RWTH AACHEN UNIVERSITY

Designing an Energy Consumption Visualization for an End User Home Automation Display

Thesis at the
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I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

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Aachen, August 2012
Konstantinos Tsoleridis

Contents

List of Figures

List of Tables

Abstract

The past years energy consumption has become a topic of public interest. People use more and more electrical devices in their homes which leads to an increased electricity consumption. Furthermore people are not always aware of the increased consumption these devices lead to. This lack of consciousness is an effect of missing feedback because energy is neither visible nor tangible. This thesis describes our efforts to build an iPad application that visualizes the energy consumption for end users. After researching existing solutions for the problem we decided that we need two kinds of visualizations. One that is suitable for scenarios where users want to get a quick overview about which energy consuming devices are turned on in their home, or in time-sensitive cases where estimations and decisions have to be taken fast. Maximizing the effects of the solar energy produced from photovoltaics is such a case. For these cases we designed a new power and energy measure which we call *Point*. On the other hand, to help users conserve energy in scenarios were more variables and parameters influence the energy consumption, we decided to create graphs that visualize quantitative data. We created three kinds of graphs: graphs that provide evidence through the visualization of influencing parameters, graphs that help detection of energy consumption trends in a household, and graphs that focus on providing comparable data. To evaluate our designs and to understand the user's preferences, we conducted a user study with 22 participants. At the end of this thesis we present the results and discuss possible future work.

Überblick

Über die letzte Jahre ist Energievrbrauch ein öfentliches Thema geworden. Menschen benutzen mehr und mehr elektrische Geräte in ihrem Alltag, was zum einem erhöhten Energieverbrauch führt. Zusätzlich dazu, ist es ihnen nicht immer bewusst, dass diese Geräte zu einem erhöhten Energieverbrauch führen. Dieser Mangel an Bewusstsein lässt sich durch das fehlende Feedback erklären da Energie weder sichtbar noch greifbar ist. Diese Arbeit beschreibt den Entwurf einer iPad Applikation die den Energieverbrauch für Endbenutzer visualisiert. Nachdem wir uns existierende Lösungen angeschaut haben, haben wir uns dafür entschieden zwei verschiedene Arten von Visualisierungen zu implementieren. Wir brauchen eine Visualisierung, die für Szenarien geeignet ist im welchen der Benutzer einen schnellen Überblick der energieverbrauchenden Geräte die gerade in seinem Haus offen sind schaffen möchte, oder für Szenarien die zeitkritisch sind und eine schnelle Entrscheidung oder Einschätzung benötigen. Für diese Fälle haben wir eine alternative Einheit, die wir *Point* nennen entworfen. Es gibt aber auch Fälle im welchen der Energieverbrauch am mehrehre Variablen und Parameter gebunden ist und der Benutzer muss die verstehen um energiesparende Entscheidungen treffen zu können. Für diese Fälle haben wir drei verschiedene Arten von Graphen entworfen: Graphen die sich auf die Visualisierung von einflussreichen Parametern konzentrieren, Graphen die die Entdeckung von Tendenzen unterstützen, und Graphen die vergleichbare Daten darstellen. Um unsere Visualisierugen zu evaluieren, und die Preferenzen der Benutzer zu verstehen, haben wir eine Umfrage mit 22 Teilnehmern gemacht. Am Ende dieser Arbeit stellen wir die Ergebnisse der Umfrage dar und diskutieren potenzielle zukünftige Arbeiten.

Acknowledgements

I would like to thank Prof. Dr. Borchers and the Media Computing Group who kindly allowed me to do my thesis, and introduced me to the field of human computer interaction. I would also like to thank the Counter Entropy team for all their support, their suggestions, and the help they provided me. I would like to thank Flo for his enormous help and suggestions, which always cleared my mind, and helped me find solutions when I got trapped in problems. Last, but not least, I am heartily thankful to my wonderful parents.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in Canadian English.

Download links are set off in coloured boxes.

File: myFile[a]

[a] file_number.file

Chapter 1

Introduction

1.1 Motivation

The increased importance of energy consumption

The past years energy consumption has become a topic of public interest. People use more and more electrical devices in their homes which leads to an increased electricity consumption. Furthermore people are not always aware of the increased consumption these devices lead to. The electricity bill does not help them understand the impact of these devices and home appliances, it does not mention where that energy is spent on (heating, home appliances, water heating, or home entertainment devices) which results in users that are neither aware of where they spent their energy nor are able to make critical decisions or changes in their lifestyle that would lead to a reduced energy consumption.

The importance of feedback in energy consumption was our motivation for this work

Studies have shown that appropriate feedback can lead to a reduction of energy usage at around 10% (in some cases even more) Darby [2000], Chetty et al. [2008]. Existing solutions like smart meters, applications for smart phones and personal computers, and displays from various home automation vendors, despite trying to give feedback to their users, have not succeeded in the market and are generally not broadly used as is home automation in general [Brush et al. [2011]].

Using iterative and participatory design methods before investing in long time behavioral studies

According to Froehlich [Froehlich et al. [2010]], HCI design methods and particularly iterative and participatory design can save time and effort and are thus useful before investing in long time behavioral studies which are actually necessary for this topic. Our intentions were to identify which visualizations and design aspects have a potential for future research.

1.2 Tablets as a new computing form factor

Tablets as a persuasive technology tool

The last years tablet computers have succeeded in becoming a new vastly recognized computing form factor. Studies [McClard and Somers [2000]] have shown the advantages that such a form factor brings to the users and how this opens new ways of interaction. Tablets have many characteristics which BJ Fogg [Fogg [2002]] mentions in his Seven Tools of Persuasive Technology. Among those characteristics are the facts that they are mobile, and easier for communicating information. Furthermore tablets enable the direct manipulation of objects and information through their touch screens. This makes them in many cases easier to use than traditional personal computers, which is another characteristic of the Seven Tools of Persuasive Technology. In addition to that newer tablets have displays with higher pixel density than traditional computers which enables them to visualize information in a great way.

1.3 Hypothesis

Our basic assumption

We assume that useful feedback about energy consumption given through a tablet computer (or end user home automation display) can help users understand where and when they consume energy, and can help them take decisions which will lead to a reduced energy consumption. For this we believe two kinds of feedback are necessary.

An energy consumption visualization based on quantitative data and graphs

First, quantitative data in a graphical form which can help users understand, explore and track where and when they spent their energy. This data should be given in a form that enables comparisons among different dates/appliances, is understandable and provides information that helps the user understand which parameters influence his energy consumption. For this we created various views with graphs that visualize quantitative data. On the other hand, users need a lot of time to perceive and analyze large numbers and graphs. We wanted to provide a second form of feedback which would be faster and easier to read and interpret, we wanted to find out what the reactions of users would be in that case and compare this kind of feedback with the one provided through quantitative data. In order to do this we simplified the measures used for power and energy consumption (Watts *W* and Watt-hours *Wh* in most cases) and replaced them with a measure which we call *Point* and a variation of it which we call *Counter Entropy Point*.

An approach towards a simplified energy consumption measure.

Figure 1.1: A *Point* and a *Counter Entropy point*

Our goals are to provide feedback for the energy spent:

- to heat and cool the house
- from the home appliances
- for lighting the house
- for home entertainment devices

The assumptions we make for the views that use the *Point* as a measure to visualize the energy consumption in comparison to views that use the typical Watt and Watt-hours measures are:

- they are faster to understand
- they are easier to understand
- users consider them to be more attractive
- they are useful despite being less informative

For the quantitative feedback we assume that they:

- provide a rich amount of useful and thought provoking data in an understandable way
- provide data that simplifies comparisons
- help users detect trends
- provide information about parameters that can influence the energy consumption

In addition to that, we want to identify the preferences of users in various data and time granularity sets.

A per occupant visualization

Finally we created two views that display the energy consumption in a per occupant basis. We wanted to find out what the reactions of users would be in this scenario.

We went through many design iterations to create views that use the above mentioned visualization systems. To evaluate our results we conducted a user study with 22 participants.

Structure of the thesis

This thesis is divided into four parts. In the first part we discuss existing energy and power consumption visualization systems in order to understand our motivation to try to create new ones. In the second part we discuss the design process of our visualizations and some of the decisions we had to take. Thereafter, we present the results from our user study. Finally we briefly summarize this thesis and our findings and provide an outlook on future work.

Chapter 2

Related work

2.1 Introduction

In this section we will present existing solutions for visualizing energy consumption in homes. We searched for various kinds of visualizations and feedback mechanisms from the basic electricity bill up to modern thermostats who try to understand the occupant's patterns in order to help them save energy.

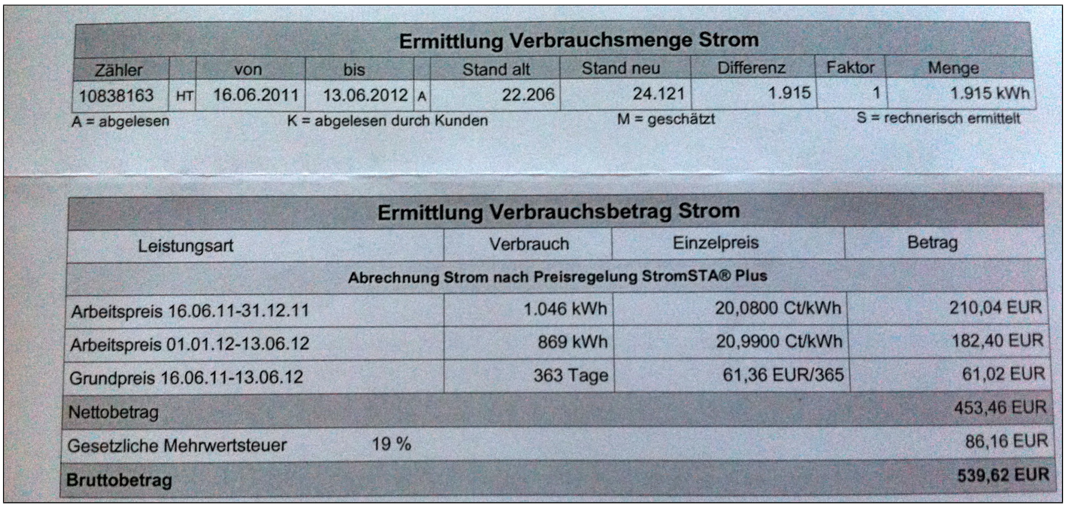
2.2 The Electricity Bill

The electricity bill is the most common way for people to get informed about their energy consumption. Depending on the place of residence and the energy company, electricity bills are mostly monthly or yearly. The information that is provided in electricity bills is usually the amount of kiloWatt-hours (*kWh*) that has been consumed during the past, the cost of every kWh and the amount the consumer has to pay to the energy company. Most of the times there are no comparisons between the current consumption and the one from the time the consumer got his last bill (see figure 2.1).

The electricity bill is the most common way for people to get informed about their energy consumption

We believe that much more information has to be provided

Additional information is required to achieve our goals



Ermittlung Verbrauchsmenge Strom

Zähler		von	bis		Stand alt	Stand neu	Differenz	Faktor	Menge
10838163	HT	16.06.2011	13.06.2012	A	22.206	24.121	1.915	1	1.915 kWh

A = abgelesen K = abgelesen durch Kunden M = geschätzt S = rechnerisch ermittelt

Ermittlung Verbrauchsbetrag Strom

Leistungsart	Verbrauch	Einzelpreis	Betrag
Abrechnung Strom nach Preisregelung StromSTA® Plus			
Arbeitspreis 16.06.11-31.12.11	1.046 kWh	20,0800 Ct/kWh	210,04 EUR
Arbeitspreis 01.01.12-13.06.12	869 kWh	20,9900 Ct/kWh	182,40 EUR
Grundpreis 16.06.11-13.06.12	363 Tage	61,36 EUR/365	61,02 EUR
Nettobetrag			453,46 EUR
Gesetzliche Mehrwertsteuer 19 %			86,16 EUR
Bruttobetrag			**539,62 EUR**

Figure 2.1: A yearly electricity bill from the utility company STAWAG located in Aachen Germany

to occupants in order to motivate and persuade them to reduce their energy consumption. Even if they are motivated enough (since after all all they have to pay their bills), there is no way to track down where this energy has been spent, neither in a per room basis nor per appliance with the information provided from the electricity bill. This indirect feedback (since it is not on demand) is hard to lead to significant savings [Darby [2000]]. A way to improve the electricity bill would be to make it more frequent and based on readings instead of estimations of how much energy the user is going to consume and then paying additional fees or receiving money back.

2.3 Welectricity: Energy Efficiency, Meet Social Networking

Building upon the electricity bill

Welectricity [1] is a website/social network which builds upon the electricity bill. Users have to manually enter information from their past electricity bills, and some information about their households into Welectricity. The social network then matches their input with other users who live

[1]http://welectricity.com/home

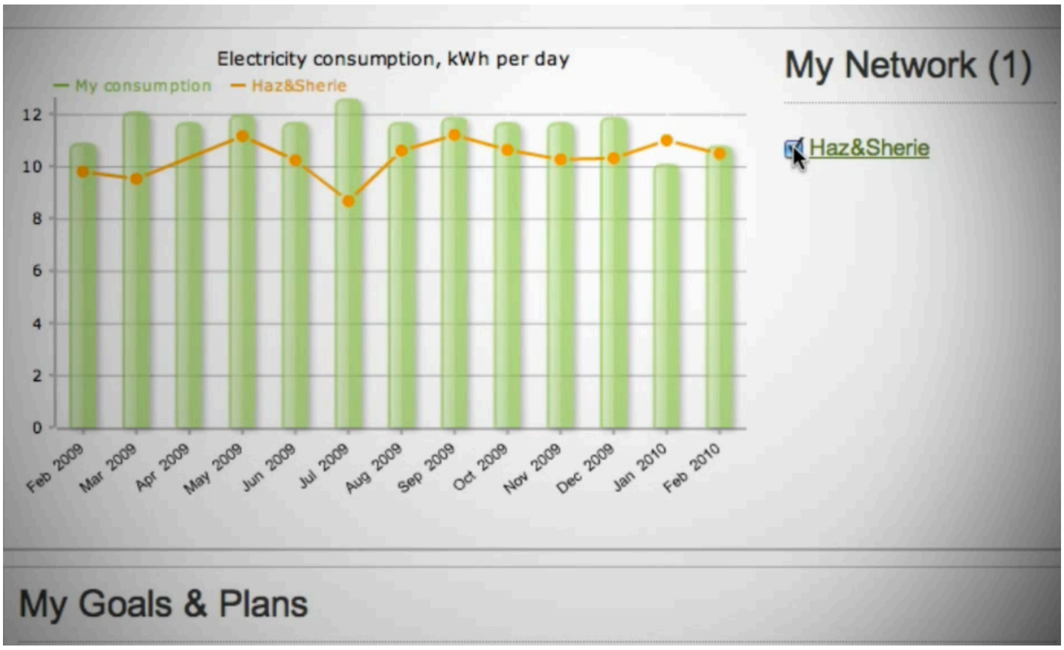


Figure 2.2: Welectricity uses graphs, social aspects and goal setting mechanisms to improve the feedback provided

under similar circumstances. After that, users can enter the information of their electricity bill every month to get updated information. The service also offers tools to automatically generate graphs that compare the energy consumption of the current month with the previous months. There are also options that allow users to set a specific goal related to their energy consumption for a month or year.

