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Welcome

It is with great pleasure that we welcome you to FSEA 2014, the AVI 2014 workshop on Fostering Smart Energy Applications through Advanced Visual Interfaces.

This workshop focuses on advanced interaction, interface, and visualization techniques for energy-related applications, tools, and services. It brings together researchers and practitioners from a diverse range of background, including interaction design, human-computer interaction, visualization, computer games, and other fields concerned with the development of advanced visual interfaces for smart energy applications.

FSEA 2014 is the result of the efforts of many people involved in its organization, including our programme committee, and others who have assisted us in putting this workshop together.

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Contents

Pervasive Visual Interfaces to Change Energy Consumption Behaviour at the Workplace

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ABSTRACT

This position paper introduces pervasive interventions at a university campus to increase the pro-environmental awareness, consciousness, and learning of employees making use of different visual interfaces. We briefly present the design of three intervention iterations. While in the first intervention the focus was on increasing awareness through information distribution with ambient learning displays on the campus, the second iteration provided personalised feedback to employees with the help of a sensor network and different client applications. The third iteration then implemented a game-based learning concept. We found that these approaches are effective on different levels and that a combination of these effective elements can lead to a sustained behaviour change among the employees.

Categories and Subject Descriptors

H.5.2 [**INFORMATION INTERFACES AND PRESENTATION**]: User Interfaces

General Terms

Measurement, Design, Experimentation, Human Factors.

Keywords

Environmental Learning, Pervasive Education, Ambient Learning Displays, Game-based Learning, Design-based Research, Mobile Learning.

1. INTRODUCTION AND BACKGROUND

Several high-level studies have shown the effect of human energy consumption on pollution and climate change [3,6]. While in the home context monetary incentives are one of the main motivational aids to save energy, these incentives are not present at the workplace. In a formative study we have conducted it has been shown that only 25% of employees in an academic organisation are concerned about the financial consequences of their individual consumption for the organization [2]. Therefore, other initiatives are needed to increase pro-environmental awareness and behaviour change at the workplace. To approach this we conducted the three consecutive intervention studies briefly presented below. On a conceptual level these pervasive interventions are based on a complex model of pro-environmental behaviour [4]. The model integrates internal factors such as personality traits or environmental consciousness and external factors such as infrastructure or political context. Additionally the authors of the model investigated and incorporated possible barriers to pro-environmental behaviour. These barriers are mainly responsible for the gap between attitude and action, also referred to as engagement gap. Among others the identified barriers were lack of environmental consciousness and knowledge, negative or insufficient feedback about behaviour, as well as missing internal and external incentives. Our interventions are based on previous research done in this area. We acknowledge this work, but do not elaborate further on that within this paper.

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2. PUBLIC DISPLAYS TO INCREASE ENVIRONMENTAL AWARENESS

This study focused on an intervention that initiates environmental learning and facilitates pro-environmental behaviour at the workplace. Thereby the purpose of the study was to (1) use ambient displays as novel approach in presenting and dealing with energy consumption and conservation information, (2) assess and evaluate the respective learning outcome and the behaviour change. The utilisation of ambient displays in this context was motivated on the authors' underlying research project on the situated support of informal and non-formal learning scenarios in ubiquitous learning environments by enabling learners to view, access, and interact with contextualized digital content presented in an ambient way.

For the experimental variation two independent variables were used, i.e. the representational fidelity as well as the level of notification of the ambient learning displays, while each variable could take one of two distinct states. This resulted in four different treatments combining the two variables and their respective levels or a 2 x 2 experimental design with four groups covering all different treatments, i.e. ambient learning display prototype with either (1) blind notification and indexical representation, (2) blind notification and symbolic representation, (3) interruptive notification and indexical representation, or (4) interruptive notification and symbolic representation. As dependent variables the theoretical construct environmental learning and the pro-environmental behaviour have been measured. For environmental learning pre- and post-test questionnaires were used to measure the single components and apply respective statistical methods. In total three components were measured directly with the questionnaire, namely:

- Confidence to estimate individual and institutional consumption and conservation potentials,

- Awareness need and estimated effectiveness of higher awareness, as well as
- Environmental concern and conservational attitude.

For the experiment four prototypes were deployed in four chosen campus buildings. Corresponding to the main characteristic of ambient displays [1], i.e. deliver information out of the periphery of attention, while being able to move between the periphery and the focus of attention, the prototypes were used to emulate ambient learning displays. Each prototype consisted of a Dell M2010 notebook with built-in speakers and webcam but without attached keyboard or mouse. The speakers were used to send out audio notifications, while the webcam was used to enhance the functionality of the notebook with a custom-built movement/attention sensor. The sensor was built using the Processing[1] development environment and the open source computer vision library for Processing.

Figure 1. Deployed Ambient Display Prototypes.

The prototypes presented precompiled slides showing three types of information, divided into parts depicting information regarding energy consumption in the building, generic saving tips, and the overall conservation potential. On each slide the most important information was highlighted in red and contextual information, such as location or timeframe, was highlighted in blue. The first part contained information depicting the average electricity consumption per working day of each employee, the whole campus, and the building the display was located in. The respective numbers were calculated based on the actual consumption of the previous year.

The prototype variation on notification level was implemented using the custom-built movement/attention sensor to trigger the notification as well as the built-in speakers to play back a respective audio file. For the interruptive treatments one audio notification was played when the sensor detected movement and another one when the sensor detected that someone turned towards the display. For blind treatments any notification was omitted. The variation on representational fidelity was implemented as two distinct means of information presentation. For the indexical representation raw data facts were used to communicate consumption information, saving tips, and conservation potentials. In contrast, topic-related icons were used for the symbolic representation of the data, e.g. light bulb icons representing 5W each. Due to the ambient nature of the deployed learning displays the employees were not asked directly to participate in the experiment and watch out for the treatment. Instead the prototypes were deployed in the entrance areas of the four buildings and all employees that responded to the pre-test were asked after the treatments to respond to the post-test assuming that they did notice the deployed ambient learning display.

Analysing the results of the pre-test and post-test data showed the following results. The group with interruptive notification and symbolic representation had the largest gain within the construct environmental learning and the group with interruptive notification and indexical representation the smallest. The largest knowledge gain could be measured for the group with blind notification and indexical representation. The largest confidence gain as well as the largest awareness gain could be measured for the group with interruptive notification and symbolic representation. The largest concern gain could be measured for the group with blind notification and symbolic representation. Furthermore the influence of the different treatment conditions on the environmental learning outcome as well as the individual component gains was explored. None of the effects were significant to demonstrate the superiority of the one prototype design against the other. Across all groups a comparison showed that the deployed prototypes significantly influenced awareness and knowledge. In total participants scored significantly better on the knowledge component and felt a significant lower awareness need after the treatment. This revealed that the deployed prototypes helped to examine and comprehend and lower the awareness need of employees. The qualitative results of the post-test also showed that there is a need for alternative ways to motivate employees to save energy at the workplace, as for instances clear incentives were missed or the provided information was to generic.

3. PERSONALISED FEEDBACK TO INCREASE ENVIRONMENTAL CONSCIOUSNESS AND KNOWLEDGE

The presented project elaborated and developed an infrastructure that supports the concept of “Energy Awareness Displays” in office buildings with the following functionality:

- Inclusion of individual energy consumption information (device specific or personal level of detail).
- Aggregation of available information extending and enriching the overall energy consumption picture.
- Sensoring and logging to measure the effectiveness in terms of energy conservation and enable the prototypical evaluation.

Based on the supporting infrastructure respective display prototypes have been developed upon the following characteristics:

- Public interactive representation of the overall and individual energy consumption in several levels of detail.
- Explorative comparison of the consumption information in relation to fellow employees, departments, and/or floors.
- Motivating and persuading conservation facilitation patterns based on the presented information, such as visual incentives.

The described approach required accessing and using external services offering the needed functionality, i.e. inclusion of individual energy consumption information, aggregation of this information, and logging. For the inclusion of individual energy

[1] http://processing.org

consumption information the Plugwise[2] system was chosen. The system provides the needed sensor hardware to manage appliances and get access to energy consumption details. Furthermore the included software allows configuring the informational access via web services. The result is a wireless smart meter plugs network that can be accessed using the bundled software. The system was set up in such a way that individual appliance, room, and group information could be accessed. A basic application programming interface (API) can be used to access this information. The existing API was slightly adapted and enhanced to deliver all needed information in the right format. All changes are implemented based on the existing Plugwise Source[3] software template engine. When requesting information from the API, the information is returned in a simple XML[4] structure that can be incorporated into applications.

For the aggregation of available information respectively the logging of sensor data the Pachube[5] system was used. The system offers a free real-time open data web services that allows to aggregate, store, and access all kinds of sensor data, e.g. energy, home automation, and weather data can be aggregated, enriched, and accessed utilising different means. The system was set up to aggregate all the available sensor data for each room, i.e. (daily) total power usage and additionally the occupation.

On top of the outlined infrastructure a mobile and a web/desktop end-user application have been developed. The applications visualise the gathered information within the infrastructure. Thus the information can be accessed and explored online or with existing institutional or personal devices, including desktop computers, tablets, smartphones, and so on. The developed mobile application is shown in Figure 2. The developed web/desktop application is shown in Figure 3.

Figure 2. Mobile Application.

As part of the design cycle the developed display prototypes and used visualisation techniques have been evaluated in user-studies to reveal which are most effective in communicating energy consumption data and motivating energy conservation. Furthermore surveys have been conducted to assess whether dynamic visual feedback and the provided facilitation patterns can promote the conservation of electricity at the workplace and measure the increased awareness on the topic as well as changed attitudes and/or changes in behaviour. Furthermore the user acceptance and interest have been measured.

The deployment of the feedback intervention in the subgroup made them aware that they are not active enough and need more information and knowledge about energy conservation at the workplace. In addition most participants of this intervention communicated the need for incentives to save energy. Results show that although the display prototypes have not been used extensively the information presented was perceived well and understood. Information granularity of the visualization has satisfied the needs of employees.

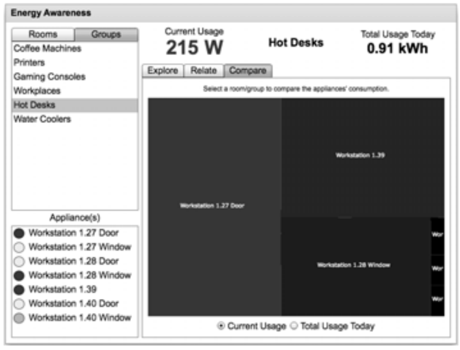

Figure 3. Web/Desktop Application.

4. GAME-BASED LEARNING TO INCREASE ENVIRONMENTAL CONSCIOUSNESS AND BEHAVIOUR CHANGE

In this study we had the goal to go beyond increasing awareness and providing personalized information and we focused on the potential of a pervasive game to increase knowledge, pro-environmental consciousness and last but not least change consumption behaviour. Our research questions for the pilot study have been the following:

- Which aspects of a pervasive game have the most potential for improving energy consumption behaviour at the workplace?
- Which aspects of a pervasive game have the most potential for improving environmental consciousness?
- Do rewards in the form of digital badges and prizes have a positive impact on consumption behaviour and environmental consciousness?

To answer these questions we have integrated different technologies. The design of the pervasive game has been done using ARLearn. ARLearn is a platform for location-based mobile learning. The platform consists of an authoring interface that enables game-designers to bind a number of content items and task structures to locations and to use game-logic and dependencies to initiate further tasks and activities [5]. Figure 4 shows the developed game-based learning application. Besides ARLearn we have used a signage solution to display content on existing displays on the campus and recruit participants for the game. For the incentive component we have integrated and used the Mozilla Open Badge Infrastructure[6]. At the end of the game the participants were asked to evaluate the game and provide qualitative feedback. The results showed that participants were

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

[3] http://www.plugwise.com/idplugtype-f/source

[4] http://www.w3.org/XML/

[5] https://pachube.com/

[6] http://openbadges.org

highly concerned about the amount of energy they are using at the workplace, especially regarding the environmental costs, such as higher environmental pollution. They were also highly concerned with what they can do personally to reduce their energy consumption and performed the suggested energy saving tips. When asked why they were not doing more to reduce their energy consumption the participants opted again for more information and detailed feedback on their personal consumption. Compared to the second iteration less participants stated that they need more incentives to save energy thus emphasising the influence of the gamification as incentive mechanism. The majority of participants was highly motivated to take more actions to further reduce their energy consumption.

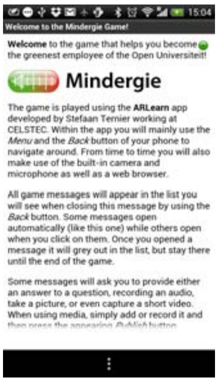

Figure 4. Game-based Learning Application in ARLearn.

When asked to evaluate the game the participants stated that the gamification was appealing. Overall the participants liked "active" game elements most. The "informational" elements were less popular, while the given rewards in form of badges ranged in between the two. Regarding the expected behaviour change, participants stated that the game in general changed their energy consumption behaviour, while the "informational" and the "active" elements were assigned with the highest potential to do so. Regarding the environmental consciousness, participants stated that the game enhanced their environmental consciousness. In this regard the "informational" elements were assigned with the highest potential to do so. Participants stated that the "active" game elements had a slighter higher potential to change energy consumption behaviour compared to the "informational" elements and vice versa for enhancing the environmental consciousness. The badge and the prizes element were in general assigned with the lowest potential, while the potential to change the consumption behaviour was higher compared to the potential to enhance environmental consciousness.

5. DISCUSSION AND CONCLUSIONS

We presented different pervasive interventions to increase pro-environmental awareness, consciousness, and learning of office employees making use of different visual interfaces. The first intervention introduced public displays at the workplace to increase the awareness for pro-environmental behaviour and energy saving potential. The results revealed the influence on awareness, confidence, and knowledge, but also asked for more personalised and direct feedback. Consequently the second intervention fostered personalised feedback about individual energy consumption at the workplace using different means. On the one hand the results showed the effectiveness and revealed the favoured kind of feedback, on the other hand participants asked again for more information and instructions to initiate conservation activities combined with the need for more incentives to sustain this behaviour. The third intervention then focused more on behavioural approaches combined with a motivational and social influence approach utilising gamification and clear incentives. The results underpinned the role and impact of these mechanisms. In sum, the results of the three interventions have provided information on different levels: For the organization the pilots have provided a good guideline how effective energy conservation at the workplace can be enabled and rewarded for employees. For our research we could collect feedback about important design decisions that will influence a large scale pilot, combining the most promising components of the single iterations, i.e. public displays to distribute information, individual displays with personalised feedback, gamification to sustain behaviour change, clear incentives and active game elements, etc.

6. ACKNOWLEDGMENTS

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Evaluating the Effectiveness of Visualizations for Comparing Energy Usage Data

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ABSTRACT

In recent years, various interactive systems and visualization techniques have been proposed to promote energy saving by encouraging people to compare their energy usage data with those of others, as well as with their own historical usage data. Many of these systems rely on conventional visualizations such as time-series and pie charts to allow making such comparisons. Unfortunately however, most of these visualizations have never been evaluated to assess their effectiveness in allowing easy comparisons of different energy usage data. In this paper we discuss the need for formal evaluation of visualizations that aim to support such comparisons, and provide a case study using an evaluation we have conducted to compare two alternative visualizations that we have developed.

Categories and Subject Descriptors

H.5.2 [**Information interfaces and presentation**]: User Interfaces—*Information Visualization*

General Terms

Human Factors; Design.

Keywords

Energy usage visualization, time-pie visualization, time-stack visualization, user evaluation.

1. INTRODUCTION

With ever-increasing worldwide energy consumption, and ever-decreasing non-renewable energy resources, there is a growing need to use energy more efficiently and make savings as much as possible. Most past attempts aiming to get people to use energy more efficiently and less wastefully have, however, been generally less than successful. One of the main reasons for this failure is due to the fact that energy consumption, particularly in the case of domestic users, is largely invisible [4]. As Fischer [5] points out, it is often difficult for users to link all their energy-consuming activities and "develop a coherent, comprehensible, and concise cognitive frame of what 'electricity conservation' could mean in everyday life."

It is, therefore, not surprising that in recent years various technologies have been proposed to assist users with managing their energy consumption by providing them with better "feedback", which in some cases have resulted in energy savings as high as 10% [3]. Although the outcomes from feedback, in terms of energy savings, can vary depending on circumstances, they can be improved when feedback is provided along with advice and information [4].

Fischer [5] uses an existing heuristic model from environmental psychology to identify various features that can make feedback more successful. One of those features, which is of particular interest here, is "comparisons". Fischer divides comparisons into "historic" and "normative", where historic comparisons allow comparing one's own current and prior energy consumptions, while normative comparisons allow comparing one's consumption against those of others (e.g. neighbours, household with similar size, income, etc.).

Many commercial companies have in recent years introduced a range of feedback tools to allow their costumers to make historic and normative comparison of their energy usage data [12, 11, 15, 1], with many claims of success in making energy savings [7]. Various studies which have tested the impact of normative comparison on energy saving have shown mixed results [5]. However, two large-scale field experiments by Ayres et al. [2] have shown that when users are informed of their neighbours' energy usage, those consuming more than average reduce their consumption by around 1-2%.

It is important to note that there is a third category of comparisons, which we define as "social" comparisons, and distinguish from normative comparisons. Social comparisons allow an individual to compare their own energy con-

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sumption against those of others in their "collective" social setting. An example of a social setting could be people living in the same house, or colleagues working in the same office. This type of comparison is different from normative comparison, because an individual living in a house, for instance, may wish to compare not only the energy usage of their entire household against their neighbours (normative comparison) but also their own individual energy usage with others living in the same household (social comparison).

In this paper we present a brief review of the types of visualization currently used to provide comparisons of energy consumption data, and identify the lack of user studies in evaluating them in terms of their effectiveness in supporting such comparisons. We then argue for the need for these types of evaluations, and provide an example case study using an experiment we have conducted, to discuss how such evaluations may be carried out.

2. ENERGY VISUALIZATIONS SUPPORTING COMPARISONS

The commercial systems referred to earlier [12, 11, 15, 1] aim to support normative or historic comparisons, generally using standard time-series visualizations or pie charts. There are also a range of other visualizations in the literature which have been designed to support mainly historic comparisons of energy usage data. Figure 1 presents a visual summary of a few of these visualization.

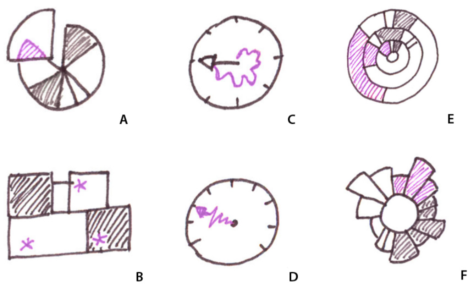

Figure 1: Sketches of various existing energy usage visualization. A: Predictive Pie [9], B: Floorplan [9], C: History Clock [9], D: Flexible Pointer[10], E: Onion Chart [13], F: Revealing Pie [16]

Monigatti et al. [9] introduce three visualizations for monitoring energy consumption. Their *Predictive Pie* (Figure 1A) uses a classic pie chart, but in a mode where energy which would be consumed by any electric device is compared to past energy consumption. It furthermore indicates, by graphical overlapping, which other device may be turned off to avoid increasing the total energy balance of the household. Another visualisation they suggest takes the actual living environment areas into account by showing a symbolic *map of rooms* (Figure 1B). Current energy consumption and living context information like lights switched on or off, helps users to identify potentially unnecessary energy usage. The third visualization by Monigatti et al. is a *radial graph* similar to a clock, but with a clock pointer of a variable length to indicate the current energy usage value. The pointer also draws a line which results in a history path (Figure 1C). In a related work, Monigatti et al. [10] integrate this history feature into the shape of the arrow itself when using the energy clock in a *speedometer-like style* (Figure 1D). By using the pointer angle for values, instead of time, and mapping the time along the pointer's length, a kind of line chart is integrated into the energy clock. Monigatti et al. do not report on evaluating any of their visualizations.

