grouping tells when data was last updated, if the performance is within

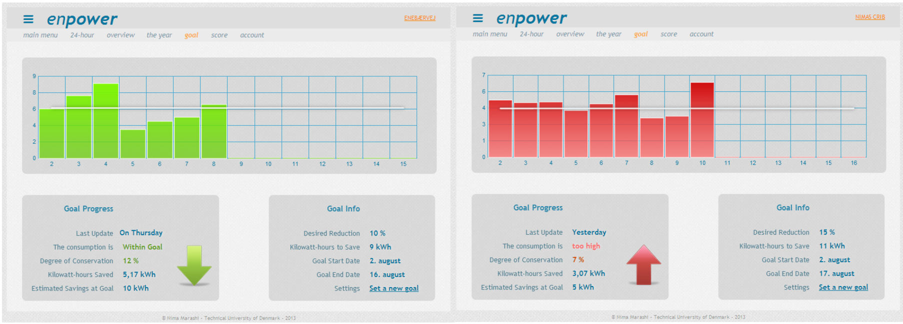


Figure 5.11: The goal view showing the household's energy saving performance with respect to the self-set goal. On the left side, the savings are within the set goal. On the right, the conservation performance does not live up to the goal.

the goal limits, the current degree of conservation, amount of saved kilo-watt-hours so far, and the estimated total amount of saved kilo-watt-hours at the goal's deadline. The grouping also holds a big green or red arrow, which quickly indicates to the user whether the goal contract has influenced the consumption positively, or not. Especially, the glanceability of the view is heightened by the arrow, as well as by the uniform color-codings.

Finally, when the goal deadline has been reached, a summary view is displayed, where the user can review the result of the goal. The system also sends out a notification to the user, which is accompanied with a summary email.

5.3.20 Saving Tips Prompts

The web-app has a ribbon in the bottom that is used to display, subtle, but noticeable saving tips at random (see figure 5.12). These saving tips are not

Figure 5.12: An example of a saving tip that is prompted to the user.

obtrusive, and fade away after 10 seconds, or on a user click.

5.3.21 Consumption Reports

Each day, provided that new data is available, an email is sent out to each account, which summarizes the current state of the household's consumption and pro-environmental performance (see figure 5.13). The purpose with this

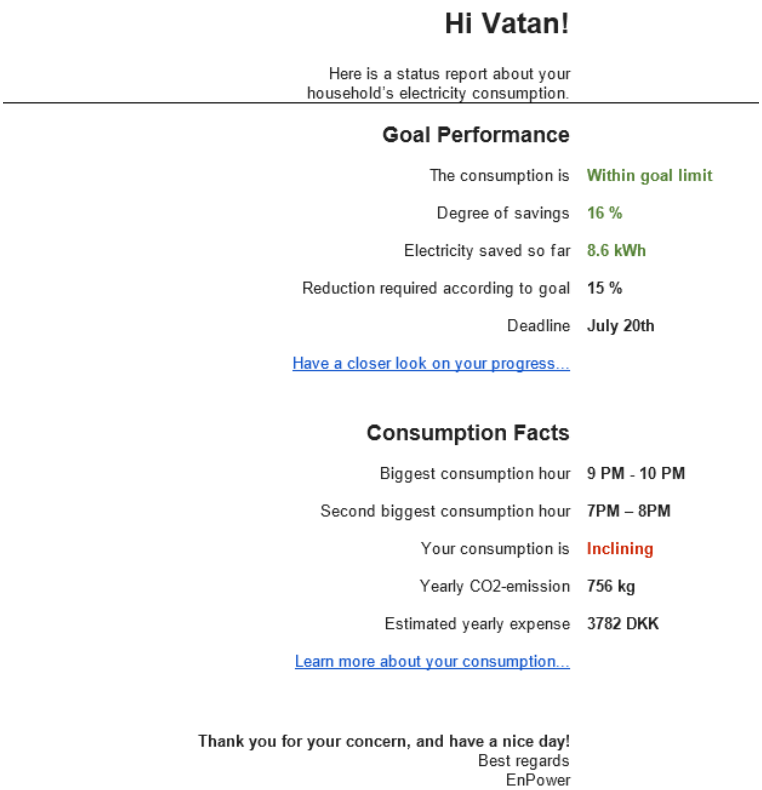


Figure 5.13: Screen dump of the daily consumption email report that is sent out to the users, if there is new data available for their household.

daily report is to 1) *push* eco-feedback to the user, and 2) persuade the user to visit the web-app.

5.4 Persuasive Design

One of enPower's objectives, as an eco-feedback system, is to motivate its users to change behavior. Being persuasive in this task must be a key skill, which the system should possess. According to [Fog02], computers can act as persuasive social actors through five types of social cues: physical, psychological, language, social dynamics, and social roles.

5.4.1 Physical Cues

These cues consist of characteristics that we normally relate to human and animals. Cues, such as eyes, face, body and movement can be used in computer systems to persuade the users to perform certain actions. In people, the degree of persuasion can be related to attractiveness, and [Fog02] argues that this also can be the case for persuasive computer systems.

In our early design of the UI, a character was introduced that acted as a guide and companion to the use cases supported by the system. The character, a symmetric, subtly smiling face of a *panda* with big, friendly eyes (see figure 5.14), was selected by the test-group as the most attractive one of the options. Thus, the panda-character is the social actor of the system.

Figure 5.14: The cartoon character used in the UI to add persuasive traits.

In [Fog02], Fogg mentions a study, performed by his team at Stanford, where participants perceived a social presence in computers, even though the user interface solely consisted of dialog boxes. We added a dialog box of sorts, in the shape of a speech-bubble, to accompany the panda. The text in the speech-bubble animates when the page loads, which makes the message from the panda seem more alive and real-time. An example use of the speech-bubble can be seen in figure 5.15.

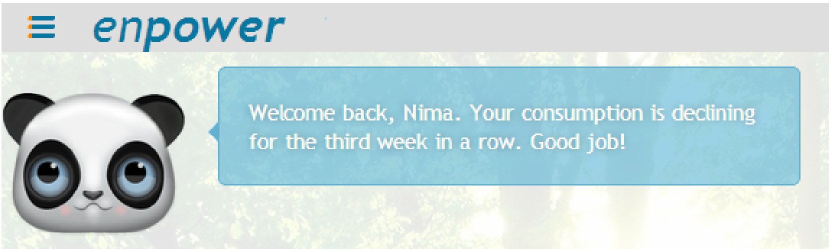


Figure 5.15: The panda's speech-bubble is used to deliver persuasive messages to the user. It animates when the page loads.

5.4.2 Psychological Cues

Psychological cues count humor, personality, feelings and preferences, among others. They also apply to computers; we can all relate to feeling anger towards a computer, or an app, if it acts unexpectedly, or crashes. Some people even shout at their computers, and affiliate it with emotions and personality.
Since enPower is a prototype, it is reasonable to believe that it has bugs and might crash every now and then. This is, however, unfortunate, because the crashes might lead the users to perceive the system as incompetent and untrustworthy. Moreover, hard errors and exceptions would reveal the programmed guts of the system, depriving the social presence. Therefore, a custom error page (figure 5.16) was designed that communicate the unexpected behavior with humor and personality, as well as exercising an underlying sense of embarrassment.

Another persuasion principle, in the area of psychological cues, is the principle of similarity, where individuals tend to accredit subjects that are similar to themselves [Taj10]. During enPower sign-up, the user is encouraged to enter a team name for the household. The entered team name is then used by the panda as its own, which forms a sense of similarity and uniformity between the user and enPower (or at least the panda).

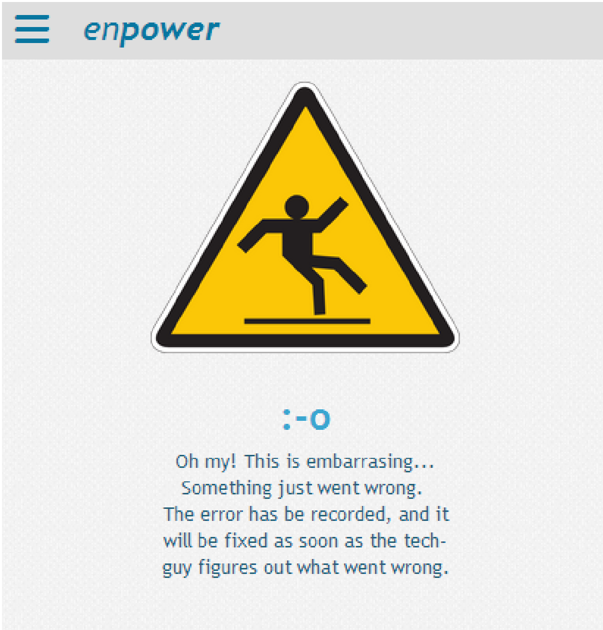


Figure 5.16: Custom error page with psychological traits, in order to uphold the persuasive appeal of the system.

5.4.3 Language

Spoken language is commonly used to create social presence and persuasion in computer systems. Especially praises have proven to be very effective, compared to generic non-praising language, in making the users feel better about themselves, get in better mood, feel more powerful, feel that they have performed well, find the interaction engaging, be more willing to work with the system, and think that the system is performing better [Fog02].
The messages and interactions used in enPower are written in spoken language, and directed to the user, rather than being generic. For example, when the user signs up for an account, this message is shown to the user: "We are now contacting the utility company and retrieving your consumption data. Go on with whatever you were doing, and we'll send you an email once your account is ready. It will take about 15 minutes". The system also frequently praises the user's effort, especially when it is conserving and pro-environmental of nature. If the household consumes within the limits of a set goal, the system shows "Good job! You have lowered your consumption and reached your goal". Even when the consumption is higher than the limit, the message to the user is encouraging: "You did not save enough energy to reach your goal limit. It happens to the

best of us. Go ahead and set a new goal".

5.4.4 Social Dynamics

Computer systems can persuade by engaging into social dynamics with the users. For example, in the process of defining a goal, the user must press a big button, with the label "READY TO SAVE ENERGY" (see figure 5.10 on page 44). The button could have simply said "SAVE" or "OK", but the "READY TO SAVE ENERGY"-statement uses commitment as a social dynamic to persuade the user into making and committing to a promise.

In the area of social dynamics, reciprocity can be powerfully persuasive. In a reciprocity study performed by Fogg and his team, participants engaged with helpful computers, and unhelpful computers. Afterwards, when asked to help the computers with a task, the participants reciprocated the helpful computers by performing twice as many tasks comparing to the unhelpful computers [Fog02].
In our case, this dynamic is played out when the user examines the consumption of a particular hour by hovering, and clicking on its corresponding bar in the visualized chart. In EnergiFyn's existing WebTools system, this action would simply show a dialog box containing the consumption value for that hour (figure 5.17).

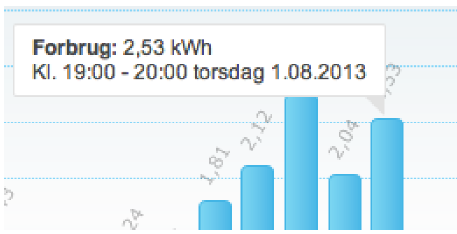


Figure 5.17: EnergiFyn's existing WebTools solution (in Danish). This dialog box is shown when the user hovers over a bar. Clicking on the bar does nothing.

This might be sufficient, but if the user has questions to the particular consumption, or have trouble relating to it, the system is not very helpful. In our design, more depth, information and guidance is provided. On mouse hover, the hour's consumption in displayed as energy resource, expense, and CO2 emission (see figure 5.18).

On mouse click a dialog box fades in on the screen, and provides even more anal-

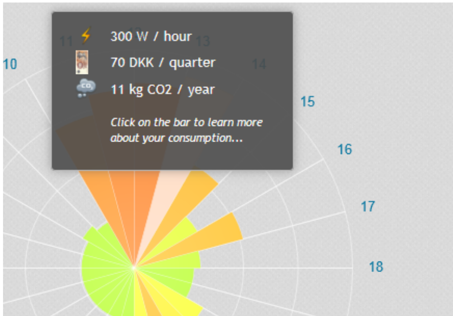


Figure 5.18: When the mouse hovers over a consumption bar, this dialog is displayed.

ysis on the consumption by explaining the size of the consumption in metaphors. Finally, a comprehensive, categorized catalog of saving tips is made available on-location (see figure 5.7). Hopefully, the helpfulness of the system is reciprocated by the user, in form of energy savings and pro-environmental behavior.