Reaching the limits of indirect feedback

Welectricity uses the electricity bill and takes it many steps further. It adds graphical visualizations, social aspects and goal setting mechanisms which greatly improve the quality of feedback [Froehlich [2009]] provided compared to the standard electricity bill. Unfortunately welectricity still uses indirect feedback, which as described above is less effective than direct feedback. It also has to be considered that people are sceptic when it comes to share information about their energy consumption [Froehlich et al. [2012]] and thus privacy matters could arise. Furthermore, web-based solutions require users to log in and access the information via the internet, which is an extra barrier [Broms et al. [2010]].

Figure 2.3: Welectricity allows users to compare their consumption with the past months

2.4 Ambient Information Displays

2.4.1 Description

Definition: *Ambient displays*

AMBIENT DISPLAYS:
Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention. Ambient displays have the ambitious goal of presenting information without distracting or burdening the user. Mankoff et al. [2003]

Ambient displays use abstractions to visualize the energy consumption

In the area of energy consumption, ambient information displays tend to use abstractions to visualize the energy consumption. There are for example ambient displays that use visualized oak trees [Holmes [2007]], rotating cycles [Heller and Borchers [2011]], and other abstract measures in order to increase the awareness of the consumers and sometimes to even emotionally motivate them to save energy.

We will shortly describe two different ambient displays. The first one is Power Socket [Heller and Borchers [2011]] and the second one is the Energy AWARE Clock (EAC) [Broms et al. [2010]]. They are both ambient displays that use different kind of visualizations and have certain design characteristics which we took into consideration when designing our own visualizations.

2.4.2 PowerSocket

How PowerSocket visualizes energy consumption

PowerSocket is an ambient information display integrated into the electric socket. PowerSocket uses a rotation animation to visualize the power consumption of an appliance connected to it. The rotation visualization consists of a luminescent spot spinning around the socket. The rotation speed and the color are determined by the power consumption. The colors vary from light green to red.

Immediately identifying high consuming devices but lacking historic data

PowerSocket is the first feedback system described in this section that utilizes direct feedback. PowerSocket makes estimations of energy consumption easy. Users can immediately understand whether the connected appliance consumes a lot of energy through the color and the speed of the rotation, both characteristics which are easy to perceive for the human eye [Dix [2004]]. What PowerSocket lacks though, is historic data which can help the consumer develop a deeper understanding. PowerSocket also lacks additional information which could help the consumers take the next step and help them make energy saving decisions. Such information is for example the time the appliance needs to be on in order to finish its task or how often the appliance gets used.

2.4.3 Energy AWARE Clock

Description of the Energy AWARE Clock

TheEnergy AWARE Clock (EAC) is an ambient information display that uses a time metaphor to visualize the energy consumption of a house. The visualization uses a dial which changes its size depending on the current energy consumption in the house. The angle of the dial represents

Figure 2.4: PowerSocket increases the awareness about energy consumption through a rotation animation that changes colors

the current time, just like a normal clock does. The dial moves in a cycle, users can choose whether a full cycle will last 1 minute, 1 hour, 24 hours, or one week. The dial leaves a trace behind as it moves and this area depicts the historic energy consumption (i.e., kilowatt-hours and kilowatts for specific time points).

An attempt to visualize historic data through an ambient information display

The Energy AWARE Clock tries to visualize a lot of information in a small display. The clock metaphor and the size shifting dial are good for making estimations but do not allow exact readings. The results of turning an appliance on can be detected in the display. If more than one appliance is turned on simultaneously though, the user cannot say which one consumes more energy. The clock metaphor combined with historic data can help occupants detect the impact certain chores have, like cooking in the afternoon for example, in the energy consumption.

2.5 Home Automation Applications for the iPad

A transition for home automation vendors

The last few years many home automation vendors who used to create software for various home automation tasks have started switching towards tablet and smartphone applications. Those applications usually try to implement some energy saving mechanisms through various ways:

Figure 2.5: The EAC uses the clock as a metaphor to visualize historic and current data of energy consumption information in a visually pleasing object

- providing energy saving modes, in which for example the lights have a lower intensity etc.
- automatically adjusting the thermostat in order to save energy
- providing some energy consumption visualizations
- offering suggestions that appear as pop ups when certain adjustments/controls are made
- showing historic data which allows the occupant to track his performance

Saving energy is not the focus of existing home automation applications

Unfortunately, after using these applications for some time, it becomes obvious that providing assistance or feedback to save energy is not their main goal. The options or visualizations are hidden in hard to navigate menus. The energy consumption visualizations are also very basic and limited to the lightning or the thermostat of the house only.

Overcoming infrastructure difficulties

Another reason that the energy consumption feedback is limited is because a complicated infrastructure is necessary to measure the energy consumption, save the data, and then visualize it. These home automation applications work using a bus system that connects the various applications with a home server. The communication between the home server and the tablets/smartphones then works through various communication protocols.

Tablets have the potential to function as energy consuming persuaders

All of the tablet applications that we have tried focus on providing controls. The potential of these applications for providing feedback though, as described in the introduction and as shown in studies [Darby [2000]]is great. The feedback provided from these Application can be direct, interactive, and offer many options concerning the time and data granularity.

Figure 2.6: The Domovea Application from Hager uses a Home server that is connected with different appliances in the house to collect data. The data is then transferred and visualized in the tablet Application.

2.6 Personal Energy Meters

Description of personal energy meters

A personal energy meter (PEM) is an electricity meter that is designed to be used from occupants who want to measure the consumption from their energy consuming devices. PEMs are connected to a socket and the energy consuming devices are then connected on top of them. They offer a small display that can display various information such as the kW the appliance is consuming at the moment, the kWh it consumed in the past and the time it was turned on. In many PEMs the user can enter the price of a kWh and then the PEM can calculate how much money the user has to pay for the energy that the appliance used. Using a monetary measure, and thus financial savings to achieve energy savings though may not be the best way in the long run, since it is too closely connected to low incomes and financial crisis [Jacucci et al. [2009]].

Figure 2.7: The energy check 3000 is a typical PEM

Using exact measures in an unattractive visualization

PEMs provide very exact information and use the most common measures to track power and energy consumption which are the kW and kWh. Studies have shown though, that PEMs are not broadly used [Kluth [2011]]. Among the reasons for this situation are that PEMs are not attractive and they can be hard to configure. In addition if the user wants to compare the consumption of devices she has to collect the data from the different meters and do it herself.

2.7 GreenPocket an iPhone Application that Focuses on Energy Consumption Visualization

GreenPocket[1] is an iPhone application which is currently in a beta phase. GreenPocket collects power and energy consumption data, and visualizes them using graphs and different time granularity sets. In addition to electricity consumption data, GreenPocket collects and visualizes water and gas consumption data. The application currently works in a demo mode where dummy data is visualized.

GreenPocket is currently still in development. The goal of the application is similar to the goal we have set, namely collect energy consumption data and visualize it for the end user.

GreenPocket offers a good user experience, collects energy consumption data, and visualizes it through carefully designed graphs

GreenPocket visualizes the current power consumption, and the electricity consumption for a specific day, a week, a month, and a year. In addition to that, GreenPocket calculates the cost in , and makes an estimation of the energy that will be consumed until the end of the day, week, month or year. The graphs used in GreenPocket are mainly bar graphs which are basically recommended for this kind of data. The developers of GreenPocket have paid attention to the Apple Human Interface Guidelines[2], as a result the controls, and navigations elements used in the application are consistent with the rest operating system. The carefully designed graphs, and the carefully designed graphs result in a much better user experience than the home automation apps which we tried.

2.8 Nest: the learning thermostat

A short description of the Nest thermostat

Nest is a product created from the Nest Labs company. It is a sensor driven, Wi-Fi enabled, programmable thermostat. The Nest thermostat uses a rotating wheel as an in-

[1] http://www.greenpocket.de/
[2] http://developer.apple.com/

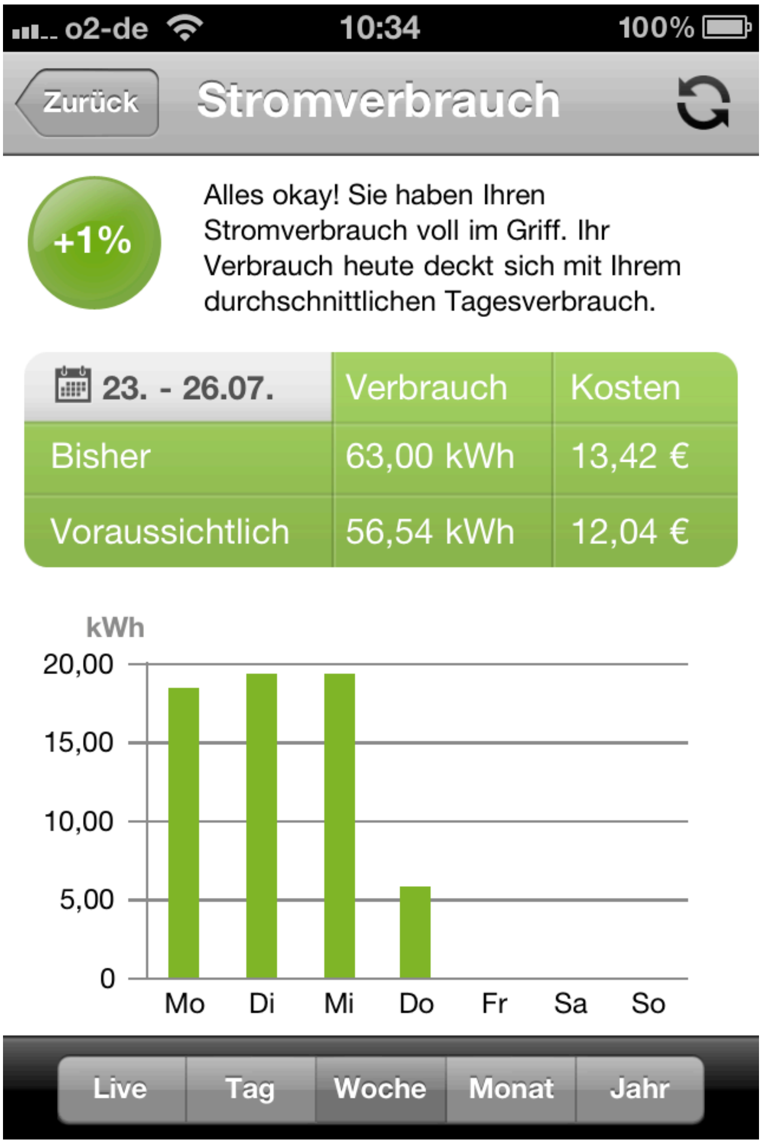


Figure 2.8: GreenPocket visualizes the energy consumption using bar graphs, and offers a user experience consistent with the rest of the operating system

put method and a display to provide feedback. It uses four mechanisms to help its users save energy, those are:

1. an auto away function
2. an auto schedule function

3. historic data
4. a green leaf that appears in historic data or when adjusting the temperature of your house

The four techniques that Nest uses to help users conserve energy

Compared to typical programmable thermostats, Nest tries to figure out what the occupant's preferred temperature is during the first week, which means "remembering" each temperature change the user makes and the time she did it. The goal is that after a week Nest knows when the user leaves his house to go to work, when she comes back, and when she goes to sleep. It also learns the user's preferred temperature. After this week the Nest thermostat does all this adjustments automatically without demanding any programming from the user. This is the auto schedule function. To utilize the auto away function the user chooses the temperature the house should maintain while she is away. This, combined with the auto schedule function can lead to decreased energy consumption. Nest also provides historic data in the form of graphs. These graphs are both aesthetically pleasing and provide enough information for the user to allow her to analyze her performance. Finally the Nest thermostat uses an abstraction similar in its logic to what many ambient information displays use. Nest displays a green leaf in its display whenever the user adjusts the temperature in a way tat consumes less energy. The leaf also appears in the historic data. It also tries to challenge the user, after a while the leaf appears only when lower/higher temperatures are set than before.

The companion smartphone and tablet applications

The Nest thermostat works with specific companion smartphone and tablet applications through which the user can choose his desired temperature, monitor the temperature of his house even if she is away from it, and see historic data about the energy consumption of his house.

Concerns that arise through the use of automation

Nest tries to combine some classical energy conserving techniques like providing historic data in a beautiful way, or using abstractions to increase the awareness, but it also goes one step further using learning algorithms. In general occupants do not enjoy programming thermostats because it usually is a hassle and in the end they want control over their life and not over their devices [Davidoff et al.

Figure 2.9: The Nest thermostat in auto away and energy saving mode

[2006a]]. Nest avoids end user programming through the use of learning algorithms. This is a difficult subject though especially in the context of a house where the occupants can have conflicting interests [Davidoff et al. [2006b]].

2.9 Summary

In this section we described different devices and software that try to help consumers to save energy. We have identified certain characteristics which we liked and mentioned our doubts or concerns for certain design decisions the creators of the systems took, or characteristics they have in general. In table 2.1 we summarize the characteristics of the devices and applications we described.