Pratt and Duewer [13] identify two problems with pie charts. Firstly, if a slice of a pie chart is much bigger than the others, the other slices become too small to be visible. Secondly, the inner area of a pie chart slice contains no more additional information than its outer border, leading to a waste of space. Therefore they suggest combining a series of doughnuts and pie charts, by stacking them on each other using different radius sizes. The resulting *onion chart* (Figure 1E) benefits from reusing the available circle space by adding different views on the same data in smaller size. However, Pratt and Duewer have not conducted a user evaluation to gauge the effectiveness of their visualization.

Valkanova et al. [16] also presents a *radial visualization* (Figure 1F), which displays energy consumption by different individuals and groups. The visualization uses colour-coded slices, placed side-by-side in a pie chart style diagram, showing the total consumption. Each slice contains multiple bars that indicate variations of resource usage, allowing individuals as well as neighbourhood groups to identify spikes and compare their usage with each other. User studies conducted by the authors reveal the benefits of individual and collective explorations. For instance, some study participants were surprised by their actual individual usage which were less than what they had imagined. People with high energy consumption, on the other hand, claimed that this type of visualization (showing individual and group consumptions) might motivate them to save more energy in the future.

Finally, Grevet et al. [6] describe the concept of "social visualizations", and discuss differences between individual-to-individual versus individual-to-group comparisons, unidimensional versus multi-dimensional comparisons, and competition versus collaboration. They also describe their own social visualization in which a set of tiles cover or reveal an underlying background image, depending on the energy usage of the owner of each tile. By assigning small communities (e.g. neighbourhoods or dorm residents) to different tiles, competing group are formed which "play" against each other for better energy performance. Grevet et al. performed a preliminary user evaluation to compare social visualizations against visualizations oriented towards individuals. They identified a positive trend for social visualizations even though they were not able to find statistically significant differences due to the small number of participants in their study.

3. EVALUATION OF VISUALIZATIONS

As the above review demonstrates, although there are a number of visualizations that aim to support comparisons of energy usage data, most of these proposed visualizations have never been evaluated by users.

We argue that user evaluations need to be conducted to test the effectiveness of proposed visualizations for supporting energy usage comparisons (historic, normative, social, or otherwise). Furthermore, such studies should not only gauge users' subjective preference for any alternative visualizations, but also objectively measure the differences between such proposed alternatives. More importantly, the aim should not just be to identify *which* visualization better supports making comparisons, but also *why* it is better.

4. A CASE STUDY

Here we will provide a case study of a user evaluation we have previously conducted to demonstrate how objective measures can be used to find out why a visualization leads to better performance in terms of supporting comparisons of energy usage data.

Our user study aimed to gauge the effectiveness of two different visualizations we have developed to allow *social* comparisons of *individual* energy usage data for several devices in one office with *collective* energy usage data for the same types of devices across a number of different offices. These two visualizations will be referred to as the *time-pie* and the *time-stack*.

Figure 2 provides a sketch of the time-pie visualization [8], showing the amount of energy (in percentages) used by four types of devices during different 2-hour time periods in a single day. The size of each 2-hour time slice is proportional to the amount of energy used during that time period.

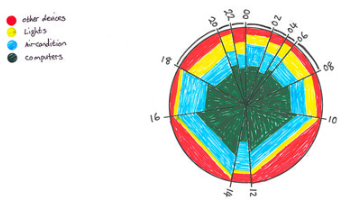

Figure 2: Sketch of the time-pie visualization.

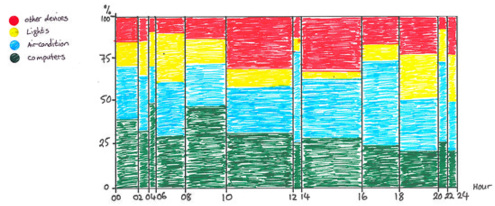

Figure 3: Sketch of the time-stack visualization.

Similarly, Figure 3 shows the time-stack version of the time-pie shown in Figure 2. Once again, each time-stack slice proportionally shows the amount of energy used in that time period, in relation to the rest of the day. Within each time-stack slice, the amount on energy used by each type of device is shown in percentages.

4.1 Collection and analysis of objective gaze data

Methods used for collection and analysis of subjective data for evaluating visualizations are generally similar to what is done in other types of user studies (e.g. in HCI), and usually rely on obtaining, for instance, users' preferences for one visualization over other alternatives. Most methods used for collection and analysis of objective data in user studies of visualizations are also fairly standard, and focus on task performance time, accuracy, error rates, etc.

As mentioned, such standard subjective and objective measures used in evaluations are important, and allow identifying whether or not a visualization is better than others in supporting comparisons. Other measures are, however, needed to allow identifying why a particular visualization may be better than other alternatives.

In our example user study, we have found gaze data to be a reliable means of objectively measuring differences between study participants' performance using different visualizations.

We used the SMI eye-tracking glasses [14] to collect gaze data while our study participants performed their experiment tasks in each of the two visualization settings. Figure 4 shows the experiment set-up, where the time-pie visualization shown on the main display provides the collective energy usage data for all the offices, the time-pie visualization shown on the right-hand tablet provides the individual energy usage data, and the tablet on the left-hand shows the study task questions.

Figure 4: The set-up used in our user study.

In terms of the analysis of gaze data, we measured the duration of fixations, and the number of gaze shifts. We also related the individual gaze data (e.g. occurrences of gaze shifts) to other task-related data (e.g. when a task started or a question was answered) to identify when, for instance, the participants were looking at different visualizations of their collective or individual usage data. Figure 5 shows a screen shot of the recorded gaze video data analysis tool, with various gaze events marked on the time-line.

These types of gaze data analyses can then be used to shed light on the results gained from the analyses of other objective, as well as subjective, data. For instance, in the case of our user study, if for a particular type of question the participants responded faster or more accurately when using the time-pie visualization than when using the time-stack visualization, the analysis of the number of gaze shifts may indicate that the participants had fewer gaze shifts when using the time-pie visualization, or perhaps they were looking at the wrong region of the time-stack visualization, as indicated by the analysis of the gaze fixations.

5. CONCLUSIONS

According to the literature, visualizations supporting comparison of individual and collective energy consumption data seem to have some positive effect on encouraging energy savings. However, hardly any user studies have been performed to evaluate the effectiveness of different forms of comparative visualizations. In this paper, we presented a case study of a user evaluation we have conducted, which relied on sub-

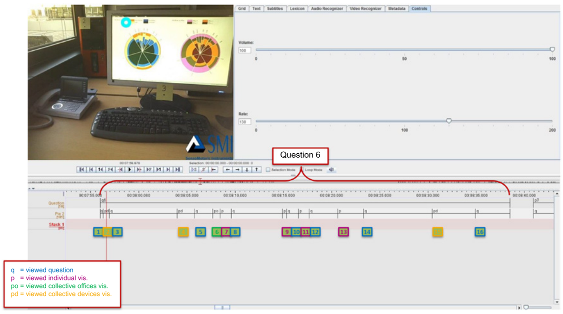

Figure 5: Annotation of the recorded gaze video data.

jective as well as objective measurements. In this study we not only measured participants' performance (e.g. time, accuracy) in using our two different visualizations, but we also recorded and analysed their eye gaze data while performing their experiment tasks. While the performance measurements gave us information on task efficiency and accuracy, eye gaze data helped us understand why one of the visualizations outperformed the other for a particular type of tasks.

Our experience demonstrates that the analysis of eye gaze data can be useful when improving existing visualizations or when designing new ones. A promising strategy for optimising visualizations, for instance, might be to try to reduce the number of required gaze shifts.

6. ACKNOWLEDGEMENTS

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Towards a More Responsible Use of Energy through Visualization of Energy Data

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ABSTRACT

This contribution is meant as a brief introduction to work on visualization of energy-related data. It recalls some general objectives, prerequisites and assumptions related to the responsible use of energy and presents a number of selected visualization approaches. However, it is not intended to provide a comprehensive review of previous and ongoing works. Rather, the paper aims to stimulate discussion on the effectiveness of different visualization types presented at the AVI 2014 workshop on *Fostering Smart Energy Applications Through Advanced Visual Interfaces.*

Categories and Subject Descriptors

H.5.2 **[Information Interfaces and Presentation]:** Graphical user interfaces (GUI), *Screen design.*

General Terms

Human Factors, Measurement Experimentation.

Keywords

Visualization of energy data, Interactive visual tools, Energy consumption, Energy usage management, Energy usage monitoring, Information visualization, Visual interfaces.

1. INTRODUCTION

During the last decade, a considerable number of attempts have been made to exploit the potential of data visualization in the context of reducing energy. As different these approaches are, they all share the aim to stimulate a more responsible use of energy. Specific objectives are:

Obj1: Avoid waste of energy. If there is a choice between two equally performing services S and S´, then the less energy-consuming service (or likewise, the service that uses energy more efficiently) should be preferred. Examples include the replacement of power-hungry devices, such as incandescent light bulbs by fluorescent or LED light sources.

Obj2: Conserve energy where possible. Energy-consuming services, which are not essential for a user's well being might not be used. Examples include turning-off lights when leaving a room, or switching-off the standby-function found in consumer electronic devices, such as tv-sets, coffee machines etc.

Obj3: Help to ease energy management. This objective accounts for the fact that a user's energy usage profile has a net effect on the power supply system to which she/he is connected. Therefore, better coordinated use of energy among users can generate positive net effects, such as peak demand reduction which in turn would allow power line operators to reduce maximum capacity provision. Measures to meet this objective are also subsumed by the term Demand Side Management [1]. The objective becomes increasingly important in areas with a high percentage of renewable but fluctuant energy resources, such as wind and solar energy.

Obj4: Rely on renewable energy resources as much as possible. The rationale behind this objective is to save the earth's fossil energy resources for coming generations. However, a real choice between different energy sources is often not available for end users.

In a broader context, further objectives may be added, , e.g., the objective to reduce energy costs related to the production and disposal of everyday products, or educational objectives, e.g., to raise pupil's interest in and general knowledge about environmental issues related to energy consumption.

Assuming rationale users, it may be expected that most users are willing to conserve energy, simply because reduced energy consumption saves them money. In addition, one may assume a common agreement on the fact that responsible use of energy is an ongoing matter of concern to everybody, which in turn relates to a "feel good" factor associated with resources-saving behavior.

While the need for energy conservation and a more efficient use of energy is commonly accepted, for the individual it is often difficult to act accordingly. Firstly, there may be an information lack about the energy costs caused by a certain activity or a neglected activity, such as leaving on lights or electrical appliances in stand-by mode.

So-called Smart Metering devices aim at filling this information gap and are an indispensible prerequisite for gathering energy consumption data. They can be either mounted at a householder's fuse box, or between a socket outlet and an electrical appliance, or within an appliance. Such metering devices measure power consumption, and make their readings available either on a build-in display, or via a data link to other applications which may provide one or the other form of visualization (examples of this are discussed in Section 2).

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FSEA '14, May 27 2014, Como, Italy

http://dx.doi.org/10.1145/2598153.2602224.

Several reviews of empirical studies (including surveys, field trials, and in-laboratory user testing) have been carried out to assess the effectiveness of different feedback methods. Darby [2] concludes that: *"... User-friendly display is needed as part of any new meter specification. Monitors would be most useful if they showed instantaneous usage, expenditure and historic feedback as a minimum"*. Fisher [3] conducted a review of 26 projects/studies and found that: *"... successful feedback has to capture the consumer's attention, to draw a close link between specific actions and their effects and to activate various motives that may appeal to different consumer groups"* and that *"... interaction and choice seem to be an important motivating factor, and that long-term feedback is helpful for forming habits"*. The majority of studies examined by Darby and Fisher deployed classical forms of feedback, such as paper-printed bills and information material.

More recent surveys by Vine et al. [4] and Froehlich et al. [5] focus on computerized feedback systems. As an outcome, they add further design considerations to the discussion, e.g., which kind of display to use, and whether feedback is given on demand (pull mode) vs. unsolicited (push mode).

Conclusions derived from such reviews are valuable sources of knowledge for designers of energy-feedback systems but tend to be general in nature. Thus, for a concrete design task at hand, they provide little advice on how to design effective possibly interactive visualizations of energy-related data. So far, only a few evaluation studies addressed design choices, e.g., [6], [7], [8], [16]. For instance, Costanza et al. [8] developed an energy monitoring system which offered the user to annotate consumption data and to play what-if scenarios. In an evaluation of their system they found that these interactive elements add to a stronger engagement with the system and greater understanding of the presented energy-data.

However, the provision of information about energy consumption and consumption patterns alone does not necessarily imply acting. Rather, assisting people in actually changing their behaviors is a much harder challenge. Froehlich et al. [5] argue that: *"... Eco-feedback designers, whether conscious of it or not, imbue their designs with some theory of human behavior"* and point out the relevance of psychological models and theories concerned with explaining and motivating pro-environmental behavior and behaviour change.

The question of how to utilize computer technology to assist people in changing behaviors, especially to get rid of bad habits, is addressed in the field of "persuasive computing". A pioneer in this field is B.J. Fogg who postulates the statement "Put triggers in the path of motivated people" as a design mantra for behavior change [9]. According to Fogg's behavior model, for a behavior change to happen three factors must coincide: the person must be motivated in principle, a trigger must be present that just-in-time reminds the user to do the right thing instantly, and he/she must be enabled to act. Adopting this model for the purpose to increase the community of energy-concerned users means:

- *Motivation:* strengthen a user's motivation to conserve energy and use energy more effectively and keep her/him sustainably motivated. Activities related to the motivation factor comprise measures to create and increase a user's awareness of energy consumption and consumption patterns, as well as measures that relate a user's individual energy consumption to a larger context.
- *Trigger:* identify opportunities at which the user should perform actions that contribute to efficient energy use, and provide appropriate notifications as triggers.
- *Enable:* set-up of usable services and a technical infrastructure as enabling means for the execution of actions as easy as possible.

2. ENRGY VISUALIZATION – A REVISIT OF SOME POPULAR APPROACHES

Is visualization a suitable measure for energy conservation? In the following we revisit several different categories of energy-related visualizations and focus the discussion on the question of their potential to increase a user's motivation to use energy in a more responsible way. However, it is not intended to provide a comprehensive survey of previous works but to present a number of samples to stimulate discussion at the workshop.

2.1 Charts and Diagrams

Energy-related data, such as time-stamped readings of energy use, can be easily visualized by means of a time chart that maps data points onto a two-dimensional Cartesian coordinate space.

As an example, Fig. 1 shows an energy consumption chart as it was provided by Google's "PowerMeter" online service [10], which was operational from October 2009 to September 2011. The chart shows a load profile of a household over two subsequent days at a resolution of 15 minutes (i.e., each depicted data point represents the accumulated load of a period of 15

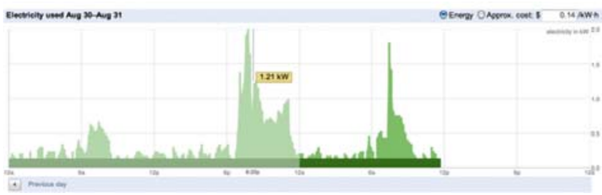

Fig. 1 Visualization of an energy consumption profile as part of the Google PowerMeter servive.

minutes). Note that smart metering devices may support higher temporal resolutions (e.g. periods of a minute and below) which makes a (near-to) real-time monitoring of energy consumption technically feasible.

In addition, aggregated consumption data are often presented in the form of a bar chart or pie chart, e.g., showing the monthly consumption of a household over a year. Such an aggregated view was also provided by the Google PowerMeter service. Fig. 2 shows accumulated daily loads over a period of nine days. The dark parts of the stacked bars represent the base-load portions per day.

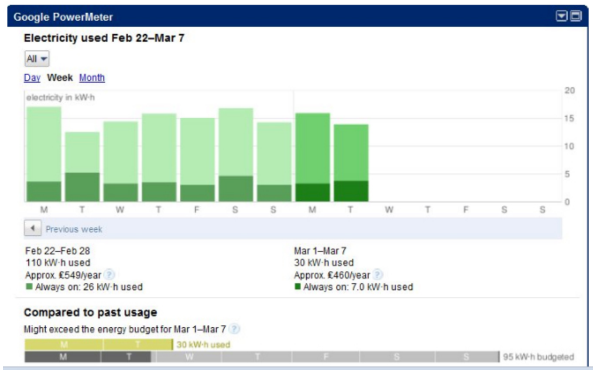

Fig. 2 Visualization of an energy consumption profile as part of the Google PowerMeter servive.

Such charts are useful to show the variance in consumption between a minimum value (the "base load") and a maximum value (the "peak load") over a certain time period. Depending on the granularity of the time scale used, certain typical consumption patterns may become apparent, such as day / night cycles, or typical peak load periods.

Google retired its PowerMeter service after only two years, because customer uptake did not match the company's expectations. As noted in several online blogs commenting on the shutdown of the service (e.g. cf. [11]), a mere visual representation of a user's energy load profile over a time period is not very likely to affect user behavior, and thus will not contribute much to one of the four objectives introduced in Section 1.

In the absence of any benchmark for comparison most users are unable to judge whether their energy consumption is "normal", exhaustive, or economical. Also, a chart alone does not provide practical hints what could be done to use energy more economically.

In order to achieve a motivational effect, the charted consumption data could be related to other data. Using charts, one option is to relate a user's load profile to the profile of a more energy-efficient user, or to the user's consumption data of a past period with a lower consumption. To this end, different charts can be aligned, or different curves could be overlaid in a single chart.

Another strategy is to relate energy consumption data to data of another type. The most straightforward approach is to associate energy consumptions (measured in Watts) with incurred costs (in currency units). A diagram that shows both, a consumption curve and a cost curve is especially useful in case of a non-linear mapping between both values. Such situations can occur due to stacked pricing models of some power suppliers.

2.2 Energy Gauges

Another way to provide visual feedback on energy consumption deploys so-called energy gauges. A popular example is the Google-o-Meter widget (cf. Fig. 3), which maps a user's current energy consumption onto a scale, similar to an analog meter device.

Using color coding and/or text annotation for the scales, such visualizations can provide easy-to-grasp real-time feedback on

Fig. 3. Mapping energy consumption on a scale using the Google-o-Meter widget.

how well a user is doing with regard to her/his current energy consumption.

However, visualizations that provide real-time feedback make the strong assumption that users are actually interested in a continuous monitoring of their energy usage.

This assumption may be adequate while driving a car, and therefore an indication of whether the current style of driving is economical or not has good potential to have a positive impact on the driver's behavior. Fig, 4 shows a part of the dashboard of a Toyota Corolla car. The "ECO" indicator in the touring meter turns off, in case acceleration exceeds a certain limit. Using Fogg's model, an eco-indicator can provide the trigger for an ecologically responsible driver who, since in control of the driving, can adopt her/his driving behavior.

Fig. 4. Part of a car dashboard with an "ECO"-indicator

In contrast, it is unlikely that users devote the same attention to a web-based dashboard that shows the current overall power consumption of a household (as it was assumed in the case in Google's PowerMeter service). The success of real-time feedback on energy consumption not only is a matter of effective visualization. Rather, the application context is perhaps the more critical factor that must be carefully analyzed.

There are also examples where energy gauges and consumption charts are presented side by side. The Applus-energie.org project [12] developed a system for monitoring the energy consumption of buildings, such as public schools. Energy feedback is given by a composition of diagrams and gauges as shown in Fig. 5. While the visualization can be accessed with a web-browser (requiring scrolling), it has been tailored for display on a public screen.

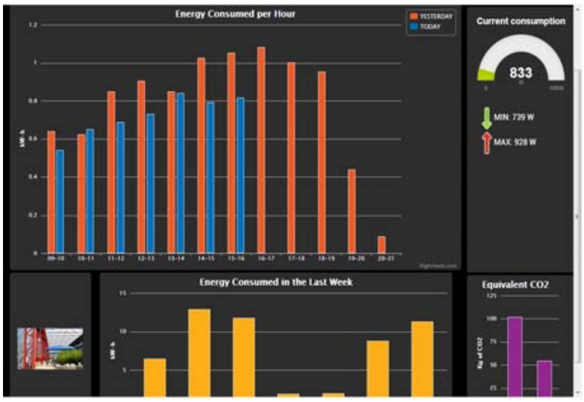

Fig. 5. Using charts and gauges for energy monitoring of a public building. (Source: http://www.applus-energie.org/)


Fig. 6. A tree metaphor for the visualization of energy consumption (courtesy by René Bühling).

