The impact of user interface design of eco-feedback systems on consumer behavior

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Abstract—Saving energy in buildings has become and remains a major issue for the planet. The last decade, systems have been developed to provide consumers with information about their energy consumption. Research has shown that the type of information displayed and the techniques used to present it have an impact on the user energy saving. This raises the question about how to display the information to the consumer in a comprehensive, attractive and non-intrusive way.

In this paper we compare and discuss the various methods of visualizing energy usage for consumers. Some of the design components of user interfaces such as historical comparisons and presentation of costs are more likely to aid in providing the consumer with an understanding of his energy usage and changing his behavior. We will extract the most effective methods from research and surveys.

The comparison of the different methods is based on the reduction of energy usage of consumers using such eco-feedback systems and if consumers keep using the eco-feedback systems for longer periods of time.
Little work has been done in the design of eco-feedback systems. We expect to find the most effective methods to visualize energy consumption data for future eco-feedback systems.

Index Terms—Eco-Feedback, interface design, energy consumption, consumption feedback systems, energy feedback

1 Introduction

Reducing energy usage in buildings still remains a major challenge.

One method of reducing energy consumption is by increasing the awareness of consumers about their energy consumption using eco-feedback systems. These are systems with integrated sensors that provide the consumers in the building with information about their energy usage. The goal is that this leads to more energy efficient behavior by the consumers in the building.

However, research has shown that the type of information displayed and the technique used to present it have an impact on the user behavior. For example, studies have demonstrated that the information provided must be intuitive, clear and simple and the UI attractive and not too intrusive (e.g. not too many notifications) so that the users keep using it and is integrated in their everyday life[9].

This means that the design of the user interface is a key factor in changing the user's energy consumption behavior and raises the question of what the most effective methods to visualize energy consumption data for future eco-feedback systems are.

Our goal is to investigate the different ways to display to the users their electricity usage. The main UI components of eco-feedback systems are: historical comparison, presentation of costs, incentive, reward and commitment. From those components we want to extract the most effective ones: the ones which are more likely to help users save energy.

Based on previous surveys we are going to compare the effectiveness of different eco-feedback systems by comparing the reduction in electricity usage. Additionally, we will combine the results/responses of surveys and interviews with users of such eco-feedback systems, to assess the effectiveness of different UI components.

2 User Interface components

Developers have been implementing different types of applications which can be classical eco-feedback systems or either games (ex ***) to make it even more attractive to the users and increase engagement.

Not only the kind of information displayed and the method of display are important, the aesthetics are also relevant for the engagement, pleasure and interest of the user[1].

These eco-feedback systems are available on smart meter, personal computer, mobile devices and house/wall displays.

In most of the eco-feedback systems some design components are often encountered. In this part they will be defined and later we will discuss their effect on users changing behavior in order to elect the most effectives ones.

Feedback Three types : Direct Indirect Inadvertent Presentation of costs

2.1 Comparison

Two types of comparison are often presented: historical and normative comparison. Historical comparison is defined as the ability of users to view their current consumption relative to past consumption . The historical comparison can be displayed on a daily, weekly, monthly or yearly basis. It is used in the majority of eco-feedback systems, because it can be easily understood by the users, especially thanks to the graphs mode display. Observing those graphs help them reminding their behavior (why they used more energy this particular day for example) and in consequence change their bad habits.

Most of the time in the historical comparison factors such as weather or households leaving for vacation are not taken into account so absolute values are analyzed whereas they should have been normalized first. Some improvements in the eco-feedback systems take those fluctuations/changes into account for more accuracy and consistency.

So the historical comparison deals with comparison with the household's prior consumption whereas normative comparison deals with comparison at a local, regional level or in a neighborhood. The effectiveness of the normative comparison comes from the fact that users are influenced by social norms and pressure, seeing for example that their neighbors consume less energy than they do should encourage them to do the same. It has been seen in previous research that such normative comparisons can lead to significant reductions in electricity usage[6, 8, 3].

We will see in the Survey part that the historical comparison is the most effective one.

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2.2 Goal setting

Environmental psychology departments have demonstrated that users need to find motivation in order to change their behavior. Some eco-feedback systems provide goal settings design components: the users can set the goal themselves or they come from the software itself or the community of users of the eco-feedback system. An example of goal a goal could be: 'reduce your energy consumption to 10% from the previous month'. Every household consumes in a different way. Therefore, households in the same neighborhood are not likely to have the same goals. Eco-feedback systems can aid users to reach their goal thanks to tips and advices. To create an energy saving positive dynamic the eco-feedback system should reward their users when they reach their goal.