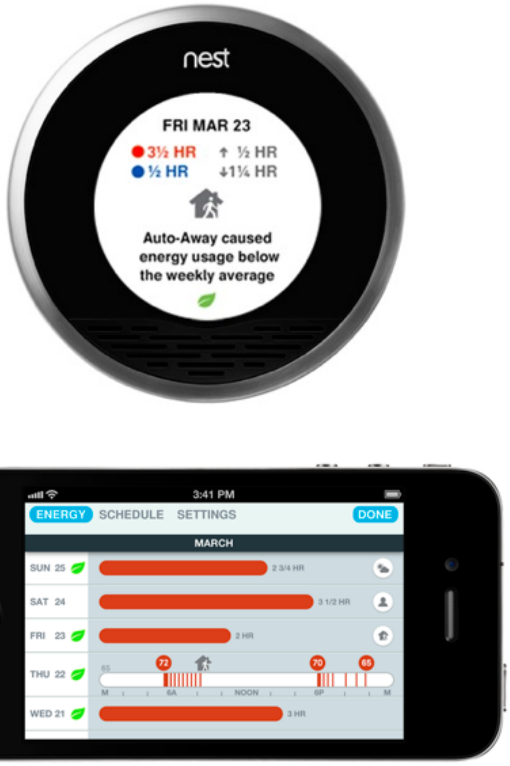


Figure 2.10: The Nest thermostat and its companion smartphone application visualizing energy consumption graphs with historic data

Table 2.1: Summary of the characteristics of the described applications and devices

Electricity bill
indirect feedback
monetary measure
Welectricity
social aspects
historic data through graphs
web based service
comparisons between past and present
Power Socket
abstract visualization
high depicting value
direct feedback
Energy AWARE Clock
historic data through an abstract visualization
can be placed anywhere in the home
Home automation tablet applications
interactive feedback/navigation through different data granularity sets
Personal energy meters
use of typical kW/kWh Measure
provide exact data
GreenPocket
user interface and navigation is consistent with the rest of the platform
collects and saves data, and visualizes them
The nest thermostat
automatic adjustments and energy saving modes
historic data through carefully designed graphs
visual abstractions for feedback combined with quantitative data

Chapter 3

The Design of the Energy Consumption Visualizations

3.1 Introduction

The Counter Entropy project, and where the data used for the visualizations comes from

The visualizations that will be displayed in this section were created to be used in an iPad application. In some of the visualizations that will be shown in this section, control elements from the iOS operating system can be noticed, such as the UISegmentedControl or the UISlider. The iPad application was aimed to be used as part of the Counter Entropy project from RWTH Aachen University. This influenced some of the design decisions, such as the logo of the Counter Entropy *point* for example. Additionally, the quantitative data used for the visualizations is from various simulations that were done for the house built for this project. These include the energy used for heating and cooling the house and the energy used from the home appliances. Some of the data had to be adapted since some of the simulations from which the data came from, had experimental character. For the *per occupant* visualization we created a scenario with two occupants. One of the characteristics of the house is that it uses photovoltaics, and we decided to consider this while creating our visualizations.
The Counter Entropy house is a 45 square meters house that

is divided in four areas which are not separated by walls. The four areas are the kitchen, the living room, the bedroom and the toilet.

3.2 Points

3.2.1 Main Idea

The benefits of using analog scales and our motivation to use a different measure

As described in the introduction, the main idea behind the points is to create an energy consumption visualization that is faster and easier to interpret, and more attractive compared to visualizations that use exact numbers. Visualizations that rely on analog scales allow faster estimations, display the range limits, and allow the easier detection of trends. A typical example is the speedometer of a car. Car speedometers use an analog scale which does not allow exact readings, but makes estimations to realize whether the driving speed is too high easier and faster compared to seeing an exact number. We can make the visualizations that use graphs and exact numbers look attractive, but users will still need more time to make estimations for the displayed values compared to visualizations that use analog scales. Furthermore the concepts of watts (*W*) and watt-hours(*Wh*), power and energy are not clear to many occupants. Through our visualizations, we want to make it clear to the user that for example, despite the fact that a kettle usually needs more power than a stove, boiling water consumes less energy in a kettle.

These problems are known, and many ambient information displays try to solve them using abstractions [Holmes [2007]]. We decided that we wanted to use a measure that combines the benefits of analog scales with the comparability and calculability of exact numbers. In the end we decided to use the *point* as a measure.

POINT:
Points are a measure of energy and power consumption. Every point represents an amount of 450-550 Watts(W) or Watt-hours(Wh) depending on whether it is shown in a view related to the present or to the past. A half point is half that amount. Points are represented as an orange circle.

Definition: *Point*

For example, if you are watching a view that shows the power consumption of your house in the present, every point shown equals an amount of 450-550W. If you are watching a view that shows the energy consumption of your house yesterday, every point represents 450Wh-550Wh. That way the user can detect that she used one and a half points to boil water in the stove and only half point to boil it in the kettle.

An example using the points system

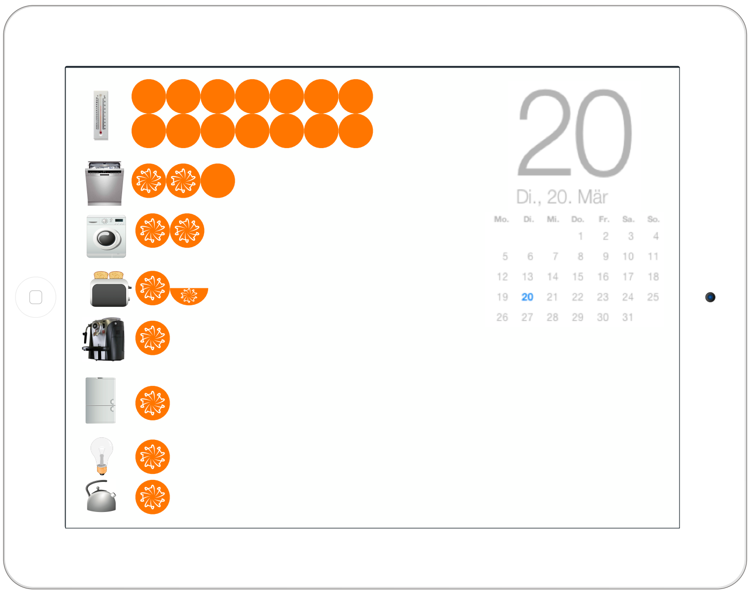


Figure 3.1: An example of an iPad using the points system.

We added a variation of a point, which we call a *Counter Entropy point*. A Counter Entropy point has the same shape and size as a normal point, but also has the logo of the Counter Entropy project in the middle. When displaying the energy or power consumption of a house, a Counter Entropy point next to a home appliance shows that the power

The Counter Entropy point and our attempts to maximize the effects of solar energy or energy used from it is provided from photovoltaics. Of course we are not able to trace where the power provided from the photovoltaics is flowing, but we wanted to visualize what the occupant is able to do with it so that she can develop an understanding of it. Furthermore, in case the photovoltaics are generating more power than the house needs, we inform the user so that she can put that extra solar energy to good use, by baking a cake for example. Our motivation behind this, is that we are not able to store the energy in order to use it at another time, and transferring it through the electrical grid is less efficient. This is a further reason why we focus on quick estimations, we wanted the above described scenario to be fast and easy. An example of an iPad using the points system can be seen in figure 3.1

Existing solution that use a similar concept

This concept is used in many existing devices. In figure 3.2 we can see how a Macbook Pro visualizes the remaining battery life with a visualization similar to the ones we created using points. This visualization does not inform the user about the exact remaining battery life in time or *Wh*, but it helps her, for example, to estimate whether she needs to take the charger with her or not. Fuel gauges in cars work similarly. They use an analog scale that is marked in certain positions. A fuel gauge does not inform the user about the exact remaining kilometers she can drive, but it can help her for example decide whether she can drive to her next destination and fill the tank later.

In the following subsections we will describe the views that use the points, the user interaction when switching from one view to another, and some design decisions we took while designing these views.

3.2.2 The Three Views That are Based on the Points System

The *Now* View

Our goals with the *now* view were to create a view through which the user could quickly get an overall picture of which electricity consuming devices are turned on in her house,

Figure 3.2: The Macbook Pro uses a concept similar to the points to visualize the remaining battery life.

whether they are consuming a lot of power or not, and whether her house is currently using more power than it is producing through the photovoltaics.

The *now* view displays the electricity consuming devices which are turned on and the amount of power they consume

The *now* view (see figure 3.3) displays the electricity consuming devices that are currently turned on. On the top of the view there is an interface element with two segments that informs the user in which segment she currently is, and enables her to switch the shown segment. Underneath it are displayed all the electricity consuming devices that are currently turned on, and the power they are consuming using the points as a measure. To inform the user about the power the house's photovoltaics are currently producing some of the devices are shown as using Counter Entropy points. Another example of the Now view is shown in figure 3.4. In this example the photovoltaics are producing more power than the house needs. The two points that are unused have the label Unused Energy next to them.

A compromise we had to do to visualize the power consumption

Although we wanted to visualize the currently used power in the *now* view, what we are actually visualizing is an estimation of it. If we wanted to visualize the currently used power, this view would probably be less useful. Let us take the washing machine as an example. A typical washing machine program lasts around two hours. During those hours the power consumption is not constant. Most of the home appliances and heating/cooling systems work similarly. To avoid the scenario where the user is watching the *now* view and all the devices are constantly changing the amount of points they are consuming, we decided to use an

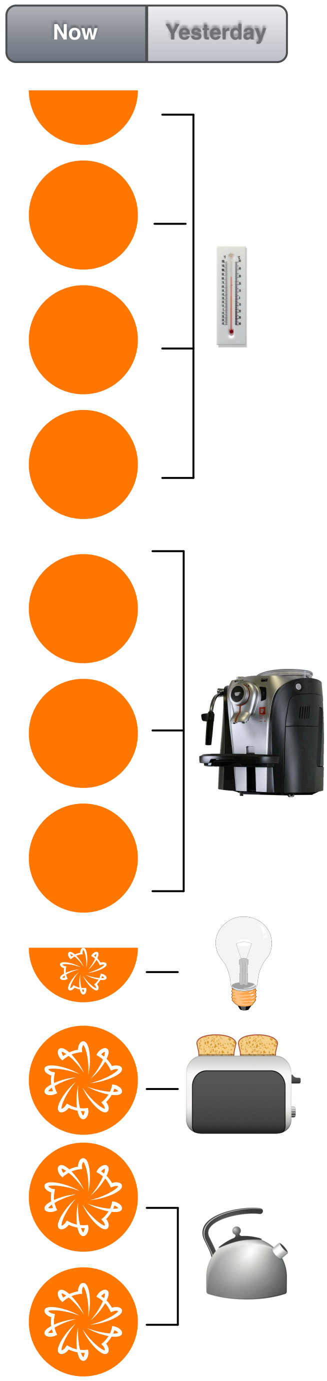


Figure 3.3: An exemplary picture of the now view

average value. For this we measured the energy home appliances consume for a typical use and how long they need for this, and calculated an average value. For example if a drying program needs 2kWh and lasts 2 hours, the average power consumption is 1kW. There are moments where the dryer consumes more energy, but in average it uses 1kW. We also used historic data and applied filters in our measurements in order to get round numbers. We did this for example for the heating and cooling system where jumps from low to high power consumption are usual.

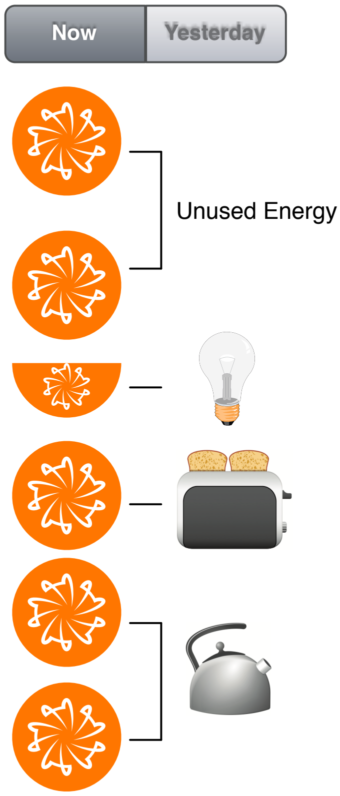


Figure 3.4: An exemplary picture of the now view where the photovoltaics are currently producing more power that the house needs.

The *Yesterday* View

The *yesterday* view visualizes the electric energy devices consumed yesterday using the points system. In this case

The *yesterday* view visualizes the electric energy devices consumed yesterday using the points system

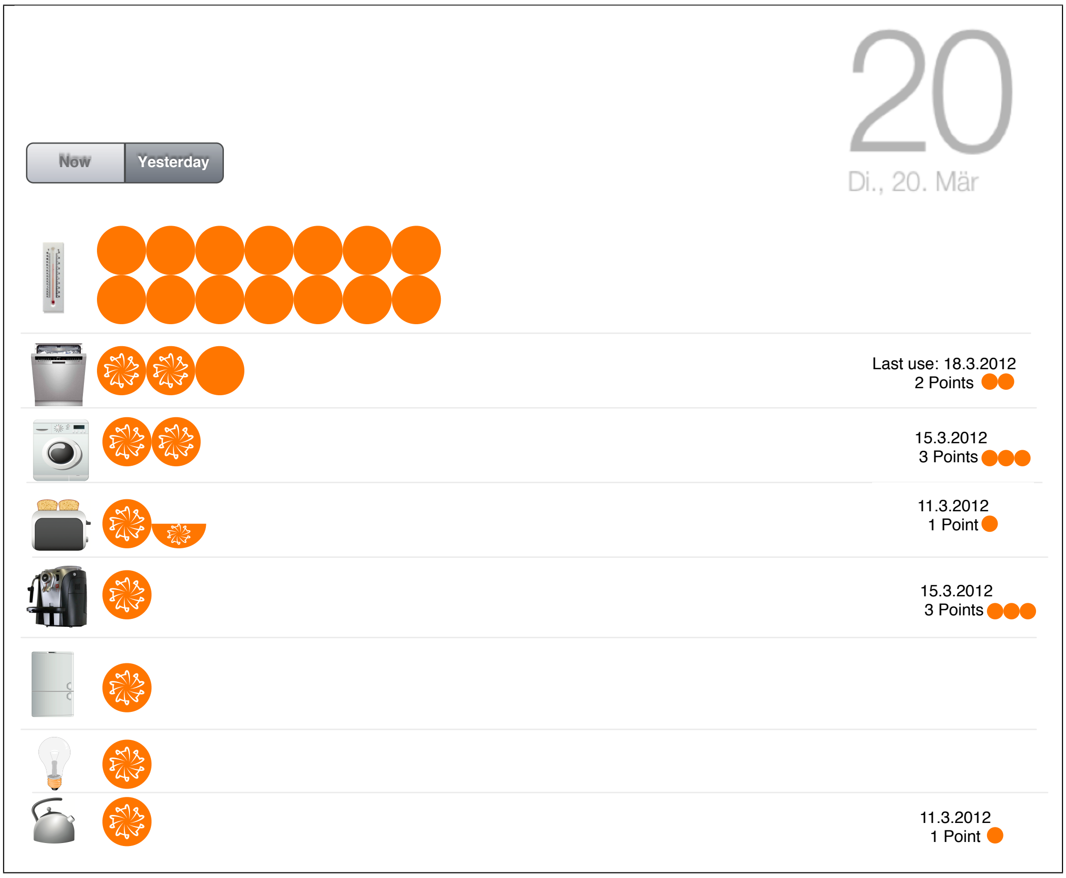


Figure 3.5: An exemplary picture of the Yesterday view which is based on the points measure.

we are transforming the *kWh* value we read to *points*. The readings are more precise compared to the *now* view as they are based on actual readings, but still they are not the exact values consumed since every point represents 450-550Wh and a half point half that amount. If for example a home appliance consumed 800Wh, we would visualize this using one and a half point, which is an amount between 775 and 825 *Wh*. This view also uses the Counter Entropy points to give a feeling to the users about what they managed to do with the energy from the photovoltaics.