2.3 Eco-Visualizations and Ambient Feedback

The challenge to make primarily invisible data – such as energy consumption, and environmental data in general- visually accessible, has led to a new sub-domain within the fields of graphics design and media arts. Holmes introduced the term "eco-visualization" for methods that inspire environmental stewardship through dynamic data visualization [13]. In the context of energy conservation, an eco-visualization can be seen as a dynamic (or real-time) mapping of energy consumption data onto a domain that (a) can be associated with an effect caused by the amount of the consumption, (b) addresses a concern of the ecologically responsible user, and (c) that is visually accessible. It deserves mentioning that the prefix "eco" stresses *ecological responsibility* rather than *economic* behavior, though in practice, ecological responsibility may lead to economic benefits, too, i.e., a lower bill for electricity, or patrol for a car.

In an eco-visualization created by Holmes, energy consumption data was first related to an amount of carbon dioxide that would result when energy is generated from fossil resources. The amount of carbon dioxide was then mapped onto a certain number of oak trees that must be planted in order to compensate for the carbon footprint of the measured energy usage.

A broad variety of further eco-visualizations have been proposed [6], some of which can be found on the web-page [14]. In the context of our IT4SE project [15] we used a tree metaphor (cf. Fig. 6) as well as a garden metaphor (cf. Fig. 7) to provide ecological feedback on energy consumption.

An advantage of eco-visualizations is their potential appreciation as decorative items in a home, at the work place, or as a background image of a computer screen. As a piece of "eco-decoration", the visualizations can provide ambient feedback on the user's energy consumption over a longer period.

However, so far little evaluation work has been carried out on the effectiveness of such visualizations with regards to the conservation of energy. A mentionable exception is the study conducted by Kim et al. [16]. They used a coral-reef metaphor as an eco-visualization for the display of the energy consumption of a computer during idle times. They report that the visualization helped to increase the user's awareness of how they use their computers, and that some user's actually changed their behavior, i.e., they set their machines more often to sleep-mode or turned them off instead of leaving them in idle mode.

2.4 Interactive Visual Data Exploration

The visualization approaches discussed so far are not designed for explicit user interaction in the sense that a user can


Fig. 7. An eco-visualization of energy consumption.
Left: flowering garden indicates consumption below average. Right: consumption far above average

actively select or modify the visual elements to explore the underlying data. However, a user-driven data exploration can help to gain a better understanding of energy-related data.

A first example is the "FigureEnergy" system developed by Costanza and colleagues [8]. The system encompasses an interactive visualization that allows users to annotate and manipulate a graphical representation of their own electricity consumption data. For a video-demo of the system see [17].

Another example of an interactive visualization of energy-data is shown in Fig. 8. The snapshot is taken from an interface that was developed at our own lab. It allows to explore different options of an energy portfolio consisting of renewable energies (wind, solar, biogas, geothermal) and conventional energy resources (coal, oil, gas, atomic power).

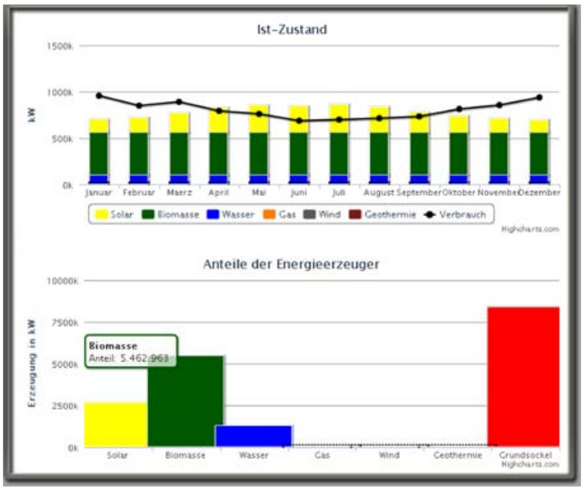

Fig. 8. Graphical UI for a simulation tool. The bars shown in the lower diagram represent different energy resources. The share of a resource can be changed by interactively changing the height of its corresponding bar.

The upper part of the visualization compares the overall amount of generated energy (shown as stacked bars) to a power load profile (line curve). The bar chart in the lower part of the screenshot consists of interactive bars which represent different energy resources.

The bars are interactive, so that a user can modify the share of a certain resource just be modifying the size of the bar with a mouse gesture.

The interface is actually part of a simulation system that takes into account historic weather data to compute the performance of weather-dependant renewable energies. The overall system was meant as a decision aid for community representatives who need to decide on investments into renewable energies (and thus is an example addressing objective obj4 of Section 1). The tool enables what-if explorations of scenarios assuming different energy portfolios. Given a certain share of renewable resources, and a certain time period (e.g., the last year), the upper diagram shows both gaps that must be compensated with conventional resources as well as over-capacities that call e.g., for energy storage capacities.

2.5 Mixed-Media Feedback

Energy-related visualizations can be used in concert with other media, such as speech and sound to achieve an intended purpose.

As an example, Fig. 9 shows some frames of a video clip that has been compiled to provide a user with a personalized summary of her/his daily energy consumption. The clip has been designed in style and length similar to a short tv-news report with the intention to show it as a replacement of a tv commercial shortly before the 8 pm news on the popular German tv channel “Das Erste”.

Using both, visual material as well as a speech channel has the advantage, that advice on energy use could be given more easily. Of course, such a video clip must comprise dynamically generated elements (e.g., charts, and spoken comments) to provide feed-back on a user’s energy consumption.

2.6 Energy-related Games

As computer games have become quite popular several attempts have been made to approach especially younger users with games as a means to raise their awareness of energy-related issues and to stimulate pro-environmental behavior. Examples comprise energy management simulations [18], [19], and pervasive multiplayer games [20], [21].

As different game concepts may be, most of them include visualizations of energy-related data in some form or another including charts and gauges as presented in the previous subsections. However, design choices may be dominated by game-specific requirements.

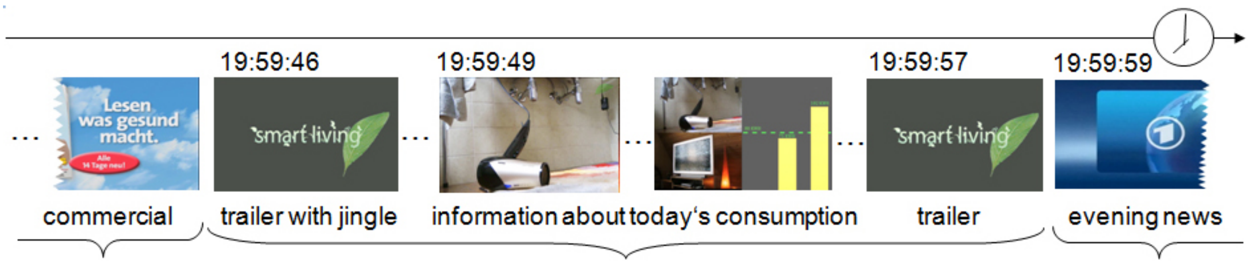

Fig. 9. A personalized video-report on a user’s energy consumption can be spliced into an ordinary tv-program, e.g. replacing a commercial advertisement just before the 8 pm evening news.

3. CONCLUSIONS

This contribution recalled four objectives related to the responsible use of energy and worked through a number of different strategies for the visualization of energy-related data. Most of the previous approaches are targeted towards energy conservation. Visualization is used to raise a user's awareness of her/his energy consumption in one or the other way. Differences exist in the style of visualization, the degree of granularity (overall consumption, vs. consumption per appliance), timely resolution (near real-time vs. aggregated over a period, such as hours, days, months, years), and whether or not interactive exploration of data is enabled.

Findings of the above mentioned reviews [2], [3], [4] suggest that conservation rates between 5% and 20% are possible if householders are provided with feedback on energy consumption. However, but a few exceptions most proposed visualization styles lack a profound evaluation of their effectiveness with regard to objectives related to a more responsible use of energy.

As users are different and belong to different cultures, such studies should take into account different user types [22] as well as differences in cultural backgrounds [23].

4. ACKNOWLEDGENT

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Towards using Exploratory Sequential Data Analysis for Smart Buildings

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1. INTRODUCTION

Buildings have been identified as being the largest cause of greenhouse gas production in the world (48%) due to over-cooling, over-heating, and over-lighting [5]. To help reduce these inefficiencies in buildings, a growing number of data analytics startups in the energy sector are working with big data and machine-learning algorithms in the cloud that will ultimately save energy for building owners and improve the sustainability of their operations. We endeavor to look beyond performing pattern recognition in the cloud by creating a solid foundation of advanced visual interfaces that support Exploratory Sequential Data Analysis (ESDA) for Building Information Modeling (BIM).

ESDA provides a framework and process for the analysis of *sequential* data and was originally presented in 1994 by Sanderson and Fisher [1] in the context of observational data in the field of human-computer interaction. In their work, Sanders and Fisher proposed the “Eight Cs” (see Figure 1) which are applied to sequential data that was collected in user studies. We aim to explore the use of ESDA in energy analytics in commercial buildings in the context of our existing Project Dasher: an interactive building dashboard that integrates near real-time sensor data into a BIM data context [2]. Through the application of ESDA on building sensor data, and in combination with machine learning approaches, we explore new tools and techniques for energy analytics.

2. PROJECT DASHER

Project Dasher [2] focuses on the use of Building Information Models to provide building owners and operators with greater insight into real-time building performance throughout the life cycle of the building.

Operating a building at its highest efficiency is not a fixed, pre-set process but a dynamic moving target that must be reassessed on an ongoing basis. Even modern low energy buildings and sustainable building designs need to respond to the ever-changing patterns of their occupants, function and context. While building performance tools have traditionally focused on the simulation and evaluation of a specific design, we are witnessing a growing need for tools that can help us to continuously evaluate and verify building performance [3]. Today, most commercial buildings are equipped with sophisticated Building Control Systems (BCS) that collect data from thousands of sensor end-points. These systems help building operation managers maintain buildings by minimizing long-term operational cost while ensuring occupant comfort. However, a key challenge is to define methods for organizing, studying and communicating data while coping with perpetual changes inherent in any commercial building.

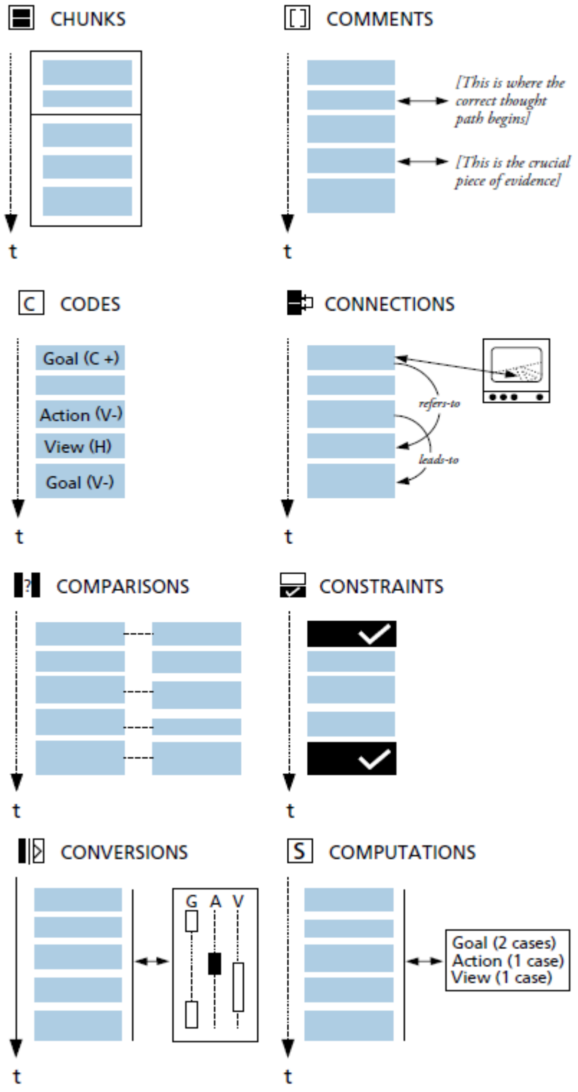

Figure 1: The Eight Cs from Sanderson and Fisher [1].

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Figure 2. NASA Sustainability Base [4] in Project Dasher

Project Dasher aims to go beyond existing building dashboards to represent a comprehensive framework for monitoring building performance. [6] It acts as a visualization hub where collected data from various sources are intuitively aggregated and presented in 3D to enhance our ability to infer more complex causal relationships pertaining to building performance and overall operational requirements. [7] In Figure 2, NASA Sustainability Base [4] is visualized using Project Dasher. This is one of the smartest buildings on Earth, but what do you do with the information it generates? The goal is to find ways to understand all that data. Next, we review the Eight Cs of ESDA in terms of the features of Project Dasher.

2.1 Codes

"Codes are abstractions of data, labels that are attached to data elements or groups of elements designed to capture the *meaning* of the data while reducing the variability of its vocabulary. Figure 1 illustrates a structured predicate coding, but the codes could just as well be simple keywords. A coding vocabulary can be developed from many sources such as theory, the data themselves, or as a result of previous analyses." [1] In Dasher, one of the primary purposes for employing BIM is to use the rich, sematic contexts and relationships encapsulated in the BIM as labels to entities. [8] For example, 3D geometric elements are not just simply triangles floating in 3-space, but a set of useful, semantic elements with meaning, purpose, and relationships. Examples of such entity labeling can be walls, doors, lamps, sensors, etc. Adding the labeling to the elements sets the necessary foundation to build higher-level analysis. Other examples include the existence of logical spaces and their functions, which can be labeled as meeting rooms, bathrooms, hallways, kitchen and more. Relationships between entities are expressed as contained by, connected to, plays role, serves function etc.

2.2 Comments

"Comments are unstructured informal or formal notes that the analyst attaches to data elements, to chunks, or even to the results of intermediate analyses. In Figure 1, comments are attached to individual data elements." [1] In the context of Project Dasher, various meta-data are attached to building elements, from the simple room names, to more complicated meta-data, such as technical specifications or maintenance schedules of mechanical equipment.

Figure 3. Top: a floor of a building is highlighted. Bottom: a cut away of a room of a building.

2.3 Chunks

"Chunks are segments of adjacent data elements that the analyst perceives as forming a coherent group. Chunking is often hierarchical—data elements are collected into chunks, chunks into larger chunks, and so on. Two chunks are illustrated in Figure 1." [1] The main example of chunks, or grouping in Dasher is the division of the building elements (doors, walls, pipes, sensors, chairs, etc.) into floors, rooms, and stations. This semantic grouping sets a rich foundation for spatial exploration of the data.

2.4 Constraints

"Constraints are applied to data in order to focus an analysis. Constraints may be thought of as a filter for the data, allowing only certain elements of the data to be visible while hiding the rest. For example, an analyst may want to focus on only those data elements that are labeled with a certain keyword." [1] When the grouping and labeling are set up, it is easier to explore and filter the data. At the bottom of Figure 3 we are able to zoom in on a particular room by cutting away the rest of the geometry. Similarly, we can easily hide and show different elements, such as HVAC, Plumbing, and Electrical as shown in Figure 5.

2.5 Connections

"Connections express the relationship among elements of data. The basic connection is the temporal, linear flow of one data element to the next. However, the unfolding of larger intentions, such as goals, themes, and solutions is often not linear, but instead skips around, interrupting other themes. Connections are a means of following threads through their nonlinear paths and identifying the relationship among their elements. Connections can also express the relationship between qualitatively different types of data." [1] Dasher gives the ability to overlay various elements such as temperatures, sensor values, HVAC, Plumbing, Electrical equipment, and graphs in one view (as seen in Figure 5), to allow us to find indirect connections between the elements. Additionally, more direct connections can also be extracted: at the top of Figure 4, we can see an example of highlighting for a given floor in the Hierarchical Sunburst Graph and see the corresponding floor simultaneously highlighted in the 3D view. This visualization operates at multiple hierarchical levels, as can

be seen at the bottom of Figure 4 where a room is similarly highlighted. This is quite useful to explore energy consumption, and combined with the ability to overlay various data in one view, lets the user find deeper cause-and-effect relationships in the data.

2.6 Comparisons

"Comparisons demonstrate the effects of different treatments of the data with one another. For example, one might compare the results of different coding schemes or the results of the same data being coded with the same scheme by different analysts. We might also compare the data from different subjects or conditions or between a model that predicts behavior and the actual behavior found in the data." [1] Or in a case of energy data, we might want to compare consumption of different floors, rooms, or even cubicles of a building, For example, in Figure 4, a Sunburst Graph Visualization gives the ability to precisely do that since different sizes of the pie slices indicate relative scale of consumption.

2.7 Conversions

"Conversions transform data in order to reveal new patterns. Conversions include converting to a new coding scheme, changing the grain of analysis, or using a new representational device, for example, a graphic timeline or flow chart." [1] There are a number of places that Dasher implements conversions and computations, as one can classify and form of visualization in this category. One interesting example of conversion of date can be seen in Figure 5, where temperature data is represented as heat map surface shading, which quickly communicates values of many sensors in a quick way. Another useful example of conversions is the Hierarchical Sunburst Graph in Figure 4. By using the sub-metering and plug-level data, it was possible to organize the data into a graph that can help identify sources of major energy consumption in a hierarchical manner.

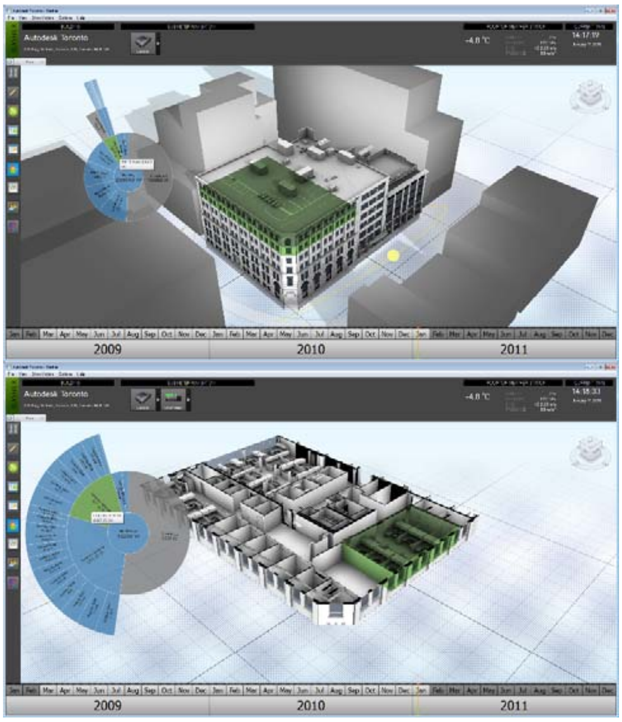

Figure 4: Hierarchical Sunburst Graph used to visualize energy consumption at different levels of the building.

Figure 5: A floor of a building with temperature heat map. Bottom images also shows HVAC and lighting systems.

2.8 Computations

"Computations reduce the data to summary representations, including simple counts, complex quantitative relationships, or tests of statistical significance. " [1] For example, Figure 3 and 4 shows visualizations where energy consumption is aggregated across different semantic elements, such as rooms or floors. Such aggregation computations are absolutely vital.

3. CONCLUSION

While we only briefly outlined a small fraction of Project Dasher's features, the purpose was to illustrate how different aspects of ESDA can be implemented in context of building energy analysis software. ESDA offers a great framework to design analysis software, and we hope to encourage a greater awarness of these techniques. In our future efforts we hope to extend our software to better support different aspects of ESDA with greater flexibility and depth.

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Why Aren't We All Living in Smart Homes?

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ABSTRACT
Visions of the Future, like the Jetsons cartoons, show homes which are smart and able to control household appliances, to make living easier and more comfortable. Although much research has been carried out into the effectiveness of different visualisation techniques for conveying useful energy consumption information to householders, and in techniques for controlling the timing and coordination of appliance use, these techniques have failed to achieve widespread penetration, and the vision still seems far from a reality. This paper examines the reasons why smart home technologies have so far failed to have any real impact, which is intricately intertwined with the design of visualisations in this context, and why we are not already living in Smart Homes. It examines these questions under four sections: Technology, Consumers, Electricity retailers and Government agencies, using examples from New Zealand's electricity sector.

