FORE-Watch - The clock that tells you when to use: Persuading users to align their energy consumption with green power availability

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Abstract. Besides saving energy, using it at the right time (i.e. when there is a supply surplus, and the power is produced by sustainable power sources such as hydroelectricity or wind) is an important possibility to achieve positive effects for the environment. To enable the user to align their behavior with the dynamics of the energy generation they need to be informed about the current status of power supply and grid capacity. Furthermore, to be able to plan their behavior and possibly delay or advance consumption activities to more proper moments they also need to have access to high-quality forecasts about the future status of green energy supply. In this paper we present an ambient display design solution based on a common watch that is optimized for providing this information in an unobtrusive, ambient and persuasive way. We present and discuss requirements identified by use of literature analysis, focus groups and end-user questionnaires, outline approaches to calculate basic power generation forecasts based on weather forecast data and present an ambient interface concept designed to meet the identified requirements. We conclude that the developed approach has high potential to support desired behavior changes, and that achieving acceptable accuracy levels for the generation forecast is feasible with relatively little effort.

Keywords: ambient display, persuasion, eco-feedback, user-centered design.

1 Introduction and Motivation

Ecological issues related to energy generation and consumption become more and more pressing, and new ways to address the arising challenges are needed urgently. Different means to help users in engaging in positive behavior have been developed, and ambient displays have been identified as very suitable means to communicate this information to the end-user. Recent work mainly focused on providing ambient feedback on the current energy consumption [e.g. 5, 6, 21]. Our work addresses the aspect of supporting people to plan their near future consumption behavior with the goal to align it with the availability of green energy (i.e. energy produced by sustainable means) thereby achieving positive ecological effects. This interest on developing methods and ambient interfaces for shifting consumption times rather than reducing consumption is generated by needs from smart grids and from user requirements.

An approach that received considerable attention in the past years is smart grids. The main idea here is to shift energy loads from peak demand times to times of less demand. Additionally, balancing of generation and consumption levels should take place at a local level as far as possible to avoid transportation losses and the need for high transportation capacities. Further details regarding power supply dynamics are discussed in section 1.1.

Recently different approaches have been developed to influence consumption behavior of users. Section 1.2 provides a detailed discussion of selected solutions and their advantages and disadvantages. One major conclusion of this analysis is that available solutions so far mainly provide feedback on energy consumption, and that there is a strong need for interfaces that support the users in planning their behavior according to ecological needs.

To successfully apply the concept in real life conditions we based the design of the ambient display on detailed user requirements collected by different means. Section 2 describes the process, methods and resulting requirements.

In Section 3 we then present our design solution – the FORE-Watch (**F**orecast **O**f **R**enewable **E**nergy - **Watch**) – and discuss it in the context of related work.

1.1 Power Supply and Smart Grids

Energy is generated by different means, and each country – depending on its natural possibilities and historic political decisions – has its own typical mix of energy sources. In the paper we focus on the example of Austria, but the basic dynamics are similar in different countries, and the general approach and methods can be applied with minor adaptations. In the case of Austria – due to its location in the Alps and the political decision to not use nuclear power – the typical energy mix is dominated by hydroelectric power (43.3% run-of-river plants and 19% reservoir power stations) followed by thermal power stations (33.9%) and wind (2.8%). Also, additional electricity needs to be imported to meet the demands [4].

Availability and production rate of green energy sources (mainly hydroelectric and wind power in the case of Austria) is highly depending on external factors most of which are related to different aspects of weather conditions. Another aspect that has to be considered in this context is the status and transportation capacity of the energy grid. The situation might arise that there is enough energy available, but not at the right place, and that the power grid is not able to transport the needed amount of energy.

Green electricity in Austria typically originates from three different sources: wind, hydroelectric generation and – to a much smaller extend – photovoltaic cells. All of these production modes are related in some way to the current or recent weather conditions. Also biomass is used in thermal power plants, however we do not further discuss this power source in this paper as generation of power by this means can be controlled by careful management and therefore is not of prior relevance with regard to inducing load shifts by consumers.