The *yesterday* view also shows the energy the home appliance consumed the last time it was used

Additionally, on the right side of the view we are displaying the points that the home appliance consumed the last time it was on. For example in figure 3.5 the dishwasher consumed three points on the 20th March which in the example is yesterday. Last time it was on though which was the 18th March it consumed two points. We decided to visualize this visualize this, to enable the user for example to, to compare different washing programs or to help her detect devices which she forgot to turn off.

The Home Appliances Points Based View

Visualizing the state and the power consumption of home appliances with points

In this view we are visualizing two things. First, we want to visualize the state of the home appliances. The user can filter between all appliances, appliances that are turned on, and appliances that are turned off through an interface element which consists of three segments and is placed on the top of the view. If the user is in the segment which shows all the appliances, she can detect whether an appliance is turned on or off through the color of the box that surrounds it. The second thing we wanted to visualize, is the amount of power an appliance uses when it is turned on. For this we are using the values we calculated as described in the *now* view.

Using the different points views combined to maximize the use of solar energy

Our goal was to make it easy for the user to decide which appliance she can turn on, in the case where the photovoltaics are producing more power in her house than she is currently using. Let us look into an example to understand how we intend this to work. We created an iPad application that consists of different views, and the user can navigate from one view to another through a Tab Bar located at the bottom of the screen. We placed the *now* view we described above in the fourth tab, and the *home appliances* view in the first tab. In figure 3.7 we visualize how the transition from the *now* view to the *home appliances* view and back works, and how the user can use it to maximize the effects of solar energy. In picture *a* the user is currently in the *now* view, and detects that (at the moment) the photovoltaics are producing two unused points of power. She taps at the first tab to navigate to the *home appliances* view (picture *b*). There she sees that to turn on the dishwasher and the washing machine she "needs" two points, so she decides to turn them on since they are both filled with dirty clothes and dishes. The user taps again at the fourth tab and goes back to *now* View (picture *c*). Now she can see that she is using all the

Figure 3.6: The home appliances points based view

power that the photovoltaics are producing.

We wanted to make the combined use of the different point views fast and easy. The process described above needs two taps and turning the appropriate appliances on. It would be even better if turning on the home appliances was possible through the application, but unfortunately this is currently only possible for a few home appliances (the only vendor we found was miele and their miele@home series [1]), and the integration of the controls to third party applications is

[1] http://www.miele-at-home.de/de/aktion/mieleathome/656.htm

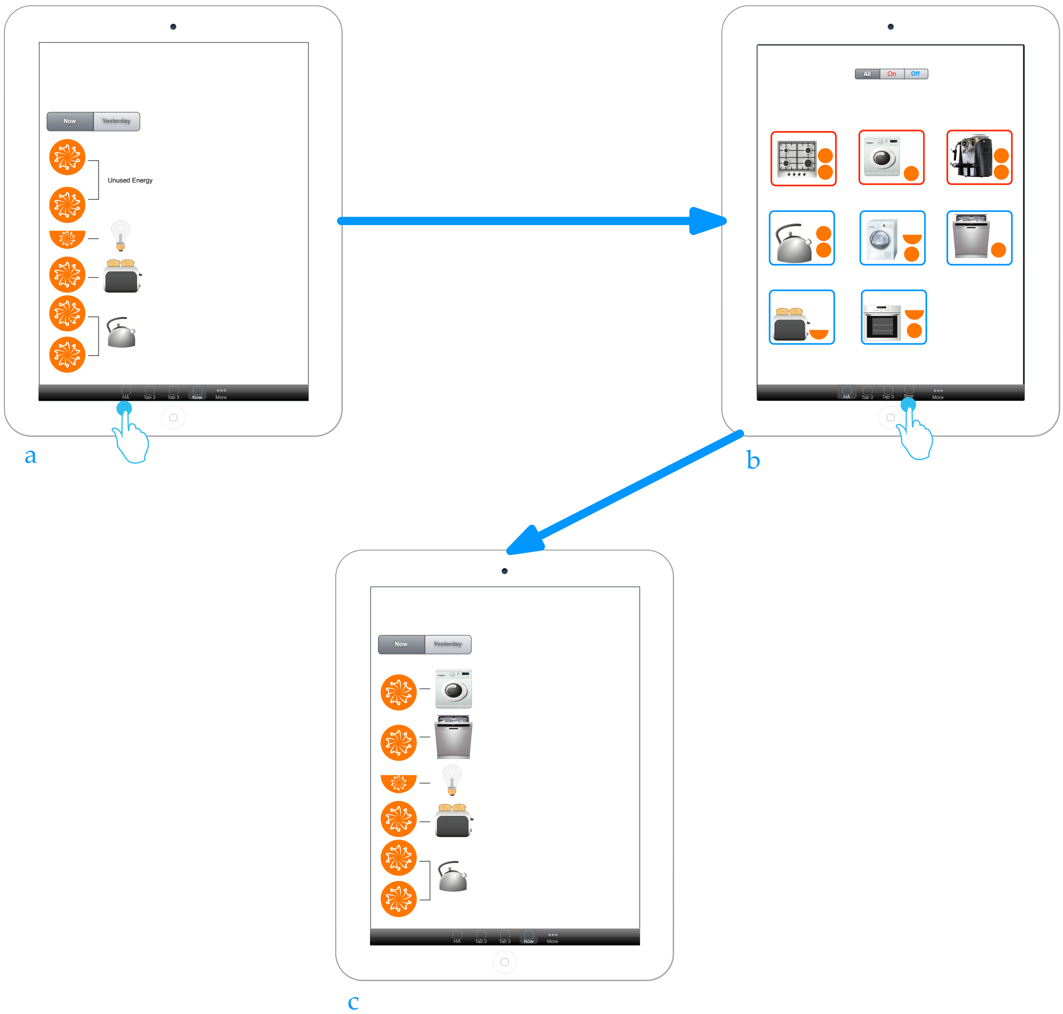


Figure 3.7: An example of the user interaction when using the views based on the points system combined

either limited or not supported at all. The goal is to enable users to use the power produced from their photovoltaics in a more effective way.

3.2.3 Iterating the Points Idea

The initial idea was to visualize the points inside a battery. This is a concept often used from mobile phones or laptops to visualize their remaining battery (see figure 3.8).

Why we avoided to use the battery metaphor.

The photovoltaics of the Counter Entropy house can produce a maximum of 7kWh which would correspond to 13 points. The idea was that we would display a battery with 13 points, and we thought that the user would understand that points represent energy due to the familiarity of the concept. Two problems would arise with this design though. First, there can be cases in our house where more than 13 points of power are used. This would result in a size-changing battery which would be confusing since batteries tend to come in fixed sizes and do not change their capacity. The second and biggest problem though, would be that batteries are energy storing objects. In our case we are not actually storing energy anywhere to spend it later. This is why we wanted to help the user ″spend″ it in an appropriate way. Giving her the impression that she is ″storing″ energy in a battery would be wrong. For these reasons we decided to avoid using the battery metaphor.

Figure 3.8: A picture showing how batteries are often visualized in mobile phones or computer screens

Why we avoided to use a separate bar for the Counter Entropy points

While we were designing the *now* view there were often suggestions that we should use one bar for the Counter Entropy points and one for the ″normal″ points. The arguments were that this would be less confusing and the power produced from photovoltaics would be easier to detect. In the end we decided not to use two bars because we did not want to give an impression of ″good″ and ″bad″ energy. The user could get a feeling that the appliances shown in normal points should be turned off and the ones shown using Counter Entropy points can remain open since they are using power from the photovoltaics. This is actually not true since we do not know where the power from the photovoltaics is used. This would be an inappropriate use of the Counter Entropy point metaphor, since we are using this point only to help the user develop an understanding about what she can do with solar energy in her house, and not to inform her about which appliances use this power.

3.3 Graphs

3.3.1 Energy Consumption Visualization for the Heating and Cooling system

For the heating, ventilation, and air conditioning system (from now on HVAC) we decided to create three views. Every view shows the energy consumption for a different time period; day, week, and year. We decided to focus on different characteristics for these views based on the fundamental principles of analytical and information design which Edward Tufte describes in his books (Tufte [2006], Tufte [1990],Tufte [1983],Tufte [1997]).

Energy Consumption Visualization for a Specific Day

Detecting influencing parameters and displaying them in an energy consumption visualization

In this view (see figure 3.9) we focussed on providing evidence and parameters that can influence the energy consumption for HVAC. We began with creating an area chart that visualizes the power consumption from the HVAC system hourly (in the final implementation it is going to be in five or ten minute intervals). In the X-axis we placed the power consumption in kiloWatts (*kW*) and in the Y-Axis the hour of the day. Then we started to investigate, through simulations, parameters that would influence the energy consumption of the HVAC system. In the end we decided to visualize the following aspects which we list in the order they appear in the view:

- The **inside/outside temperature** is the most influencing parameter. We are using a line chart with two lines for this.

- The **intensity of the sun**. This was complicated since both the intensity and the position of the sun were relevant resulting in many variations which were hard to visualize through icons. We decided to simplify this and use four different levels of sun intensity which are: night, clouds, sun with clouds and sun.

- Whether the **stove and the oven were used**. Since the Counter Entropy house is a small house without walls separating the rooms, turning the stove or the oven on generates heat which can increase or decrease the power consumption of the HVAC system. In houses where the rooms are separated with walls, this would influence only the kitchen. To visualize this binary value (appliance on or off) we use a tick mark at the time of day it was turned on. We use the same visualization for the aspects described in the next two points.

- Whether the **curtains** were set to automatically open and close. Open curtains allow sunshine in the house, which can be positive if the occupant wants to heat it or negative if she wishes the house to be cooler. In the Counter Entropy house the curtains can be set to automatically open or close in order to save energy.

- Whether the **windows were open for longer than 10 minutes**. This can highly influence the power consumption, especially if the windows are large and are placed opposite one another at both ends of the house. We decided to use the 10 minute mark as the minimum amount of time typically needed for a house to be adequately ventilated.

Providing evidence leads to a deeper understanding of the subject, and makes knowledge transfer possible

Our goal with this view was to identify whether users are interested in seeing influencing parameters, and whether it would be possible to develop a deeper understanding of energy consumption if the appropriate data was shown. Edward Tufte explains the importance of showing and integrating evidence [Tufte [2006]] in quantitative data. The amount and the nature of the variables, and the fact that

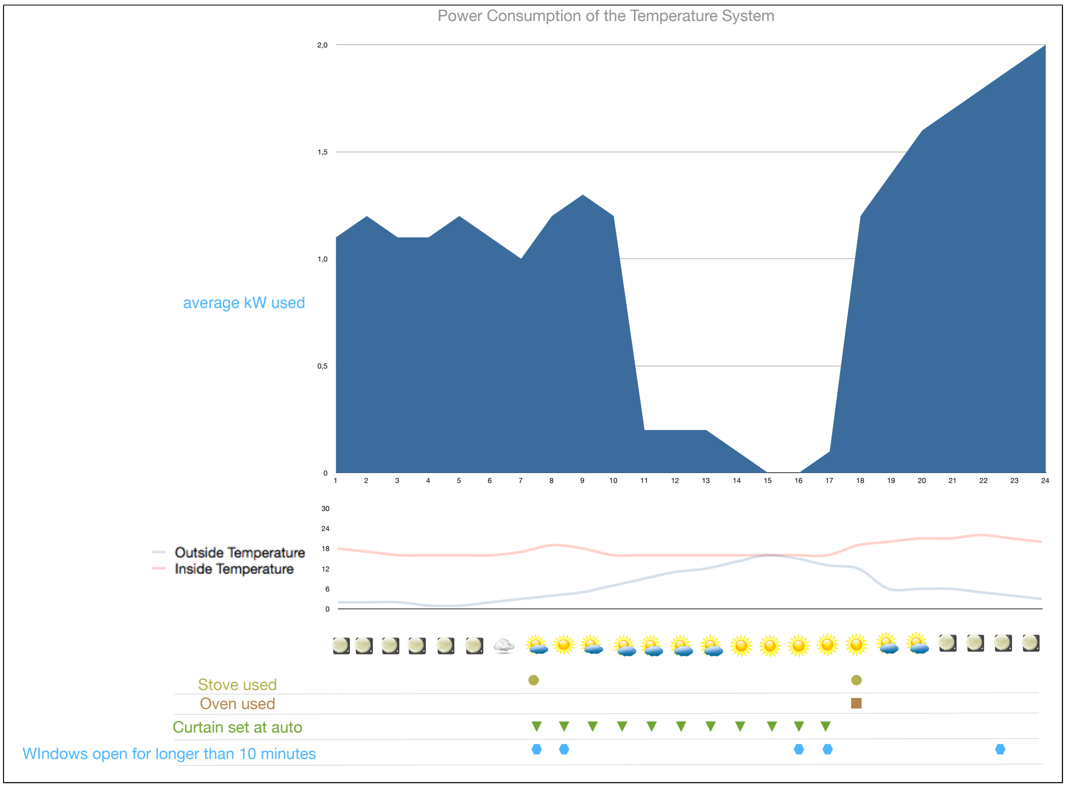


Figure 3.9: The power consumption of the HVAC system for a specific day with the parameters that influence it visualized

all the data is dynamic, makes the analysis of this view a complicated task. We wanted to visualize the influencing parameters in a helpful way so the viewers can analyze their energy consumption, and discover the causes behind it themselves. That way, we believe they can develop a deeper understanding of energy consumption.