1. INTRODUCTION
The Smart Home is defined as "a home that incorporates advanced automation systems to provide the inhabitants with sophisticated monitoring and control over the building's functions. For example a smart home may control lighting, temperature, multi-media, security, window and door operations, as well as many other functions" [1]. By controlling household appliances, the Smart Home has the opportunity to make living easier and increase energy efficiency at the same time. Examples for easier living could be; automating lights' usage depending on brightness levels, automating air conditioning systems to switch off and opening windows at appropriate times. Energy efficiency could be achieved by delaying appliances to use cheaper off-peak energy; this would save money and reduce the demand on peak hours. If these Smart Homes are capable of bringing benefits at a household level (making living easier and improving energy efficiency) and also on a nationwide level (reduce load on peak hours and perform load smoothing), why are we not living in them? This paper will provide answers to this question under four headings: Technology, Consumers, Electricity retailers and the Government agencies.

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2. TECHNOLOGY
Home automation technology is used inside Smart Homes to automate devices and appliances, to add convenience, save money, to improve energy efficiency and make living easier. This technology has the task to monitor and control appliances within the home, monitor the environment within and outside the home, and provide information to household members. The technology used to perform these tasks might include motion sensors, temperature sensors, video cameras and programmable lights. These technologies have been available since the 1970s, and home automation systems have been around for over three decades. So it is surprising that not one system has been able to make it to the mainstream [2]. Brush et al [2] conducted semi-structured home visits to 14 households with home automation, and found four main barriers to acceptance that need to be overcome by these systems: high cost of ownership, inflexibility, poor manageability and difficulty in achieving security. However, the technology is still evolving and when solutions do overcome these barriers more acceptable and affordable Smart Homes will emerge.

3. CONSUMERS
The New Zealand residential sector is estimated to account for 33% of New Zealand's electricity consumption [3]. This sector also shows almost no change in energy efficiency with only a 0.003% pa energy efficiency improvement rate [4]. This is surprising as appliances for the home are becoming more energy efficient; for example, a 10 year old refrigerator could cost twice as much to run as a modern refrigerator [5]. This section will look into why consumers are not buying energy efficient appliances and Home Automation systems.

Figure 1: An Energy Rating Label which gives an indication on the appliances energy usage and energy efficiency. Image from [6]

3.1 Energy Efficient Appliances
In New Zealand it is mandatory for some appliances such as refrigerators, freezers and clothes dryers to have an Energy Rating label (see figure 1), this label is a good indication on how energy efficient this appliance is and how much energy it consumes per year. The Energy Efficiency and Conservation

Authority (EECA) performed a study with 750 New Zealanders and found that when buying electronic appliances, price, functionality and reliability were more important to them than energy efficiency [7]. This could indicate that Energy Rating labels do not provide enough incentive for consumers to purchase energy efficient appliances, especially when a lower rating appliance is cheaper to buy.

3.2 Home Automation Systems

Below are some common barriers that prevent consumers from buying Home Automation systems:

High Cost**:** Kerber (2012) found that 50 percent of consumers would only spend around $60 for a device that could save them 10 percent of their electricity bill. If we look at the costs for home automation systems (approx. $5,000 to $15,000 USD) we can clearly see the price range for home automation systems is far beyond what consumers are willing to spend.

Awareness**:** Another reason these systems are not widely integrated is because more than half of the consumers do not know about them. This can be seen in a survey by the Consumer Electronics Association, where more than 64% of consumers said they are unaware of electricity management systems [8].

Time consuming**:** Most systems require configuration and installation which can be a hassle and can discourage consumers as they do not want to spend the time installing, learning and configuring a system.

Frightening**:** These systems may seem frightening to the consumer as it can monitor and control personal appliances automatically. This may be frightening as the consumer may feel the Home Automation system will take control and limit their usage. They may also be afraid hackers taking control of their appliances.

Incentive**:** There are no clear time-of-use electricity rates, so consumers have no financial incentive to shift their electricity consumption. Neither are there incentives by government/utility providers and obvious major comfort incentives. As a result, consumers are not willing to go through the pain of buying, installing, configuring and maintaining a home automation system.

If home automation systems were to overcome these barriers by being low cost, widely advertised, simplistic and have financial incentives, we may see more consumers willing to buy Home Automation systems.

4. ELECTRICITY RETAILERS

Electricity retailers are becoming more aware of the importance of energy efficiency, and most of these companies in New Zealand now provide tools for consumers to track their usage. Some tools, such as the Good Energy Monitor (GEM) from Mercury, go even further and allow goal setting, comparison, prediction, message alerts and also energy saving tips [9]. These tools are great as they promote energy awareness and efficiency. However, this report is more focused on why these electricity retailers are not promoting more energy efficient technology such as Home Automation systems to allow automated load shifting and reduction in appliance usage.

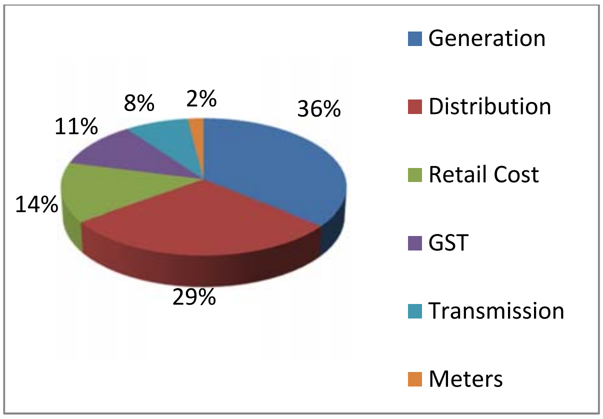

Figure 2: What the typical Residential Consumer pays for in electricity cost. Source [10]

To understand this we have to look at how consumers are paying electricity retailers for their electricity usage. Figure 2 shows that the money paid to the electricity retailers is split into shares paid to different agencies in the electricity sector. Electricity retailers typically receive only 14% of the price paid by consumers. The price the consumer pays is made up of two parts: a “fixed charge” and a “usage charge”. The “fixed charge” is to ensure the retailers do not lose money. It covers the costs of using the distribution and transmission power lines. Furthermore it is static as the distribution companies charge a fixed price (each day) to have the resources available to supply households with electricity, regardless of how much electricity is being used (this also covers what the distribution company pays the Transmission lines company to use their network) [11]. Electricity retailers make most of their profit through the “usage charge”, which is the charge for each unit of electricity being consumed. Generally, the more electricity one consumes, the more profit is returned to the retailer. This is why these retailers are hesitant in promoting technology such as Home Automation, as it could reduce electricity consumption, resulting in a lower profit.

However, since electricity retailers are competing to recruit and keep customers by catering to their needs, we may see more retailers promoting Home Automation systems when they are better known and more desirable.

5. GOVERNMANT AGENCIES

There are many different agencies which all play an important part in the electricity sector. This section will focus on the Energy Efficiency and Conservation Authority (EECA). The EECA is a government agency which is responsible for promoting energy efficiency. This includes improving energy use in New Zealand homes. EECA does this through a number of residential initiatives stated below [12]:

Product standards and labeling: Energy efficiency standards and labeling for certain products such as fridges and dryers are regulated in New Zealand by EECA. This allows consumers to compare energy use through labels (e.g. the Energy Rating label shown in figure 1) and to keep out non energy efficient products from the New Zealand Market.

The Energy Spot: A TV campaign that has aired series since 2009 which promotes energy efficiency to homeowners and businesses, by providing practical information and advice on energy use. Around 2.4 million New Zealanders have viewed this series and 41% of these viewers have said it has influenced them in reducing energy consumption [12].

RightLight: RightLight is a website and an information campaign to encourage consumers to find energy efficient lighting alternatives. One of the approaches is a webpage tool which allows users to compare different light bulbs, to find the most energy efficient and cost effective alternative.

Energywise information: A programme which uses a website, brochures, advertising and media releases to provide information on energy-related decisions. This includes information on general home energy efficiency, government funding, energy choices and also energy labeling.

Warm up New Zealand – Heat Smart: A four year programme which ran from 2009-2013. It provided insulation subsidies for homeowners with houses built before 2000. This subsidy ranged from 33 to 60% of the total cost of insulating the house to a required standard. This programme was a success and managed to insulate 235,000 New Zealand homes [12].

Warm up New Zealand – Healthy Homes: This programme started in 2013 and is a follow up to the Warm up New Zealand – Heat Smart programme. It provides free insulation for households with a low-income, with the aim to provide a warmer, drier and healthier home to people who need it most.

Smart Homes can improve energy efficiency and with government subsides there would be more incentives to buy Smart Home technology; however there is no such subsidy in New Zealand. If we look into the residential initiatives of EECA, we can see they are more focused on providing a warmer and healthier home than providing Smart Home Automation. This is understandable as the mean temperature for New Zealand living rooms and bedrooms in winter fails to meet the World Health Organisation (WHO) optimum indoor temperature which is 18°C to 24°C [13].

6. CONCLUSION

This report has provided answers to the question "Why aren't we all living in Smart Homes?" by examining the issue under four headings: Technology, Consumers, Electricity retailers and Government policies. It has shown that this question cannot be answered with one simple reason, but instead is influenced by many reasons from each different section studied above. However, all hope is not lost. When Smart Home technology becomes cheaper, more flexible, easily manageable and secure, we will see this technology being widely acknowledged and promoted. This will lead to more consumers wanting these systems, and may lead to financial incentives (such as subsidies and/or lower electricity prices at certain times of the day) from electricity retailers, as they try to compete for consumers. Once this happens we will see more integration of Smart Homes, with household members living more comfortably and energy efficiently.

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Watt-a-Feeling - Raising Energy Production Literacy through a Tangible Installation

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ABSTRACT
Nowadays energy supply is ubiquitous and pervasive. It is everywhere and nowhere. One cannot see or grab hold of energy. This invisibility and intangibility may lead people to misconceive what is energy, thus underestimating its production costs and subsequent financial and environmental impacts. Further, the units of measure of electricity (e.g. kilowatt) are notions difficult to contextualize and understand. In this paper we propose the design of an installation aimed at raising energy production literacy through playful interaction. We propose Watt-a-Feeling, a tangible public installation that resorts to the metaphor of an X-ray vision of a household wall in an attempt to increase energy literacy by exposing to householders where (which source) their energy is being provided from. Interaction with the installation begins with a visitor producing (locally) enough energy to reveal the X-ray vision combined with short comparative facts that should help the public contextualize the production of energy within the larger context of regional energy consumption.

Categories and Subject Descriptors
H.5.2. [**User Interfaces**]: Prototyping

General Terms
Design, Human Factors

Keywords
Sustainability; Aesthetics; Prototyping; Public Displays; Feedback

1. INTRODUCTION
The goal of energy service providers is to provide the service as transparently as possible. Energy consumers (in the eye of the provider) shouldn't be concerned with where and how their energy arrives to them, but simply that the service is easily available and accessible. This is no longer true. Through the rapid proliferation of (environmental) news through the Internet and television, consumers are ever more aware of the affects that un-sustainable behaviors have on the environment.

Meanwhile, coal is still the main resource used in electrical energy production, accounting for about 40% of the total energy worldwide [1]. This energy source is the most pollutant of all and contributes significantly to the emissions of greenhouse gases [2]. In recent years the percentage of renewable energy in the grid increased, however so has the worldwide demand for energy. This increase in energy demand implies that the actual quantity of coal burned in power plants will decrease at a slower rate than expected. More precisely residential (domestic) energy consumption is responsible for 36% of the electrical usage worldwide, and specifically, 26% of the energy consumed in Europe. While appliances are getting more energy efficient, households now own more appliances than in the past. Small appliances are currently responsible for over 50% of the total household consumption [3]. This increase in the amount of small appliances raises an issue of control: it gets increasingly harder to account for ones' consumption when it is divided among different devices. However, it has been shown that humans have control of up to 50% of the electricity consumption in a building [1] and therefore there is a potential for end-consumers to reduce energy consumption and, per consequence, increase financial savings. This implies that savings in the domestic electricity sub-sector are significant in the worldwide energy consumption scenario and merit focus.

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Governments are promoting the deployment of smart meters, which will provide end-consumers with immediate feedback about their energy consumption [4]. These devices are referenced in literature as eco-feedback devices. Eco-feedback has seen strong contributions from the engineering, psychology and economics research fields, and has proven to be efficient in reducing individuals' domestic energy consumption, with electricity savings ranging between 5 and 15% [5]. The outcome of eco-feedback research has already reached the public market, with different commercial devices, ranging from cheap single outlet monitoring to more expensive full house disaggregated consumption systems. Such systems display electricity consumption as kWh or monetary cost. Despite the advances in commercial eco-feedback devices researchers have pointed out that electricity is still a vague concept to end consumers [6].

More so, other's have argued that the traditional kWh representation is not an adequate form of feedback for end consumer, especially when presented as big aggregated data [7]. Likewise, displaying the collective or individual environmental impact is not an straightforward task, and is normally depicted as pounds of CO_2 emitted, or by the number of trees necessary to offset the values of the emissions [3]. These emission values are normally estimations based on pre-set values and do not account for the different generation techniques used to produce the electricity being consumed, i.e., is the energy being used is generated from fossil or renewable sources. Therefore these representations are too disconnected from consumers' routines and their environment (e.g. location, weather, time of the day).

2. RELATED WORK
2.1 Approaches to Eco-feedback
Artists and designers have joined the pro-environmentalism and sustainability challenge. In particular, through the use of technology and aesthetically rich interventions they present

information and data through visual metaphors or animations of the impact on the environment. An example of engaged public artistic installation, recalling the attention of building dwellers to their energy consumption, is the 7000 Oaks and Counting [8] initiative. The installation reveals through a public projection an estimate of the number of trees needed to offset the CO_2 generated during the production of the electricity consumed in a specific building. Similarly, the Stepgreen [9] system, displays a set of animals (seals, polar bears and fishes) living on a melting iceberg, as a tool to motivate the individual to take sustainable actions, which would in return prolong the lifespan of the iceberg. Moreover, in the public projection art installation domain, "The Nuage Vert" installation was directed to Helsinki's domestic electricity consumers, and aimed at raising awareness by making the effects of producing the electricity for the city visible [10]. This was accomplished by a laser projection displayed directly on the smoke being emitted by one of Helsinki thermal stations. The Power-Aware Cord [11] is a re-design of a common power strip that displays a visualization of the electricity passing through it. The author argues that the intangible/invisible nature of electricity makes consumers take it for granted. With the approach of showing the electricity flowing through the cord the authors aimed at users' playfulness as a trigger for exploration of the different electrical devices. The Watt-Lite [12] installation also aimed at making energy visible. The installation consisted of three projections representing the current consumption, and the current day's maximum and minimum values. The Watt-Lite succeeded at raising awareness and thus enabling discussions in the workplace on the electricity consumption behaviors. While the abovementioned projects succeeded at raising awareness and representing the intangibility of electricity, the actual impact in the environment is not represented, thus end-consumers are still unaware of their individual (or collective) impact on the environment.

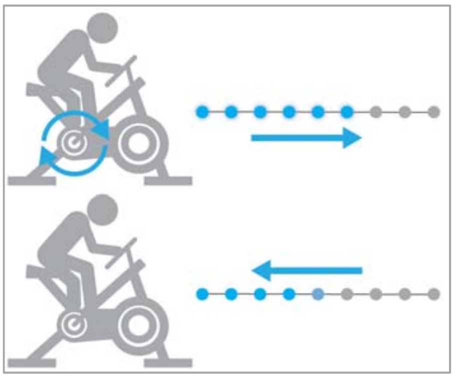

Figure 1: A representation of the micro-production of energy to "power the installation". Top the user has produced almost the required amount, while the bottom has stopped generation.

2.2 Electricity production feedback

Electricity production feedback provides a different approach to depict an accurate impact on the environment through the consumers' actions, by informing them from which sources the energy is currently being generated. Tracing the individual consumption to the different origins of electricity (wind, hydro, fossil and etc.) is a difficult task to accomplish. As result, eco-feedback systems that depict the electricity production are mostly tested in micro generation scenarios and have reported an increase in awareness and acknowledgement of the electricity consumption [10][11]. In [15], the authors observed that end-consumers, with solar panels installed in their homes, followed their production closely, monitoring the weather to better understand its effects on production and consumption. The close relationship between the consumption and production of energy helped participants adapt their routines, and presented them with concrete data of their contributions to the environment—helping households decrease their utility bill. A similar observation was made in [16] where the authors deployed a dashboard display with different widgets that showed information about energy consumption and sustainability. They observed that households with solar panels used the weather widget to better understand the production values. Furthermore Pierce et all [14] argue that micro-generation feedback systems should be designed not only to help consumers save money but also appeal on users satisfaction of using their own "green" energy, produced locally.

3. Watt-a-Feeling

Our proposed design builds on the state of the art in terms of eco-feedback systems that provide real-time information about energy consumption and production. The goal for the Watt-a-Feeling installation is to inform consumers on the source of their electricity in a way that is easy to understand and to relate. Literature reports increase awareness when consumers have the option of knowing the source of their electricity (section 2.2). Additionally, it has been shown, in the examples reported in section 2.1, that tangible and public installations promote discussion and user exploration. Thereby the Watt-a-Feeling installation aims at using the ease of access and playfulness of tangible interaction, to display information that is valuable to consumers but could otherwise be hidden. We envision three aspects to the Watt-a-Feeling installation that when combined convey its message to the viewers:

1. Representing energy production data through a physical installation that employs the elements used to produce the energy (or are a byproduct of), as a display of their production quotas, enhanced with an information and graphics from data sources.
2. Raising energy literacy through contextualizing energy grid production with "human-powered" micro-generation.
3. Promoting playful interactions by having viewers/users actually touching the different elements used in the installation. Creating, thereby, memorable interactions that support learning the information presented by the installation.

Our aim with the Watt-a-Feeling installation is to raise energy production literacy, thus allowing the consumer to understand how, depending on certain conditions, the power grid has a higher flux of "green" energy. We hypothesize that the more environmentally concerned could change energy consumption household routines to coincide with the higher availability of "green" energy in the power grid.

3.1 Electricity generation

We are building upon a real-world scenario of an isolated closed network corresponding to a medium-sized European Island. Besides the naturally isolated network provided by the Island, we also take advantage of the easy access to consumption and production information provided in real-time by the utility company. In addition, the Island's renewable energy penetration is significant for wind, solar, hydro-electrical and waste sources, making it a perfect deployment for an extended eco-feedback system that integrates global production with individual consumption. Altogether this allows tracing every watt that is feed into the grid back to a unique generation source. Additionally, there is also the possibility to query daily data from the past year and gather information about which generation source (and their quotas) where used in that day in particular. The electricity production data is represented in Mega Watts and grouped in fifteen minutes intervals.

3.2 Displaying Energy Production

Energy produced for the public grid is an order of magnitude of 10^6 (MW). Thus we argue that it would be hard for the audience to, for example, connect the amount of electricity produced by a hydro plant with the electricity consumed by their daily routines. To help consumers contextualize the produced energy from the different sources we introduce an "active step" that the viewer has to surpass in order to interact with the installation. We propose that viewers produce a certain amount of watts before being able to interact with the installation. The amount of energy (watts) they produce is later used as an effort comparison between their micro-generation of energy, and powering common devices and household appliances, or related to the energy currently produced in the island.

To present the overall energy production of the Island we resort to an X-ray metaphor of a wall. We use a physical representation of a wall where the concrete has been removed and the electric wires are visible. On the top of the wall there is a representation of the electric cable that brings electricity from the "outside" (the grid). At the bottom there is a normal electricity outlet. We hypothesize that this analogy speaks closely to the visitors due to their familiarity of how they interact with electricity (the wall and the power outlet). Another element was added that it is normally invisible: the wiring within the wall. In a normal electricity installation this would be a simple wire with electricity running through it, and its source would be invisible to the consumer. However in the proposed installation the "behind-the-wall" scene displays how the main power source line is divided into four and similarly to the X-ray metaphor, each pipe has a gap whereby the user can see what is passing through (see Figure 2). We aim at revealing what is normally invisible about the electricity running through the wire by adopting something the viewer recognizes and can relate to, and that is also representative of the source of electricity being consumed. Water is used to represent hydroelectric power, light is used to represent photovoltaic energy, smoke represents the energy produced in the thermal plants, and finally the wind power is represented by air passing through the small gap. Through this mapping we are able to represent the elements used to generate said electricity and by altering its volume, represent the quota that each source has on the power grid, in real time. This allows the installation to dynamically adjust its "state" and in some cases the difference is considerable (e.g. a time period with 10% renewables in the grid against another time period with 70%). We believe that this fact will keep users/viewers interested. Moreover we also argue that seeing the installation in different occasions (for example a rainy day, or a day with a lot of wind and sun) will build users knowledge of how the availability of electricity sources is related to variables such as weather or time of the day.