Possible output of a wind park is directly related to the wind speed. Based on knowledge of placement of major wind parks, their nominal capacity as well as localized forecasts of wind speeds it is relatively easy to develop a forecast of wind power production that is sufficiently accurate. For example, detailed forecast models are developed by the project *WindFX* at the University of Innsbruck [22].

The output of photovoltaic installations is directly related to the sunshine intensity and duration. Again, provided the location and characteristics and amount of installed photovoltaic elements are known, it is relatively easy to model and forecast the power generation of the photovoltaic cells.

The third relevant source of green energy in Austria is hydroelectric power. The power output of a hydroelectric power station is mainly related to the flow rate of water, which itself depends on the current and past weather conditions. As it takes time for water to drain off and collect in creeks and rivers, forecast of hydroelectric power generation is much more complex than in the prior cases. Fortunately, this is an active area of research, e.g. [8], and models of related areas especially flood prediction can be reused to develop accurate forecasts.

The typical temporal dynamics for these production means naturally possess different characteristics. Whereas production of wind power can change rather fast, the changes in the production of run-of-river power plants are much slower. These differences in the characteristics naturally need to be considered for the design of the persuasive ambient display, especially with regard to providing the users with actionable feedback – see section 3 for more details.

Besides these influences related to power production also the status of the grid and its power transportation capability needs to be considered for example to be able to estimate if the produced green energy actually can be distributed to the customers. Basically, the management of energy grid networks is based on the balance of demand and supply. To be able to do so already now different planning and forecast methods are used to be able to better match the supply with the demand [12], and these information can also be used as input for the calculation of recommendations for the users.

1.2 Persuasive technology and energy feedback for influencing energy consumption patterns

Within the recent years the utilization of different approaches and (persuasive) technologies for influencing the energy consumption patterns of the end users have been developed [7]. Existing methods to manage (i.e. reduce or temporarily shift) power consumption could be clustered into three main approaches.

First, paper-based efforts try to make energy consumption more visible by increasing the frequency of the traditional paper-based bill. People receive their energy bill more frequently e.g. every month compared to once a year.

Second, dedicated software programs visualizing the present and previous energy consumption across time were developed. Thereby users can compare e.g. their monthly consumption. Example systems for this approach are the *PowerMeter* by Google [10], *Hohm* by Microsoft [18], and *GreenPocket* [11]. *Hohm* and *PowerMeter* are accessible through web, whereas *GreenPocket* is available as smartphone app.

Third, dedicated ambient devices within the user's home are used to provide information for the consumer. Ambient devices are characterized by a high stimulating nature and therefore have the possibility to attract the users' attention, make consumption visible in real time and support behavioral change. *Wattson* [21] for example provides real-time information about the actual energy use in kilowatt hours (kWh) as well as monetary values. Additionally it glows in different colors depending on the amount of used energy. This feature is also used by the *Power-Aware Cord* [13], which represents energy consumption through glowing pulses, color, and intensity of light. Another system that guides energy consumption is called *Energy Orb* [6]. This orb provides visual feedback whether at the present moment it is relatively good or bad to consume energy. The *Energy AWARE Clock* [5] provides feedback on the past energy consumption on the clock-face thereby enabling the users to develop a good overview and understanding on their past consumption patterns.

1.3 Effectiveness of energy feedback/management methods

The general goal of the described methods is to make energy consumption more transparent to the individuals and thereby initiate a behavioral change towards a more pro-environmental management of energy. Consequently, there is high interest in evaluating and quantifying the achievable effects, to compare the effectiveness of different approaches, and to study which effects the introduction of different methods has on the everyday life of people.