5.4.5 Social Roles

Computers can virtualize social roles, such as doctors, teammates, opponents, teachers, pets, or guides.
One of the testers pointed out that "it would be cool, if the panda had a conversation with you". This input led to the idea of having a Apple Siri-like conversation window with the panda, in where the panda would ask questions that the user could answer to by choosing from a set of pre-defined answers. The questions would test the user's knowledge in energy saving tips, and a score would be given, based on the outcome of the test. In such a scenario, the panda would take the social role of a guide, or a teacher.
However, the usage of social roles can also have negative impacts on persuasion. For example, adult authority figures might work on the elderly, but not on teenagers.

5.5 Visual Design

Good visual design of a website is more than just pleasing the eye. It impacts understandability, readability, and navigability, among other things, and in my opinion, it plays a substantial role in how persuasive and convincing its content is. The visual design of the website is inspired by the a set of rules and guidelines, which are put forward by Scott Klimmer[4] in his video presentations about visual design, in relation to Stanford University's online Human-Computer-Interaction course[5]. Here are some selected features of the visual design:

Groups

Related information is grouped into boxes, and boxes are separated by whitespace.

Grids

Content is aligned into grids and sub-grids (see figure 5.19).

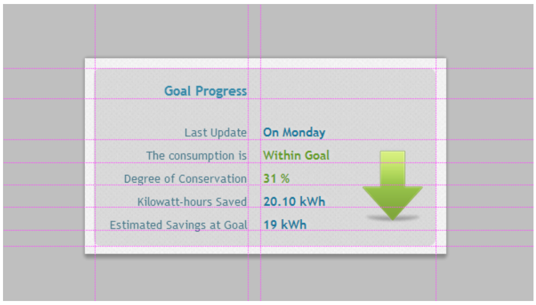


Figure 5.19: Using boxing and grids in one of the information boxes in the goal progress page design.

Menu structure

Users can navigate via a circular menu (see figure 5.20) that animates in as a layer over the screen, by clicking on a dedicated menu button. Generally, circular menus are quicker for users to navigate through, both theoretically, according to Fitt' Law, and empirically [CHWS88], but they can also be perceived as difficult and unorthodox by some users. Our test group also gave feedback on the circular navigation, where users found it informative, but not helpful "to tell you where you are". Therefore, a linear menu is also present at the top of each page. This menu also acts as a navigation breadcrumb, which highlights the active page.

Information scent

The circular menu delivers substantial information scent to the user, by displaying a header, and a short description about what can be found on the page. The latter is also called a speaking block navigation, in contrast to title navigation. More notably, the menu item is placed into a color-coded ring that signals the

[4] Assosiate Professor of Computer Science, Stanford University
[5] https://www.coursera.org/course/hci

Figure 5.20: The circular navigation menu animates in when the menu button is pressed. It contains information scents and status indicators for the underlying pages.

status of the particular eco-feedback dimension. For example, the goal section's ring is green when the goal limit is being held, red if it is not, and yellow if no goal has been set. The yellow ring blinks several times on each load, in order to attract the user's attention to set a goal. Thus, the menu contains scents of what the different navigation paths contain, and leaves trails for the user to follow. Moreover, all elements in the web-app, including the navigation elements, display tooltips on hover, which contain explanations and descriptions.

This concludes the chapter on design. In the next chapter we explore how some of the explained concepts from this chapter are implemented in the enPower eco-feedback system.

Chapter 6

Implementation of the Eco-feedback System

This chapter describes how the design work of the system is implemented into a compound of horizontal and vertical prototype components, which together comprise the enPower eco-feedback system. The description is not meant as a detailed specification of the system, but rather a demonstrative overview, along with selected in-depth-going examples.

6.1 Methodology

The implementation work was conducted in parallel with the analysis and the design phase of the system, following an agile, evolutionary mindset. A product backlog was created with a prioritized gross-list of all the features of the complete system, each pointing to a requirement from the analysis. The reported bugs, change- and feature-requests from the testers were also kept in this backlog. The gross-list was then continuously updated and re-prioritized. The items with the highest priorities in the backlog were broken down into specific, defined tasks, and written on post-its placed around the workstation. Most tasks were implemented using Test Driven Development (TDD) [Bec03] resulting in a set of task-specific unit tests.

6.2 System Overview

EnPower is based on the Microsoft .NET 4.0 technology, which runs on top of a Microsoft IIS 7.5 web-server. At the time of writing, it is hosted on a public server, sponsored by Odense Kommune, and can be accessed on `http://energikort.dk`[1].

The system has a multi-tier architecture consisting of five tiers: User Interface (UI), Domain, Utility, Communication, and File System Data Access (see figure 6.1). Each of these tiers contain components that concern certain operations of the overall system.

The UI-tier is a ASP.NET web application with user controls, pages, charting components, style sheets, and client-side script libraries. The rest of the tiers are resided in a separate .NET dynamic link library (DLL). The data presented in the UI relies on entity object instances from the Domain-tier. These objects are instantiated and populated with data from utility components in the Utility-tier. These services function as brokers between the underlying domain-independent components, and the Domain and UI-tier. The File System Data Access tier provide file system persistence services for system configuration, user accounts, caching, logging, and web-site statistics. Finally, the Communication tier communicates with the external Philips HUE Bridge, that controls Light Sphere instalaltions, and controls the current eco-feedback website at EnergiFyn, resided on an EMT WebTools Server[2], for acquisition of consumption data.

The rest of this chapter explains the workings of the tiers and their subcomponents.

6.3 Domain

The domain tier holds an object oriented model of the entities found in the general domain of eco-feedback and energy. It contains an entity for each data resolution of a consumption reading, e.g. `HourlyReading` and `MonthlyReading`. The common characteristics of the reading classes are generalized in an abstract base-class called `Reading`. All reading has timestamps, meter values, and consumption values. Readings reside inside of a collection in the `ConsumptionReport` object, which binds them to a specific user account in the system. An account

[1] The reader is welcome to take a tour of the system, while it is still online, through `http://energikort.dk`, using customer no 577999 and pin 71203.

[2] How data is provided to EnergiFyn's website is not in the scope of the enPower system.

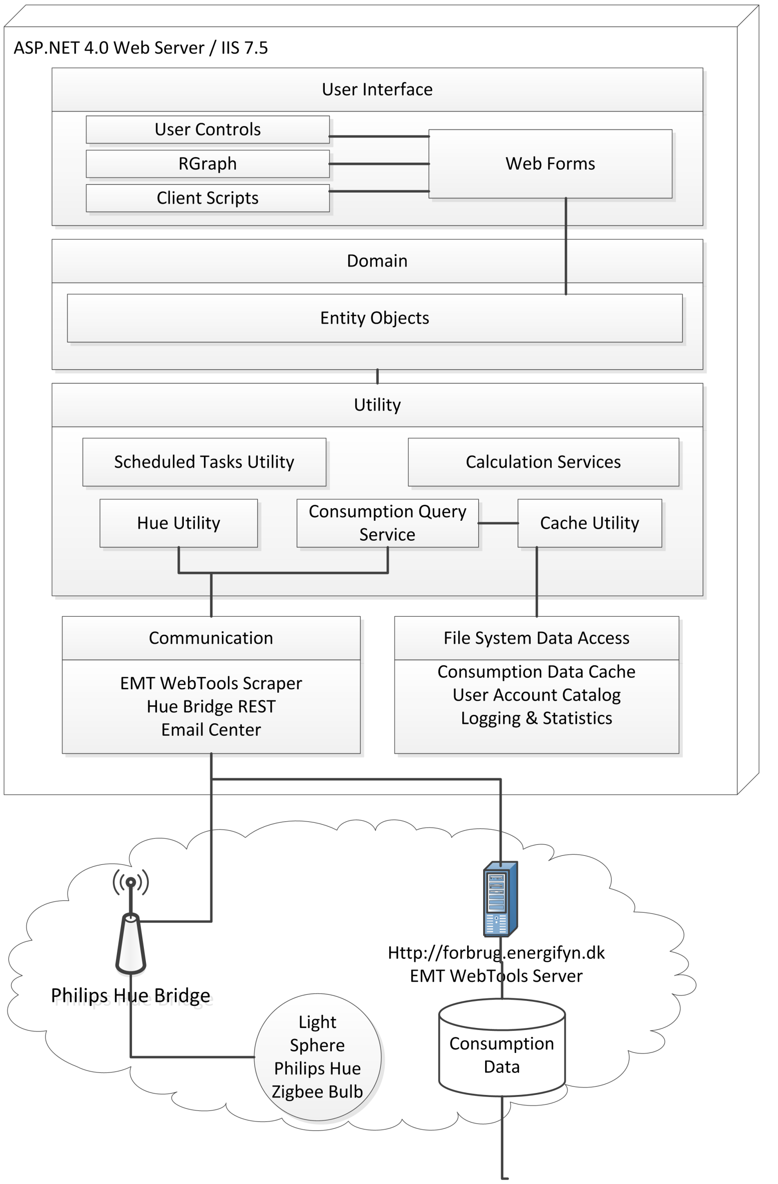


Figure 6.1: The multi-tier architecture of enPower, and the external components it communicates with.

is represented by the `UserInfo`-class, which holds all the information that the system has about a household, along with the user account's goals, Light Sphere communication info, etc. A class diagram of selected classes from the Domain tier can be seen in figure 6.2.

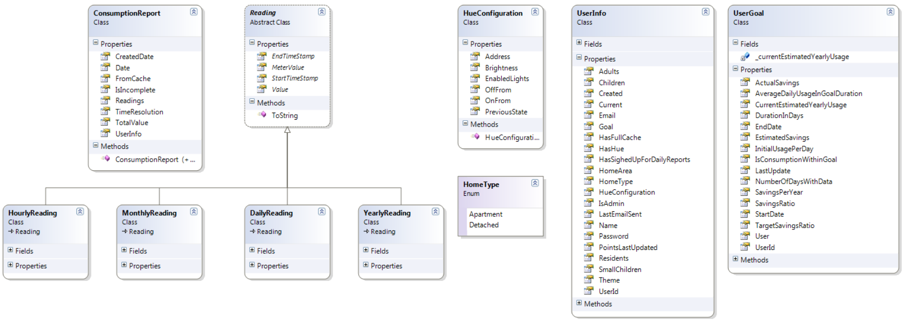


Figure 6.2: Selected classes from the Domain tier.

6.4 Data Acquisition

The Communication tier has a HTML scraper tool, `EmtWebToolsScraper`, which performs a login call onto EnergiFyn's EMT WebTools website. Subsequently, the tool holds a browser session to the site, which it controls with HTTP GET and POST requests. These requests are sent through a HTTP-helper class, `BrowserSession`, that was created for the purpose. For example, the scraper can change the size of the time window with the following method:

```
public string SetTimeResolution(TimeResolution resolution)
{
    TimeResolution = resolution;
    return PostToVisualizationController("{'id':1,'method':'
        setZoomlevel','params':['" + Enum.GetName(resolution.GetType
        (), resolution) + "']}");
}
```

The message formats that are used in the HTTP requests, along with the parameters they take, was found by listening to the HTTP calls that were made from the client computer, when the third-party website was rendered inside of a local browser. `EmtWebToolsScraper` has similar methods for setting the time cursor, navigating the consumption window back and forth in time, and finally retrieving the consumption readings of the time window in comma-separated values (CSV), which is how consumption data is imported into the system.

The scraper tool is used by the Consumption Query Service. Here, the `ConsumptionUtility` class has a comprehensive list of methods that make consumption data available in memory for the rest of the system. Each method orchestrates a sequence of calls to the scraper tool, which returns data in CSV format, that is finally parsed into domain objects:

```
var scraper = new EmtWebToolsScraper();
scraper.Login(user);
scraper.SetTimeResolution(TimeResolution.day);
scraper.SetEndDate(date);
var csv = scraper.GetCsv();
...
report = new ConsumptionReport(csv, scraper.TimeResolution, user);
```

Annoyingly, when requesting a month's consumption report from the EMT WebTools website, it returns the daily values rounded to the nearest integer. To bypass this problem, the system instead relies on daily reports with accurate, hourly values.