Graphs that Help the Detection of Trends

For the weekly energy consumption of the HVAC system, we decided to use two techniques described from Edward Tufte: the small multiples and the sparkline.

Definition:
Small Multiples

SMALL MULTIPLES:
A small multiple is a series of illustrations of postage-stamp size that are indexed by category or a label and are ordered by a quantitative variable. At the heart of quantitative reasoning is a single question: Compared to what? Small multiple designs answer directly by visually enforcing comparisons of changes, of the differences among objects, of the scope of alternatives. For a wide range of problems in data presentation, small multiples are the best design solution. Tufte [1990]

Definition:
Sparklines

SPARKLINES:
Sparklines are small, high resolution graphics embedded in a context of words, numbers, and images. Sparklines are data-intense, design-simple, word-sized graphics. Tufte [2006]

Sparklines are often used to detect trends in stock courses

Sparklines are often used to visualize stock courses (see figure 3.10). Sparklines take up a small amount of room, can display a trend based on adjacent data in a clear and compact graphical representation, and help the detection of patterns. These characteristics make them suitable to visualize stock courses. We thought that the same would apply to energy consumption, and that users would be interested in this kind of information.

Using sparklines to visualize power consumption

The result we came up with can be seen in figure 3.11. In this view we use a sparkline to visualize the power consumption for every day of the week. The X-axis is used for the power consumption in *kW* and the Y-axis for the time. In these views we are using hourly measurements, although sparklines can be more data dense. To give a context to the data, we are showing the highest and lowest values as red and green dots, the highest and lowest temperature during the day and how sunny the day was.

The user interaction for switching between the daily and monthly views

This visualization could also be used for a monthly power consumption visualization. Figure 3.12 shows an exemplary image of an iPad showing the monthly power consumption using a typical calendar interface. Users can navigate through the months using the top bar. If they want more details about a specific day, they can tap that day in

Figure 3.10: An image showing stock sparklines (picture from http://www.bissantz.de/)

the calendar and the *daily* energy consumption visualization for this specific day will appear. They can navigate back to the monthly view through the segmented control in the top (see figure 3.13).

A view that focuses on detecting trends

Our goal with this view was to detect whether users would be interested in detecting trends in their power consumption. This view is not suitable for exact readings like the *daily* visualization. It provides more data in less space and thus not every value is readable. On the other hand the detection of trends is easier both due to the nature of the graph we are using (sparkline instead of an area chart), and because we are providing more comparable data (the consumption of seven days or a whole month instead of just one day).

The Yearly Energy Consumption Visualization for the Temperature System

Using cumulative data to enable more comparisons

For the yearly energy consumption visualization we decided to use two different graphs (see figure 3.14). First, we are using a bar graph (figure 3.14 *a*) that compares the

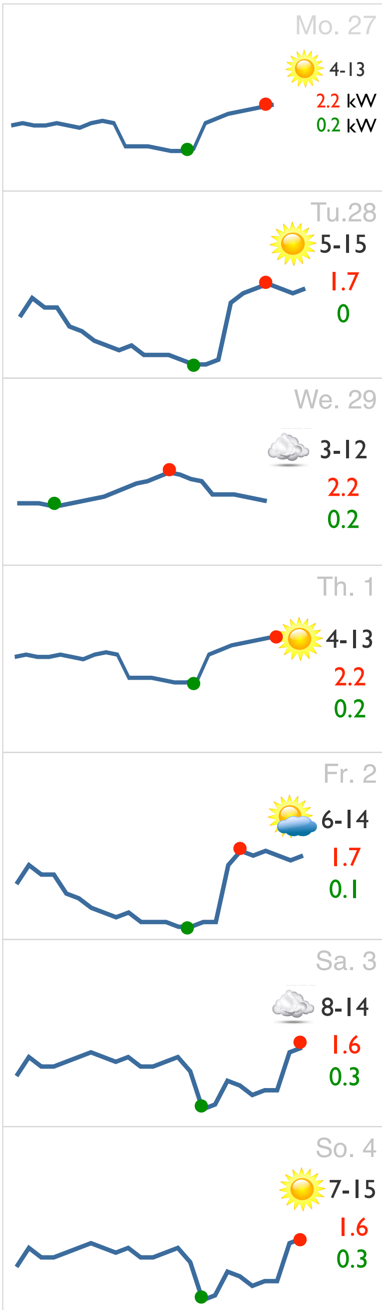


Figure 3.11: In this view we combine the sparkline and small multiples techniques to visualize the power consumption of the HVAC system for a whole week

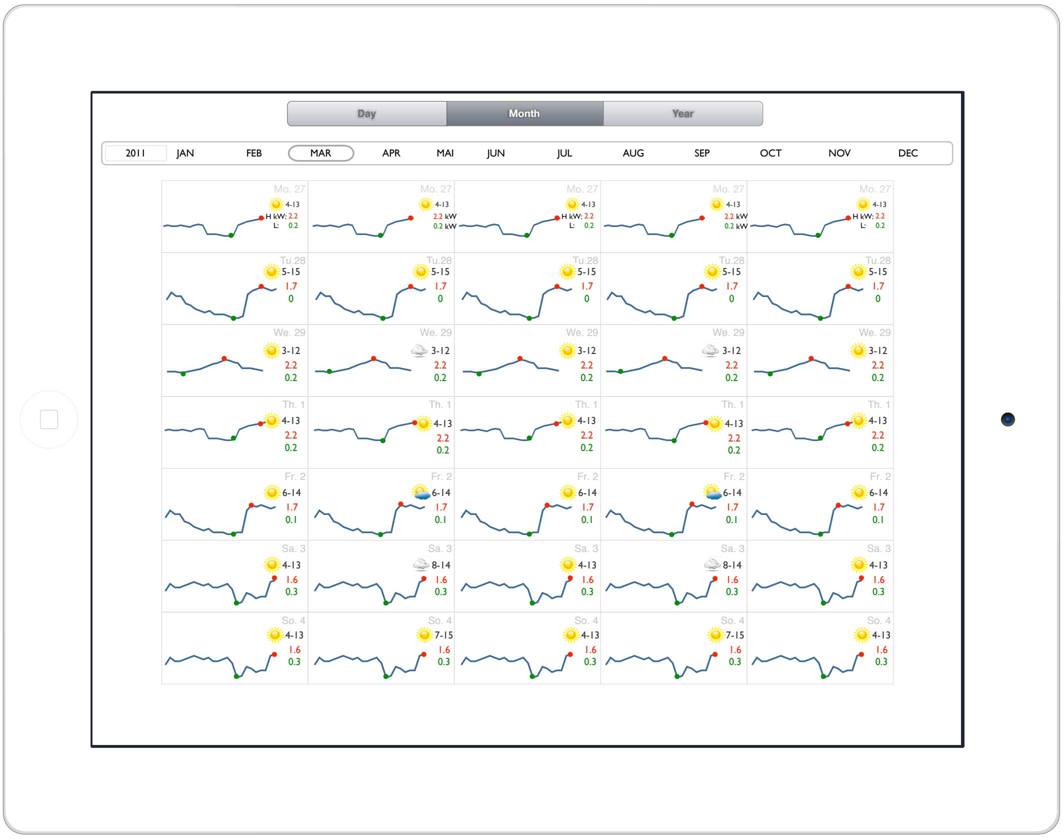


Figure 3.12: A monthly power consumption visualization using sparklines and small multiples

Figure 3.13: The navigation between the *monthly* and the *daily* view

consumed *kWh* for every month between the last and the current year. That way the user can detect her monthly consumption and compare it to other months. In addition to that we wanted to enable the user to compare her performance between this and the previous year. For this comparison the bar graph would not be appropriate since the trend of less or more consumption compared to last year may not be constant during the whole year. To solve this we are using an area graph (the one the one on top). The months of the year are set on the X-axis, and on the Y-axis we display the cumulative energy consumption in *kWh*. The result is a size increasing area that goes from January up to December and visualizes the total energy consumption for last year, and an area that begins in January and goes up to the current month. This graph gives the viewer direct information regarding her yearly consumption compared to last year. In addition to that this graph allows the detection of trends by noticing the curves of the graphs, and allows the user to estimate her energy consumption until the end of the year.

We wanted to make the comparison of the consumed energy both for every month and for the whole year possible. Our goals were to detect whether users would prefer a graph that visualizes the yearly energy consumption in a per month basis or cumulative.

3.3.2 Energy Consumption Visualizations for the Home Appliances

Using three different data granularity sets for the energy consumption of home appliances

Data granularity refers to the degree with which data is sub-divided or grouped [Froehlich et al. [2012]]. We decided to visualize the energy consumption for home appliances in three different ways. The first one is a per year energy consumption visualization, the second one a per use for every home appliance visualization, and the third one visualizes what a home appliance can do with 1kWh. All of the visualizations we will show here are exemplary, our goal was to detect which of the three data visualizations users would prefer. All of the views have a segmented control above them, which simplifies the navigation from one to another and informs the user what she is currently viewing.

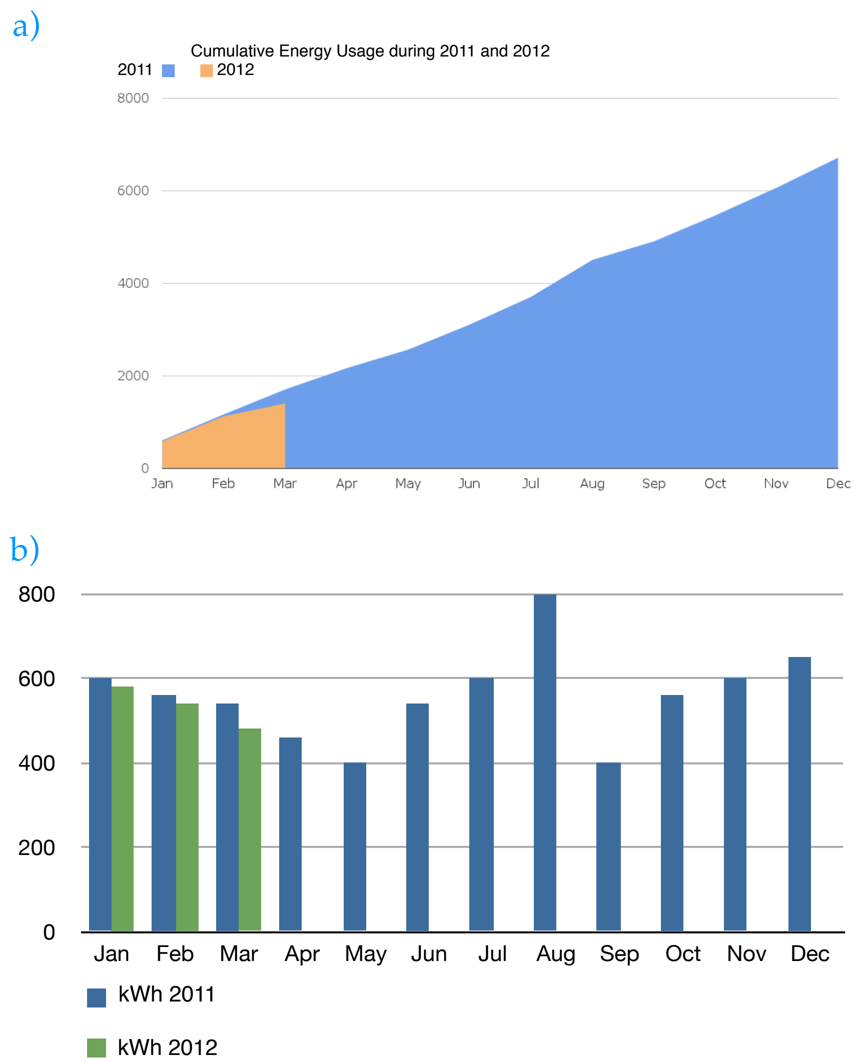


Figure 3.14: The yearly energy consumption visualization for the HVAC system

The *Per Year* View

In this view we are using two bar graphs. In the first one (figure 3.15 *a*), we display the consumed energy for each appliance in *kWh* for the last and current year up to this date. Showing the values up to date for both the current and the last year, enables the user to identify whether her performance is improving or not. In the second bar graph (figure 3.15 *b*) we are visualizing the *kWh* the home appliances consumed during the last year. This enables the user

Displaying the consumed energy for the previous and current year up to date, and the total of previous year for every home appliance