Darby [2] provides a comprehensive meta-analysis of numerous empirical evaluations on the effectiveness of different types of energy feedback. Feedback which is provided in real-time from a display monitor is labeled *direct feedback* by her. A typical example for this kind of feedback is the above-mentioned *Wattson* system. Achievable savings using this approach are between 5 and 15%. Besides this direct feedback effectiveness of indirect feedback was analyzed. Information that is provided through *indirect feedback* has been processed before reaching the energy consumer and does not use real-time data. Typical examples are paper-based bills or the above-mentioned Google *PowerMeter* and Microsoft *Hohm*. Identified effects on savings for indirect feedback reach from 0-10%. Darby argues that this wide range of effects is described through the quality of information that is prepared for the end-users. To describe how best cases of feedback are designed, Fischer (2008) has reviewed 29 published studies. According to her, computerized feedback with interactive elements works best.

2 Identifying Design Requirements

Starting point for the design work was our goal to design an ambient device that allows users to align their energy consumption with requirements from production and distribution within the grid as described above. The design process was based on input from different sources, both theoretical and user-based.

2.1 Requirements Identified in Related Work

Energy-consumption-related information is traditionally provided through websites, smartphone applications, home displays, ambient devices but also paper-based efforts. Several scientific research studies and analyses describe how users interact with those technologies and how they process this data e.g. [2, 7, 15, 16]. In the following we focus on four main requirements from a user perspective, which we incorporated for our work.

First, there is the question about how to present the information about energy consuming behavior to motivate a long-term change. Studies showed that kilowatt hours or CO_2 units are hard to understand for the traditional users [2], which leads to the fact that people prefer monetary units in energy-related displays [15]. However, financial savings are not a long-term motivator for a behavioral change [15, 20]. Jaccuci et al. [16] suggest that the main energy feedback should address knowledge and action synergically, and that it should be combined with energy conservation tips to increase the impact of the feedback.

Second, feedback is traditionally provided based on past or present energy consumption (e.g. information about the total consumption of the previous day/week/month, or also real-time information). There is no possibility to change this amount of energy consumption any more, and for the future there is also the question about how to change consumption. Consequently there is the need to instruct consumers about how to behave in the future. Tailored suggestions and energy-saving tips are therefore highly important to guide the users for the future [7].

As a *third* main aspect we want to mention is comfort. Energy consumption is highly associated with comfort. Gerdenitsch et al. [9] for example studied behavioral barriers that prevent energy-savings within the domestic context. Results showed that besides a lack of attention (e.g. forgetting), comfort is a major barrier. According to this study it is important to allow people to satisfy their needs of comfort, but at the same time to also inform them about potential savings.

Finally there is the requirement of tailoring the feedback. Some kind of personalization of energy-related information on the specific socio-demographic, behavioral and also contextual variables is recommended by several authors [1, 7, 16]. Midden et al. [19] also pointed out that tailored feedback is more effective than comparative feedback. Also results of a literature review by Fischer [7] suggest tailoring the information given to the motives and also norms of the specific target group.

2.2 Requirements Identified in a User Interface Workshop

As a follow-up on previous work and studies, we conducted a co-design workshop based on the inspiration card technique [14], which was already successfully used in other research projects that focused on sustainability [3]. The purpose of the requirements and design workshop was to collect and identify requirements and ideas for the design of ambient interfaces with the goal to persuade people to save energy. 52 inspiration cards were prepared and used as basis material for the workshop. The cards focused on the following areas: visualization, electricity devices, state-of-the-art ambient displays, motivation slogans, household areas/rooms, state-of-the-art energy saving interfaces, different granularities of information (overview vs. detail), different types of information (money saved, energy tips, energy saved compared to other, etc.), and timing aspects (energy saved today, last month, last year, etc.). The 6 participants were split up into 3 groups of 2 with the task to combine the inspiration cards into the ideal ambient persuasion interface for energy information. The results were discussed and analyzed both together with the participants and post-hoc by the researchers, and the following main requirements could be identified:

Placement. Two main spots could be identified as good placement opportunities for ambient energy displays: First the kitchen, as that's the place where people come together. Second, the antechamber, as that's the place where one notices a display before leaving or when coming home.

