

Exploring Aesthetic Visualization for Promoting Consumer Energy Conservation

by

Mengting Sun

B.Sc., Simon Fraser University, 2011

B.Eng., Zhejiang University, 2011

Thesis Submitted In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the

School of Interactive Arts and Technology
Faculty of Communication, Art and Technology

© Mengting Sun 2014

SIMON FRASER UNIVERSITY

Summer 2014

All rights reserved.

However, in accordance with the *Copyright Act of Canada*, this work may be reproduced, without authorization, under the conditions for "Fair Dealing." Therefore, limited reproduction of this work for the purposes of private study, research, criticism, review and news reporting is likely to be in accordance with the law, particularly if cited appropriately.

Approval

Name: Mengting Sun
Degree: Master of Science
Title of Thesis: *Exploring Aesthetic Visualization for Promoting Consumer Energy Conservation*
Examining Committee: Chair: Brian Fisher
Associate Professor

Lyn Bartram
Senior Supervisor
Associate Professor

Alissa Antle
Supervisor
Associate Professor

Carman Neustaedter
External Examiner
Assistant Professor

Date Defended: March 21, 2014

Partial Copyright Licence



The author, whose copyright is declared on the title page of this work, has granted to Simon Fraser University the non-exclusive, royalty-free right to include a digital copy of this thesis, project or extended essay[s] and associated supplemental files (“Work”) (title[s] below) in Summit, the Institutional Research Repository at SFU. SFU may also make copies of the Work for purposes of a scholarly or research nature; for users of the SFU Library; or in response to a request from another library, or educational institution, on SFU’s own behalf or for one of its users. Distribution may be in any form.

The author has further agreed that SFU may keep more than one copy of the Work for purposes of back-up and security; and that SFU may, without changing the content, translate, if technically possible, the Work to any medium or format for the purpose of preserving the Work and facilitating the exercise of SFU’s rights under this licence.

It is understood that copying, publication, or public performance of the Work for commercial purposes shall not be allowed without the author’s written permission.

While granting the above uses to SFU, the author retains copyright ownership and moral rights in the Work, and may deal with the copyright in the Work in any way consistent with the terms of this licence, including the right to change the Work for subsequent purposes, including editing and publishing the Work in whole or in part, and licensing the content to other parties as the author may desire.

The author represents and warrants that he/she has the right to grant the rights contained in this licence and that the Work does not, to the best of the author’s knowledge, infringe upon anyone’s copyright. The author has obtained written copyright permission, where required, for the use of any third-party copyrighted material contained in the Work. The author represents and warrants that the Work is his/her own original work and that he/she has not previously assigned or relinquished the rights conferred in this licence.

Simon Fraser University Library
Burnaby, British Columbia, Canada

revised Fall 2013

Ethics Statement



The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

- a. human research ethics approval from the Simon Fraser University Office of Research Ethics,

or

- b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University;

or has conducted the research

- c. as a co-investigator, collaborator or research assistant in a research project approved in advance,

or

- d. as a member of a course approved in advance for minimal risk human research, by the Office of Research Ethics.

A copy of the approval letter has been filed at the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Simon Fraser University Library
Burnaby, British Columbia, Canada

update Spring 2010

Abstract

Consumer awareness of energy use and their act in energy conservation are inextricably linked because the former enables informed decision-making and motivates behaviour change. Various feedback techniques have been developed to increase consumer knowledge and problems with traditional methods such as pragmatic charts are the lack of engagingness and integrity with the context. As an alternative, we explore the effectiveness and utility of using aesthetic visualization as feedback for consumer energy use, as we believe its more attractive display will increase aesthetic interest and better fit with the environment. In our two-staged study, we first investigate its effectiveness in comprehension and then further explore its ability in supporting decision-making and understanding within a simulated gaming context. We conclude that aesthetic visualization is a promising approach due to its advantage of engaging people with visually interesting display while maintaining comprehensibility, supporting at-a-glance awareness and enabling informed decision-making.

Keywords: feedback, aesthetic visualization, pragmatic visualization, energy conservation, sustainable HCI

Dedication

To my dearest parents,

for raising me with courage to start this journey.

And to my lifelong friend,

for turning my sorrow into joy on this journey.

Acknowledgements

First and foremost, I would like to express my special appreciation and thanks to my senior supervisor Professor Lyn Bartram, for her continuous support, guidance, insight and encouragement throughout the course of this thesis. She has made my thesis research a joyful experience and helped me grow as a student.

I would like to thank Professor Alissa Antle, for her help and advice on this research. And I am grateful towards Professor Carman Neustaedter for agreeing to be my external and taking time to review my research design.

I would also like to give special thanks to Professor Diane Gromala and Jeremy Mamisao, for their professional design support in the development of the visualization prototypes. Thanks also to our research lab manager Gordon Pritchard, for all the technical support and advice. And more thanks go out to my colleagues in the Humans, Visualizations & Interfaces lab, for their support and friendship.

Thank you NSERC and GRAND NCE for funding this research.

Finally, I would like to show my gratitude to my family, especially to mom and dad for their endless love and support. And I am thankful to all my close friends, for their help and company.