The performance of this approach is, however, poor. The EMT WebTools web-application response time is slow, as is the download of the CSV file. The whole process gets even slower, if we need to synthesize a month's consumption report by using several CSV files. This is why caching is an important and vital part of the user experience.

6.5 Caching

Each time the Consumption Query Service is requested for consumption data, it first asks the `CacheUtility` class if a cached version of the data already exists. If not, it retrieves the data through the scraper tool, stores it in the cache, and returns it to the caller.

The Cache Utility serializes and de-serializes consumption reports through the File System Data Access. However, the storage of the cached reports can easily be reconfigured to other data storage sources, such as a database. Besides saving to and loading data from the cache store, the Cache Utility also provides methods for pro-actively building up the cache of new accounts, and for pro-actively updating the cache with the newest consumption data. The performance boost that is achieved with this caching technique is huge compared to the performance of the legacy website.

6.6 Scheduled Tasks

The system supports periodic execution of tasks that are either vital for the system, or steps in longer running routines, such as updating the Light Sphere's color status. The execution interval is configurable in the administration module (see section 6.8.1.1), but currently the tasks must be hard-coded. The following periodic tasks are performed for each user account in the system:

- Build up the entire cache structure if the user account is new.
- Send welcome email if the user account is new.
- Check if new consumption data is available and update the cache accordingly.
- Check if the user account has specified the web-address of a Light Sphere, and update the Light Sphere's status to reflect the current hour.
- Send out the daily consumption report to the user account.

6.7 Philips HUE and the Light Sphere

For the development of the Light Sphere, Odense Kommune kindly sponsored a Philips HUE system[3] to the project. Philips HUE is a commercial product that consists of Zigbee[4] bridge, and three LED bulbs that are fully programmable with respect to brightness, hue and saturation. The Light Sphere is simply a FADO table lamp from IKEA with one of the HUE bulbs installed inside.

The bridge is connected to a wireless router from where it provide RESTful webservices to control the bulbs (see the developer site of the HUE on `http://developers.meethue.com/`). If the router is configured properly, the bridge can also be reached from outside of the home network, which is exactly how the enPower web-application communicates with the HUE bridge. Although, this also means that there is some manual work of router configuration, port forwarding, and dynamic DNS configuration related to each Light Sphere installation. The way that the the web-server remotely controls the Light Sphere in practice is quite interesting, and we will therefore look closer into the routine that makes the remote control possible.

[3] `http://www.meethue.com/`

[4] The Zigbee is a wireless standard for electric appliances: url(http://www.zigbee.org/)

The system communicates with the Light Sphere through the Hue Utility component in the Utility tier, which packages and transmits the instructions in RESTful HTTP requests. When the task scheduler determines that a user account has a configuration for a HUE/Light Sphere, it calls the `SignalCurrentHourVsAverage` method on the `HueUtility` class, in order to update the Light Sphere's color through the Internet:

```
1  public static void SignalCurrentHourVsAverage(UserInfo user)
2  {
3      if (!user.HasHue)
4          return;
5
6      HueConfiguration hc = user.HueConfiguration;
7
8      if (!IsWithinAllowedPeriod(user, hc))
9          return;
10
11     DateTime lastDayWithData = ConsumptionUtility.GetLastDayWithData
           (user);
12
13     DateTime startDate = lastDayWithData.AddDays(-14);
14
15     var hourlyAverages = ConsumptionUtility.GetHourlyAverages(user,
           startDate, lastDayWithData);
16
17     int hour = DateTime.Now.Hour;
18     double spec = hourlyAverages[hour].Value;
19     double max = hourlyAverages.MaxObject(r => r.Value).Value;
20     double min = hourlyAverages.MinObject(r => r.Value).Value;
21
22     var hue = RatioToHue(max, spec, min);
23
24     var newState = new HueStateObject
25     {
26       bri = hc.Brightness,
27       on = true,
28       sat = 255,
29       hue = hue,
30       transitiontime = 10
31     };
32     foreach (var light in user.HueConfiguration.EnabledLights)
33         SetState(hc.Address, newState, light);
34 }
```

The routine first assures that the user account indeed has a configuration with contact information to a Light Sphere specified (line 3), and then extracts the configuration information in line 6. In line 8 a subroutine is called, which checks if the current time is inside or outside of the user account's quiet hours. Then, the time stamp of the latest available data in determined (line 11), and is used to retrieve a 24-hour report of average hourly hours for the 14 days up to the latest available data (line 15).

The code in the lines 17-20 gets the average value for the current hour by a look-up in the retrieved `ConsumptionReport` from line 15, along with the highest, and lowest consuming hours. These values are then passed to the subroutine `RatioToHue` in line 22, which takes the minimum and maximum values as the absolutes for the most green and the most red color hues, and then places the current hour's specific value, `spec`, somewhere between the two. For example, if the maximum value is 0.81 kWh, the minimum is 0.25 kWh, and the specific value for the current hour is 0.79 kWh, the routine will return a very reddish hue value.

The `HueStateObject` is a data transfer object (DTO), which holds the information that we want to send to the Light Sphere. The lines 24-31 instantiates this DTO with information about the Light Sphere's brightness, standby-state, saturation, hue (the calculated value from line 22), and the transition duration, which is the number of seconds it takes for the Light Sphere to go from its current state to this new one. After the instantiation of the DTO, each of the user account's Light Sphere installations (if more than one) is iterated through and passed on to the `SetState` method, which serializes the DTO to the JavaScript Object Notation (JSON) format and readies a HTTP PUT message. This message is sent through the Internet to the household's router, on to the Zigbee bridge's RESTful web-service, translated into Zigbee packets, and finally transmitted sans wire to the bulb inside of the Light Sphere, which immediately obeys the command.

6.8 User Interface

As earlier mentioned, all the components of the user interface reside in an ASP.NET web-application which serves the system's pages to browser clients. Most pages are composed of server-side ASP.NET user controls, as well as client-side HTML5 components, and JavaScript libraries. Finally, at some relevant points the UI uses iOS-specific directives in order to provide better user experience on these devices, as well as on mobile devices in general.

6.8.1 Pages

All pages in the UI are `System.Web.UI.Page` derivations, and use the same ASP.NET custom master page, which is responsible for rendering the general site layout, menus, styling, etc. Some of the pages are reachable for anonymous visitors, whereas others require authentication. Few pages also require the admin-flag set in the user account, in order to be accessible. Table 6.1 lists the system's UI pages.

Table 6.1: List of all the UI's pages.

Name	Server-relative address	Access
Home page	/Home.aspx	Authenticated users
Login/Signup	/Login.aspx	Anonymous users
Error page	/Open/ErrorPage.aspx	Anonymous users
System administration	/Pages/Admin.aspx	Authenticated super-users
Overview	/Pages/DailyAnalysis.aspx	Authenticated users
Account page	/Pages/EditProfile.aspx	Authenticated users
Goal-setting and progress	/Pages/Goal.aspx	Authenticated users
24-hour view	/Pages/HourlyAnalysis.aspx	Authenticated users
Year view	/Pages/MonthlyAnalysis.aspx	Authenticated users
Web site statistics	/Pages/PageViewStatistics.aspx	Authenticated super-users
Score board	/Pages/ScoreBoard.aspx	Authenticated users
Consumption analysis utility	/Pages/UserStatistics.aspx	Authenticated super-users

Most of the layout and design of the pages have been covered in the chapter on design (see chapter 5).

6.8.1.1 Administrative Pages

The System Administration page allows the system administrator to perform certain tasks on each user account, including impersonation, setting up a Light Sphere and sending commands to it, resetting goals, sending consumption status emails, force cache update and complete cache buildup, performing scheduled tasks, and deleting accounts. It also provides GUI for the system settings, such as how often scheduled tasks should execute, the maximum disk space allowed for the cache, price of a kWh, CO2-emission per kWh, and finally the system's email settings. A screen capture of the page can be seen in figure 6.3.

The other administrative pages, that are only available to super-users, are used for the evaluation experiments, as described in chapter 7.

6.8.2 UI Components

Most pages include one or more ASP.NET custom user control, derived from the `System.Web.UI.UserControl` type. These user controls are again composed of traditional web controls, such as text boxes, check boxes and buttons, as well as HTML5/CSS3 components based on newer web technologies, such as the HTML canvas object.

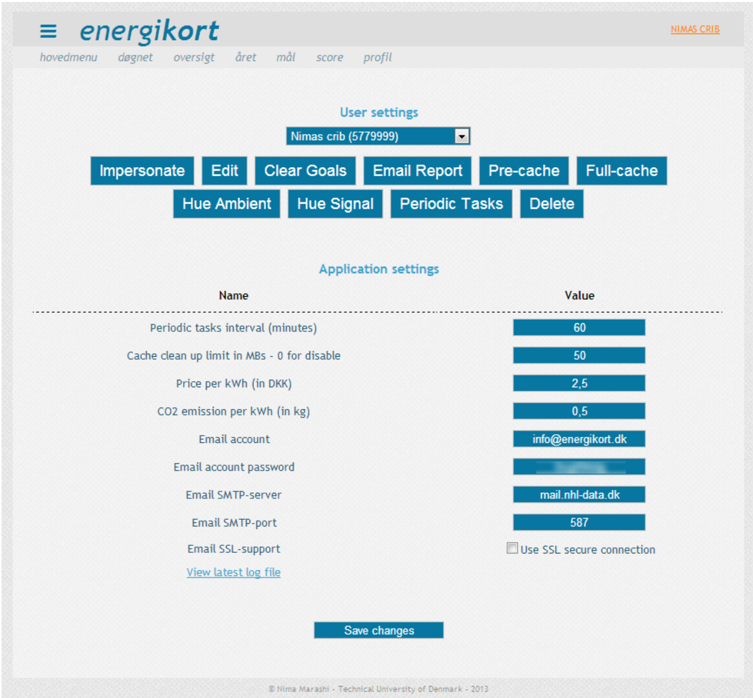


Figure 6.3: The system administration page.

For example, the Goal.aspx page contains the `GoalSettings` and `GoalHistogramChart` user controls. The `GoalHistogramChart` user control includes a rich, client-side charting component, RGraph[5], based on the HTML5 canvas object. All of the charts used in the UI are based on RGraph, which provides several chart types that are highly programmable. The RGraph library resides on the web-server as JavaScript files that are downloaded to the clients machine, where they are executed.

The down-side of using HTML5/CSS3-based components is that it sets high compatibility requirements to the client's browser, because the specification for the technology is still under development. However, they do not require the clients to install third-party software, such as Adobe Flash, or Microsoft Silverlight, but are still capable of delivering very powerful graphics and interactions that was not possible in the past. Also, they can be rendered on smart phones and tablets, such as the Apple iPhone and iPad.

[5] `http://www.rgraph.net`

6.8.3 Responsive Design

According to the online web statistics tool, StatCounter [Sta13], mobile devices accounted for 14.44 % of all web page views in March 2013, whereas the share was just 0.6 % in January 2009. This development has emphasized the necessity of designing web sites for both desktop and mobile devices.

Many websites have adopted this way of thinking by developing a separate mobile-friendly version of their website. However, the newly coined term, *Responsive Web Design* (RWD), formulated by Ethan Marcotte in 2010 in his article of the same name ([Mar10]), suggests a different, and more unified approach to cross-platform website design. RWD is basically about designing web applications that are aware of, and respond to the characteristics of the device and platform they are rendered on.

EnPower uses RWD through the use of the CSS `media` directive, among other things, which allows different CSS-styling rules to be applied on the pages, depending on what device the browser client is running on. Thus, following this design mentality, the system tailors the layout, charts and even the visibility of certain components through awareness of the platform and the screen real-estate that the user has at hand.

6.8.4 iOS Support

In addition to RWD, the user interface has been optimized to work better on iOS devices through a set of meta-tags that has been developed by Apple. However, this decision was not made to favor the system towards iOS users, but because many of these meta-tags are understandable by other mobile platforms, such as Google Android and the Windows Phone OS.

To take some examples, the meta-tags below make sure that the page is not scalable, is rendered at a 100% zoom, can be installed as a web app, and has its own icon and splash screen:

```
<meta name="viewport" content="user-scalable=0 initial-scale=1.0" />
<meta name="apple-mobile-web-app-capable" content="yes" />
<link rel="apple-touch-icon" href="/img/iphoneIcon.png" />
<link rel="shortcut icon" href="/img/favicon.png"
  type="image/png" />
<link href="/img/splash-640x1096.png" media="(device-width: 320px)
    and (device-height: 568px)and (-webkit-device-pixel-ratio: 2)"
    rel="apple-touch-startup-image">
```

The working of these metatags on an iOS device can be seen in figure 6.4.