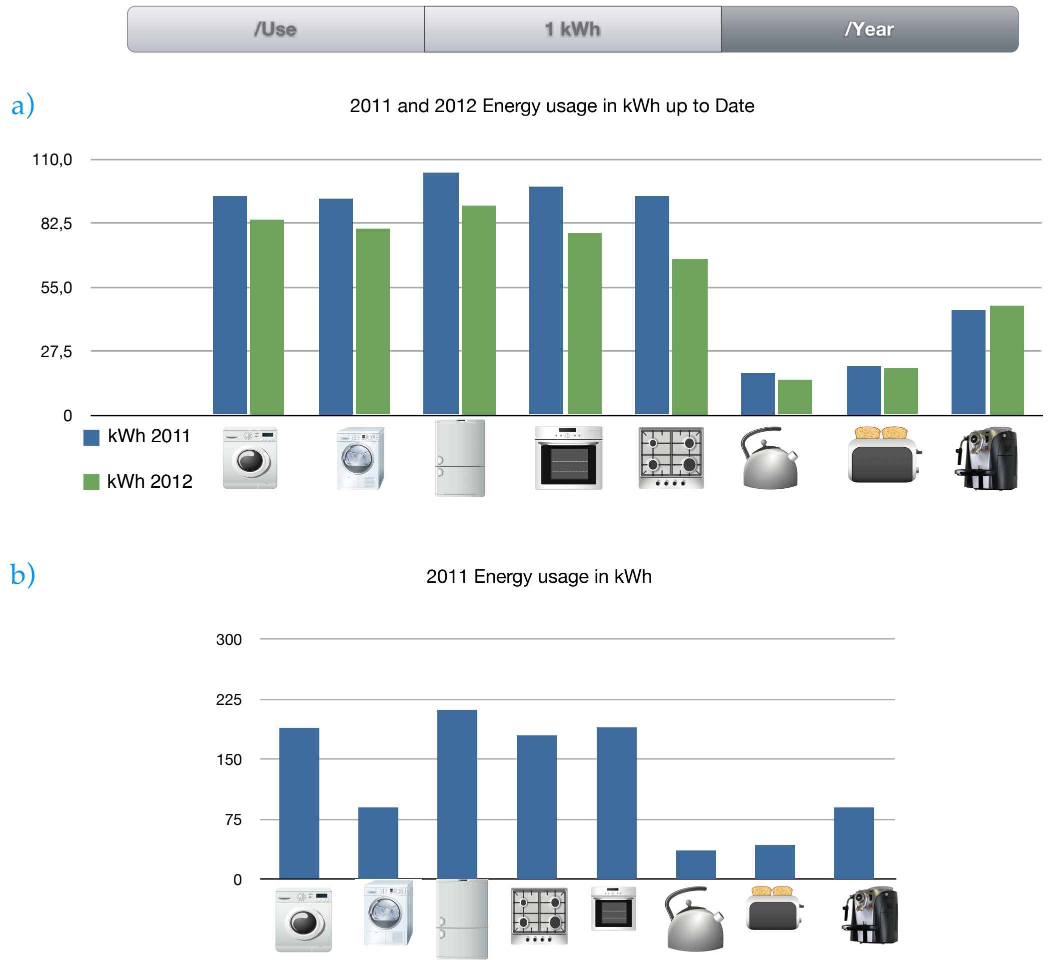


Figure 3.15: The *per year* energy consumption visualization for home appliances

to detect which home appliances consume the most energy in her house, but also to make an estimation for the energy she is going to consume this year.

Putting data in context

Our goal was to put data in a context. Informing the user only about this or last year's energy consumption would not be enough to determine whether she is reducing her energy consumption or not. The key here we argue is that we are visualizing last year's consumption up to this date, and the fact that we are displaying all three data sets (this year's consumption, last year's, and last year's up to date) in a small area.

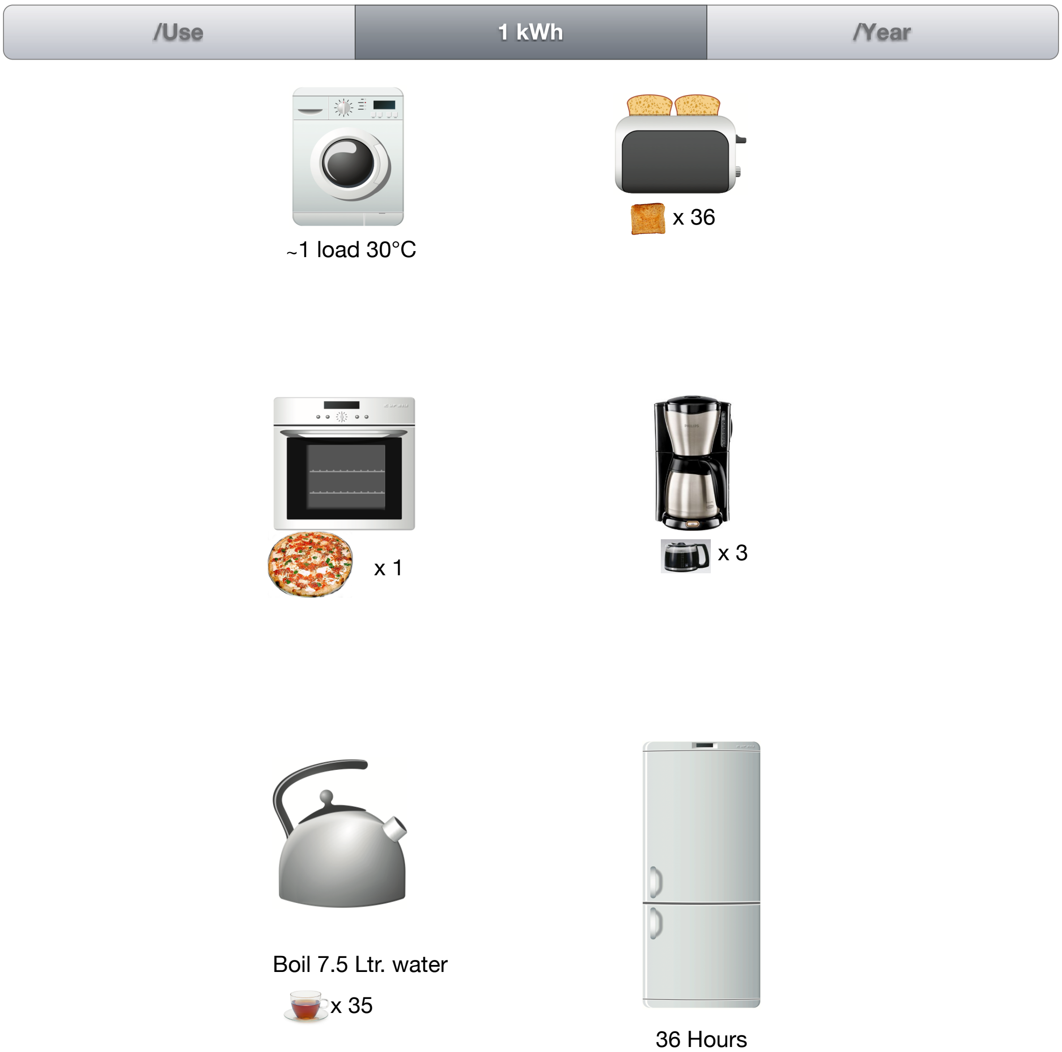


Figure 3.16: The *1kWh* energy consumption visualization for home appliances visualizes what a user can do with a home appliance when it uses 1kWh

The *Per Use* and *1kWh* Views

In these views we are displaying an icon of each home appliance, and the relevant data in a small text box underneath it. The data comes from the given power consumption for the home appliances the vendor states, and from our own measurements and calculations.

Home appliances vendors usually give an estimated yearly energy usage for the home appliances they are selling. This

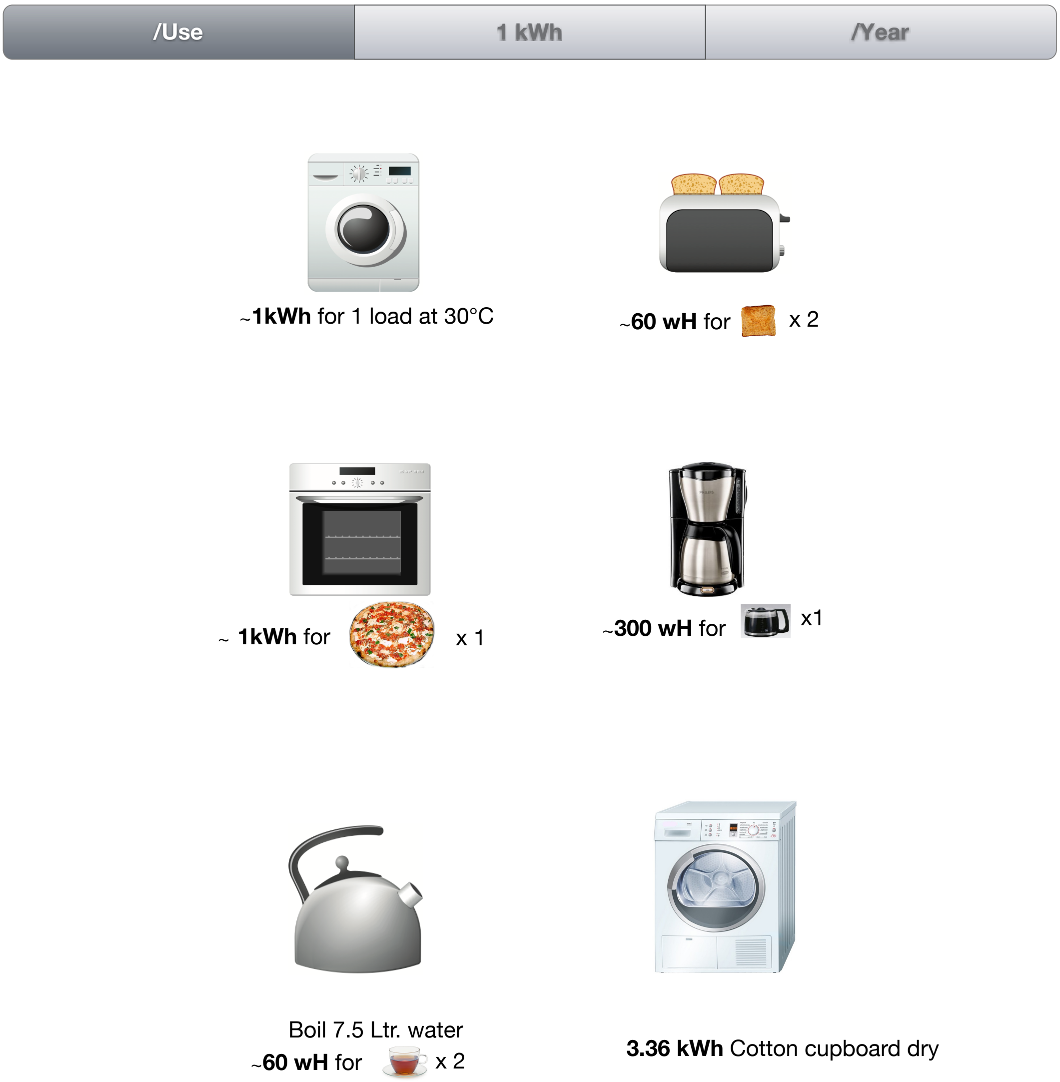


Figure 3.17: The *Per Use* energy consumption visualization for home appliances

The per use visualization helps estimating consumption based on own needs, and the 1kWh helps understanding the impact home appliances have in the electricity bill

information can be useful for home appliances that are constantly turned on, like a fridge for example, but for certain home appliances the consumed energy depends on how often the appliance gets used and thus from the amount of occupants who are living in the house. To solve this problem we added a per use energy consumption visualization. In this view we are displaying the amount of energy a home appliance consumes in a typical usage. In this case with one usage we mean whenever the occupant uses this appliance to accomplish a single task, like for example brew a cup of coffee, bake a pizza and so on. Furthermore, we decided to implement a visualization where we are showing what the user can do with a home appliance with 1kWh. Our motivation to do this was the fact that the electricity bill, which is the most common way for occupants to get informed about their energy consumption, uses the *kWh* as a measure.

3.4 *Per Occupant* Energy Consumption Visualizations

Showing the energy consumption broken down by occupant

The Per-Occupant views show the energy consumption broken down by occupant rather than by home appliances. We especially wanted to explore how thought provoking users would find this visualization. Our goals with these views were to see the reactions of users and how they would compare this kind of visualizations with the others. We did not focus on its practicality or how we could actually develop a method to trace who really used the home appliance. The views we will describe and show below use estimated and not calculated data, and should be considered as high fidelity prototypes.

The *Home View*

A view that visualizes the most energy consuming appliances for every occupant

The first view we created (see figure 3.18) visualizes the average energy each occupant consumes every day, the home appliances that she uses and consume the most energy, and the sum of the energy she consumed during the year. This exemplary view uses two occupants. We are using a small picture for each one of them. We placed the home appliances or entertainment devices she uses the most, and the bar graph that shows the energy she has consumed during this year under her picture. We are using a stacked bar graph whose first section shows the energy the occupant consumed this year, and the second section is a "limit" we have set for the occupant's consumption. This limit is based on the average energy consumption per person living in Germany. We are using this limit to help the occupant es-

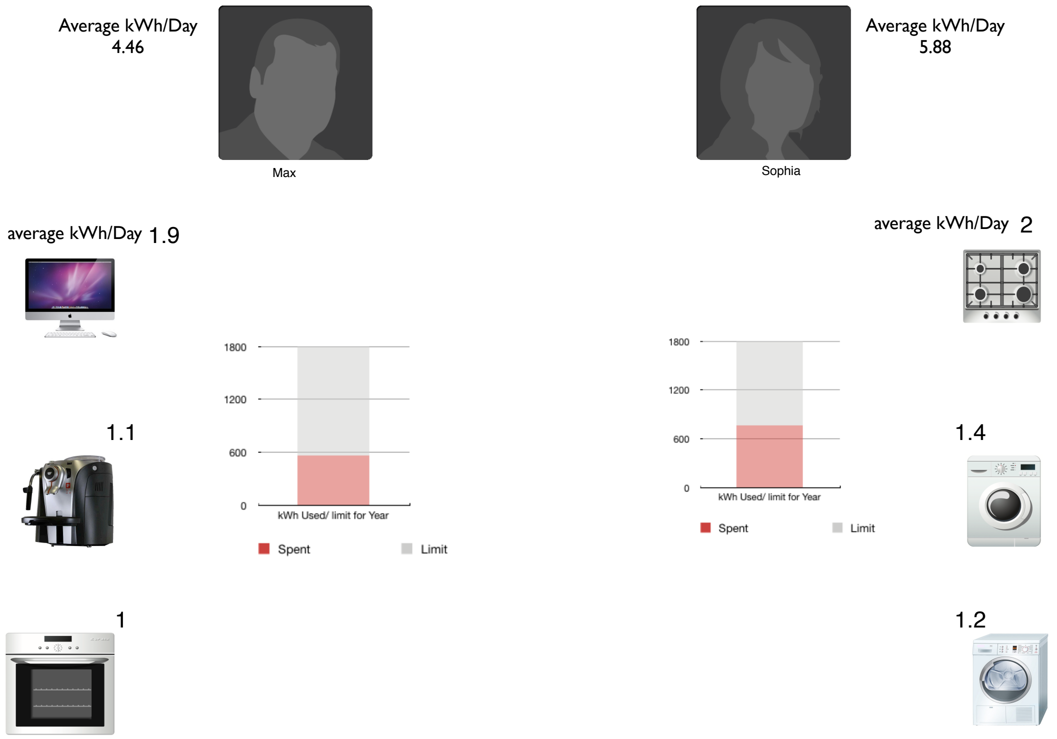


Figure 3.18: The *Home View* visualizes the average energy consumption for each occupant, and the appliances she uses the most

timate how much she should be consuming every month, whether she will be above or under this limit and to put the data in a scale. Above the home appliance's picture, we are showing the average energy this appliance consumes every day.