Information. Participants wanted a simple presentation of energy saving potential for the current situation of their specific household as well as a suggestion of several options how to save energy. General and unspecific tips (such as e.g. switch of the lights when not used) or household changing tips (e.g. buy energy saving devices or don't use a game console) were not appreciated.

Timing. The information should be visible the whole day and the user can decide when to take action. Also users would like to have timely feedback to see that a behavior modification actually changed their energy consumption.

Attractiveness. Participants did not want a novel "electric device" (such as the *Energy Orb* or *Wattson*), but something attractive or something they can hide, e.g. inside of a kitchen cupboard.

Social Rewards. Participants did not want to have a direct social comparison in energy saving behaviors between household members or neighborhood.

Reduction. Participants only wanted very reduced information, with the focus on when and how one could save energy in the household to be „in the green" (independently of how green is defined, money, nature, etc.).

2.3 Requirements Identified in Online Survey

To further inform design we were also interested in learning which energy-consuming everyday activities such as cooking, washing and ironing consumers are willing to shift or delay, and how big the temporal window for this actions were. An online questionnaire was used to collect data from volunteers regarding these questions. The questionnaire listed ten common activities and users where required to answer whether they are willing to postpone or shift this activity and in case of yes, for what amount of time in the maximum.

Additionally, participants were asked the same question with regard to recharging electro-vehicles. This is not yet a common activity, however recharging vehicles is expected to have great impact and opportunities for the smart grid and shifting demand loads.

A total of 66 users (23 male, 43 female, average age 31.2 ± 8.93 years) filled in the questionnaire. As we suggest the housing situation as a main mediator variable we asked participants about their actual status. Most of the participants (60.6%) resided together with one other person, 24.2% of participants lived alone, and 15.2% lived with three to five people in the same household. Table 1 summarizes the main results from the questionnaire.

Table 1. Results from online questionnaire regarding willingness to shift activities according to ecological needs

	Number of valid answers	Mean	Median	Minimum	Maximum
Cooking	65	1h:34m	1h:30m	0h:00m	3h:00m
Dish washing	65	12h:44m	6h:00m	0h:00m	48h:00m
Washing machine	64	21h:25m	24h:00m	0h:00m	48h:00m
Entertainment electronics	61	3h:38m	0h:00m	0h:00m	48h:00m
Showering/bathing	63	2h:17m	1h:30m	0h:00m	24h:00m
Vacuuming	62	25h:54m	24h:00m	0h:00m	48h:00m
Ironing	50	26h:23m	24h:00m	0h:00m	48h:00m
Blow-drying & shaving	62	4h:55m	0h:10m	0h:00m	48h:00m
Cleaning	63	24h:26m	24h:00m	0h:00m	48h:00m
Gardening	49	29h:25m	48h:00m	0h:00m	48h:00m
Charging electro-vehicle	31	9h:44m	2h:00m	0h:00m	48h:00m

Analyzing the results from the questionnaire, we can identify two distinct planning horizons for the end users. A first set of activities is directly related to personal needs (e.g. cooking, personal hygiene), and users are only willing to shift actions in a very narrow time window, typically 10 to 30 minutes. A second set of actions is related to different housekeeping activities (e.g. cleaning, washing, and vacuuming). Here the time window for shifting actions is much bigger, and typically users are willing to delay actions for one day (24h). Therefore, the ambient display should be able to communicate the action guidelines for two different time horizons.

Short term planning. First, the ambient display should be able to communicate the green energy forecast for the next 12 hours very precisely. Additionally, the display needs to provide a sufficiently detailed temporal resolution to allow people to plan short-term activities.

Medium term planning. Second, the display should support the planning of activities with regard to a medium term perspective (i.e. one day). In contrast to the short term planning no detailed temporal resolution should be displayed, as the forecast information will be not very adequate, but an overall recommendation (whether to delay activities for one day or not) should be provided.

3 Design Solution: The FORE-Watch

Based on the identified design requirements and also influenced and inspired by related work (especially the energy aware clock [5]) we developed a design solution we call the *FORE-Watch*. The central design element of the solution is a common and fully functional clock. The clock is enhanced with three additional items: the outer ring, the inside gauge and the history view (see Figure 1).