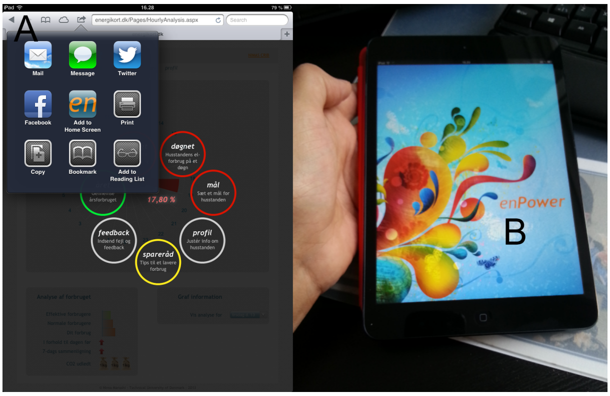


Figure 6.4: A) The apple-mobile-web-app-capable meta-tag tells the Safari browser on iOS devices that the web-app can be installed on the home screen. The apple-touch-icon meta-tag provides the icon.
B) This is the splash screen that is visible for a limited time while the web app is loading, and is provided via the apple-touch-startup-image meta-tag.

This concludes the chapter about the implementation of the eco-feedback system.

CHAPTER 7

Evaluation and Results

7.1 Objectives

The main goal is to find evidence to substantiate the assumption that enPower is effective as a persuasive eco-feedback system. To reach this goal, a study was conducted on a set of anonymous Funen households through a period of two weeks. However, before this study was started, a pilot test of the system was carried out, which had the objective of identifying and eliminating problems with the system. Finally, a case study was carried out on a parallel track, to evaluate the Light Sphere in the home of a Funen family.

7.2 Pilot Test of the Web-app

The pilot test was carried out in parallel with the design and implementation phases of the system. Much of the testing was carried out informally, and through casual conversations (often over phone). Therefore, here, we will focus on the documented heuristic usability testing, which is based on Jakob Nielsen's heuristic evaluation technique [NM90].

Four of the participants from the original test-group (as mentioned in 5.1), two of which were experts, were individually asked to evaluate the system through ten design heuristics (see table 7.1), and take note of any violation of the heuristics, as well as any other inappropriateness they encountered.

Table 7.1: Evaluated Design Heuristics

#	**Heuristic**
1	Visualize system status
2	Use familiar words and language
3	Navigability and freedom
4	Consistency and standards
5	Error prevention
6	Recognition rather than recall
7	Flexibility and efficiency
8	Aesthetic and minimalist design
9	Help users recognize, diagnose, and recover from error
10	Help and documentation

7.2.1 Results

The feedback from the four participants resulted in a total of 28 responses of which five were critical (see table 7.2). Most of the reported problems and errors were corrected, and a few were ignored, either because they were based on misunderstandings, or because they were out of scope.

Table 7.2: The responds from the heuristic evaluation of the user interface. BA, MM, KA, and AV are the initials of the four participants. The values in the columns below each participant represent the number of problems and errors they identified.

#	Heuristic	BA	MM	KA	AV	Total	Critical
1	Visualize system status	2		2		4	1
2	Use familiar words and language	2		1		3	
3	User control and freedom	2	1			3	1
4	Consistency and standards					0	
5	Error prevention		2			2	
6	Recognition rather than recall	1				1	
7	Flexibility and efficiency				1	1	
8	Aesthetic and minimalist design	1		1	3	5	1
9	Recognize, diagnose, and recover from error	1	2			3	2
10	Help and documentation	1	2	1	1	5	

The responses can be found in figure E.1 (in Danish) in appendix E.

7.3 Ambient Eco-Feedback

For the evaluation of the Light Sphere I chose a family of four people, two parents with their two children, who accepted my invitation of testing out this alternative way of receiving eco-feedback. The evaluation consisted of an experiment, where the household would have the Light Sphere installed in their house for a period of 14 days. The objectives of the experiment were 1) to detect if the consumption could be shifted away from the peak-load hours, and 2) to detect an overall decline in the family's consumption. The family lives in a relative big house of around 220 m2 divided between two floors. The children live on the top floor, with their own rooms, living room, and bathroom. The parents live on the main floor, where the kitchen, the dining room, and the two living rooms are to find. One of the reasons for choosing this family for the evaluation of the Light Sphere is that the parents both work at home. Therefore, there is an almost continuous electricity consumption going on from they wake up, and until they go to sleep. Therefore, the Light Sphere will have the potential of being influential throughout the entire day.

The Light Sphere was placed in the living room, which, by the family, was identified as the most trafficked. The Philips HUE bridge was attached to the home's wireless router, in which the necessary ports were opened, in order for the bridge to be accessible from the web-server. The household had an account created in the web-app, and the account was linked to the IP-address of the Philips HUE bridge and thereby the Light Sphere. The quiet hours, where the light would not be on, was set to 11PM-8AM. The web-app was programmed to update the Light Sphere once every 60 minutes, where it changed its color hue to correspond to the present hour's 7-day average consumption, relative to the other hours. On the first day of the experiment, the family was educated in how the Light Sphere worked and how their hourly consumption average was represented by a color spectrum between green and red. Besides this short introduction, the family was told that the purpose of the experiment was to test the technology behind the Light Sphere for my thesis. No other information was given, and the household did not receive other feedback during the experiment, other than that of the Light Sphere.

7.3.1 Results

The experiment spanned from June 1st-14th. The 14 days prior to the experiment, May 17th-31st was used as baseline (figure 7.1 displays the average daily consumptions of both periods). Here, the family used 270 kWh of electricity, with an average of 19.3 kWh per day. On average, they spent most energy

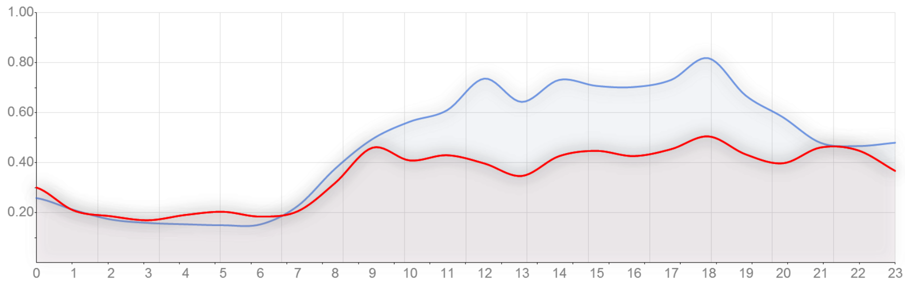


Figure 7.1: Hourly averages of the test-household's consumption between June 1st-14th (red line). The blue curve represents the averages from the baseline period between May 17th-31st.

between 6PM-7PM. with a consumption of 0.82 kWh. During the experiment, the family used 201 kWh of electricity, with an average of 14.3 kWh per day, and thereby saved **25.7%** electricity. Their most consuming hour was, again, 6PM-7PM, but only with a consumption of 0.50 kWh, which means that the load during the peak-hour decreased by **39%**. Finally, the standard deviation σ during the baseline period was $\sigma = 0.23kWh$, and dropped to $\sigma = 0.11kWh$.

7.4 Experiment on Funen Households

This experiment was prepared in cooperation with the chief of business development at EnergiFyn. The preparation consisted of two meetings, and a number of mail correspondences, where the details of the experiment was established. Through EnergiFyn, a group of 190 customer households, with yearly consumptions between 2,000-8,000 kWh, were selected at random. The lower consumption limit of 2,000 kWh ensures that the selected customers are not already as efficient as possible. The upper limit tries to exclude houses that rely on electric heating systems, and households with too many residents. A targeted letter was sent out to each household with the following message (translated from danish):

Master's Thesis - Technical University of Denmark (DTU)

Dear EnergiFyn customer,

For my master's thesis at DTU I need to investigate the use of my software "Energikort" on the Internet. For this I ask for your help.

By the help of the software, you can follow and get an overview of your electricity consumption down to the hour. The software tool helps to answer questions such as:

- How much electricity will we be spending this year, and how much is it going to cost?
- How much CO2 do we emit daily?
- What uses the most electricity, LCD or LED TV?
- In which hours of the day do we spend the most electricity?
- How is our energy consumption compared to other, similar households?

How do we get started?

Go to www.energikort.dk and sign up using the customer number and PIN that you find on your electric bill. Then, simply use the software as you want for 14 days.

As a gesture of appreciation, EnergiFyn acknowledges participants with a ticket to Odense Zoo.

I would ask that you sign up before July 1st.

Thank you in advance and best regards, Nima Marashi

The reasoning behind inviting 190 households to the study was to acquire around 30-50 participants, and we estimated the chance for a household to accept the invitation would be around 25%. The maximum of 50 participants was first and foremost because it was considered to be the system's current safe limit of concurrent users. Secondly, it was the maximum number of Zoo-tickets that could be sponsored to the study.

The experiment was set to be carried out during the first two weeks of July 2013. In these two weeks, each participant's usage of the web-app was automatically recorded with the purpose of analyzing correlations with the consumption. Furthermore, EnergiFyn was asked to provide consumption data for a large control group (3,000-5,000 customers) during the same two weeks.

The objective of the study is partially to find evidence of a decrease in the consumption of the study group during the evaluation period, compared to the same period the year before, and partially to find a decrease in the average consumption of the study group, compared to the control group, during the evaluation period.

7.4.1 Results

Out of the 190 invitation letters that was sent out to the Funen households, only 15 signed up for the evaluation, which is under 8%. Out of these, 6 had to be excluded, both before, during, and after the experiment, because they had meters that reported data too irregularly.

7.4.1.1 The Households

The 9 participating households consisted of 8 detached houses and 1 apartment. Their yearly consumption for 2012 was 3,380 kWh on average, ranging from 2,134 to 5,508 kWh. The number of residents was between 1-4, with a home area between 94-185 m2. The specifics are described in table 7.3.

Table 7.3: The participating households and their specifics. Note that the number of adults, children and the home area are self-entered by the users, and are not verified.

Account name	Adults	Children	Area (m2)	Housetype	Yearly usage	Daily usage
Esther	1		155	Detached	2134	5,85
Nesdam	2		156	Detached	3020	8,27
Nilo	2	2	142	Detached	4173	11,43
Jørgen	1		94	Detached	4513	12,36
Benneberg	2	2	155	Detached	5508	15,09
Pernille	1	1	114	Apartment	2412	6,61
5664035	2		150	Detached	2720	7,45
gertz	2		124	Detached	2445	6,70
Bjergfyrvangen	2		185	Detached	3495	9,58
Average	**1,67**	**0,55**	**141,67**		**3380**	**9,26**
Total					**30420**	**83,34**

7.4.1.2 Web-app Statistics

The invitation letter was sent out on June 25th, and the following day, June 26th, the web-app had 37 page views. Each page view represents a participant visiting a specific page in the web-app. During the timespan of the experiment (July 1-14th) a total of 123 page views (including users that were later excluded) were served (see figure 7.2).

The page views are distributed between five pages and is depicted in the chart in figure 7.3. Unfortunately, since the energy saving tips view, and the user

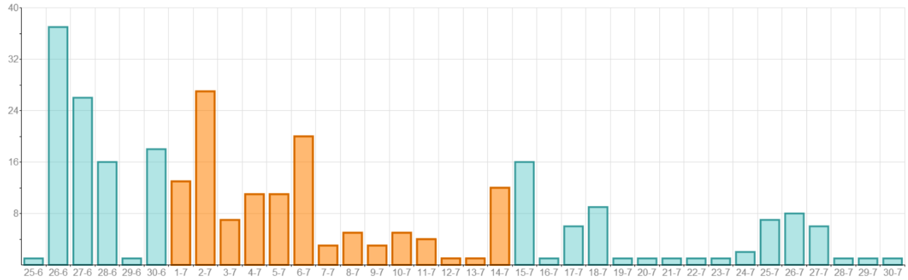


Figure 7.2: Page view statistics for the study on Funen households. The orange bars represent the page views, which occurred within the timespan of the experiment (July 1-14th). The bars before and after the highlighted bars represent page views pre- and post-experiment, respectively.

feedback view both are dialogs that are implemented with client-side scripting, they are not represented by the page view numbers, which are server-side pages. Also, visits to the login/sign-up page were not recorded.