The *Home Appliances* View

A view that visualizes which occupant uses every home appliance

This view (see figure 3.19) visualizes what percentage of each home appliance's energy consumption each occupant consumed, visualized with a pie chart. In addition to that, the average energy consumption per day for each device in *kWh*, and its percentage related to the total energy consumption are also visualized.

Using a pie chart instead of a bar graph

This is an exemplary view that uses only three home appliances and a personal computer. Pie charts are in general

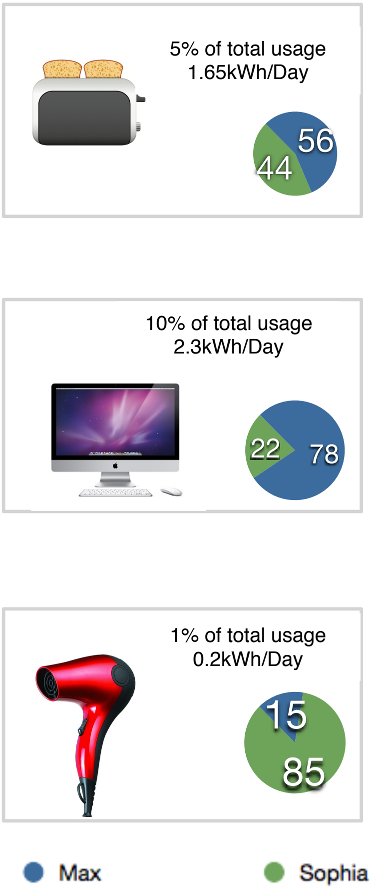


Figure 3.19: The *Home Appliances View* visualizes what percent of each home appliance's energy consumption each occupant consumed

considered less effective when the variation among the proportions is small [Griffiths [2008]]. On the other hand, we wanted to show the relationship of each proportion of the data to 100% and for this task and since the proportions are basic and only two we chose a pie chart instead of a bar graph.

Chapter 4

Evaluation

4.1 Form of the User Study and Demographics of the Participants

To evaluate whether we achieved the goals we described in the introduction and in the description of each view, we conducted a user study with 22 participants, 11 of which were female and 11 male. Their age varied between 19 and 40 years, with the average age being 26 years. Twenty participants were students and two were graduates. The subject of the students varied between architecture, computer science, engineering disciplines, economics, and technical communication. All of the participants said that they were interested in conserving energy in their home, but nine of them do not consider themselves to be ″green″ or ″eco-friendly″.

22 participants with the average age being 26 years

The user study had the following form: all the views we described in the last section were presented with descriptions, in the order we described them to the viewers. Every view and its description was followed by some comprehension questions. After that, we asked questions specific to every view. At the end of every different visualization method (points, graphs, per occupant) we asked some summarizing questions. At the end we asked some summarizing questions about all three visualization methods. The user study consisted of 43 questions, and the average comple-

The user study consisted of 43 questions tion time was around one hour.

4.2 Evaluation of the User Study

4.2.1 Evaluation of the Views based on the Points

General Acceptance of the Points Concept

Visualizations that use points are faster and easier to understand, and visually more attractive

In the introduction we explained our hypothesis for the points system. We assume that points have certain aspects and characteristics which differentiate them from the traditional measures of *W* and *Wh*. In the user study at the end of the points section, we evaluated whether those characteristics are true. We assume that visualizations that use the points as a measure have the potential to be faster and easier to understand, that users consider them to be more attractive, and that they are useful despite being less informative. The majority of the respondents (81%) agreed that these visualizations are faster and easier to understand (95%), and 86% agreed that they are visually more attractive. The majority (86%) of the participants also agreed, that they are interested in historic data visualized through a points system.

Energy consumption visualizations with points are perceived as informative and useful

The one aspect on which the participants did not clearly agree is, whether points are informative and useful. We formulated the question in a way that implied that using *points* is both more useful and more informative. The usefulness of points derives from the fact that they allow faster and easier estimations, and not from the fact that they are more informative. Despite the way we asked the question, 50% of the participants positively evaluated points in this aspect (see figure 4.1).

The idea of the points was evaluated as higher than the implementation of the views, partially because of the lack of interaction in the user study

59% of the participants evaluated the idea behind the points as very good, and 36% evaluated it as good. 5% of the participants evaluated the implementation of the views with the points system as very good, 68% as good, and 18% as bad (see figure 4.2). This shows that there is room for improvement in the design. In fact nine of the participants

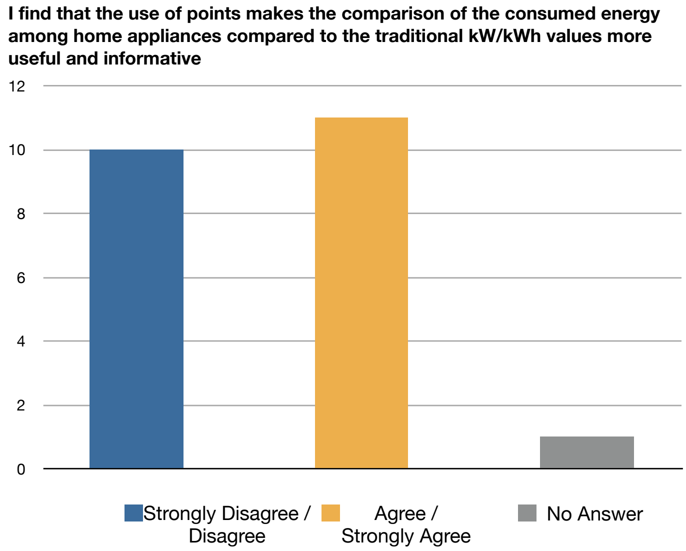


Figure 4.1: Points evaluation: informativeness and usefulness of points system

failed to answer the comprehension questions of the *yesterday* view correctly ("Which home appliance consumed the most energy yesterday ?"). One of the participants said "I would definitely use such a visualisation (referring to the points in general), but only think that the last use consumption is unnecesary...", another one said that she confused the last use consumption with the yesterday consumption, and one even suggested to use an average per use consumption for every home appliance instead of the last use consumption. There were also some very positive comments such as "Yes I would use it and even recommend it to others, because it provides you all the information needed in order to save energy in your house. It is easy to understand and very effective!". In general we believe that points offer benefits compared to the *W* and *Wh* measures, and the participants of the user study showed that they are interested in a measure with these characteristics.

Using Points to Maximize the Use of Solar Energy

Participants answered that they would like to get informed

Participants appreciate the usefulness of points in a house with photovoltaics

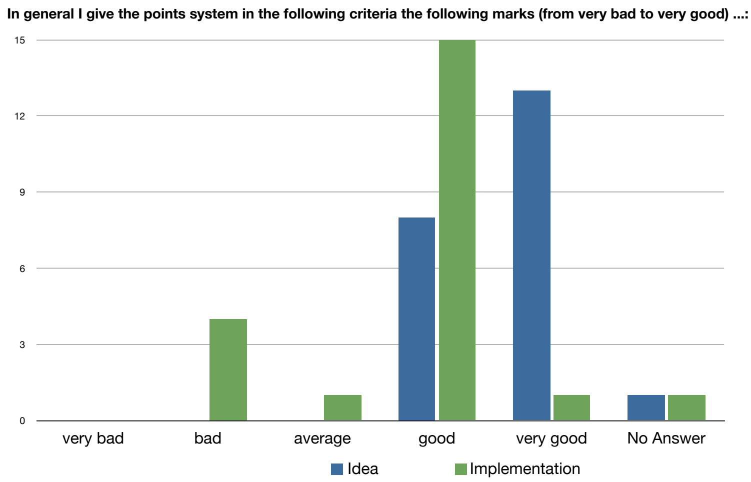


Figure 4.2: Points evaluation: evaluation of the idea and the implementation

about what happens with the solar energy their homes produce (86%). We reproduced an example of the interaction shown in figure 3.7. After showing them the *home appliances* view and asking a comprehension question about it, we displayed an instance of the *now* view with two unused Counter Entropy points, then we asked which home appliances they can turn on and still maintain a positive energy balance. Unfortunately the way we formulated the questions, and the form of the interaction, which is not the same as we intend it to be in the iPad application, resulted in many participants not understanding that they had to look at the *home appliances* view which was in the previous page to decide which home appliances they can turn on. This resulted to a lower percentage of correct answers (59%) than we expected. Despite this, when asked whether the combination of the *home appliances* view with the *yesterday* view, can simplify the decision making of which appliances should be turned on in a house with photovoltaics, 77% answered positively (see figure 4.3).

The characteristics of points make them suitable to use for time sensitive cases where estimations and decisions have to be taken fast

We also asked our participants to think of scenarios where they could use these two views combined. One said, that he would use it in order to decide when to use his washing machine or dishwasher. Another said ”it would even make fun to try and keep a positive energy balance”, some-

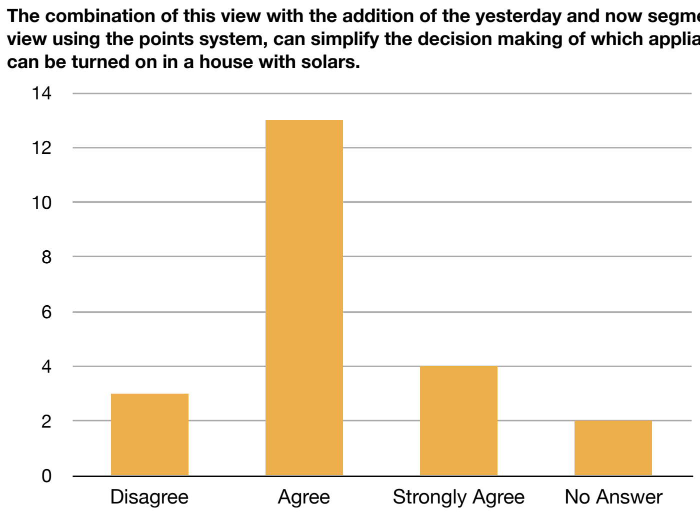


Figure 4.3: Points evaluation: combined use of views to maximize effects of solar energy

thing which we did not intend to do with our design. The characteristics of points make them suitable to use for time sensitive cases where estimations and decisions have to be taken fast, maximizing the usage of solar energy is such a case, and our participants showed great interest in it.

4.2.2 Evaluation of the Visualizations that Use Quantitative Data and Graphs

The importance of providing evidence

Participants considered the view in figure 3.9 that shows influencing parameters to be the most useful and informative, and the most attractive as well. This may sound contradicting since this view provides a lot of information in order to be evaluated as the most informative, but in the same time is not too complicated in order to be considered unattractive. All of the participants agreed that it is informative and useful, which is unique among all the views we asked our participants about. 77% of the respondents considered it as attractive, the second most attractive according to the participants was the *per occupant* view for the home appliances,

The most informative and useful graph is also the most visually attractive also with 77% but with less participants strongly agreeing with the fact that it is attractive.

Visualizing influencing parameters can help users develop a deeper understanding about a problem

Among the questions we asked the participants that were related to this view, was whether they are interested in seeing parameters that influence the energy consumption of their HVAC systems and home appliances, 95% agreed to it. We also asked them whether a view that provides such information can help them develop a deeper understanding about energy consumption, and 82% agreed.

Evaluation of the Graphs that Focus in Making Trends Visible

Detecting trends in energy consumption visualization is less useful than understanding the parameters that influence it

The graph in figure 3.11 that focuses on showing trends, was evaluated as the least informative and useful (36% disagreed that it is useful and informative), followed from the first *per occupant* visualization. 73% of the respondents agreed that this graph helps them detect trends, so the design of the graph can be considered successful. From the comments the participants wrote though, it is clear that the detection of trends would not help them reduce the energy consumption. One of the participants answered to the question about whether this view helps the detection of trends: "Maybe, but how does this help the consumer to behave better at this point?". The inspiration for this view came from sparklines used to visualize the course of the stock market. In this context the detection of trends is important since it helps the detection of correlations between stocks, and the detection of patterns that could be repeated in the future. In the case of energy consumption, these seem to be characteristics not greatly appreciated from the participants of our user study, or at least not as much appreciated as other characteristics.

On the other hand, this view brings many benefits to the navigation between the different energy consumption visualizations as shown in figure 3.13. In this case the detections of trends (and thus the detection of outliers) would probably be more appreciated, since with one tap the user is able to see a detailed view of the day. Unfortunately the participants of the user study could not experience this kind of interaction.

The Time Granularity Preferences of The Respondents for the HVAC System

Between the two graphs shown in figure 3.14, respondents answered that they prefer the comparison to be in a per month basis (45%), the same percentage answered with both (see figure 4.4), and only 9% said that they would be satisfied with a view that visualizes the cumulative energy consumption for the current and last year. In general though 95% agreed that they are interested in a comparison of the consumption between the current and last year. Our intention with the graph that uses the cumulative data, was to make this comparison easier but as it seems, users can interpret and prefer a per month comparison better.

Users prefer a per month and a per week visualization for energy consumption

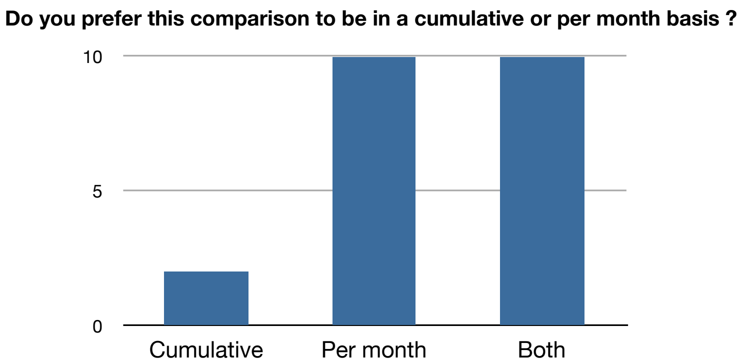


Figure 4.4: Graphs evaluation: per month and cumulative data

This assumption can further be enhanced from the question we asked the participants: "In general I prefer a visualization with daily/weekly/monthly/ yearly energy consumption for heating my home.", where 59% answered with monthly, 50% with weekly, 32% with yearly and 23% with daily (the participants could choose more than one answers) (figure 4.5).