4. IMPLEMENTATION

4.1 Electricity production quotas

The electricity production data is obtained through a partnership with the local electricity company responsible of the distribution of the electricity in the island. The process is as follows: every 15 minutes the provider places updated quotas for thermal, wind, solar and hydro production under a URL, a web-service implemented in our server queries the production information and inserts it in an aggregated database. The production data is made available under another web-service, providing real-time and historic information about the energy generated in the island.

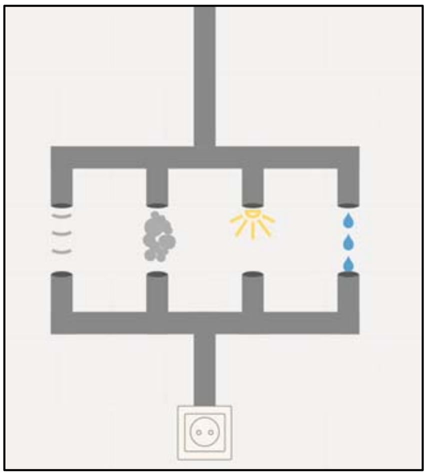

Figure 2: Scheme of the proposed installation

4.2 Human powered electricity generation

We envision a micro-generation technique to generate a target value necessary to "power up" the installation, i.e., functions as an initial form of interaction with the installation. The energy produced does not influence the installation except for the purpose of contextualizing one's effort in producing it with values displayed on the installation. We plan to use a stationary exercise bicycle to harvest the electricity. The "powering up" of the installation is a progressive revealing of the undelaying X-ray vision by an electric motor unrolling an opaque sheet of material. We plan to attach a common bike dynamo to the wheel of the exercise bicycle. The electricity generated is then read from the dynamo. The electricity will be averaged and summed until the agreed threshold is reached. At the same time a LED array is being lit up at the same cadence as the electricity is being generated. Likewise if the electricity generation is stopped the LEDs are turned off. This LED array will be placed on top of the power that connects the bike to the installation, to display the users' performance. All the processing in this phase, will be made by an Arduino microprocessor, which is connected to the LED array and reads the electricity being produced through the analog input. Figure 1, presents a scheme of the electricity generation process. The amount of electricity generated by the user is also presented via a small display. This information is later contextualized against the total electricity produced in the island and the electricity used to accomplish a simple task in one's everyday routine, for example:

"You and 10 friends would have to pedal for a week, to generate the same energy produced by the photovoltaic installations in the last hour".

"You produced enough energy to light up your room for 10 minutes".

4.3 Electricity sources representation

We plan to represent the different sources of the electricity as follows: The smoke created from a smoke machine shall represent the thermal source of electricity. The smoke density should convey more (or less) his quota. A water pump and a reservoir shall be used to implement the representation of the hydroelectric energy. Both the smoke and water used in the representation will work in a closed circuit. The wind energy representation will be achieved by using a computer fan, a pinwheel will be placed in the gap that will help visualize the quantity of air passing. We plan to portrait the photovoltaic/solar energy by two sets of optic fiber cables connected to the top and to the bottom of the opening, on the top of the opening a set of LEDs are installed and will be used to modulate the amount of light passing by.

All the hardware described above is controlled by an Arduino microprocessor, which will query the webserver that stores electricity production data. Further, the Arduino will adjust the representation of the production quotas (in real-time) of the different sources by varying the intensity through motors—used to blow wind/smoke, pump water, and vary the intensity of a set of LEDs that will represent the solar power. Adjacent to the tangible installation a touchscreen shall represent the information in more detail to help disambiguate the abstract representation, specifically of quotas. The purpose of this interface is twofold: first, the viewer may define a hypothetical scenario by altering environmental conditions, e.g., night time, rain, sunny, etc, and second to provide viewers with additional information to complement the tangible representation. We hypothesize that through this playful interaction the viewers should be able perceive how renewable energy sources are directly affected by the conditions that afford them. The parameters selected by visitors through the interface are reflected on the tangible representation (through the Arduino) with further production information being displayed on the interface.

5. Conclusions and Future work

In this paper we proposed Watt-a-Feeling, a tangible public installation that aims at raising the publics' energy literacy through playful design and by representing the disaggregated energy production sources. The interaction was designed to allow for collaborative play while at the same time as a tangible, measurable form of contextualizing energy. The effort to produce energy then is related to everyday consumption habits helping better contextualize the efforts necessary to harvest the electricity that is nowadays ubiquitous in modern life. We further argue that the proposed installation should help consumers to understand the logic behind concepts such as peak demand shifting, or the different electricity tariffs, and thus, possibly preparing them for the future of the smart grid, where for example, in certain situations one may choose to buy electricity based on their production source.

At the time this paper was written, the development of the installation had already initiated. Section 4.1 is fully implemented while sections 4.2 and 4.3 are under design. The proposed installation is to be exhibited publically at the regional technology institute.

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The Social Power Game: A Smart Application for Sharing Energy-Saving Behaviours in the City

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ABSTRACT

In this paper, we introduce Social Power Game, a mobile game application that aims at encouraging energy saving through social interaction. Instead of an individual energy analytic approach, this game incorporates social interaction and gamification as crucial principles for curbing energy consumption, fostering community collaboration and increasing people's intrinsic motivation. Based on an interdisciplinary research conducted in Switzerland, this paper describes motivations, design and interaction mechanisms for the application.

Categories and Subject Descriptors

H.5.1 [**Multimedia Information Systems**]: Artificial, augmented, and virtual realities, H.5.2 [**User Interfaces**]: Theory and methods, K.8.0 [**Personal Computing**]: Games.

General Terms

Design, Management, Human Factors.

Keywords

Energy reduction; Energy Data Analytics; Gamification; Behaviour Change, Interaction Design, Social Network, Pervasive Game.

1. INTRODUCTION

How to integrate energy information into daily life patterns represents today a promising challenge for interaction designers. By presenting real time usage, costs and data analytics, Home Energy Management displays allow users to visualize their home energy performance and control its specific consumption. In studies aimed at exploring factors that influence motivation in energy saving behaviours, feedback mechanism is shown to be one of the most effective strategies in reducing energy consumption at home [1] [2]. According to previous research, further motivation-specific design issues concern rendering energy consumption habits more visible and presenting them in a friendly way [3]. In-home displays have been one of the first ways to deliver tools and instruments for energy visualization. Recently, energy service companies became aware that feedback rewards and social competition are two of the main driving forces already being used to encourage people participation in energy-conserving related applications. Therefore, local energy service companies such as OPower and MyEnergy in the USA, have started promoting energy saving through social comparison [4]. They found that social feedback can lead up energy savings ranging from 11% to 36,5%. However, the idea that interaction and communication design could be applied to enhancing energy usage feedback opens a process through which new technologies and portable media can contribute to and become an integral part of the way people live [5]. In addition, mobile applications have started a process in which analytical tool and self monitoring features are being intertwined with social media. This emerging trend not only catches users' interest but also suits utilities, local operators and telecommunication strategies.

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Figure 1. Social Power Game application.

Creating graphical visualizations of a user's consumption allows a potential energy saving activity. Moreover providing socially mediated feedback, such as practical recommendations created by peers, can encourage participation and raise awareness on how to impact less on energy consumption [6].

While social media use and neighbors competition techniques have become common features in Energy Management tools, collaboration and cooperation are not predominant methods. In this research, we will investigate social game mechanics as an alternative to individual merits based on a self monitoring approach.

2. RELATED WORK

Recent energy and climate policies call for a step change in how individuals consume energy in order to fight climate change and contribute to a more sustainable energy consumption model. This is especially true for the residential sector, which in Switzerland covers 40% of the national energy consumption. Even if some approaches point at reducing per capita average energy consumption, such as the 2000-Watt Society launched by the Board of the Swiss Institutes of Technology [7], the attainment of such long-term social change is difficult: people are seldom aware of the amount of energy they use and of the difference they could make by changing their day-to-day behaviour or by investing in energy efficiency measures.

By providing accurate, real-time energy use data, smart meters are becoming an important management tool for helping people understand and quantify energy use. Not surprisingly, a growing number of smart energy displays and devices has recently emerged as new energy-saving tools [8][9]. One of the benefits of this important trend is that it gives research and smart technology markets important insights on the responsiveness of consumer behavior to such tools: an aspect which is crucial to the development of a more sustainable society in regard to energy consumption. Next to real-time energy consumption rate displays and smart Energy Management tools try to engage people participation by providing additional quantitative information on energy (kWh and costs), customized messages and links to social media platforms.

Emerging energy service companies mainly oriented towards consumers [10] have recently adopted "gamification" - the use of game design techniques and game mechanics in a real-world context - as a strategy for increasing motivation in making a change and acting to save energy (and money). However, such games are quite different from our project. While badges, points, ranking, and social competition are the most common approach to design gamified application, there are other social interaction dynamics that we could consider. In that way our game would create a full coherent world for participants that stresses cooperation instead of individual merits.

The collective group game-play amplifies what players are able to achieve in the real environment.

3. SOCIAL ENERGY PROJECT

3.1 Design Goals for Social Power Game

Please Games as interactions can be considered feedback mechanisms that offer people a series of immediate and meaningful practical challenges for acting and sharing. In this section we introduce a mixed action-oriented approach that aims at integrating cultural technologies (such as mixed-game applications) with Energy Management tools. The game concept called 'Social Power' is inspired by the metaphor of the hive as a natural structure created by multiple entities working in parallel. Like hives, game scenarios are composed by several energy-related points of interest (POI) created by the players. Hives are located in a real world map and they coincide with the POI where people go through their energy consumption patterns.

Developing a game system providing an immersive, coherent, tangible experience based on daily surrounding is the first step for enhancing awareness on the energy people handle. Coupled with such tangible context, design goals lead to the definition of game mechanics and missions meant to provide a unique gaming experience. The design goals of Social Power Game can be summarized as follows:

1) Tangible: The game system should provide visible links between physical locations and energy saving behaviours occurring at those places.

2) Social: The game should increase the social awareness of energy saving behaviours by providing a collaborative construction of knowledge.

3) Integrated: The game interface should offer an easy management and clear graphical visualization of comparative elements and social data.

4) Meaningful: Motivation to change unsustainable patterns could also be achieved by social interaction dynamics and social approval of the energy-saving experiences shared by people.

Indeed, the resulting collective energy saving behaviour is a social effect that impacts our environment. In this way, community-based media seem to be determinant since they can act on it.

As a consequence an important finding in energy management design field is to draw from Data Centered to Player-Centered Design [11] for understanding players' expectations, knowledge gaps and motivations. That pragmatic approach finds in social and mobile experiences their power. Community-based media and game-based systems are social attractors and connectors that offer the opportunity to actively trigger participation over time to local/global energy strategies. While self-monitoring visual feedback was implemented in various studies and projects, how to provide interactive feedback at a social level has been less explored until now. In this project players act in favour of a common primary goal - moving closer to the 2000-Watt Society - and sharing knowledge practicing energy saving together with the community and friends.

3.2 An Energy-Sharing Game

Interactive social media coupled with mobile games are creating unprecedented opportunities for a participative, action-oriented approach involving the end-user. This is an aspect of fundamental importance, considering that individuals make decisions not only according to their state of environmental awareness and concern, but also according to their willingness to act and their belief that their actions will be effective and beneficial [12].

The design strategy for giving tangible experience is making players do things for real [11] [13]. Energy Hives can be tagged on a shared map, created, explored and commented. In this first version of the project, the social dimension of the game is set up with only two factions. Instead of a geographical division, we wanted the players to choose to play the Yellow or Blue faction when they start.

The game is a persistent parallel system able to track households' energy consumption. Players can contribute to their faction and the whole society in three ways:

1) Saving energy: the closer players get to 48kWh at day, the more experience points they add to their faction;

2) Play collaboratively: creating/discovering energy 'hives' and mapping them on the shared map as point of interest (POI);

3) Cooperating with the community and friends by completing missions.

The competition is not absent from the game: Yellow and Blue factions performances are constantly compared. Moreover different missions provide more focused challenges to encourage active participation and cooperative gameplay.

3.3 User Interface Design

Figure 1 shows a screen of the game application. The interface is designed for mobile smart devices (smartphones and tablets) and should provide a sense of control and progression. Players go through three main sections: (1) Personal View, (2) Energy Hives view, (3) Network view.

3.4 Personal View

The player's profile screen (see Figure 2) shows the household's energy consumption data. We consider consumption data not just a number but a performance indicator: it is compared to the average of a sustainable daily consumption. Depending on this ratio players contribute in term of experience points to their faction.

Figure 2. Profile screen showing: player's energy consumption and social contribution, experience progression, missions and friends.

In this project contextualized in Switzerland, we defined this goal at 48 kWh, according to the daily average for a 2000-Watt Society. Such a goal provides a simple parameter for correlating the individual energy use with a specific local strategy. Additional small-term social missions will customize the player experience. Open and closed missions, friends' and personal scores of the day, week, month and year complete the overview of the player's personal actions and contribution in the profile screen.

3.5 Energy Hives view

Energy is a property of all surroundings and an essentially invisible flow embedded in objects, buildings and electronic devices. The method of creating a visible link between energy and consumption patterns provides players with a tool for tagging energy-saving recommendations into the real environment. Energy Hives (see Figure 3), labeled by faction colors, represent collections of green behaviors and players' activities around energy. These are measured in term of embodied exp points. From a gameplay point of view, Energy Hives serve as a way to balance the game by allowing heterogeneous groups (size, cities) to have a chance to play at the same level.

While household consumption measures heating, cooling, and electricity, Energy Hives point at introducing wider energy-related information such as in transportation, infrastructures, groceries and more.

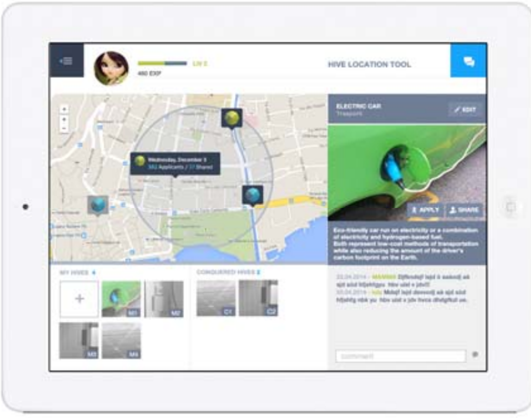

Figure 3. Hives Locator: mapping of energy hives for an electrical car.

Actions designed around Energy Hive locations are: adding a new hive, sharing with friends, applying for a faction's hive, adding comments. This type of content could make an ecological and green attitude more visible and tangible. Energy finds a tangible link with people's surroundings and is labeled in the real environments, so that players could learn best practices and share tags on energy saving tips while contributing to their group.

3.6 Network view

The social dimension is another important feedback mechanism that can influence users' actions and, as a consequence, enhance awareness of energy consumption.

Figure 4. Network view showing the player's and his/her faction consumption and contribution to reach 2000-W Society.

Considering that studies in game design indicate that games in cooperative goal structure are most effective in promoting positive attitudes [14], there are sound reasons to explore interfaces for cooperative, collaborative and competitive social interactions. Figure 4 shows the most prominent feedback: a visual comparison between the player's and his/her faction consumption average, between the players' contributions to their faction and between factions. Within the game, collaborative short term missions will be proposed to emphasize the social nature of the game.

As support for cooperation, a dialog boxes is available at any time next to the blue button. Additional eco-information shows the contribution of all players to society: energy saving (kWh and costs) and CO2 abated.

Social Power Game is an early stage project not yet implemented as mixed-game application. Further research will be needed for extending this work and creating synergies among game design, interaction design and social behavior research.

4. INTERACTIVE FEEDBACK

Although some Energy Management displays provide real-time consumption at the individual level, implementing clear goals based on real needs and perspectives could change both energy related communication and public involvement in energy reduction issues. Mobile gamified interfaces can contribute to societal involvement in energy saving since their design consider the primary components of interaction between people and the energy in their surroundings: human activities and the environmental resources (energy) they use by means of those actions. The design of gamified interfaces for energy saving should be easily integrated to daily life in order to overcome the lack of knowledge on how people impact global energy consumption. In this way players' missions should be carefully designed for increasing the attention on micro interactions. Following game design fundamentals in designing pleasure [11], previously stated interactive feedback for the Social Power Game becomes the key for structuring players meaningful actions and defining rewards and leveling up feedback.

To assess the change in designing energy-related interactive interfaces, analytical approaches may be integrated with more personal and motivational systems. Therefore, we suggest an interesting direction for future research: investigating how gamification techniques and social media could contribute to Energy Management interfaces.

5. CONCLUSIONS

In this paper, we proposed design details and motivations for the Social Power Game application. The application is designed to integrate social interaction in Energy Management tools through gamification. On a more abstract level, this project combines multiple design perspectives to tackle the challenge of fostering environmentally more friendly and better uses of energy. Therefore, it aims at becoming a model for the development of further applications in the areas of energy efficiency, social media and digital services.

This project concept is based on our interdisciplinary research called ‘Handle Energy’ conducted with University of Applied Sciences and Arts of Southern Switzerland (SUPSI), Züricher Hochschule für Angewandte Wissenschaften (ZHAW), Fernfachhochschule Schweiz, and in collaboration with the two Energy Electricity agencies of Massagno, Canton Ticino and Stadtwerk Winterthur, Canton Zurich. As future work we plan to implement a pilot project with improved visualization and to extend it at a transnational level.

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Advanced Visual Interfaces for Smart Energy: Focusing Where it Matters Most

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ABSTRACT
Targeting reductions of electricity usage among consumers in their homes has been very popular among researchers, industry, and research funding organizations. Here we look behind the application surface to examine where visual energy-savings applications might have their greatest impact. We analyze residential, commercial, and industrial sectors in the US and observe differences regarding energy use, economic incentives, and leverage per establishment. We then give examples of industrial and commercial energy-savings applications being developed at Mitsubishi Electric and supported by its North American Research Laboratory, MERL.

Categories and Subject Descriptors

General Terms
Algorithms, Measurement, Performance, Design, Economics, Human Factors.

Keywords
Energy use, Reducing Greenhouse gases, visual interfaces

1. INTRODUCTION
Reducing greenhouse gas emissions through influencing humans to reduce and control consumption of energy is a goal for many in the visual interface and visualization research communities. Aside from the design and evaluation issues, we believe our research community should also consider the targets of the applications in light of the end goal to reduce emissions. The target that has figured largest to date appears to be electricity usage in the residential sector. In a 2010 survey, 41% of eco-feedback HCI papers were found to be about residential electricity usage as were 92% of the environmental psychology papers included in the survey [10]. But are these the application targets that will move us the furthest and the most quickly towards the end goal? In this paper we will examine data on energy consumption across consumer, commercial, and industrial sectors and also consider factors related to economic incentives and leverage. We argue that of the three sectors, reducing greenhouse gas emissions through energy savings in the residential sector (and particularly through influencing individual end-users) is in fact the most challenging. Commercial and industrial applications would appear to offer better chances for high impact.

Our investigation is grounded in an analysis of data available on energy usage in the US. While not necessarily representative of energy use worldwide, the US is the second largest emitter of CO_2 emissions [21], so it is instructive to consider the US case. We will look at total energy consumed and then break down the residential, commercial, and industrial sectors where visual interfaces for energy-savings are widely applicable for reducing energy consumption. It is important to understand not only energy consumption totals within sectors as a whole but also a factor we call leverage. We consider leverage to be related to the consumption of energy per establishment since, generally speaking, decision-makers operate on an establishment level. We will compare and contrast the average leverage factor afforded to residences, commercial buildings, and industrial facilities. We'll also look at economic incentives and other factors that might influence the likelihood of success for energy reduction applications. Then we will comment briefly on electric utilities as a special case for visual analytics applications. Finally, we will give brief examples of energy-savings applications being developed at Mitsubishi Electric supported by its North American Research Laboratory, MERL.