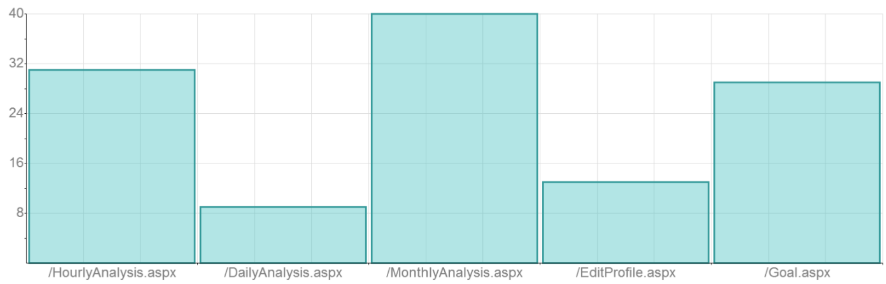


Figure 7.3: The page views distributed on pages.

If we look at the distribution of page views between participants, we find that 5 of the 9 users were active during the experiment's lifetime. Three of these (gertz, 5664035 and Jørgen) stood for 91% of the views (see figure 7.4).

However, even when not all households used the web-app actively, they all received daily consumption reports through email, and thereby received eco-feedback.

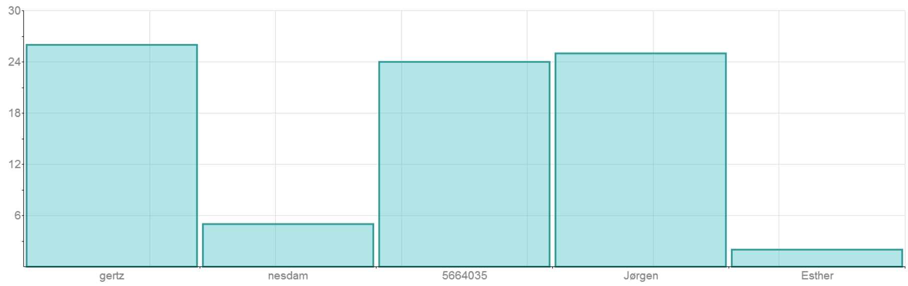


Figure 7.4: The page views distributed between users.

7.4.1.3 Consumption Analysis

The 9 participating households had a total consumption of 818 kWh during the 14 days of the experiment, which averages to 91 kWh per household ($\sigma = 24.26kWh$), or 6.5 kWh per household per day. The individual consumptions spanned between 61-132 kWh, with a median of 80 kWh (see table 7.4).

Table 7.4: The consumption measurements during the experiment compared to the consumptions for the previous year.

Account name	Adults	Children	Area (m2)	Housetype	Yearly usage	Daily	First 2 weeks in july 2012	Average	During experiment	Average	Decrease (%)
Esther	1		155	Detached	2134	5,85	99	7,07	61	4,36	38
Nesdam	2		156	Detached	3020	8,27	101	7,21	104	7,43	-3
Nilo	2	2	142	Detached	4173	11,43	104	7,43	127	9,07	-22
Jørgen	1		94	Detached	4513	12,36	87	6,21	75	5,36	14
Benneberg	2	2	155	Detached	5508	15,09	119	8,50	94	6,71	21
Pernille	1	1	114	Apartment	2412	6,61	99	7,07	63	4,50	36
5664035	2		150	Detached	2720	7,45	83	5,93	80	5,71	4
gertz	2		124	Detached	2445	6,70	95	6,79	82	5,86	14
Bjergfyrvangen	2		185	Detached	3495	9,58	151	10,79	132	9,43	13
Average	**1,67**	**0,55**	**141,67**		**3380**	**9,26**	**104,22**	**7,44**	**90,89**	**6,49**	**12,70**
Total					**30420**	**83,34**	**938,00**	**67,00**	**818,00**	**58,43**	

During the same period in 2012, the participating households jointly consumed 938 kWh of electricity. Here, the average consumption per household was 104 kWh for the entire 14 days, or 7.44 kWh per household per day.

Thus, the consumption of the participating households, in the period of the experiment, was **12.7 %** lower than the same period in the previous year. Two households consumed more than the year before, whereas 7 consumed less (see figure 7.5).

The groups' consumption in the days leading up to the experiment window was also examined in order to identify an already existing bias compared to the year

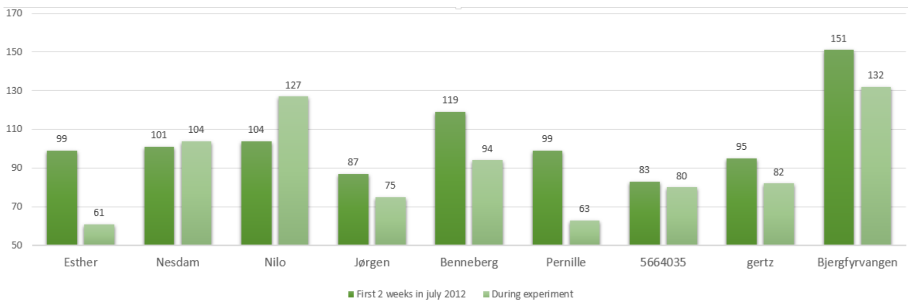


Figure 7.5: Visualization of the participating households' consumption during the experiment compared to the year before.

before. Looking at a 90-day window prior to July 1st, the total consumption in 2013 was -0.5% compared to the same window in 2012. Shrinking the window down to 45 days before the experiment start, the difference was -5.4%. Finally, for the 30-day and 15-day window the difference was -8.7% and -6.3%, respectively. Ergo, a bias did exist prior to the experiment, even though it was not as big as the registered difference during the experiment. If the bias of -6.3%, which existed just prior to the experiment, is subtracted from the 12.7% decrease during the experiment, there is still a decrease of 6.4%.

Figure 7.6 gives an overview of the trends in the consumption in the time before, during, and after the experiment, as well as the baseline observations from the year before.

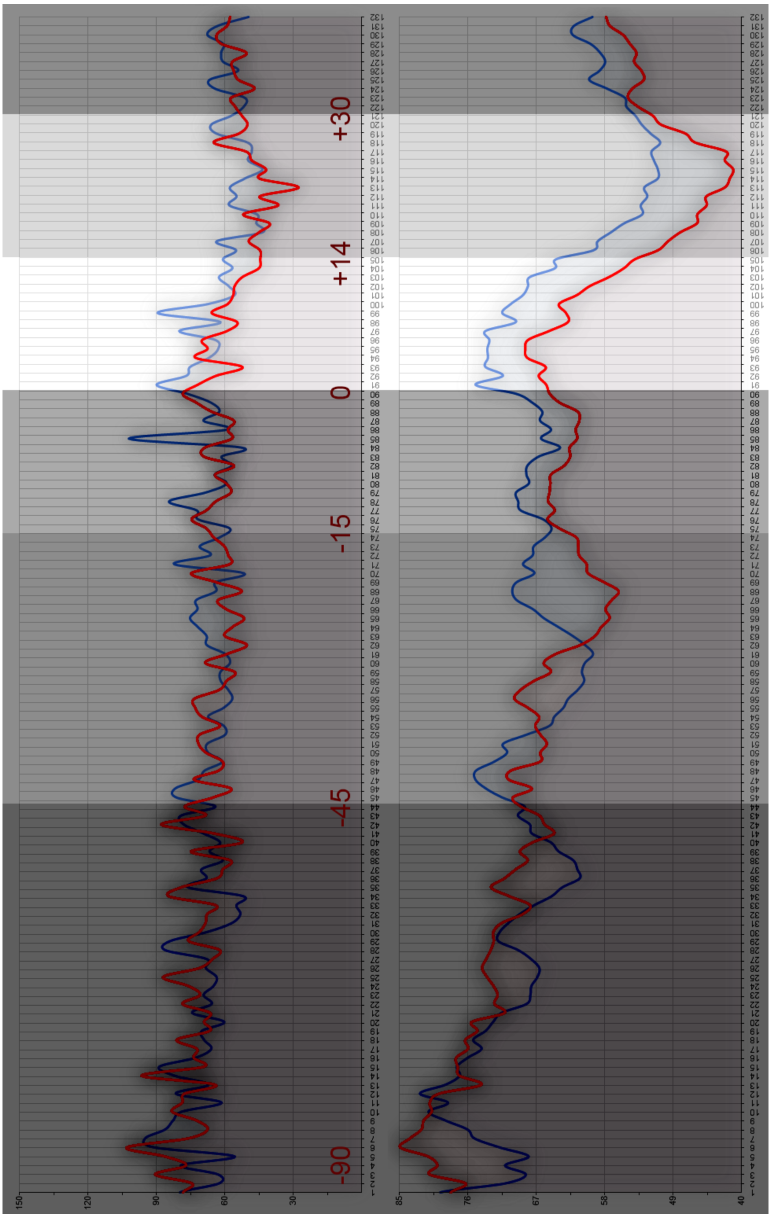


Figure 7.6: Red curve represents 2013, blue represents 2012. Both charts (upper and lower) visualize the day by day consumption of the experiment group before, during, and after the experiment window. The experiment time window is the most illuminated time slot in the chart.
The upper chart is an accurate plotting of the day to day values. The lower chart is a moving average plot, where each value is a weighted average of the previous 7 days.

The groups' consumption *after* the experiment was also examined. Here, in a 14-day time window after the experiment, the consumption was still almost 13% lower than the same period in 2012. Note, that the participants still had access to the web-app, and received emails, unless they opted out. The page view statistics, in figure 7.2, shows some activity on the web-app, even after the experiment has ended. From the start of August the system was reconfigured to only send out daily reports for users that actively opted in, and the default value was set to false. In the following 10 days, which is the most recent data available at the time of writing, the decrease in this year's consumption, compared to last year's, has dropped to 2.8%.

Finally, the consumption between July 1-14th 2013 was examined for 2,435 households, who were roughly in the same consumption span as the test group (45-147 kWh, that is 15 kWh below and over the test groups' span of 61-132 kWh). This control group had a consumption of 97.7 kWh ($median = 98kWh, \sigma = 25.56kWh$) for the period. Thus, the households from the experiment, with an average consumption of 90.9 kWh per day per household, used 7.0 % less electricity. Interestingly, this value is very close to the bias-corrected value of 6.4 % decrease that the test-group had, compared to 2012.

This concludes the evaluation chapter. The next chapter discusses the results and the findings of the experiments, among other topics.

Chapter 8

Discussion

In this chapter, I will address and discuss the objectives of the thesis, along with the conducted experiments and their results. I will also reflect on the magnitude of the problem, and put my work in perspective to it. Finally, I will describe how the findings of this thesis can be used by others in future projects.

8.1 Experiments

Before the problems of peak-cutting and pro-environmentalism in general are discussed, I will discuss the results of the experiments, including their trustworthiness.

8.1.1 Ambient Eco-feedback

Many features were designed for the Light Sphere that did not make it to the implementation phase. However, the fact that a proof-on-concept prototype of the Light Sphere was implemented, with an end-to-end connectivity in the designed architecture, is indeed a satisfactory milestone for the project.

The experiment on ambient eco-feedback, as described in section 7.3, chapter 7, showed some very promising results, even if it was a more a demonstration of the possibilities with the Light Sphere, and less a scientific experiment. Even so, the drop in electricity consumption, as well as the disperse of consumption away from the peak-load hours without any other feedback than that of the Light Sphere, suggests that ambient feedback techniques have huge potentials in provoking pro-environmental behavior. There was, however, feedback from the test household that could suggest a paradox in the outcome of the experiment. Even though the family was explicitly informed that the Light Sphere's information was based on hourly averages of the past days' consumption, and that the feedback therefore was not real-time, the father had trouble understanding why the light would be red at times where they did not use any notable electric devices. This comment came after the experiment. Therefore, there is reason to believe that they had received feedback from the device under the false assumption that it was somehow related to their actual consumption in the current hour. If this is the case, it is paradoxical that pro-environmental behavior was provoked through inaccurate eco-feedback, and might by serendipity be the proof of a placebo-like effect in eco-feedback systems. Alternatively, the experiment can be perceived as a very high-fidelity mock-up experiment, where the participants use the system as if it was real-time, when it really is simulated real-time. After all, one of the intentions of using averaged values for the calculation of the Light Sphere's color for a specific hour was to fill the void of real-time data.