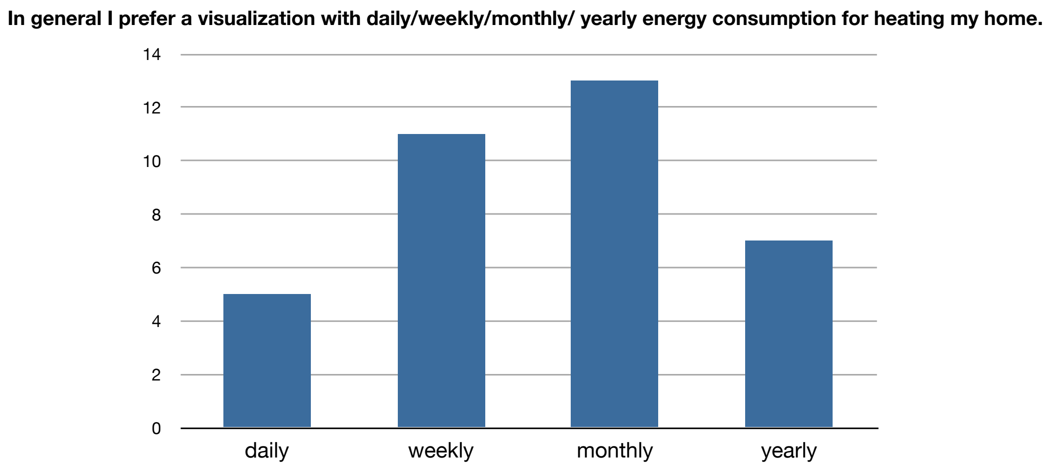


Figure 4.5: Graphs evaluation: time granularity preferences

Respondents Prefer Comparable Data and Visualized Influencing Parameters Instead of Trends Detection

Influencing parameters and visualized evidence are the most appreciated aspects of the respondents

Comparable data was preferred in the question "In general I prefer a view with a focus in: providing evidence/ influencing parameters (1st View), demonstrating trends (2nd View), demonstrating comparable data (3rd view), or all of them (you may choose more)?" with 77%, followed from evidence and influencing parameters with 73%, and 32% of the participants answered "with trends. Despite the mention of every view after every aspect though, all of the graphs provide comparable data, and both visualized influencing parameters, and the detection of trends enable additional comparisons. In fact if we consider the results for the graph that visualizes the influencing parameters (it was evaluated as the most visually attractive, and as the most informative and useful), and the fact that we chose it for the daily consumption (which was the less preferred of the time options), we can argue that influencing parameters and visualized evidence are the most wanted aspects of the respondents.

Evaluation of the Views that Visualize the Energy Consumption of Home Appliances

We asked our participants which of the three energy consumption visualization for home appliances they prefer (per year, /1kWh, or per usage). 55% answered with the per year and per use views, and 41% with the per 1kWh view.

Points are the preferred way to visualize the energy consumption of home appliances

When we included the points visualization for the home appliances in the question, the majority of the participants (77%) chose the points as the preferred visualization (see figure 4.6). This result was unexpected since all of the graphs provide information in more detail. On the other hand, the participants probably had in mind all of the points views and the benefits that derive from using them combined when they answered this question. This is another argument though, that shows the great interest the participants have showed towards an alternative power and energy measure with the characteristics of the points.

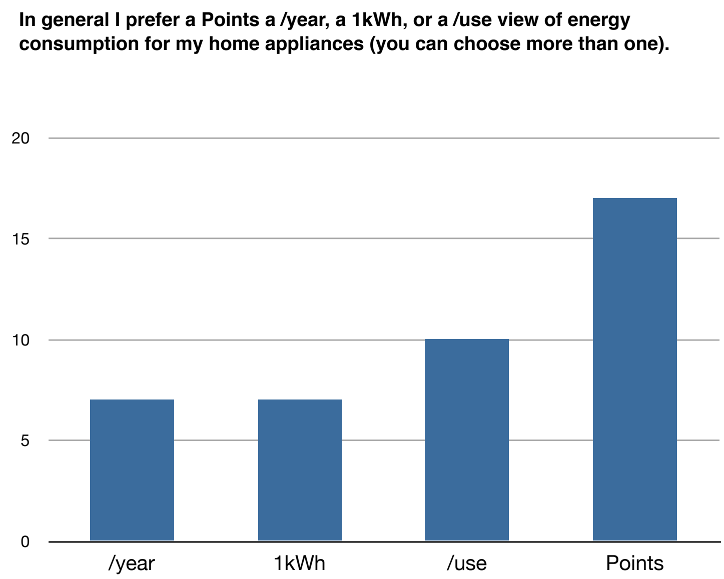


Figure 4.6: Graphs evaluation: preferred visualization between a points visualization, a per year, a per 1kWh, and a per usage data set

4.2.3 Evaluation of the *Per Occupant* Visualizations

We failed with our assumption about the per occupant visualizations

Our assumption with the *per occupant* visualizations was that users would consider them to be the most thought provoking. This is a new way to visualize energy consumption that was unseen from the occupants, and we wanted to research their reactions. We asked our participants which viewing method they consider to be the most thought provoking. The results do not indicate that they consider the per occupant views to be more thought provoking than the others. 55% chose graphs as the most thought provoking views, 36% the points and the same percentage the *per occupant* visualizations. Some of the participants mentioned their concerns about how a system could trace which occupant used every home appliance in order to accurately visualize its energy consumption. One respondent said that he would use this kind of visualization "for a healthy competition between family members or occupants".

4.2.4 A Comparison Between All Visualizations

Graphs are the most thought provoking, informative, and useful visualizations, points are the most visually attractive, and easy to understand

At the end of the user study we asked our participants to choose the most thought provoking (which turned out to be the graphs as described above), the most visually attractive, the easiest to understand, and the most informative and useful type of visualization. Visualizations with points turned out to be the most visually attractive (59%) followed from graphs with 36%. 73% chose points as the easiest to understand way to visualize power and energy consumption followed from 45% of the participants who chose graphs.

Points are preferred for visualizing the energy consumption of home appliances, but for situations where the energy consumption is related to many variables, visualizing influencing parameters is preferred

The biggest variation was in the most informative and useful way to visualize power and energy consumption where 86% agreed that the graphs we designed are the most suitable for this manner, followed from points with 36% (see figure 4.7). At the end of the points section, we asked whether visualizations that use points make the comparison of the consumed energy among home appliances more useful and informative and users agreed with this assumption (see figure 4.1). Points were also the preferred view-

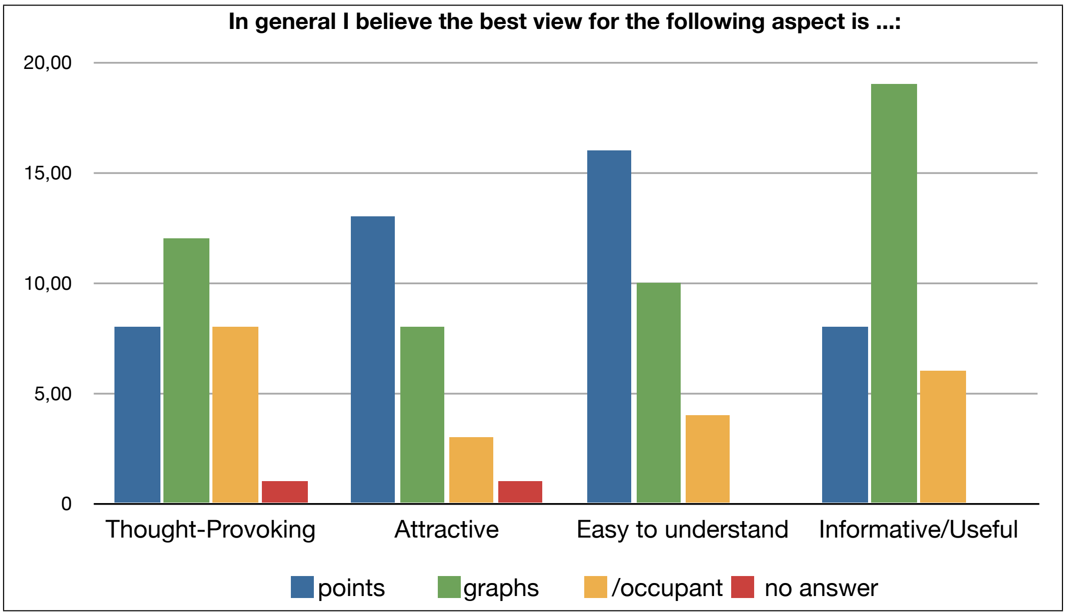


Figure 4.7: Comparison of All the Viewing Types

ing system after the participants came in contact with the graphs we designed for the energy consumption of home appliances (see figure 4.6). From these results we can derive that points are preferred for visualizing the energy consumption of home appliances, and graphs for the HVAC system. The reason for this we argue is that points work well in the scenario with the solar energy, something which can lead to saving energy. On the other hand graphs provide evidence that can help users develop a deeper understanding, and thus conserve energy in scenarios where more variables and parameters influence the energy consumption (like with the HVAC system).

Chapter 5

Summary and future work

In the previous chapters we presented the ideas and described the development process of the energy consumption visualizations we created. In this chapter we will give a summary of the important aspects and our findings, and we will discuss possible future work.

5.1 Summary and Contributions

The way we used the design, implement, and analyze process in our work

In this work we designed energy consumption visualizations for an end user home automation display. We decided to design an iPad application that would visualize the energy consumption of the Counter Entropy house in two different ways. First, we decided to visualize the energy consumption through a *points* system with the goal to simplify and accelerate the perception of energy consumption. In addition to that we decided to visualize the energy consumption using quantitative data and graphs. With these views our goals are to provide information that will enable the occupants to develop a deeper understanding about energy consumption.

We can divide our work into three basic steps:

1. We looked for related work and found out that existing applications focus on providing controls and automations instead of trying to help the occupant conserve energy. There are also solutions that demand from the user configurations and manual data input, and solutions that try to understand the occupant's habits and then make automatic adjustments. We decided to focus on collecting information and visualizing in an appropriate way to the user.

2. We collaboratively designed the graphs with the help of mechanical engineering and architecture students who also participate in the Counter Entropy project. For the design of the points visualizations we used data from simulations, and had to make calculations and estimations in order to simplify the rich amount of quantitative data into graphical elements that are visually more attractive, and simplify the understanding of energy consumption.

3. We evaluated our results with a user study with 22 participants. After that we analyzed the results and came into conclusions which we present in section 4—"Evaluation".

The findings of our study

Some of the findings include the time granularity preferences for users. Users prefer energy consumption visualizations for weekly and monthly data sets compared to yearly and daily data sets. The participants of the user study showed less interest for graphs that helped the detection of trends compared to graphs that visualize comparable data sets, and views that visualize influencing parameters. Users are also interested in interactions between views (see figures 3.7 and 3.13) that can help them reduce their energy consumption.

Our main contributions though are the idea of the points system, and the graph that provides evidence about the consumed energy through the visualization of the influencing parameters.

Points are an effort to create a more accessible power and energy measure

The points system is an effort to create a more accessible power and energy measure, that combines the benefits of ambient information displays, analog scales, and in the same time is calculable and comparable. The point system was designed to be used in scenarios where users want to get a quick overview about which energy consuming devices are turned on in their home, or in time sensitive cases where estimations and decisions have to be taken fast. Maximizing the effects of solar energy is such a case (see figure 3.7).

Visualizing the causalities of household energy consumption

The graph shown in figure 3.9 was evaluated as the visually most attractive, and the most useful and informative. In additions to that 82% of the participants agreed that the information provided from this view can help them develop a deeper understanding about energy consumption, and 95% expressed their interest in such information. The causalities of household energy consumption are an important first step towards reaching an energy sustainable lifestyle. The design characteristics for this graph should also be mentioned, we wanted to visualize all the relevant information in a single graph. The information is placed in a way to help the user track the effects of chores and weather circumstances the time they occurred. For this we created a series of parallel lines similar to sparklines to visualize the various binary values we wanted.

5.2 Future Work

In this section we will present ideas and suggestions which arose during the process of the thesis, and we did not implement. The participants of the user study suggested many improvements and additional feature we could do in some further iterations of our visualizations. The most suggestions are for the points system, for which the participants showed great interest.

Implementing a Goal Setting System

In our visualization we have not added any goals that the occupants and users should reach. In the first design phases we considered various ways to enable the setting of goals to users, but we had difficulties finding a mechanism that could work for all the users and is well integrated with our visualizations. As it turns out, using a ”one-size-fits-all” solution, setting the same goals to differently motivated individuals at different stages of readiness and willingness to change does not have the desired results [He et al. [2010]]. The design of a goal setting mechanism that is integrated with the visualizations we created is a further next step.

An interactive user study

We had not the possibility of conducting an interactive user study because neither the Counter Entropy house was built, nor the iPad Application and the necessary back end systems were built at the time this thesis was written. For these reasons we were not able to conduct an interactive user study where we would be able to better evaluate the characteristics of the points and the effectiveness of the user interactions.

A field study

The real effectiveness of the visualizations we created, and whether they can help users reduce their energy consumption or not will only be figured out in a field study with several households.

Appendix A

User Study

File: The user study we conducted[a]

[a]http://hci.rwth-aachen.de/ tsoleridis/BachelorThesis/UserStudy.pdf

Appendix B

Raw Data of the User Study

File: Raw data of the user study we conducted[a]

[a]http://hci.rwth-aachen.de/ tsoleridis/BachelorThesis/UserStudyResults.numbers

Appendix C

User Studies

File: The user studies[a]

[a]http://hci.rwth-aachen.de/ tsoleridis/BachelorThesis/UserStudies.zip

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Index

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