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2. ENERGY USE ACROSS SECTORS
The well-known flowchart of US energy use by Lawrence Livermore National Laboratory and the US Department of Energy [7] shows that in 2012, total energy use was estimated to be 95.1 quadrillion BTUs (quads). The residential, commercial, and industrial end-user sectors collectively consumed approximately 43 quads (45%) of this total, the remainder consumed by transportation (26.7 quads, 28%) and rejected energy from electricity generation (25.7 quads, 27%). In order to break down these figures further, we'll be looking at other data sources between 2003 and 2009. Even though the total energy use in the US has fluctuated somewhat over this period, the fluctuations are not significant enough to be material for our arguments here.

2.1 Residential
For the residential sector, the U.S. Energy Information Administration reports that in 2009 there were 113.6M housing units using 10.18 quads [2], roughly 10% of the total energy used nationwide. This results in 89.6M BTU/household, 34.9M BTU/household member, and 45,500 BTU/ft2.

As far as electricity usage goes, 4.388 quads (1286 billion kWh) of electricity were used in the sector for the year, with 38.6M

BTU (11320 kWh) /household consumed. But an even bigger source of fuel than electricity was natural gas at 4.694 quads. Space heating was the dominant use of natural gas (63%) while electricity was more evenly spread across a number of uses including space heating, water heating, air-conditioning, refrigeration, cooking, clothes washing and drying, dishwashers, electronic appliances, and lighting. Targeting electricity usage alone in the residential sector would address 5% of the total energy consumed nationally. Since its uses are diverse, however, multiple behaviors may have to change to make a difference (not, for instance, simply turning up or down a thermostat).

Looking at the economic factors, total residential energy expenditures come to $230B annually, $2024/household/year, or $1.03/ft2/yr. [2]. Energy management in the residential sector has often focused on electricity usage with applications offered through electricity providers. OPower, considered a highly successful program to reduce electricity consumption in residences, includes comparisons to neighbors in their reporting. They reported saving an average of 2.8% in electricity usage [8], or an average of $.03 a kWh [19] in electricity costs. However, given that the price of electricity in the US averages around $.10 per kWh [6], the savings in dollars for the end consumer is not all that significant. Even an optimistic projection of total energy savings (20%) in utility bills on average would result in a savings of $265/year for all primary energy, or $190/year for only electrical loads. Given that the installed cost of many available Home Energy Management Systems (HEMS) systems can range from a few hundred to over a thousand dollars, the economics of this situation are daunting when left up to individual households. It has been found in studies of demand-response programs that cost savings is often not a sufficient motivator at any rate; improving the environment and averting risk of blackouts may be equally important [11]. In fact, a debate has been raging in the literature regarding whether consumers act rationally or not when it comes to energy consumption behaviors [21].

In sum, reducing energy consumption in the residential sector is a complex enterprise where economics and leverage offer particular challenges. Government and utility policy will likely be the determining factor to achieve wide deployment, necessary for success. Focusing only on electricity usage alone narrows the area of opportunity further. At best, such a target addresses only 5% of total energy consumed in the US.

2.2 Commercial

The picture for commercial buildings that emerges is quite different from residential even though the total energy consumption is within striking distance—in 2012, 10.6 quads for residential; 8.3 for commercial. In 2003, the most recent year for which the Commercial Buildings Energy Consumption Survey (CPECS) is available [1], there were 4.859 million buildings, including malls, included in the survey consuming 6.5 quads. An average building thus consumed 1.3 billion BTUs. Compared to an average residence, an average commercial building consumed 15X the energy, as shown in Table 1. Considering that there can be one individual responsible for energy management for an entire building (or even sometimes a campus or a set of commonly owned buildings), there is a striking difference in the potential of a single decision maker to affect energy savings. Of course this depends on whether there are steps than can effectively be taken at a building or campus level.

The energy cost per square foot of commercial buildings is almost a third again as much as residential ($1.51/ft2 commercial vs. 1.03/ft2 residential). Further, the annual energy costs on average per commercial establishment are $22,200 compared to $2024 for residential. 20% savings on energy bills would yield $4440 in annual savings on average, although these savings would be magnified with larger buildings or campuses. These potential dollar savings for commercial buildings are likely to be significant enough to get the attention of building managers and owners, and it can be safely assumed that rational decision making would be driving these behaviors.

Building Energy Management Systems (BEMS) are a growing business in the US and elsewhere. They typically employ multiple types of data analytics: predictive, decision, and visual, requiring a human in the loop. The objective of a BEMS is to actively and constantly re-adjust the operation of a building's systems in order to maintain the comfort of occupants while simultaneously minimizing energy expenditure. A BEMS would typically control heating, ventilation, and air conditioning (HVAC) systems, but might also have access to other equipment such as motorized shades, variable transparency windows, or lighting. An informal sampling of BEMS vendors suggests that most are advertising payback periods of 1-2 years.

Installation costs for BEMS are non-trivial. An active BEMS includes multiple sensors, a computational platform, and remotely controlled actuators. However, a factor working in favor of BEMS costs is that BEMS can easily be deployed as a remote service, leading to significant economies of scale: a single human operator can serve as the building energy manager for many commercial buildings. In contrast, deploying home energy management as a remote service is problematic from an occupant privacy point of view.

The impact of energy-inefficient and faulty operation is another factor that is magnified in commercial buildings and campuses. Commercial buildings often have a diversity of types and sizes of HVAC equipment, which often interact in unforeseen and problematic ways. In addition, scheduling maintenance is often quite challenging, and dashboards that provide information about energy performance can be very helpful in these applications. As an example, a fault detection and diagnostic method was implemented on a number of buildings on a corporate campus in Washington state to classify and rank the importance of the tens of thousands of alarms coming from the HVAC systems installed in the buildings [5]. As a result of these analytics, a number of faults were identified which, when repaired, were estimated to save thousands of dollars (the largest of which, when repaired, resulted in an annual savings of $11,291 by itself). As a result of installing analytics software, it is estimated that this corporate campus was able to reduce the total energy consumption by 6-10%, representing tens of thousands of dollars in reduced energy bills. Examples such as this can provide sufficient justification of the system installation cost.

We have focused here on BEMS, but efforts also exist in providing feedback to human occupants in commercial buildings to change their behavior to increase savings further [4].

2.3 Industrial

On its face, the industrial sector shows even greater leverage for potential energy savings than the other two sectors discussed above. The percentage of total US energy consumption in the industrial sector is greater than the residential and commercial sectors combined, and the number of establishments is far fewer. The US Energy Information Administration estimated that total energy consumption in 2006 by the US industrial sector as just over 21 quads. At the time, they reported 170,166 non-duplicative establishments contributed to this total. An average establishment thus used approximately 123.5 trillion BTUs. As shown in Table 1, the leverage of an individual establishment in the manufacturing sector is 1400 times that of an average residence and 93 times that of an average commercial building.

Factory operators are highly motivated to reduce costs, energy use among them. As pointed out in [12], analyzing electricity consumption in conjunction with product line data can not only save energy costs but also increase the productivity of a product line as a whole. Factory Energy Management Systems (FEMS) have emerged to use readings from dedicated modules for energy measurement within a factory automation network to estimate the specific energy consumption and completion time per production unit, average breakdown rates, etc., detect anomalous cases, and alert an operator or an analyst, so that countermeasures can be taken. Visualization plays a critical role.

Table 1: Comparative Leverage per US Establishment

Sector	*Total energy used (quads)*	*# establishments (M)*	*Energy use per estab. (M BTUs)*	*Leverage factor*
Residential	10.6	113	90	1X
Commercial	6.5	4.9	1326	15X
Industrial	21	.17	123529	1400X

Table 1 shows a summary of the three sectors we have been discussing with data in each row coming from the most recent studies available from the US Energy Information Administration in that sector. Our main point should be clear. By large factors, individual residences have the least leverage to reduce overall energy consumption, followed by buildings in the commercial sector and facilities in the industrial sector. Other economic and social factors compound these differences. Nevertheless, it is quite true that other factors not discussed here may influence the potential for energy savings success. Examples would include current efficiency of energy usage and necessity of energy usage. For instance, factories have no choice but to use power to produce goods but homeowners could potentially go without power for certain periods if they were so motivated.

3. Electric Utilities

Electric utilities consume a large amount of primary energy resources to generate electricity--38 quads in the US in 2012 [7]—most of which uses carbon-based fuel. Obviously, a goal is to increase the use of environmentally friendly energy resources (wind and solar) relative to carbon-based resources. However, energy production from these sources is intermittent, depending on the vagaries of wind and sunlight. Several already difficult planning problems are made significantly more complex by increasing penetration of renewable power sources with intermittent output. Deciding which generators are to be turned on or off (unit commitment) is difficult due to its high combinatorial complexity even when power demand is known with complete certainty. The same is true for economic dispatch, which takes into account the operations to produce energy at the lowest cost subject to operational limits of generation and transmission facilities. In practice, as with most planning problems, human planners take a significant part in determining the final output. Uncertain power availability as a result of intermittent output forces the planner to consider multiple possible scenarios for future power demand. Human planners in the planning loop must be able to see and reason with such uncertain information, a great opportunity for visual analytics methods to contribute towards planning applications.

An even more general problem for electrical power utilities is that of wide-area situational awareness (WASA), that is, determining the general health of an electrical network from collected sensor data. Of particular interest for WASA purposes are the detection of anomalies that might signal an existing or future fault and loss of service. By some estimates, the average electrical utility collects about 80TB of operational data per year, with a trend to increase to 200TB/year when smart meter deployment is completed. Visual analytics are likely to be a key technology for deciding whether identified anomalous situations are associated with an actual fault, or not, in such a big data application.

4. R&D at Mitsubishi Electric

Mitsubishi Electric is developing applications to reduce energy consumption in all the sectors discussed in this paper [12] [14][15], but particularly in the commercial and industrial sectors. Its R&D organizations in Japan have developed advanced distribution management systems tested in an extensive Smart Grid demonstration project including fully functioning electrical distribution networks with a heavy concentration of solar energy generation [14]. They have also developed advanced technologies for office building energy savings [15]. MERL, its North American research laboratory, has developed technology to contribute to these efforts, particularly analytical methods. For example, MERL's algorithms for load-flow analysis have led to lower electrical losses and power generation costs for distribution management systems [13]. MERL has also developed predictive analytics methods for solving the unit commitment problem under uncertainty [17] as well as methods to save energy in buildings by pre-cooling or pre-heating the building thermal mass, using less expensive off-peak energy [17]. In the railway industrial sector, MERL collaborated on optimization methods to allow regenerative braking to increase energy savings by managing and distributing the recovered energy across a network of trains rather than within a single train [16] .

As for research in visual interfaces and visualization for energy savings, MERL has proposed methods for spatial-temporal information visualization applied to building energy management [9] and also collaborated on methods for visual querying and visualization for set-valued event data in electrical grid planning [20]. Figure 1 illustrates the spatial-temporal visualization method we called Wakame in visualizing a complex interaction across adjacent zones in a building caused by faulty equipment. The visualization concept is to use situated radar graphs that extrude upwards over time. Each of the radar graph's dimensions is a normalized sensor measurement, and the extrusions produce shapes that may take advantage of human shape recognition. In this example, periodicity of temperature fluctuations can be immediately recognized and also the spatial spread of the excess daytime temperatures that began in the zone second from bottom right.

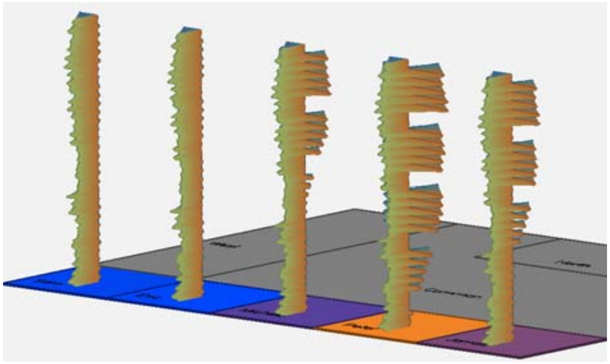

Figure 1: Visualization of cascading effects of an HVAC fault

5. CONCLUSION

Given the apparent skew of interest in the HCI and visualization research towards residential electricity savings, we have analyzed energy usage across three sectors in the US—residential, commercial, and industrial—in order to examine the question of where research in advanced visual interfaces and visual analytics might look for maximum effect. Looking at the factor of leverage (the amount of energy that an average establishment in each of these sectors consumes), we concluded that the residential sector was the most challenging target to reduce greenhouse gas emissions, followed by the commercial and industrial sectors. We also examined economic incentives and sociological factors that reinforced those conclusions. We then gave examples of research and development at Mitsubishi Electric and MERL that is addressing energy savings in the commercial and industrial sectors, including operations of electrical utilities. We hope to have at least raised questions that researchers might consider when searching for energy-savings application targets for their visualization and HCI research.

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Interactive Visual Tools for the Planning and Monitoring of Power Grids

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ABSTRACT
In this contribution we argue that power grid design and monitoring is an application domain that could greatly benefit from novel visualization techniques as well as from advances in interactive graphics. To support our point of view we refer to some selected works including an interactive tool for planning grid extensions, and a simulation environment for micro grids.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: Graphical user interfaces (GUI), J.6 [**Computer Aided Engineering**]: *Computer-aided design, industrial control.*

General Terms
Algorithms, Design, Experimentation, Human Factors.

Keywords
Visualization of Energy Data, Interactive Visual Tools, Power Grid Design and Simulation.

1. INTRODUCTION
Visualization techniques and graphics-based interactive editing tools are widely used to support engineers and operators in task related to the planning, analysis, and monitoring of power grids. In practice, however, many of the tools in use rely on simple 2D schematic graph layouts with icon-based graphical node representations for grid components such as generators, transformers, or connectors, and drawn edges which represent power lines. A typical example of a commercial tool is the PowerFactory [1] systems which comprises a graphical 2D editor for the computer-aided design of power grids. However, many graphical user interfaces of commercial tools in this area still provide its users with a look-and-feel of the late 1990s. In this position statement we argue that power grid design and monitoring is an application domain that could greatly benefit from novel visualization techniques as well as from advances in interactive graphics. In the sequel, we refer to some selected approaches to support our point of view.

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2. SUPPORTING GRID ANALYSIS TASKS
Planning and monitoring of power grids comprises a number of analysis tasks which can be supported through dedicated visualization techniques.

In an article published in 2001 Overbye and Weber [2] argue that power system visualization tools can aid their comprehension and expedite decision making in many task contexts. The article makes reference to an accompanying web page where examples of some interactive visualizations of the US power grid can be found [3]. Among these visualizations are contour maps that highlight a certain aspect of the grid, such as power transmission routes, or regional power prices. These visualizations have been included into the interactive power system simulation package "PowerWorld" [3].

Romero and colleagues are concerned with the detection of vulnerabilities of power grids [4]. To display large amounts of historical data records regarding past events and failures, they have developed so-called “Parallel Interactive Bargrams”. This visualization technique enables users to quickly identify the most affected electrical assets per type of incident, and, to see which electrical assets co-occur with others.

Klump and Eber [5] propose a number of special-purpose visualization techniques to highlight certain properties of a power grid. This includes animated arrows to visualize power flow in a grid, transmission dynamically sized pie charts for assessing location and magnitude of line overloads at a glance, and several contouring techniques, e.g., to show available transfer capability of areas which could transfer power to other areas where additional power is needed.

Wong et al. [6] developed a so-called “GreenGrid” visualization in which critical grid parameters such as transmission line impedances and voltage phase angles are visually emphasized. In a user study they performed a head-to-head comparison between their GreenGrid visualization and a traditional geographic-topological grid layout. The GreenGrid visualization outperformed the geographic layout when users had to identify the position of electrical generators and the flow paths of electricity.

Greitzer and colleagues [7] compared task performance of grid operators who had to solve two grid analysis tasks. One group had access to visualization tools while the members of a control group received grid information through tabular displays. They found a positive effect of the visualization aid for one task but surprisingly not for the other task. As a possible reason they mention unfamiliarity and lack of training with a graphical tool.

These examples demonstrate that novel visualization techniques can nicely complement more traditional grid displays and enable users to perform some tasks faster and more accurately but may require some learning efforts for using them effectively.

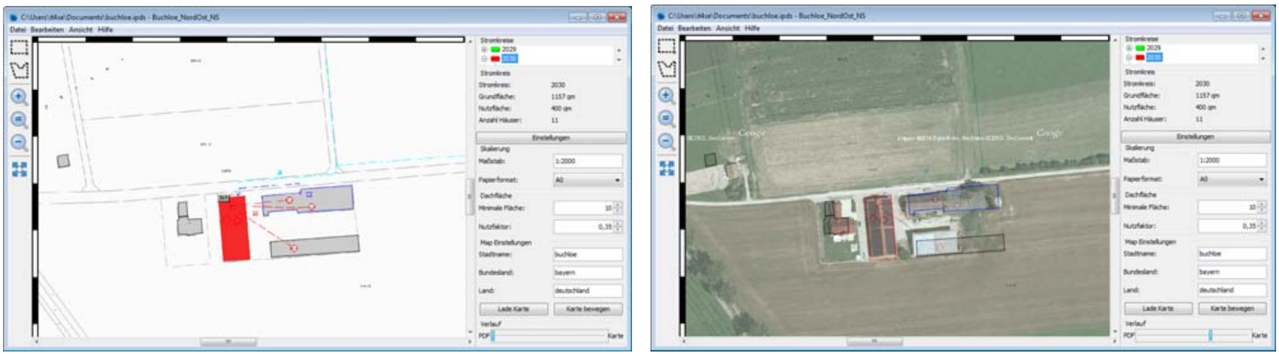

Figure 1. An interactive cadastral map with power lines (left) can be overlaid on a satellite image.

3. GRID PLANNING FOR ADDITIONAL SOLAR POWER FEED-IN

In some countries, an increasing number of private users mutate to so-called "prosumers". They are not only mere consumers of electricity but also become producers due to privately installed and operated renewable energy generators such as roof-mounted photovoltaic panels (PV-panels), or wind turbines.

While an increased share of renewable energies may contribute to the implementation of a politically encouraged energy turnaround from fossil fuels to renewable sources, it challenges grid planners with the problem of additional power feed-in from such privately operated sources. On a sunny and windy day feed-in from renewable resources may exceed the available grid capacity and in turn seriously impacts grid stability.

In order to prepare for counter measures, grid operators need to consider future scenarios with an increased share of solar power and examine whether the capacity of an existing grid will still sufficiently meet the requirements of power quality, and if not, which components should be upgraded (e.g., larger cable sizing), or in which way a grid needs to be extended (e.g., by installing additional lines and transformers). Examinations of this kind are usually performed with the assistance of dedicated power system analysis software, such as PowerFactory [1]. Typically, such programs rely on schematic maps to display local wiring together with other grid components, such as transformers, of a concrete power grid.

However, calculations are performed on the provided input data. Since the result of such capacity calculations impacts decision making on whether or not to invest into a certain grid infrastructure, it is decisive that capacity calculation are performed on the basis of accurate assumptions about possible future scenarios. Unfortunately, it is difficult to predict in detail where additional PV sources may appear in the future as the installation of new PV panels is to a great extend in private hands (especially in rural areas by the owners of houses and land).

Interviews with grid planners revealed that the amount of not yet used roof surfaces is a good starting point for making assumptions where new PV panels may appear in the future. Therefore, a grid planner may consult two sources of information: i) a cadastral map that shows the boundaries and ownership of land parcels and buildings together with the topological structure of an existing power grid, and ii) an aerial view (e.g., a street map or an aerial image) for identifying roof surfaces which are suitable for additional PV panel installations.

To assist grid planners in making accurate assumptions about potential additions of PV panel installations and its corresponding additional power feed-in to an existing grid, we have developed an interactive planning tool (IPDS) [8]. The tool takes into account the schematic representation of buildings as given by the cadastral map, sums up the map area covered by buildings, and uses this information for an estimate of potential additional power feed-in through PV panel installations.