8.1.2 Study on Funen Households

The careful claim of this experiment is that the electricity consumption of a household can be decreased by approximately 7% through the use of an eco-feedback system that uses scientific theories and techniques from the fields of psychology and HCI. In order to assess the validity of this claim, we have to discuss the limitations of the experiment behind it.

First and foremost, the duration of the experiment is very short when making comparison to the same time window in the previous year, as well as when considering the variations that can occur in a household's electric consumption during 14 days. E.g. there is no way to say if the number of residents have varied between the baseline and experiment observations: some residents might have been on vacation, and others might have had guests staying. Also, the short duration of the experiment makes it hard to eliminate behavioral variations such as spending less time at home because the weather is good, or eating out more, and cooking less.

Secondly, the size of the test-group, consisting of only 9 households, makes the statistical correctness of the experiment doubtful. Also, the selection of the households is not demographically representative to the control group of 2,435 households, other than that the very low consuming (<45 kWh) and very high consuming (>147 kWh) households were filtered out.

Finally, no additional information was retrieved from the participating households. It is possible that post-experiment questionnaires and interviews could have contributed to the understandability and credibility of the experiment's results.

These limitations were not addressed, partially because they were out of the scope of the thesis, and partially because they would have demanded time and resources that would necessarily be taken from the development of the system itself.

However, it cannot be said that the experiment and the results it found were taken out of thin air. Even if the observations in no way can be said to be representative for all households in general, several arguments can be laid out that support the plausibility that the participating households' consumption behaviors were in fact affected.

One argument is the assessment of differences between the consumption in 2012 and 2013 that already existed when the experiment was initiated. By examining the consumptions prior to the experiment a bias was found, and the actual decrease of 12.7‰ in the consumption, during the experiment period, was adjusted accordingly.

Then, there is the fact that the same level of decrease in the group's consumption existed throughout July, right until the dispatch of daily consumption reports was seized. Interestingly, the group's consumption in August, at least for the data available at the time of writing, was only about 2% lower than the year before. This could be an indication of a correlation between eco-feedback and energy conservation. Of course, if this postulate is true, it suggests that the increased awareness brought by eco-feedback is either temporarily, or it does only result in behavior change if it is accompanied by constant feedback.

Also to consider, is the comparison to the control group, consisting of nearly 2,500 households in the same area. This comparison showed a decrease of 7% in the test group's favor, which corresponds to the bias-adjusted decrease observed in the 2012-comparison.

Finally, and perhaps most notably, a 7% decrease fits very well in what other, similar eco-feedback systems report to have achieved. For example, in a review of around 20 studies, and 5 compilations on eco-feedback systems, Fischer found typical decreases in consumption between 5-12% [Fis08].

8.2 Reflection

As we briefly explored in the introduction, the world's energy reserves are depleting. It is out of scope of this project to explain how the depletion works, but it is safe to say that the human civilization plays a crucial role in the matter.

In Dan Browns novel, Inferno, a mad, but extremely clever scientist delivers indisputable mathematical facts for the extinction of the human race and the collapse of the planet's ecosystem, if nothing is done to address the explosive growth in the world's population. In the fictive novel, the mad scientist's solution to the problem is to spread a synthetic killer virus, in order to stop the population growth and thereby stop the exponential pace in which the planet's resources are depleting. The book is of course fictive, and the mad scientist's ways of reasoning are, well, mad. But the proofs that are delivered are based on factual data, and they must be addressed in one way or another, if we want to avoid the collapse of our civilization. Therefore, the strongest motive, if seen from the view of the world's health, is to preserve the planet's resources, by changing peoples energy consumption behaviors, and by shifting to sustainable energy resources.

A lot can also be gained from eliminating peak loads on the electricity grids. Analysis of the consumptions from the experiment on the Funen households show that peak-hours can get as high as 175% of the average load. If this observation is applied to the rest of the country's power-grid, it requires the grid to be prepared to deliver the extra demand, even if it means that less preferred production methods must be taken into use. With sustainable energy sources, such as wind and solar power, it is difficult to predict the amount of power that can be produced at a given time. Thus, even if the energy demand for peak-hours can be pre-calculated, the weather conditions for production of sustainable energy sources is not controllable, and it is uncertain if the entire demand can be covered by these sources. Therefore, conventional power plants, which are more expensive and polluting, must be set into use each day to support the demand of the peak-hours. In the other end, during the off-peak hours, when the energy demand is at a low, sustainable production sources are still producing electricity. If the produced electricity is larger than the demand, the excess amount of energy cannot be stored, and must either be used, be transported to other locations, where the production is lower than the demand, or it is simply lost. Plainly put, the current energy ecosystem is unintelligent and inefficient. The extra expenses that the utility companies have due to inefficient use of the produced power are added to the customer's bill, and the price on electricity is therefore influenced by the peak-load demands, even if the given customer actively avoided using electricity in the peak-hours. Some utilities have introduced new price models, where the price on electricity is regulated throughout the day, in order to reward off-peak consumption and punish consumption during peak-hours. A number of these companies even offer free electricity during the night hours, as a mean to move as much consumption from the peak-hours, as possible. Ergo, peak-cutting is a motive for all involved parts, as well as a drive towards pro-environmentalism.

8.3 Future Work

For three full years, I worked at a software company that provided eco-feedback solutions to utility companies, among other things. Here, I held the position of full-time software engineer, working on several eco-feedback products, including flatscreen-TV kiosks targeted towards larger audiences, personal iGoogle gadgets, web-sites, and mobile apps. My work at this company was very result-oriented, and did not include research in the relevant fields, which I now think was a wasted opportunity. I have now worked on this thesis full-time for six months, and I have only scratched the surface on the available research for eco-feedback technologies. I wish that I had the knowledge I have now, then, and that the direction of the company, and the utility companies we worked with, saw the necessity, and the opportunities in investing in research.

With that said, I am still only a novice on the subject. Several times during my work on this project, at times when I felt on top of the literature, and was confident about the novelty of my work, I have been put to shame. For example, the idea for the Light Sphere came partly from the 1976 research on using lamps for peak-cutting [KPP76], and partly from the potential I saw in the Philips HUE as an ambient display. I was thrilled when I thought of the idea of putting the HUE bulb into a spherical lamp, and using it as an ambient indicator for creating awareness about peak-hours. I even programmed a proof-of-concept prototype that later was built into the final product. In the literature map I had created, I had not managed to find anything like the Light Sphere, but I had not considered the possibility that others might have had the same idea as me: to hack an existing ambient product into an eco-feedback device. This was exactly the case with the Ambient Stock Orb, that was hacked into an eco-feedback device by a manager from Southern California Edison [Tho08]. My point here is that there are much more competent people out there writing books and post-doctorates about the subject, and these people have a lot to offer to the utility companies searching for eco-feedback systems, as well as to the companies that develop and sell these solutions. The businesses related to the energy sector should cooperate with the scientific community, and consult, or even hire, researchers from the fields of HCI and behavioral and environmental psychology, because providing eco-feedback to consumers is about so much more than just a piece of software.

We are just scratching the surface of what is possible. The requirements that the analysis in chapter 4 found (along with the design ideas of chapter 5) can advantageously be built on to deliver a much more rich, efficient, and streamlined eco-feedback-experience than the one I was able to prototype during the relative short timespan of the thesis.

Imagine, for instance, a multi-storey office building, where each floor have a Light Sphere installed. Here, the Light Spheres could function in hourly-average mode, as it does in enPower's design, or they could color-index each floor according to their consumption compared to the other floors, so that the most consuming and least consuming floor would have red and green lights, respectively. Both solutions would provoke a healthy competition between the floors, and presumably decrease the consumption of the entire company. The same approach could be used in schools, student dorms, or even on street level.
The ambient eco-feedback could also be delivered via other senses, than just vision. Imagine a small, low-volume speaker placed in a home's hallway, or bathroom. When the household's consumption is kept within an acceptable limit, the speaker plays soothing, cheerful music. When the household's consumption is over the limit, the music changes to gloomy, melancholic tunes. An even more radical thought is the idea of an aroma-therapeutic eco-feedback device, which sprays a fresh scent of lavender, peppermint, or even cookies each morning, given that the household kept their consumption within the limits. Note, that these ideas all fit within the requirements for an eco-feedback system, which were disclosed in the analysis earlier.

Chapter 9

Conclusions

The objective of this thesis, and the entire project related to it, was to investigate how energy consumption could be translated into persuasive feedback visualizations, with the purpose of increasing awareness among consumers, and developing pro-environmental behavior. A part of this objective was also to investigate if and how the system could use ambient visualization to provoke pro-environmental behavior, as well as to lower consumption during peak-load-hours. Finally, it was the aim of the thesis to evaluate the efficiency of the system by conducting experiments on actual households.

The analytic work consisted of a review on the related literature, where psychological models for behavior change, and pro-environmental motivation techniques were analyzed, among other things. The output of the analysis was a sound understanding of what makes eco-feedback systems efficient. This understanding, along with a set of requirements to the system, went through an iterative design-process, which made use of rapid prototyping, and feedback from test-users to mature itself. The design was then explained and classified in the field of eco-feedback systems through the eco-feedback design space. The final eco-feedback system was implemented using state-of-the-art web-technologies and made ready for evaluation through experiments.

Two experiments, related to the objectives of the thesis, were conducted. The Ambient Eco-feedback experiment aimed at cutting peak-levels by using the implemented version of the Light Sphere design. The household, on which the experiment was performed on, went from using 0.82 kWh to 0.50 kWh of electricity during the peak-load hour, which is a decrease of 39%. The family's overall consumption also fell by 25.7% during the experiment. However, there is reason to believe that the feedback was wrongfully perceived as real-time, which questions the validity of the result.

The purpose of the second experiment was to investigate if the enPower web-app implementation could make a test-group aware of their electricity consumption with decreased consumption levels as a result. The test-households had access to the enPower web-app, and received daily consumption reports on email. Through the duration of the experiment a consumption decrease of 12.7% was detected (6.4% when corrected for bias). The test-group's consumption during the experiment was also compared to a control group consisting of nearly 2,500 households. Here, the test-group used 7.0% less electricity than the control-group.

However, because of the circumstances of both experiments, such as their short lifespan, and the lack of consideration for certain factors that could change the outcome, their results should be considered as cautious indications, rather than definitive conclusions. Thus, to answer the hypothesis of this report: There are slight indications that feedback, both through ambient, as well as attention-demanding visualizations provokes pro-environmental behavior on Danish households from Funen by lowering peak-levels and generally decreasing the use of electricity. However, there is a need for additional experiments that account for the scientific pitfalls and statistical errors related to these experiments.

Appendix A

A Survey on Domestic Consumption

To pinpoint the areas of interest for the analysis, an online survey was created, and posted on Facebook. The questionnaire revealed the following points of interest amongst the 53 respondents:

- **47% admit that they use more electricity in their home, than what would be ideal.**
  This could be indication of a state of dissonance between belief and performance by some consumers, and gives breeding ground for the theory of cognitive dissonance as discussed in section 4.2.3.
- **26% do not know the circa size of their last electricity bill.**
  Generally, the proximity of feedback to electricity consumption is very low, because bills are typically sent out quarterly. Still, it is a kind of feedback, and without it the consumer would not have sense of the amount of the consumption.
- **53% do not know the price of 1 kWh electricity.**
  Related to the previous point, it is problematic that the price of electricity is unknown to the consumer. It corresponds to shopping for groceries at a store, where there are no price tags, and the bill is sent out months later.

- **42% see the connection between domestic energy usage and environmental issues as "very small" compared to "the impact from the industries and the corporate world".**
  In Denmark, in 2010, the total residential electricity consumption was 8,649 GWh. For businesses and industries it amounted to 14,057 GWh[1], which is the equivalent of 38% and 62% respectively. Thus, a good portion of the respondents show an unjustified disclaim of responsibility. However, 55% acknowledge that "there is a connection of crucial importance".

- **Only 17% think about conserving energy on daily basis.**
  The majority of the respondents (74%) answered that they put some effort into energy conservation, and that they think about these issues weekly, which indicates that the breeding ground for a pro-environmentalist mentality exists.