2.3 Disaggregation or appliance specific breakdown

Disaggregation or appliance-specific breakdown allows consumers to have a better understanding about which appliance consumes what so it is easier for them to change a particular behavior. It helps consumers to understand the impact of a specific behavior or the use appliance to answers questions like "if I let the TV on for 5 hours, how much do I consume?".

Rewards & penalization allow users to earn rewards if they reduce their energy consumption or in the contrary to be penalized if they waste energy. A system of rewards and penalization encourages behavior that leads to energy conservation and discourage wasteful behavior.

The incentive design component is related to the rewards & penalization design components. Users can be rewarded in a financial or non-financial way. Financial incentives can be credit on a electricity bill and non financial incentives can be prices such as an energy efficient lamp or reaching higher levels in the game. Previous research [7] has shown that incentives can result in significant electricity use reductions.

3 Presentation of the information inside the components : graphical, numerical and textual presentation

In this section the following questions will be answered : What is the best and most effective way to present the information inside the key design components identified in the previous part ? What do the users understand easily texts or graphs ? Kind of presentation that the users prefere graphical vs Text =¿ guidelines of Smith and Mosier More information about the chart pie, bar chart, tabular presentation understanding among users.

4 The Surveys

Several studies researching the effectiveness of consumer feedback on electricity consumption have been done before. This section will discuss the results of some of these studies.

In a study from S. Karjalainen[5] from 2010, interviewing and paper prototyping were used to find the best ways to present information for maximum energy reductions. In this study, interviews with consumers were held to find out about their attitude towards energy monitoring and what kind of feedback they understand and prefer.

The qualitative interviews showed that 8 out of 14 interviewees actively try to save electricity at home, while all 14 responded they want to monitor electricity consumption. The interviewees also indicated that they prefer to receive feedback via a bill, web page or dedicated wall display rather than a mobile phone.

Additionally, 8 paper user interface prototypes were developed. Table 1 shows an overview of the UI components present in these prototypes.

The prototypes were shown to consumers, to find out how well these interfaces are understood by them. The prototypes were displayed to the consumers one by one and after showing all the prototypes, they were asked if they understood the prototypes and asked to choose the prototype they would prefer to use themselves.

Table 1. Overview of information presented in the different prototypes by Karjalainen[5]

	Prototype							
UI component	1	2	3	4	5	6	7	8
Historical comparison	×							
Normative comparison		×	×					
Goal setting		×						
Consumption (kWh)	×	×				×	×	×
Power (W)				×	×			
Costs (Euro)		×				×		
Environmental factor (kg CO_2)			×					
Household total	×	×	×	×	×	×	×	
Disaggregation day/night							×	
Disaggregation by device					×	×	×	×
Chart	×			×	×		×	×
Other pictorial		×	×					
Table						×		
Other numeric		×	×		×			×
Textual			×					
Chooseable time period		×	×	×		×	×	×

Table 2. Nr of participants that understood and preferred for each of the prototypes. Total participants: 14.

	Nr of participants that understood prototype	Nr of participants who preferred prototype
Prototype 1	14	1
Prototype 2	14	1
Prototype 3	8	0
Prototype 4	12	0
Prototype 5	7	1
Prototype 6	14	7
Prototype 7	13	1
Prototype 8	14	3

The results of the survey can be seen in Table 2. Most prototypes were understood by the participants. Problems with understanding were mostly due to the fact that many people are not familiar with the scientific units used and do not, for example, understand the difference between W and kWh. Secondly, people in general do not understand how CO_2 emissions relate to energy consumption. In contrast, information presented in charts and tables is understood easily by the participants.

Participants were also asked some general questions about how important they find certain aspects of eco-feedback systems. The questions were answered using a scale of 1 to 5, where 5 was very important and 1 not important at all. The question with the average of the response of the 14 participants can be seen in Table 3.

Table 3. General questions about eco-feedback systems

Question (*How important is it to...*)	Avg.
be able to compare your household's consumption to other households?	3.6
be able to compare your consumption to your prior consumption?	4.4
have a target level for consumption?	3.5
know the consumption of individual devices?	4.1
receive information on actions which would save energy?	3.9

The results of this study by Karjalainen found the following UI components most valued by consumers: presentation of costs, device-specific breakdown of energy usage and historical comparison.