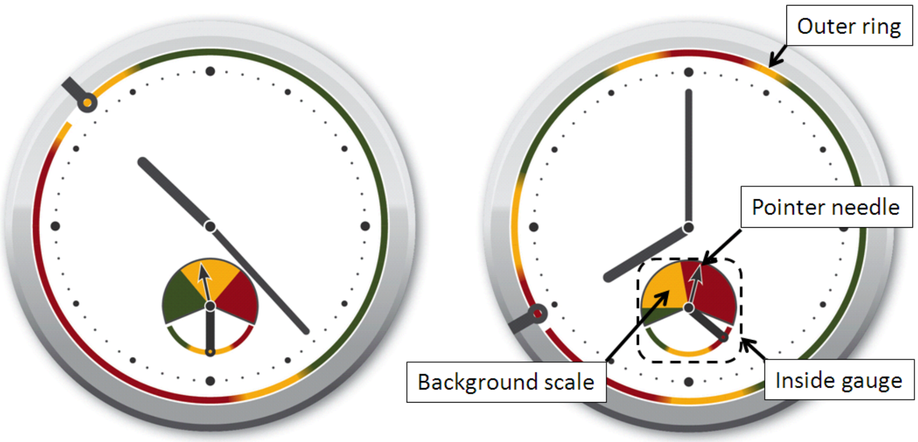

Figure 1. The FORE-watch design shown in two different situations

The outer ring. The main function of the outer ring is to display the forecasted availability of green energy for the next twelve hours. Availability is displayed coded in the three traffic light colors: green indicates there is plenty of green energy available, yellow that there is some green energy available and red, that it is expected that there will be a lack of green energy. This display allows the users to immediately perceive the forecast for the next hours, and to also see this directly in context of time. Therefore it supports the users to make decisions whether they use energy for required tasks immediately or whether they want to shift the activity to another time slot. For example a user might delay starting the dish washer until after having been gone jogging, in case the outer ring shows that green electricity probably will become available only one hour later.

The semantic color-coding of the forecast (i.e. whether the outer ring shows green, yellow or red) is calculated relatively on basis of the forecast for the next twelve hours, not absolute. Individual forecast values for the next 12 hours are calculated, and moments with values in the top third of this period are shown green, the middle third yellow and the lower third red. This is done to always provide meaningful possibilities to act more sustainable for users within this time frame. This is especially important because of the temporal characteristics of hydroelectric power generation. Generation here changes very slowly, and using absolute or long term instead of relative and short term calculation methods would result in an undifferentiated display (e.g. only showing red for the next 12 hours) that doesn't allow users to adapt their behavior within their limited temporal horizon for planning activities (compare section 2.3).

The inside gauge. The inside gauge consists of two main elements. The pointer needle and the background scale. The pointer needle shows the current amount of energy consumption of the household which is provided by a smart meter.

The rotatable background scale provides a semantic indication (again using the three traffic light colors) whether the current consumption is low (pointer needle in front of green segment on background scale), average (yellow) or high (red). In contrast to other design solutions the semantic definition of what is ‘good’ or ‘bad’ is not static but influenced by the current status of availability of green energy. In the interface this is indicated by the rotatability of the background scale, which is adapted in real time. To communicate the link between the status of the availability of green energy (indicated by the position of the short hand on outer ring) and the degree of rotation of the background scale the background scale is equipped with a handle that moves over an arc which shows a color gradient from green through yellow to red. The similar indicator symbols at the short clock hand and the handle of the background scale are designed to communicate this connection to the users.

History overview. A third functionality that is provided by the clock is that it allows viewing a historical record of one’s own behavior. To not annoy the users with too much visual clutter, this overview is only visible at explicit request by tapping anywhere on the clock face. The display automatically disappears after a short activation time of 5 seconds. In contrast to most existing approaches the clock however shows a weighted consumption history. The view shows the cumulated time the user spend with their pointer needle over the red, green and yellow area of the background scale.