- **45% think that politicians and governments "can do the most for solving the world's environmental issues". 53% gave the answer, "the individual".**
  The idea behind this question was to get a grasp of where people considered the locus of control to be; at higher powers, or at oneself. The survey indicates the distribution to be roughly half-and-half.

Thus, from the survey, the a list of objectives can be outlined for the analysis:

- Exploitation of the consumers' state of dissonance between belief and performance.

- Investigation on how expenses related to electricity consumption can be made explicit, not only for the duration that are covered by the bills, but for various periods of time, including, daily and hourly.

- Investigation on how people's attitude can be changed towards their behavior's impacts on the environment (with respect to have individuals take responsibility for the domestic electricity consumption, and to place the locus of control at themselves).

- Exploration of techniques and tactics that make consumer's think about their consumption more frequently (e.g. multiple times per day).

[1] http://www.ens.dk/arkiv/pressearkiv/presseservice/fakta-og-noegletal/fakta-om-elforbrug

A.1 Survey Data

The survey has been translated from Danish. Some comments have been left out due to irrelevance.

Number of respondents: 53

1. Is your electricity consumption more or less than ideal?

- 25 (47%) More
- 23 (43%) Ideal
- 5 (9%) Less

2. Do you know the size of your household's last electricity bill (ca. in DKK)?

- 4 (8%) Less than 500 kr
- 18 (34%) 500-1500 kr
- 13 (25%) 1500-3000 kr
- 4 (8%) More than 3000 kr
- 14 (26%) Do not know

3. What is the price of 1 kWh, in DKK?

- 4 (8%) 0,25 kr
- 25 (47%) 2,50 kr
- 0 (0%) 25 kr
- 24 (45%) Do not know

4. What is the connection between the energy consumption in people's homes, and environmental issues?

- 0 (0%) There is no connection.

- 22 (42%) There is a connection, but it is very small compared to the impact from the industries and the corporate world.
- 29 (55%) There is a connection of crucial importance
- 2 (4%) Do not know

5. How much do you care for protection of the environment?

- 9 (17%) Very much
- 39 (39%) Somewhat
- 5 (9%) I do not care

6. What do you do to save energy in your household?

- 9 (17%) I do a lot, and think about these issues on daily basis
- 39 (74%) I do some things, and I think about these issues on weekly basis
- 5 (9%) I do not do anything, and do not think about my consumption at all

7. Who can do the most for solving the world's environmental issues?

- 24 (45%) Politicians and governments
- 1 (2%) God
- 28 (53%) The individual

Additional comments from responders

1. "I think that we should be much more aware about our consumption (lights, stove, etc) and remember to turn of on switches, TV and everything that can be spared."
2. "We are conserving energy by using the tumble dryer less frequently."
3. "I switch of the lights in rooms that are empty. Use low-energy bulbs."

4. "I use more than necessary, because I think to my self "it's just this little bit of energy", but it sums up and means a lot."
5. "It is hard to concretise how electricity is spent, and what the consequences are. I barely know what a kWh costs."
6. "The entire household uses LED lights. Among the "energy-sinners" i the home, we have a work station PC, and an aquarium (380L)."
7. "Use low-energy bulbs. Turn of the lights when you leave a room. Check everything before you go to bed, and turn of devices that are not necessary. Turn of electrical devices after use. Go for low-energy devices, when buying new stuff, etc etc etc"
8. "I am convinced that it is crucial for the environment that the individual conserves energy. But I find it very hard to limit my consumption. Part because of bad habits, and part because I forget to do so."
9. "I always look for energy-standards when buying new appliances."
10. "There are chargers for various gadgets that are always plugged in. These are the sinner in my home."
11. "We try to watch out for our energy usage, but when you need energy, you just spend it without further thoughts."
12. "It is a shame that we aren't better at protecting our environment (including myself)"
13. "I leave the lights, computer, TV on when I leave the house for 1-2 hours, because I cannot bear to turn them on again. I know that I shouldn't do the things above, but I know that it doesn't cost me anything and I'm lazy. "

Appendix B

The Eco-feedback Design Space

This chapter contains the design sub-spaces, from the eco-feedback design space (see figure B.1) that are trivial to the design of enPower, or are of less importance.

B.0.1 Effort to Access

In order to use the web-app, the user must login with an EnergiFyn customer number and pin code on a device connected to the Internet. However, an option is given to remember the user's credentials, and the web-app can be installed as an app on smartphones, which lessens the effort to access.

B.0.2 Temporal Grouping

The temporal groupings for the three views, "the year", "overview", and "24-hour" are respectively by month, by day, and by hour. The Light Sphere's is by the hour.

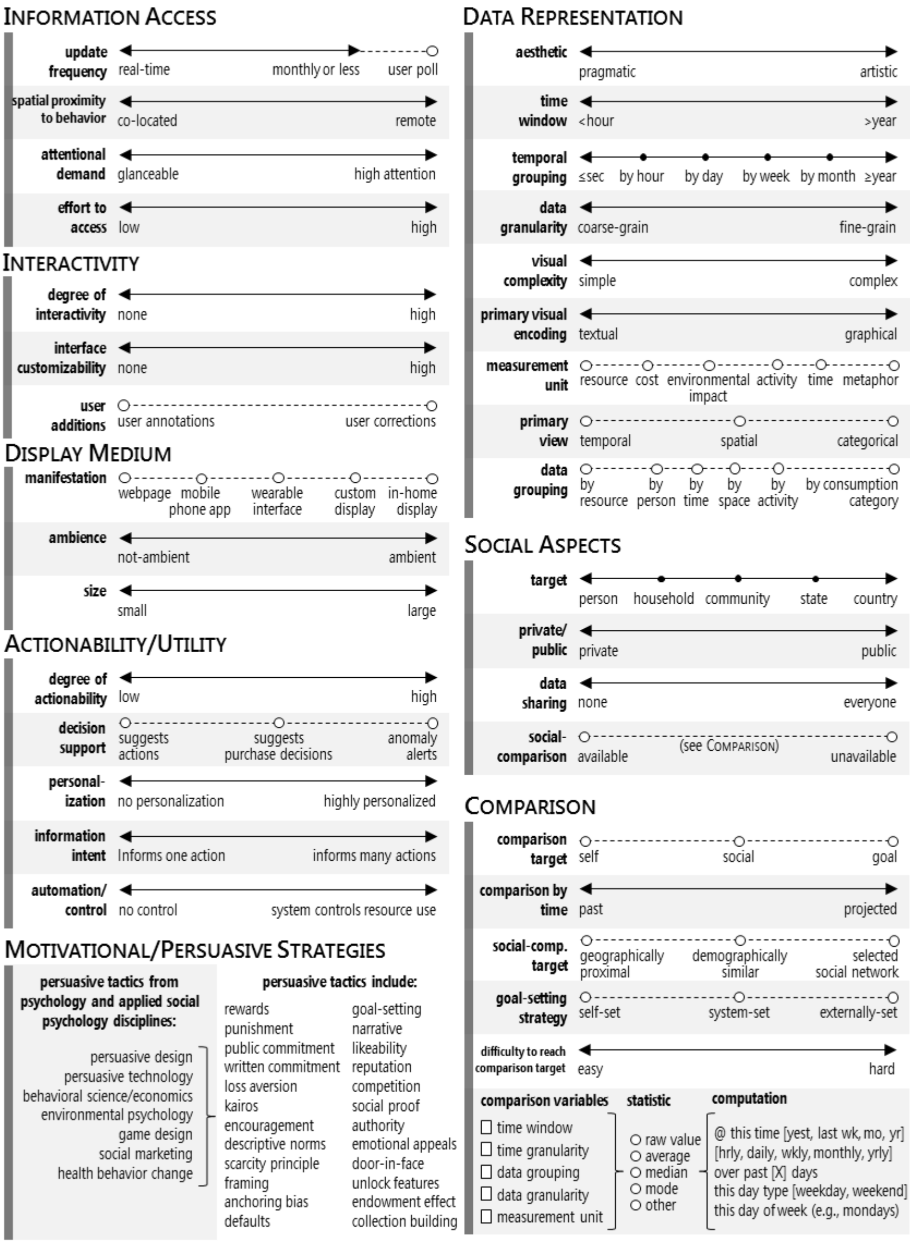


Figure B.1: An eco-feedback design space, by Jon Froehlish, along with its dimensions and sub-spaces- [Fro09].

B.0.3 Data Granularity

EnergiFyn's customers have one electricity meter per house, which also defines the granularity for enPower. If data could be categorized by room, or by outlet/device, the design of the system would change significantly and open up for interesting possibilities. The data granularity is not in the scope or control of the project.

B.0.4 Private/Public

The feedback is private to the household, and is protected by security credentials. Still, there is a public dimension through the list of high scores.

B.0.5 Animations

The user interface uses animations in various scenarios. Visualization charts use animations when they are loaded, or updated, e.g. when the user navigates to another time-span. However, these animations are not necessary for the functionality or understandability of the system, and are solely added to add to the feeling of interactivity, and to impress the users with rich graphics.
Other animations include the fade-in sequence of the navigation menu and dialog boxes, as well as the dimming effect of the screen when these controls are in front, and the easing fold-out of the tree structure in the energy advice dialog. These all have a purpose, including minimizing clutter on the screen, and guiding the user's focus towards the change in the interface.
Finally, there are animations, that are directly related to a feature. One of them is the blinking yellow ring around the goal-view menu-item in the circular menu. This blinking animation is supposed to remind the user about the lack of a goal, and persuade the user into creating one. Another example is the goal-setting knob, which animates smoothly between the percentages of a given goal. This knob animates with the help of click-dragging with the mouse, using the mouse's scroll-wheel on top of it, or using touch gestures.

B.0.6 Degree of Actionability

This subspace evaluates how easy it is to know what action to take, while receiving feedback from the system.

The feedback visualizations compare the household's consumption with average, and efficient households. If the household is informed that their consumption is higher than either one of these reference values, they know that the necessary action is to bring down the overall consumption. The same goes for hourly spikes in the consumption that exceed the aforementioned values. These gradually have more of a reddish color the higher they are compared to the efficient consumers. Here, it is obvious that the electricity usage in that particular hour must be lowered, in order to match the efficient consumers and become pro-environmental. Still, the degree of actionability is low compared to a system that informs the users exactly what device or behavior is using how much electricity. This could be helped through the tagging feature discussed in section 5.3.11.

B.0.7 Personalization

The household can define events, or alarms, which will trigger once their criterion is met:

- Notify me when the current load on the power grid is over/below x% of the peak-load.
- Notify me when the household's average consumption in the current hour is over/below x kWh.
- Notify me if yesterday's consumption was higher than the daily goal I have specified.

These notifications improve the degree of actionability, as well as the system's decision support.

Also, personalization through the usage tagging feature, as discussed in section 5.3.11, would greatly heighten the degree of actionability and provide powerful decision support.

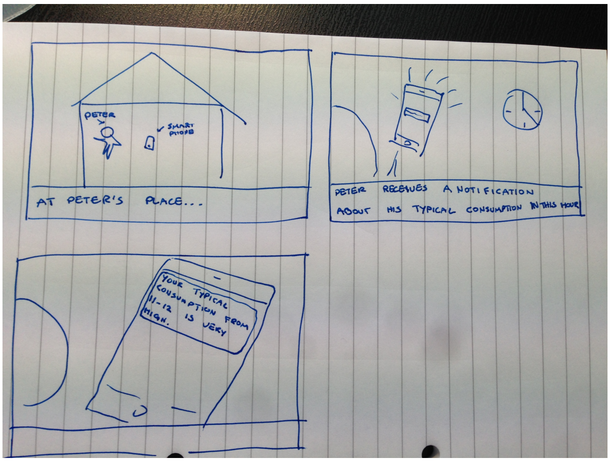
Appendix C

Design Evolution

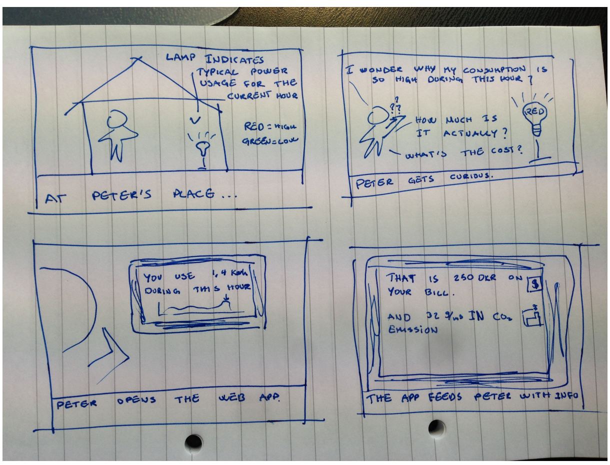
This chapter in the appendix contains some of the design artifacts from the evolutionary design phase of the eco-feedback system.