To allow for the exploration of different scenarios, the tool supports several options for selecting objects, shown on the map. For example, all buildings which are connected to a certain grid circuit can be selected by selecting the corresponding text label of that grid in a tree view.

Since the underlying cadastral maps do not show roof shapes, an aerial image may be considered in addition. To this end, IPDS can import aerial views of a region from the Google Maps service. This aerial images serve as background on which cadastral maps with grid lines can be gradually superimposed. By means of a slider, the transparency value of the satellite image can be continuously adjusted between 100% transparency, i.e., only the cadastral map is visible (left-hand frame of Fig. 1), and 0%, which displays the background map fully saturated. As shown by the right-hand frame of Fig. 1, a value of 20% renders the background map partly visible so that roof shapes are well recognizable.

Such an overlaid view provides a grid planner with additional information about the actual roof shapes, and thus enables more accurate estimates of the roof surface area on which additional PV panels may be installed. In case of an aerial image being available, one can even go a step further and try to deploy image analysis techniques for an automated classification of roof shapes.

To this end, we experimented with some simple edge detection filters, such as a Sobel discrete differentiation operator. Fig. 2 shows an aerial view of two gable roofs. After edge detection, roof princes appear as edges that run parallel to a pair of edges which belong to a roof's side boundaries.

4. GRID SIMULATORS

A further promising application area for advanced interface technology is grid simulation. As an example, we developed a

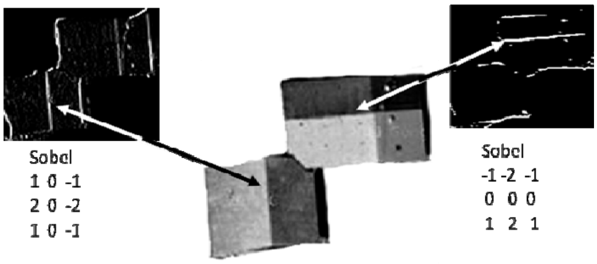

Figure 2. Automated detection of gable roofs by means of Sobel discrete differentiation operators for edge detection.

web-based editing and simulation tool called *Micro-Grid Simulator*. It has been designed as an easy-to-use service for users interested in performing a cost-benefit analysis of investments into renewable energy generation, and self-sufficient neighborhood grids. The basic idea is to enable the definition of hypothetical micro grids composed of renewable energy generators and then simulate energy production over a given time period based on recorded real-world weather data.

The Micro-Grid Simulator is a classical client / server application. The client-side software contains an interactive grid editor (cf. Fig. 3) for the definition of generation scenarios. Users first load a map of interest (from the Google Maps service). Then some generators (PV panels, wind turbines, or biogas generators) can be defined, just by dragging their corresponding icons onto the map. Clicking on an icon opens a template for the setting of generator-specific configuration parameters.

In addition, an object representing a home can also be associated with an average energy consumption value. This enables the user to compare simulated consumption with simulated generation over a certain time period.

Optionally, different icons and their associated generators can now be interwoven into a micro grid. To this end the user draws connection lines between the icons on the map. This feature allows a user to hypothetically join up with neighbors and simulate the result of aggregated energy production. Moreover, it is possible to define several independent micro grids as input for a single simulation run.

The simulation is based on weather data sets recorded by regional measurement stations of the Helmholtz Institute in Munich. The data sets contain minute-by-minute measurements of global solar radiation (in Watts/sqm) and average wind velocity (in m/sec). For simulator testing we gained access to weather data of the years 2005-2010 recorded at a measurement station located at Augsburg University of Applied Sciences. Arbitrary time spans can be specified for simulation runs. This way a user can run simulations for different years and compare the results (e.g. the output of a solar panel in a rainy summer versus in a hot summer).

For the presentation of simulation results the *Micro-Grid Simulator* takes advantage of the JavaScript library "Highcharts" [9]. The curves shown in left-hand frame of Fig. 4 represent output of different renewable energy resources over a time period. The visibility of curves can be switched on and off, and a peek function enables interactive inspection of data points. In addition, pie charts are used to compare energy consumption (blue sections) with generation from different resources. For example, the left-hand pie chart shows a micro-grid constellation in which consumption exceeds production by solar panels and a wind turbine.

Figure 3. Screenshot of the *Micro-Grid Simulator*. Renewable energy generators (such as solar panels and wind turbines) in order to perform a cost-benefit analysis on the basis of recorded regional weather data sets.

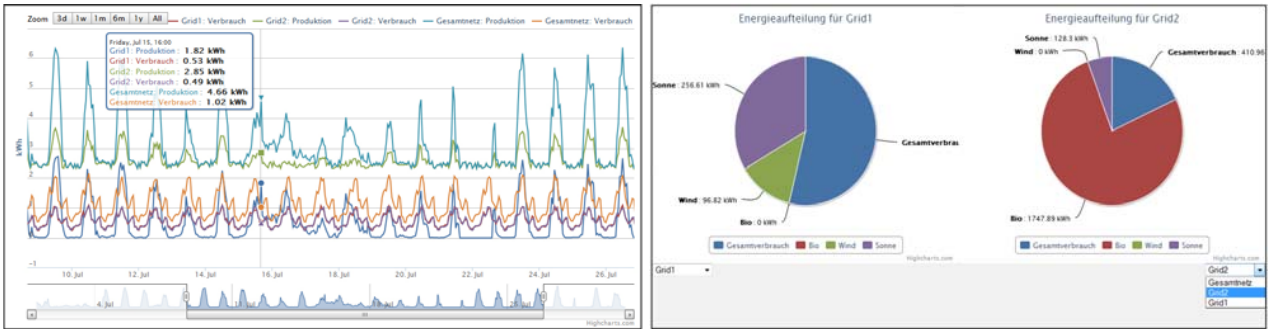

Figure 4. Presentation of simulation outcomes produced by the *Micro-Grid Simulator*. Left: line charts showing power production of different renewable generators over a time span. Right: Pie charts are used to compare energy production of different sources with energy consumption (blue sections). All diagrams are drawn with the JavaScript library Highcharts [8].

5. CONCLUSION

Advanced visualization and interface techniques are highly relevant for tools and systems that are to assist engineers and operators in grid planning, analysis and monitoring tasks.

As a concrete example, we presented the IPDS tool which assists a power grid planner in making accurate assumptions about potential additions of PV panel installations to an existing grid. In its current version, the tool supports several core functions, foremost the estimation of roof surface area of buildings, which are connected to a certain grid circuit and thus are candidates for additional PV panel installations.

In addition, we sketched the web-based Micro-Grid Simulator that allows a user to perform a cost-benefit analysis of investments into renewable energy generation, and self-sufficient neighborhood grids. The front-end of the simulation system comprises a graphical map-editor for the specification of simulation scenarios.

6. ACKNOWLEDGENT

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Smart Energy Interfaces for Electric Vehicles

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ABSTRACT

Electric vehicle charging strategies rely on knowledge of future vehicle usage, or implicitly make assumptions about a vehicle's usage. For example, a naïve charging strategy may assume that a full charge is required as soon as possible and simply charge at the maximum rate when plugged in, whereas a smart strategy might make use of the knowledge that the vehicle is not needed for a number of hours and optimise its charging behaviour to minimise its impact on the electricity grid. These charging strategies may also offer vehicle-to-grid services.

To achieve this functionality, a driver needs to specify the details of the next trip—or sequence of trips—in order for the charging strategy to perform optimally. This paper explores the value of next-trip information, and presents a potential user interface to assist a driver with providing these details.

Keywords

Electric Vehicles, Smart Charging, Smart Grid, V2G

1. INTRODUCTION

There has been much research focussed on smart charging strategies for electric vehicles (EVs), for example [1, 4, 5]. The foremost goal of a charging strategy is to ensure that an EV has sufficient charge to meet its travel requirements; however, the energy needs of an EV rarely require the full capacity of its battery, and hence the excess capacity can be used to support the electricity grid—a concept known as vehicle-to-grid (V2G) [3]. Secondary goals of a charging strategy may include the ability to schedule charging during off-peak periods, actively minimise peak loads, provide ancillary services to the electricity grid, or utilise intermittent renewable energy when it is available.

All charging strategies either make assumptions about the future use of an EV, or require input from the driver. A *greedy* charging strategy could assume that the vehicle will be used again very shortly and require an urgent full charge, and hence charge at the maximum rate as soon as the EV is connected to the grid. While this approach will achieve the goal of providing the EV with sufficient energy for its journey (if possible), it imposes significant demands on the electricity infrastructure [6].

A smarter strategy could charge the battery at a variable rate according to available electricity generation from intermittent renewable sources. The full battery capacity may be used for grid storage, as long as the primary goal of having sufficient charge at the time of next departure is met. This approach has been demonstrated to greatly assist with the integration of large-scale renewable electricity sources [5], however it does require knowledge of the future use of the vehicle; both the time of next departure, and the distance of that journey.

EV chargers are produced by a number of companies (e.g. General Electric, Leviton, Schneider Electric, Delta Group), and typically offer a simple user interface consisting of a display to show the current state-of-charge, provide the ability to delay charging to make use of off-peak energy, and have RFID interfaces for billing purposes. Currently available chargers do not offer the ability for the driver to specify the parameters required by an advanced charging strategy, which is the focus of this paper.

Modern EVs, including plug-in hybrids (PHEVs), offer visualisations within the vehicle. For example, the Toyota Prius incorporates a sophisticated dashboard visualisation to show energy flows between fuel, battery and the vehicle. These types of display will become more important when considering external energy flows between the vehicle and charging sources, which may include distributed generation owned by the driver.

With comparatively limited range and long charging times, EVs introduce a concept known as "range anxiety"—the fear that an EV might not have sufficient energy to complete a journey. It therefore becomes an additional challenge to plan longer journeys to include intermediate recharging stops. A number of websites contain databases of charging stations and provide the facility to plan routes to include charging stops, for example [7, 2].

2. THE POWER OF KNOWLEDGE

Previous work has explored the energy balance between electricity generation and load using an agent-based simulation, taking into account the variability of wind generation and the introduction of large numbers of EVs [5]. Smart charging strategies reduce the grid impacts of EVs, and help accommodate intermittent generation sources. How-

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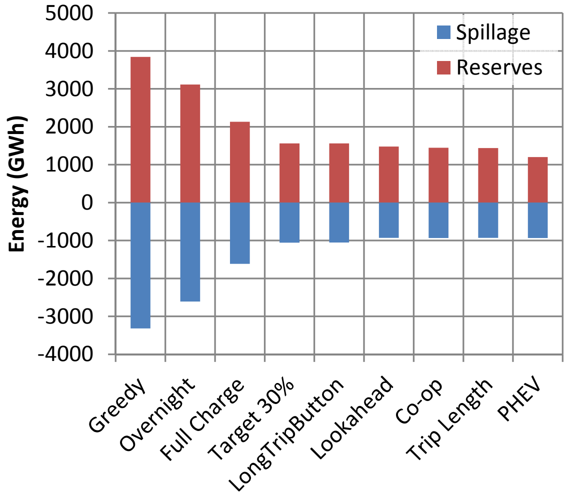

Figure 1: Energy balance by charging strategy

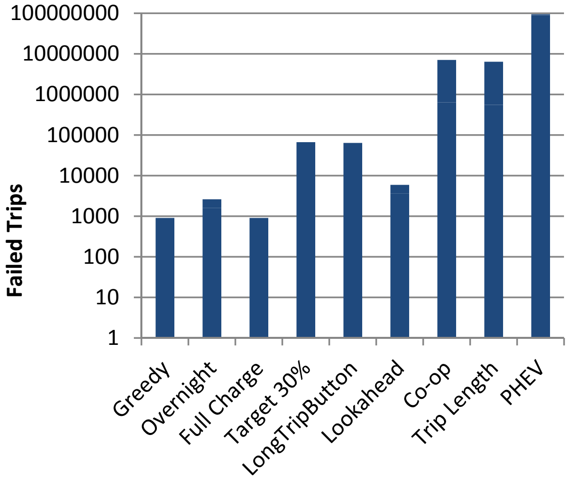

Figure 2: Failed Trips by charging strategy

ever, achieving this relies on the assumption that future trips are known in advance, so that charging strategies have information to work with. In this paper we build on the existing simulation framework to explore the implications of having limited access to future trip information, in order to establish the importance of user interfaces to assist a driver with providing details for upcoming trips.

The parameters of interest include the time of next departure **(T)**, the length of the next trip **(L)**, notice of an upcoming long journey **(N)**, and the specification of multiple—or multi-stage–trips in the immediate or near future **(M)**. These parameters are tested for their effects on energy spillage (excess generation potential where no storage is available), energy required from reserves during generation shortages, and the number of trips that are unable to be completed due to insufficient charge at the time of departure. The simulation is run over one year, for one million EVs, and a generation profile of 30% wind and 70% base load.

A description of charging strategies follows, including the information required by each.

Greedy (-)
When connected, charge until full

Overnight (-)
Charge between the hours of 0100 and 0700

Full Charge (TN)
Target a full charge at the time of next departure using the *Co-op* strategy

Target 30% (-)
Target a 30% charge using *Greedy*, then use *Co-op*

Long Trip Button (N)
Similar to *Target 30%*, but allows the user to invoke a full charge for an upcoming long trip

Lookahead (TLNM)
Target a sufficient charge at the time of next departure to enable completion of a sequence of upcoming trips, using the *Co-op* strategy

Co-op (TLN)
Target a sufficient charge to enable the next trip at the time of next departure, while adjusting charge/discharge (V2G) rates to match available supply

Trip Length (LN)
Target a sufficient charge to enable the next trip using the *Greedy* strategy, then revert to *Co-op*

PHEV (-)
The *Co-op* strategy with no charge target; fuel is used when electricity is not available for charging

From the results shown in figures 1 and 2, there is a clear trade-off between the energy balance and the number of failed trips. Charging strategies that have access to more information about the future behaviour of a vehicle tend to perform better overall; in particular, the *Lookahead* strategy is very competitive in terms of energy balance while maintaining an acceptable level of failed trips—but also requires the most detailed information about the upcoming use of the vehicle.

3. USER INTERFACES

Charging strategies tend to perform better with access to more information about the upcoming use of the vehicle. These parameters may be learnt to some extent, however there are always exceptions to regular usage patterns. This information must therefore be specified by a driver though a user interface. This could range from a simple "full charge" button that provides notice of an upcoming long trip **(N)**, to a sophisticated multi-stage journey planner that can assist with route planning in addition to providing charging strategies with the information required. It is imagined that the proposed user interface will be implemented on a touch-enabled display within the vehicle itself, and utilise gestures such as pinch zoom. It may also be useful to have the interface accessible remotely (i.e. web-based or mobile) for situations where the requirements change while the driver is away from the vehicle.

Figure 3 illustrates an example user interface that allows a driver to specify details of the next trip to be completed

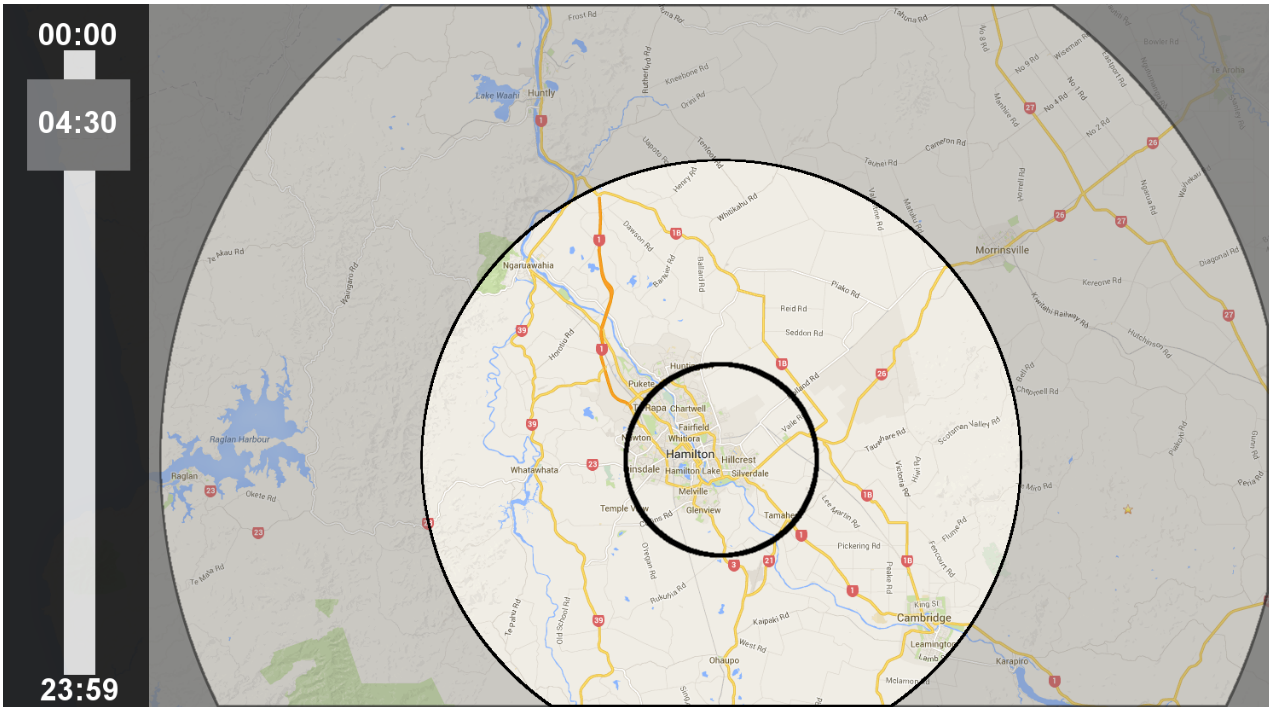

Figure 3: Visual interface to specify the next trip

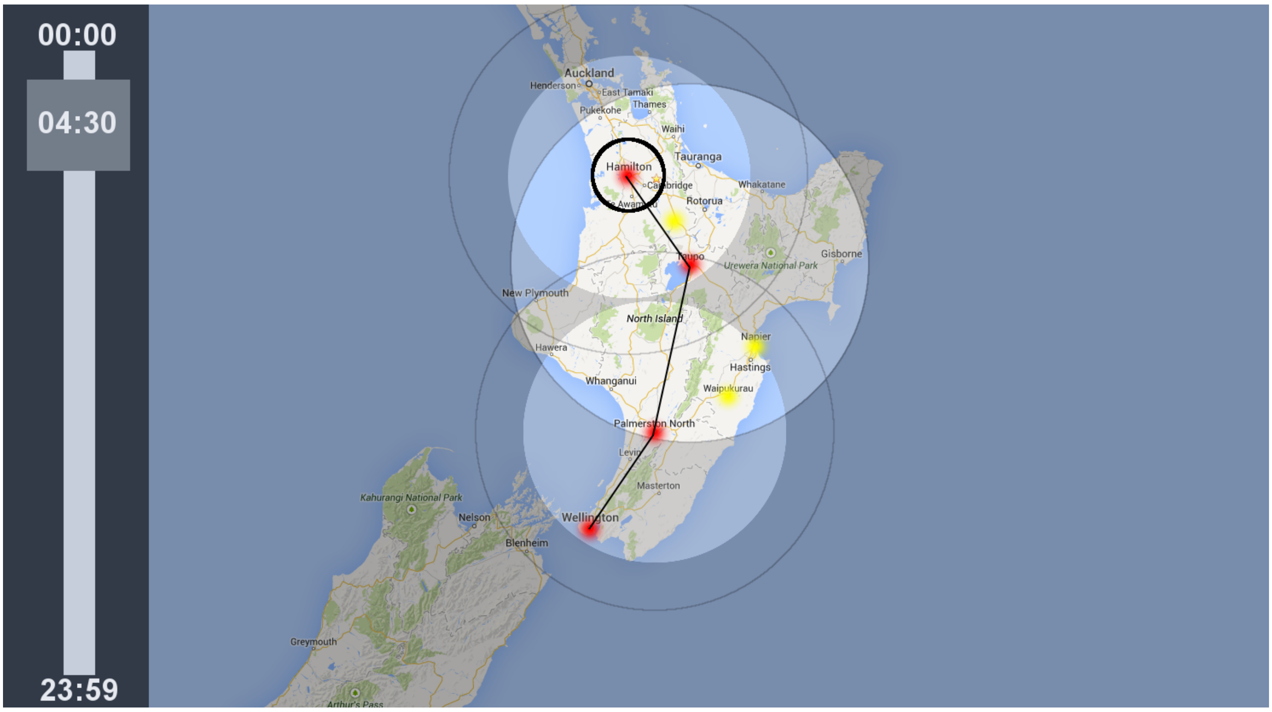

Figure 4: Visual interface to plan a sequence of trips

by the vehicle. On the left is a slider that specifies the time of next departure **(T)**, while the main area illustrates the current location and estimated range of the vehicle. The outer circle represents the range of the vehicle at full charge, while the innermost circle represents the range at the vehicle's current state of charge. The intermediate circle represents the charge target required at the time of departure **(L)**, which may be adjusted by selecting a destination on the map. There is no reason why the current state of charge cannot be greater than the target; in this case, the surplus energy becomes available to support the grid.