Tomorrows Forecast. Together with the history overview the user also activated the display of the forecast for the next day. The feedback contains an overall estimation whether delaying consumption options is a recommended alternative or not based on the current forecasts.

3 Future Work

The next step in the development of the *FORE-Watch* is the long-term evaluation of its effectiveness in real conditions. Within the PEEM project (http://peem.cure.at) *FORE-Watches* will be installed in 30 households and be running there for at least 9 months. Electric power consumption will be measured and recorded in real time. Effects of the *FORE-Watch* will be evaluated both, quantitatively and qualitatively. We’ll compare the power consumption patterns with the predictions and analyze whether significant effects in consumption shift can be found. Qualitative data from interviews with household members will further help to understand the dynamics of the *FORE-Watch* on consumption behavior.

Besides the evaluation of the approach we will look into applying the concepts and design solution to similar areas. We are especially looking into the areas of solar energy plants, traffic density, local production of energy, and price development.

References

1. Abrahamse, W., Wokje, A., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology, 25(3), 273–291.
2. Darby, S., 2006, The effectiveness of feedback on energy consumption. A review for DEFRA of the literature on metering, billing and direct displays. Environmental Change Institute, University of Oxford.
3. Davis, J., 2010, Participatory design for sustainable campus living. In Proceedings CHI Extended Abstracts. ACM, New York, NY, USA, 3877-3882.
4. E-Control: Ökostrombericht 2009
5. Energy AWARE Clock, http://www.tii.se/node/5984
6. Energy Orb, http://www.ambientdevices.com/cat/orb/PGE.html
7. Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? Energy Efficiency, 1, 79-104.
8. Garc, M.B. & Dubus, L., 2007. Forecasting precipitation for hydroelectric power management: how to exploit GCM ' s seasonal ensemble forecasts. International Journal of Climatology, 1705, pp.1691-1705.
9. Gerdenitsch, C., Schrammel, J., Döbelt, S., Tscheligi, M. (2011). Creating Persuasive Technologies for Sustainability – Identifying Barriers Limiting the Target Behavior. Persuasive 2011.
10. Google PowerMeter, http://www.google.com/powermeter/about/
11. GreenPocket, http://www.greenpocket.de/
12. Gross, G.; Galiana, F.D., 1987, Short-term load forecasting. Proceedings of the IEEE, Volume:75, Issue:12.
13. Gustafsson, A. & Gyllenswärd, M. 2005, The Power-Aware Cord: Energy Awareness through Ambient Information Display. In Proceedings CHI 05, ACM, NY, USA.
14. Halskov, K. & Dalsgard, P., 2006, Inspiration card workshops. *In Proceedings of the 6th conference on Designing Interactive systems (DIS '06).* ACM, New York, NY, USA, 2-11.
15. Hargreaves, T., Nye, A., Burges, J., 2010, Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy 38, 6111-6119.
16. Jacucci G., Spagnolli A., Gamberini L., Chalambalakis A., Björksog C., Bertoncini M., Torstensson C., Monti P. (2009). Designing Effective feedback of Electricity Consumption for Mobile User Interfaces. PsychNology Journal, 7(3), 265 – 289.
17. Kollmuss, A., Agyeman, J., 2002. Mind the Gap: why do people act environmentally and what are the barriers to. Environmental Education 8(3), 239-260.
18. Microsoft Hohm, http://www.microsoft-hohm.com/
19. Midden, C.J.H. ; Meter, J.F.; Weenig, M.W.H.; Zieverink, H.J.A. (1983) Using feedback, reinforcement and information to reduce energy consumption in households: A field-experiment. Journal of Economic Psychology, 3(1), 65-86.
20. Neuman, K. (1986). Personal values and commitment to energy conservation. Environment and Behavior, 18 (1), 53-74.
21. Wattson, http://www.diykyoto.com/uk
22. WindFX, University of Innsbruck, http://imgi.uibk.ac.at/dynamics/windfx