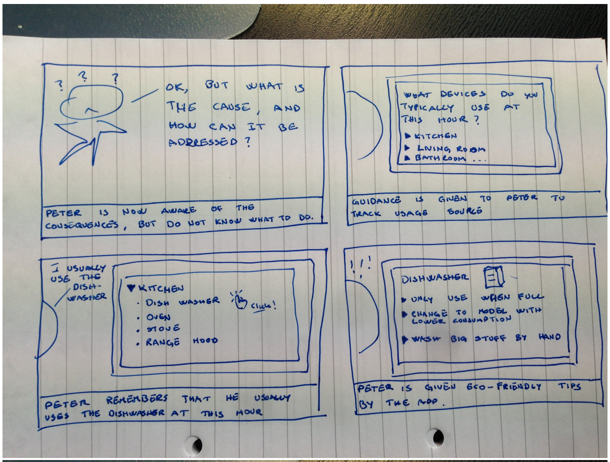
C.1 Storyboarding

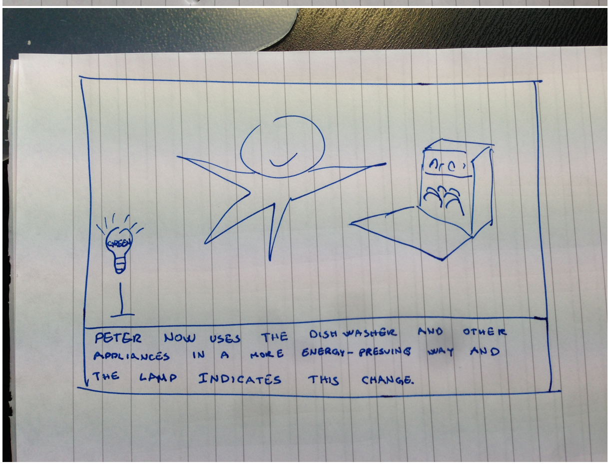
Through the conceptual design of the use cases for the system, the technique of storyboarding was used. For example, the following drawing tells the story of how the user, Peter, receives push notifications, when he enters an hour of the day, where his consumption tends to be high:



The drawings below show the interplay between the user, the Light Sphere, and the web-app from a user experience perspective:

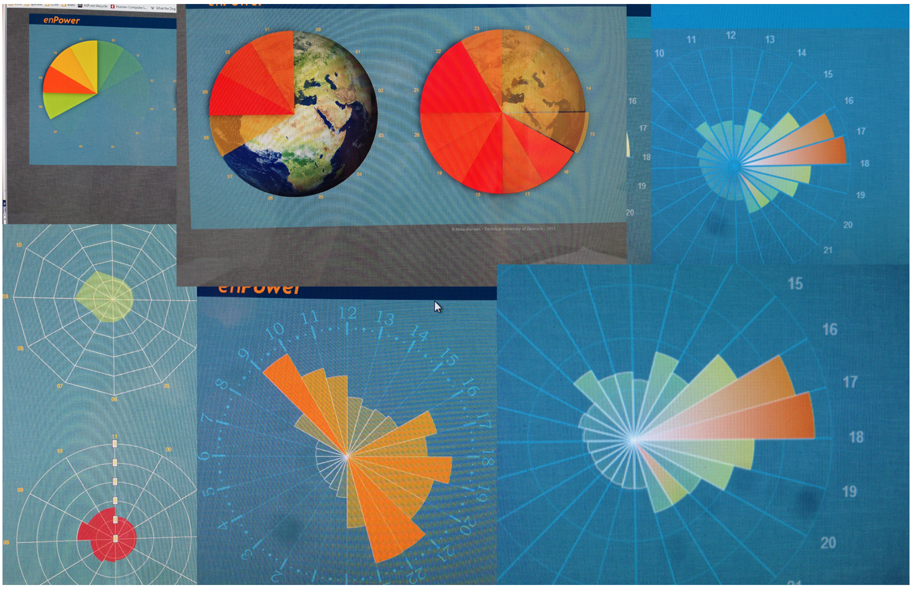






C.2 Prototyping

A lot of prototypes design were made for the user interface. The following image is a subset of the prototypes that were made for the 24-hour view, until the rose chart was chosen.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Appendix D

Fulfillment of Requirements

Requirement ID	Description	Fulfilled
1	The user should receive information and education about environmental issues when he is actively reviewing his energy expenditure. The system should deliver guidance to the user about how the environmental issues can be solved through pro-environmental actions.	Yes, e.g. through the energy advice dialog and saving tips prompts.
2	The system should clearly render visible the economical costs related to the user's electricity consumption. It should also visualize possible financial rewards related to conserving energy.	Yes, in all of the views, e.g. the 24-hour view, and the goal view.
3	The eco-feedback system should encourage moral reflection. This could be about how environmental issues affect nature and wildlife. The user's conserving behavior should be rewarded with achievements and symbolic rewards.	Partially. The home screen's background shows pictures of nature/wildlife, or pollution depending on consumption.
4	The system should favor intrinsic motivation over extrinsic by encouraging education and self-improvement over rewards and punishment.	Partially, through the goals and the ability to learn about energy advices.
5	It should be emphasized, for the user, that he has an impact on consumption aspects, such as the next energy bill, amount of emitted CO2, exploitation of sustainable energy sources, etc.	Yes (except exploitation of sustainable energy sources).
6	The system should create a feeling of guilt in the user, if the user performs poorly in regards of energy conservation. On the other hand, the system should create a feeling of satisfaction, if the user excels in energy conservation.	Yes, for example through the home screen background picture.
7	The system should deliver collectibles to the user, if the user conserves energy. The degree of conservation, as well as the amount of collected collectibles should be shared with other users.	Partially - the system compares the user with other users through a score board.
8	Information and education should be easy to understand, and easy to remember. Additionally, they should be delivered as prompts that are easy to spot, and given with high proximity to the behavior they concern.	Yes, but not with high proximity to behavior.
9	The user should be able to set a conservation goal of choice, for a desired duration.	Yes.
10	The system should deliver continuous feedback to the user on goal progress, and the degree of conservation compared to the goal.	Yes, daily emails are sent out, and the goal progress view can be used to track progress.
11	The system should be able to send out informative and attentional notifications to the users.	No.
12	The system should grade the household in accordance to the household's energy conservation performance.	Yes, but indirectly through comparisons with normal and efficient households.
13	The user should be able to post the household's performance to social networks.	No.
14	The eco-feedback system should function as a personal informatics system, and drive preparation, collection, and integration of data.	Yes, e.g. through reflection points.
15	The user should be able to navigate between different time resolutions, including, yearly, monthly, daily, and hourly views. Drill-down navigation between time resolutions should be made possible.	Yes.
16	The user's first encounter with the system should have an emphasis on the current amount of losses due to the practiced consumption behavior. The system should in general emphasize on potential loss over potential gain. This could be applicable to future projections, comparisons with historical data, etc.	Partially - the system encourages the user to create a goal as the first step. Here, the current losses are described to the user.
17	The eco-feedback system's user interface must be based on web technologies, in order be a platform independent.	Yes.
18	The user interface should be device- and platform-aware and have a responsive design that adjusts to the devices characteristics.	Yes.
19	The system can advantageously include a physical component that can raise awareness of the household's current consumption through ambient information that is understandable through glaceability.	Yes.
20	The system's ambient indicator device should create awareness about when peak-hours occur, and when the off-peak hours are located in the 24 hours of the day. The information should be delivered in an ambient, glanceable manner.	Partially - peak-hours are based on the household's own data, and not on city-wide, or national-wide data.
21	The system's ambient device should have a notification state that can signal notifications, and persuade the residents accessing the web-app.	No.
22	The system's ambient device should be able to deliver multiple types of information through ambience and glanceability.	Yes, however only one information is displayed on it at the moment.

Appendix E

Responses from Heuristic Evaluation

Title	Heuristic	Status	Severity	Tester
Man kan se menuen i login-siden, selvom den ikke virker. Er det meningen, eller er det en fejl?	1	Fixed		BA
Synes godt der kunne være grafer i emailen. Det ville se bedre ud.	1			BA
Mangler beskrivelse af hvor man befinder sig.	1	Fixed	Critical	KA
Måske du skal sætte maxlength på felterne i din oprettelses formular, men godt du har fået sat lidt validering på. Kunne måske godt gøres tydeligere, hvis kundenummeret er forkert. Men godt man nu får en besked om hvad der er galt som bruger	1	Fixed		KA
Når man første gang ser grafen tænker man "hvad er det?", måske også på grund af den manglende beskrivelse af hvilket punkt man er inde under, og man får ikke nogen hint når man holder musen over.	2	Fixed		BA
Jeg har svært ved at forholde mig til kWh. Aner ikke hvad det betyder i kroner og øre. Jeg kunne derfor godt tænke mig at den info var suppleret med en pris.	2	Fixed		BA
Tænkte ikke lige videre over det... Men måske man lige kunne lave en title til det også, hvor der står at det er et mål man kan følge...	2	Fixed		KA
Jeg kan ikke finde logge ud knappen???	3	Fixed	Critical	BA
Når man trykker på spare tips, så ved man ikke at man kan trykke på søjlerne, måske man skal lave en cursor: pointer, så det bliver til en hånd.	3	Fixed		BA
Måske det skal være muligt at sætte målet derinde hvor man også ser sit forbrug.	3	Fixed		MM
Jeg kan slet ikke bruge menuen på android. Den klikker et andet sted end jeg trykker.	5	Fixed		MM
Regner målsektionen rigtigt? Synes det er svært at validere	5	Afslået		MM
Det virker usammenhængende, at der kommer en dialog op, når man trykker på grafen i døgnvisningen. Hvad er sammenhængen?	6	Fixed		BA
Det tager alt for lang tid at vise forbruget pga. grafen der laver noget fancy animation i starten.	7	Fixed		AV
Feedback dialogen virker ikke, hvis man åbner, lukker og vil åbne igen.	8	Fixed		AV
Selection highlight har den samme farve som baggrunden.	8	Fixed		AV
Der er nogle layout fejl rundt omkring.	8			AV
Den tilsendte email (statusrapport) ser helt forkert ud. Jeg kan ikke se den nederste halvdel.	8	Fixed	Critical	BA
I øvrigt, så synes jeg analyse af grafen og sammenligning bør stå i samme side, for det er der man ser statistik om sit forbrug og kan sammenligne med andres. I venstre side kan man så navigere hvilken dag man vil hen til... Jeg synes det vil være mindre forvirrende hvis man deler det sådan op. Men det er selvfølgelig subjektivt	8	Fixed		BA
Når man trykker på spareråd, så er der et område I bunden af siden, som ikke er mørk, ligesom resten af baggrunden.	8	Fixed		KA
Der er står point idag + 40. dernæst total: 20?? Teknisk fejl? :P	9	Fixed		BA
Der kommer en hård ASP.net fejl, når jeg prøver at tilgå highscore.	9	Fixed	Critical	MM
Det er ikke muligt at logge ud. Den logger bare ind igen. (IE9)	9	Fixed	Critical	MM
Der er problemer med Internet Explorer 7, men det er ikke oplyst nogen steder, og der står heller ikke hvilken browser der anbefales.	10			AV
Det fremgår ikke helt tydeligt hvad man sætter et mål for?	10			BA
Tal for strømforbrug hos effktive forbrugere er sat for lavt efter min mening, for 2 voksne og 2 børn. Hvis man kigger hos DONG f.eks. så er den langt højere for 4 personer.	10	Considered		KA
Måneds analysen: Det vil også være rart hvis man kan lave en hover på søjlerne hvor de enkelt tal står.	10	Fixed		MM
Når man stiller et spørgmål, svare du/I så via mail? Det står ikke her hvordan i vil svare...	10			MM

Figure E.1: The responses received from the heuristic evaluation.

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