The example shown is of a driver planning to travel from Hamilton to Cambridge at 04:30, with a relatively low state of charge at the present time. The charge target is set to reach Cambridge at a minimum, and as the time of departure approaches, the inner circle will change in radius according to the characteristics of the charging strategy in use.

Figure 4 shows an expansion of the idea to assist with the planning of a longer journey, involving several intermediate charging stopovers. In this example, the driver is planning a journey from Hamilton to Wellington, with stopovers in Taupo and Palmerston North. The outer circles again represent the fully-charged range from each selected charging station (shown in red), while the highlighted areas represent the charging targets to be achieved at those points. Alternative charging points (shown in yellow) may be selected, and will update the display accordingly.

Once the driver has explored possible routes, the sequence of upcoming trips **(M)** becomes available, so that a charging strategy can begin preparing the vehicle for the journey.

4. DISCUSSION

The development of advanced visual interfaces to support the adoption, integration and use of EVs is of particular interest. EVs provide significant opportunity towards the goal of reducing greenhouse gas emissions through having zero tailpipe emissions themselves, while also supporting the integration of intermittent renewable generation sources; however, they are not without their own challenges. Their successful adoption will require fundamental changes in both electricity grid operation and driver behaviour. A critical part of easing the transition is providing tools to help drivers to understand the performance limitations of EVs, and make the most of opportunities such as revenue from providing ancillary services to the grid.

The concept of a "smart grid" involves a great deal of automation and interaction with end users. This is especially true when considering EVs. It is imagined that an end user can specify goals, create a plan to achieve the goals with the assistance of advanced visual interfaces, and then leave the details to automation. In the example presented in this paper, a driver may specify a goal of "travel to Wellington tomorrow", and with the assistance of a journey planner might incorporate several stopovers along the way. Once this is finalised, a charging strategy can take over with a primary focus to enable the journey, and, where possible, make the vehicle's battery available to provide ancillary services.

This paper has described how the performance of electric vehicle charging strategies is affected by the level of information available, and provides an example visual user interface that allows a driver to specify this information, and also help plan longer journeys that involve intermediate charging stopovers. There are a number of factors that the proposed interface does not address, including provision for return journeys, destinations without charging facilities, and the exploration of how much time is spent at intermediate stopovers when planning routes.

5. FUTURE WORK

Future work should include the implementation and evaluation of the visual interfaces presented in this paper. Any user interface will require some effort from the driver; it is important to ensure that the effort is justified when compared with the benefits achieved.

Both versions of the interface use circles to denote the range of an EV. This seemingly ignores terrain and road layout; however, charge targets could be calculated as being able to reach any point within the circle by the most direct route, plus some safety margin, rather than relying on straight-line distances. In other words, the circles could represent minimums rather than absolute distances. This aspect must be considered in the implementation and evaluation. If circles prove insufficient, more complicated polygons may be the solution—at the expense of a more cluttered interface.

While this paper has presented preliminary results of how the performance of charging strategies is affected by limited access to information, there are many (often conflicting) factors to consider when comparing the overall "performance" of a charging strategy, and indirectly, user interfaces.

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Visualizing a Control Strategy for Estimating Electricity Consumption

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ABSTRACT
This paper investigates the potential of applying different control measures on low power and high power appliances with the goal of evolving efficiency in electricity consumption. The research involves carrying out simulations on their power consumption readings to set up a control system. The study discovers savings on all appliances under study to be 12.8% Kw, not minding occupancy rate of the building. Air-conditioners have the greatest impact of a 6% Kw contribution on savings. This would lead to a substantial contribution when converted to pricing rates. The results from the study indicate that control measures should be extended to peak periods and power saving measures extended to more appliances.

Keywords
Control measures, efficiency, simulation, occupancy rate, savings.

1. INTRODUCTION
This research proposes a control strategy to estimate electricity consumption which can be used to improve efficiency in electricity usage. Due to the importance of having an efficient electricity consumption system, various studies have addressed the issue of finding a solution to this problem. This varies from the use of sensors, which regulates and control electric usage, to the efficient allocation and scheduling of electric power supply [1]. A previous research derives a speed control strategy to improve operations of renewable source of electricity by promoting manufacture of wind turbines [2]. It is based on the Newton's method, which is a numerical technique.

A paper introducing the use of a smart meter, comprising of an energy consumption controller (ECC) is used to determine whether electricity prices would fluctuate if users shift their energy consumption schedule of high load household appliances to off-peak hours to reduce energy expenses [3]. In the analysis, Heating Ventilation and Air conditioning (HVAC) systems are investigated. These are considered to be high power appliances. Efficiency in electricity consumption was applied to control of Heating Ventilation and Air conditioning systems (HVAC) because of their large energy footprint, [4]. This involves building a mathematical model of the temperature dynamics of the room, and combining this model with statistical methods allows us to compute the heating load due to occupants and equipment using only a single temperature sensor. A paper [5] introducing a load shedding algorithm to maximize efficiency under certain requirements was presented. It employs an algorithm with penalty function method (PFM) and the simplex method (SM) compiled by C++. This algorithm leads to rapid computation speed.

Past research of determining efficiency in electricity consumption is mainly based on control of high power appliances; it does not consider control of low power electrical appliances. The current research seeks to investigate if it is possible to obtain better performance level when controls of low power appliances are considered, together with high power electrical appliances. This research work will implement a control strategy for computing electricity consumption with the goal to minimize electricity wastages in the system and ultimately the costs. This will take into account energy consumption for each electrical appliance, varying time intervals for each appliance, which are used for decision making.

2. METHODOLOGY
The methodology developed in this research involves electricity consumption based on real electricity consumption measurements which are collected from individual appliances through the use of installed power meter connected to electricity grid in the Faculty of Computer Science and Information Technology building, Universiti Malaysia Sarawak where data in this research study is collected from. The study models electricity consumption in order to find out control effects of

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applying power saving measures on low power and high power appliances.

The simulation of time-based electricity consumption visualizations for low power and high power appliances used in this research study is carried out to evaluate the level of efficiency in their electricity consumption. The research is based on real-time electricity consumption data collected for low power appliances; computers, closed-circuit TV (CCTV) and high power appliances; air-conditioners, electricity lightings over a period of time while simulation is carried out for individual appliances.

By applying control measures between the periods October 2013 – December 2013, consumption measurements are obtained for the four appliances under study. For application of control measures to the various appliances, the air-conditioners were switched off at certain periods of the day, i.e. between 6p.m – 12 midnight. The lighting systems in level 1 of FCSIT building were replaced with lighting-emitting diode (LED) lights; CCTV's were connected to power back-ups and power saving measures was applied on computers in level 1 of the building within a period of time. Figure 1 shows a model to determine efficiency in electricity consumption by considering low power and high power appliances.

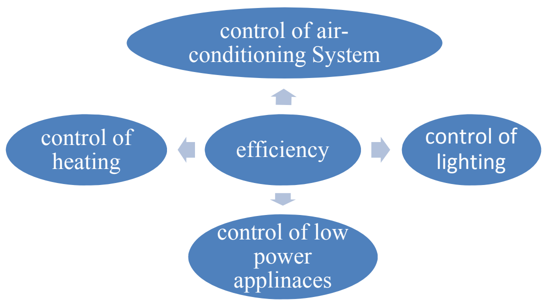

Figure 1. Control strategy to determine efficiency in electricity consumption.

To formulate models for electricity consumption systems, firstly, the different types of appliances that would be considered are identified. In order to effectively model the electricity consumption problem, this research measures and controls electricity consumption for the selected appliances, the frequency of consumption for each appliance and at what time of the day electricity is consumed by these appliances.

In this research, the standard deviation (SD), which is the square root of the variance, is used to compute variations between measurements obtained from appliances while applying power saving measures (controlled) and measurements obtained from appliances without power saving measures (uncontrolled). The study applies SD in order to calculate the percentage difference between the respective measurements for controlled data and uncontrolled data, whereby investigating the degree of effectiveness of the application of power saving measures to individual appliances.

This research utilizes a similar technique applied in a study on genome biology, [6]. It uses SD to measure level of variability between experiments conducted for perfect match (PM)-only model and experiments conducted for PM/mismatch (MM) difference model in the model-based expression indexes (MBEI) study. In the study, variability between the two experiments is reduced for lower SD estimates and provides a natural method of investigating variations and reliability between two techniques in model analysis.

SD can be expressed as:

$$SD = \sqrt{\frac{S_1{}^2 + S_2{}^2}{n-1}} \quad (1)$$

where,

$$S^2{}_1 = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \mu)}{n-1}} \quad (2)$$

For $x_1, x_2, \ldots, x_n$ independent variables denoting meter readings without power saving measures.

$$S^2{}_2 = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \mu)}{n-1}} \quad (3)$$

for $y_1, y_2, \ldots, y_n$ independent variables denoting meter readings while applying power saving measures.

μ = population mean and n = sample size.

3. SIMULATION RESULTS

Electricity consumption data simulations were made using the Matlab and the SPSS software in order to compute daily meter readings for each appliance, over the duration of the given period. The software utilizes daily electricity consumption data readings and takes into account power consumption for each appliance.

Figure 2 present the trend of daily electricity consumption for selected low power and high power appliances under study in 2013.

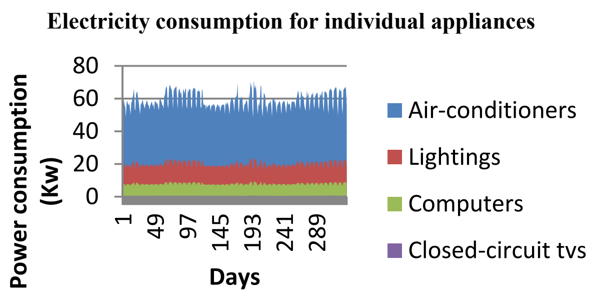

Figure 2. Electricity consumption for Appliances (Source: Jan 1-Dec 31, 2013).

It shows clearly that consumption for the high power appliances, i.e. air-conditioners and lighting systems are very much higher than those for low power appliances, i.e. computers and CCTV's. The consumption for low power appliances fall below a daily value of 35 Kw, while that of high power appliances are of higher consumption values.

Power saves or control measures were applied to appliances by making comparison with actual meter readings for appliances without the application of power saving measures in order to find out power savings for each appliance.

In the analysis carried out, computations of variations in the application of power saving measures to individual appliances yielded the following SD values:

Table 1: SD values obtained for applying control measures to individual appliances

Appliances	SD
Air-conditioners	6
Lighting	2
Computers	1
CCTV's	0.1

Figure 3-6 shows comparisons for the selected appliances between simulated data for daily electricity consumption and their respective control measurements.

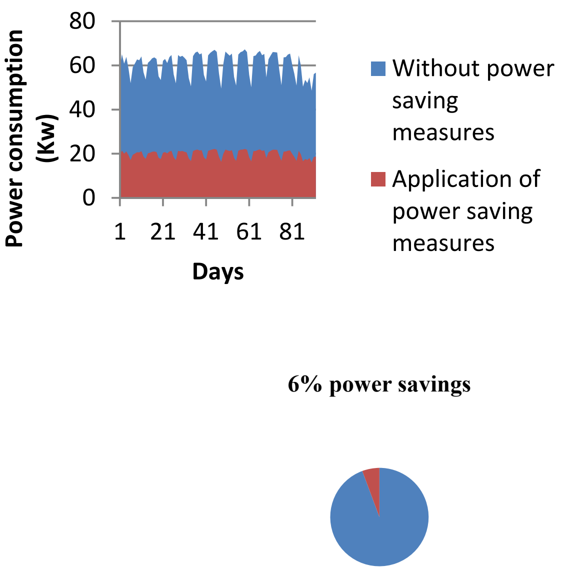

Figure 3. Controlled vs uncontrolled power consumption for Air-conditioners (Source: Oct 1- Dec 31, 2013).

For Figure 3, an inefficient situation without switching off the air-conditioners would lead to an over-consumption of 6% Kw by comparison with the controlled case.

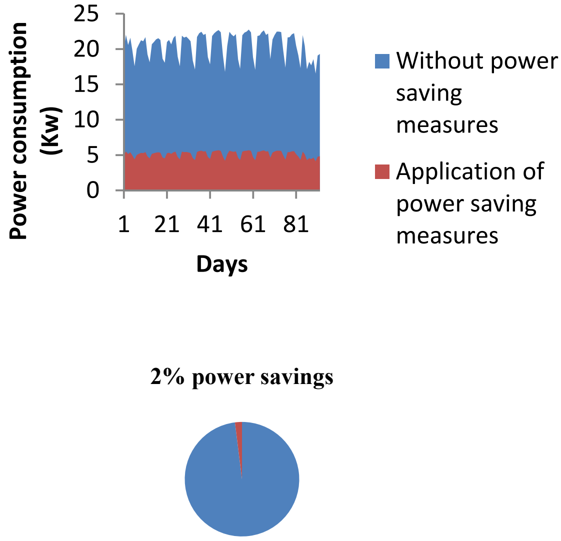

Figure 4. Controlled vs uncontrolled power consumption for Lighting (Source: Oct 1- Dec 31, 2013).

From Figure 4, an inefficient situation without using LED lightings would lead to an over-consumption of 2% Kw by comparing with the controlled case.

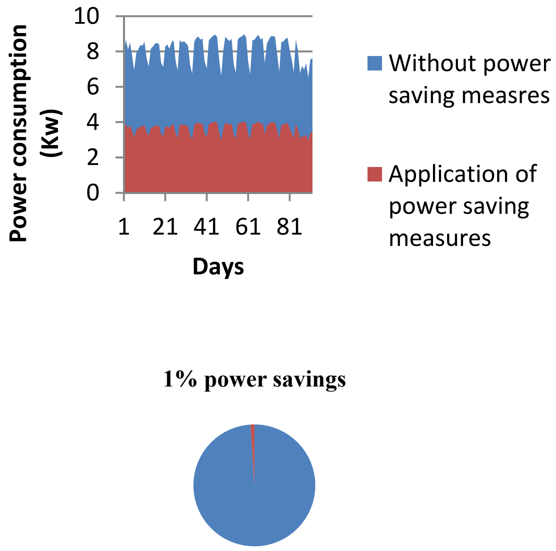

Figure 5. Controlled vs uncontrolled power consumption for Computers (Source: Oct 1- Dec 31, 2013).

From Figure 5, an inefficient situation without applying power saving measures to computers would lead to an over-consumption of 1% Kw by comparison with the controlled case.

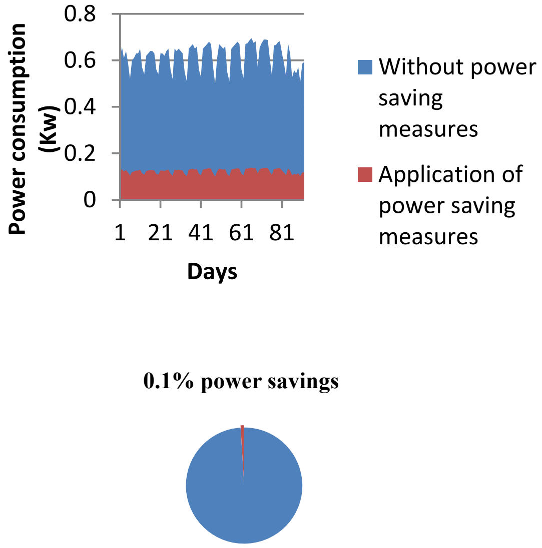

Figure 6. Controlled vs uncontrolled power consumption for CCTV's (Source: Oct 1- Dec 31, 2013).

For Figure 6, an inefficient situation without using power-backups would lead to an over-consumption of 0.1% Kw by comparison with the controlled case.

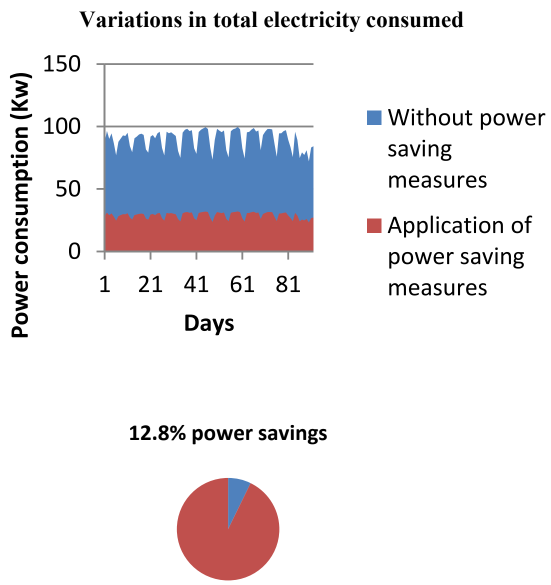

Figure 7. Controlled vs uncontrolled power consumption for total electricity consumed (Source: Oct 1- Dec 31, 2013).

The research investigates the gains obtained with the application of power saving measures on low power and high power appliances. Considering all appliances under study, SD = 12.8, which gives an over-consumption of 12.8% Kw by comparison with the controlled case (Figure 7). Comparing the application of control measures on the different appliances, most savings is obtained from controlling for efficiency in air-conditioners; an estimate of 6% is saved in Kw, which makes it the most high power consuming appliance in this study.

It is observed that the respective area charts for individual appliances presented in Fig. 3 to Fig. 6 indicate substantial higher consumption compared to power savings represented by their respective pie charts. The results from the study show that while there is over-consumption without the application of power saving measures, the resulting power savings for individual appliance differs depending on whether it is low power or high power appliance, and the power consumption show fractional savings, which albeit will have an effect on total electricity costs.

4. CONCLUSION

This paper tried to analyse the performance of applying power saving measures on low power and high power appliances to enhance efficiency.

The first part investigates power meter measurement of different appliances, including readings from applying control systems on the appliances. Electricity consumed was measured by the power meter, with and without application of power saving measures. In the research, it is discovered the control on air- conditioner has a saving of 6% Kw and the control on CCTV's has a savings of 0.1% Kw. This would infer some multiples of costs would be saved when converted to pricing rates. More over the overall contribution to savings when a combination of low power and high power appliances are considered in this study is 12.8% Kw. Evaluating these values, it can be inferred that the control system can have more savings in the system when control measures are applied to all appliances consuming electricity.

The controls on appliances are applied according to specifications in the research study and could be extended to cover more time schedules. The study shows that electric savings are more when applied to off-peak periods when most appliances are not much in need and could be more when control measures are applied during peak periods. When adjusting air-conditioner use, energy savings are still higher even during off-peak periods, as this research focusses on data collection during off-peak periods. As against what is in use now, a decentralized air-conditioner system is preferable for each office or meeting rooms and air-conditioners are switched off when not in used so as to be able to further reduce electricity wastages.

The research show that electric lighting savings are more when LED bulbs are used, not minding daylight availability of users. Electricity wastages would further be reduced if occupancy sensors are introduced into the building. This is because lighting in many meeting rooms and toilets would be turned off when not in use and wastages would be reduced as occupation rate decreases.

Further study would investigate control measures been applied to appliance during peak periods, when occupancy rate is higher, to determine the amount of electricity consumption that would be saved. Also more appliances would be considered to increase further energy savings in the system.

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