Research from 2010 by Peschiera et al.[6] provides more insight into the effectiveness of the *normative comparison* component. In their study, they tried to find out if there are differences in energy savings when participants only view personal electricity usage information versus participants also viewing average building occupant usage and usage of peers in their personal network.

To examine if such normalized comparison information motivates electricity-saving behavior, they fitted 83 rooms of a dormitory building in New York City to measure the electricity usage.

They divided the occupants participating in the study into four distinct groups:

- *Group A* – ability to view individual historical comparison with past vs. present utilization.
- *Group B* – same as group A, but with additional ability to view individual vs. average electricity usage of all other participating occupants.
- *Group C* – same as group B, but with additional ability to view electricity usage of peers in that individual's network.
- *Control Group* – No access to electricity usage information.

At the start of the study, occupants received an email explaining how to access their personal electricity consumption reports. During the study, they received several more notification emails to remind them that their electricity usage report was ready.

Three days after the initial email, the average electricity consumption for Group C was 34% lower than the consumption of the Control Group and 20% lower than the consumption in the period before the study. After sending the second consumption notification email, the average electricity consumption dropped to 45% below that of the Control Group (28% less than before the study). Group B only saw a significant reduction after the second notification email and Group A did not have a significant improvement.

These results show the added value of using electricity consumption data from peer networks (*normalized comparison*) in reducing consumers energy consumption.

Another study from R.K. Jain et al.[4], a prototype eco-feedback system was built, with five key design components:

- *Historical comparison* - ability to view historical electricity consumption in three modes (24h, to date and last week)
- *Normative comparison* - ability to view the average electricity consumption of friends
- *Rewards and penalization* - ability to get points or lose points based on consumption behavior
- *Incentives* - ability to redeem points for prizes
- *Disaggregation* - ability to find out the consumption of specific devices

The prototype was designed to allow users to go to any of the key design components with a single click from the main view.

The system gathered and stored data on logins and use of the system in a database for later analysis.

Participants were divided into three groups: one group had access to room-level electricity usage data and consumption information for participants in their peer network added to the historical comparison graphs. The second group only had access to the room-level electricity usage data. The third group was a control group without access to the eco-feedback system.

The researchers formulated and tested three hypothesis, namely:

Table 4. The results for the first hypothesis

	Users who reduced consumption	Users who increased consumption	p-value
Mean user logins	5.13	2.60	.028

Table 5. Correlation between user logins and the use of specific design components

Mean user logins by component used	Users who used feature	Users who did not use feature	p-value
Historical comparison	4.61	1.67	.0009
Normative comparison	5.00	2.40	.12
Incentives/rewards	4.49	1.25	.0001
Disaggregation	4.60	4.00	.64

1. Users who reduced their energy usage relative to the control group, will have visited the eco-feedback system more often than users who increased or maintained their energy usage.
2. Users that use: historical comparison, normative comparison, incentives/rewards or disaggregation will login more than users that do not use this feature.
3. The sign of the number of reward points a users views on their first login correlates with the number of times a user will log into the eco-feedback system.

In Table 4, the results of performing an analysis of the login data can be seen. The data in this table confirms the hypothesis that users who decreased consumption logged in more often (almost twice as often) than users with an increased consumption.

Table 5 shows the correlation between logins and use of specific design components. From these results, it can be concluded that users who used the *historical comparison* feature, on average logged in 3 more times that users that did not use that feature. Additionally, users that used the *incentives* feature logged in more that 3 additional times compared to users that did not use that feature.

For the *normative comparison* and *disaggregation* features, the p-value is not significantly low to reject the null hypotheses.

In Table 6, the results for the third hypothesis can be seen. Users who viewed a positive number of points on their first login, logged in 2.5 more times than users that got to see a negative number of points on their first login.

In another paper, Erickson et al.[2] build a city-scale eco-feedback system aimed at reducing electricity consumption. The system provided households with fine-grained feedback about the electricity usage and has incentives, comparisons and goal setting for encouragement to save energy.

The user interface of the portal can be seen in Figure 1. It is divided into 6 bands:

Table 6. Correlation between the sign of the number of points on first visit and number of logins

	Users that viewed positive points	Users that viewed negative points	p-value
Mean user logins	4.79	2.10	.0059

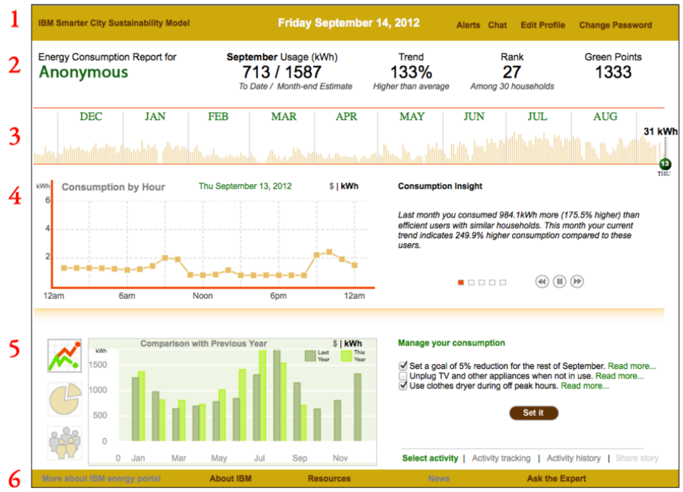

Fig. 1. The electricity portal divided in the 6 bands.

1. Header, with date and menu access.
2. User name, usage to date, estimate of current month's usage and three incentives: trend (for self comparison), rank (among other households) and 'green points', which can be collected with actions such as completing one's profile.
3. Daily electricity usage displayed in kWh or in dollar.
4. A graph of todays consumption and a textual comparison of the users electricity consumption.
5. A graph allowing users to view their energy usage compared to the previous year, broken down by load or compared to 30 similar households. It also has a component where users can view and set their goals.
6. Links to general information.

The portal was made available 765 households in a few contiguous neighborhoods in the city of Dubuque in the United States and the project ran for about 20 weeks. Use of the portal was logged and surveys and interviews were held to find out about the experiences of the users of the portal.

Out of 765 households, 266 (35%) logged into the portal at least one time. In the survey, respondents were asked to estimate how often they used the portal. The responses were as follows:

1. five or more times per week – 12%
2. about once a week – 18%
3. occasional use – 31%
4. rare use – 25%
5. not applicable / do not recall – 14%

In the survey, participants were also asked about the UI components whether they usually looked at them, if they needed more explanation, if it helped them to better understand their electricity consumption and if it encouraged them to undertake action. The responses in percentages to these questions can be seen in Table 7.

The first four components, which are the most looked at are all time-based graphs/metrics.

All 266 participating households reduced their electricity usage. Compared to electricity consumption of the previous year, they saved on average 31,817 kWh during the project. This amounts to a monthly reduction of 3.7%. In the survey, 69% of the respondents indicated that the portal increased their understanding of how they consume electricity.

Table 7. The UI components, ordered by popularity with the answers by participants to questions in percentages

	Usually looked at it	Was entirely clear	Helped to understand use	Encouraged to act
Consumption timeline	93%	53%	76%	49%
Consumption by hour	87%	53%	79%	52%
Comparison with previous year	87%	55%	58%	44%
Monthly usage	81%	49%	58%	45%
Consumption insights	77%	38%	46%	47%
Comparison with neighbor	67%	33%	30%	28%
Consumption by load	64%	40%	48%	31%
Trend, Rank, Points	64%	32%	41%	44%
Manage your consumption	62%	46%	34%	35%
Alerts	32%	33%	24%	19%
Facebook chat	10%	27%	1%	1%

5 Results

The previous parts and the guidelines that some eco-feedbacks systems researches have established allow us to extract some requirements that the UI of eco-feedback should meet in order help the developers implementing softwares as effective as possible for the users. In the first subsection "famous" guidelines will be presented and in the second one the list of requirements.
List of requirements : Sustainability, Non-intrusiveness , Intuitiveness.

6 Conclusion

In this paper, we looked at different user interface components used in eco-feedback systems. Based on several studies, we conclude that problems with understanding these interfaces for consumers are often caused by unfamiliarity with the scientific units used or how CO_2 relates to electricity usage.

Out of several studies, it can be concluded that interface components that present information in charts and tables are easily understood by consumers, especially when they concern time-based graphs/metrics. Most valued by consumers are UI components that present information about costs, per-device-breakdown of electricity usage and historical comparison.

It can also be concluded that using electricity usage information from peer networks can lead to more consistent energy saving when compared to only showing the users own electricity usage.

The use of incentives to motivate consumers to save electricity is also effective in making consumers use the eco-feedback system, especially when they start with a positive number of points.

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