Table of Contents

Approval.....	ii
Partial Copyright Licence	iii
Ethics Statement.....	iv
Abstract.....	v
Dedication	vi
Acknowledgements.....	vii
Table of Contents.....	viii
List of Tables.....	x
List of Figures.....	xi
List of Acronyms.....	xiv
Glossary.....	xv
1. Introduction	1
1.1. The Problem.....	2
1.2. Our Approach.....	4
1.2.1. Why Aesthetic Visualization?	4
1.2.2. Research Overview	5
1.3. Methodology.....	6
1.4. Thesis Organization	8
2. Background	10
2.1. Raising Awareness – Initial Step to Energy Conservation	10
2.1.1. Importance of Consumer Energy Conservation	10
2.1.2. Intervention Studies.....	13
2.1.3. From Feedback to Behaviour Change.....	16
2.2. Review of Interactive Research on Sustainability	19
2.2.1. Sustainable HCI: an Overview.....	19
2.2.2. Ubiquitous Computing	20
2.2.3. Survey of Eco-Feedback Technology.....	25
2.3. The Approach of Aesthetic Visualization with Ambient Displays	30
2.3.1. Artistic vs. Pragmatic visualization	30
2.3.2. Infographics.....	32
2.3.3. Design requirements	33
2.3.4. Evaluation.....	35
2.4. Discussion.....	37
3. Motivation and Goals	39
3.1. Motivation.....	41
3.2. Goals.....	42
3.2.1. Study 1	43
3.2.2. Study 2	43
3.3. Limitations	45
4. Study 1: the Effectiveness of Aesthetic Visualization	46
4.1. Design of Three Visualizations.....	46

4.1.1.	SolarVis1: A Graphic Abstraction of Solar Panels as Calendar Entries	47
4.1.2.	SolarVis2: A Non-photorealistic Rendering of an Apple Tree.....	48
4.1.3.	Excel Charts: Example of Pragmatic Visualization	49
4.2.	User Study	50
4.2.1.	Hypotheses.....	51
4.2.2.	Participants.....	52
4.2.3.	Procedure	52
4.2.4.	Results.....	53
4.2.5.	Discussion	68
4.3.	Summary.....	69
5.	Study 2: Energy Conservation Game	71
5.1.	Research Design.....	71
5.1.1.	Research Questions	72
5.1.2.	User Study.....	73
5.1.3.	Data Collection and Analysis	74
5.2.	Energy Conservation Game	77
5.2.1.	Game Design.....	78
5.2.2.	Visualization Design	81
5.2.3.	System Implementation	86
5.3.	Results	88
5.3.1.	Participants and Their Energy Understanding.....	88
5.3.2.	Game Performance	90
5.3.3.	Game Logs	101
5.3.4.	Impressions on Visualization Design.....	104
5.3.5.	Preferences of Location at Home	106
5.4.	Discussion.....	108
6.	Conclusion and Future Work	112
6.1.	Research Questions Revisited	113
6.1.1.	Study 1	113
6.1.2.	Study 2	114
6.1.3.	Design Implications	115
6.1.4.	Summary	116
6.2.	Contributions	116
6.3.	Future Work	117
	References.....	120
	Appendices.....	126
Appendix A.	Study 1 Documents	127
Appendix B.	Study 2 Documents	137
Appendix C.	Design Exploration – Past Versions of Tree Visualization Design.....	142

List of Tables

Table 2-1.	Key Findings of consumer opinions and preferences toward electricity management programs (Accenture, 2010).....	12
Table 2-2.	The Transtheoretical Model of behaviour change stages progress (He, Greenberg, & Huang, 2010).	18
Table 2-3.	Design Strategies for Effective EV (Pierce, Odom, & Blevis, 2008)	29
Table 2-4.	Lessons learned from designing several generations of ambient information visualizations (Skog, Ljungblad, & Erik, 2003).....	37
Table 4-1.	Study1: Alignment Chart.....	51
Table 4-2.	Statistical result for Two-Way ANOVA test (accuracy, basic understanding question)	55
Table 4-3.	Detailed results for basic understanding questions and analyzed reasons.....	56
Table 4-4.	Statistical result for Two-Way ANOVA test (time, basic understanding question)	58
Table 4-5.	Detailed results for basic understanding questions and analyzed reasons.....	59
Table 4-6.	Statistical result for Two-Way ANOVA test (accuracy, comprehension question)	61
Table 4-7.	Detailed results for comprehension questions and analyzed reasons.....	62
Table 4-8.	Statistical result for Two-Way ANOVA test (time, comprehension question).....	63
Table 4-9.	Detailed results for comprehension questions and analyzed reasons.....	64
Table 4-10.	Statistical result for Two-Way ANOVA test (appeal)	65
Table 4-11.	Statistical result for Two-Way ANOVA test (location).....	67
Table 5-1.	Study 2: Alignment Chart.....	77
Table 5-2.	Game Stories.....	80
Table 5-3.	Summary of data features of all three visualizations	85

List of Figures

Figure 1-1.	Design-oriented Research (Fallman, 2007).....	7
Figure 1-2.	Research-oriented Design (Fallman, 2007).....	7
Figure 2-1.	Secondary Energy Use by Sector, 2008 (Natural Resources Canada, 2012).....	11
Figure 2-2.	GHG Emissions From Secondary Energy Use by Sector, 2008 (Natural Resources Canada, 2012).....	12
Figure 2-3.	Power-Aware Cord (Gustafsson & Gyllenswård, 2005)	23
Figure 2-4.	The Element (Gyllensward, Gustafsson, & Bang, 2006)	23
Figure 2-5.	The Firefly Stairway (Miller, Rich, & Davis, 2009)	25
Figure 2-6.	Living and Robotic Plants (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2005)	25
Figure 2-7.	The Ténééré (Kim, Kim, & Nam, 2009)	26
Figure 2-8.	Nuage Vert (Evans, Hansen, & Hagedorn, 2009)	27
Figure 2-9.	Use-contexts plotted according to dimensions of dweller control and third-party control (Pierce, Odom, & Blevis, 2008)	28
Figure 2-10.	The gamut of data-based visualization (Kosara, 2007)	30
Figure 2-11.	Weather Composition (Ljungblad, Skog, & Holmquist, 2004)	32
Figure 2-12.	InfoCanvas (Miller & Stasko, 2001)	32
Figure 2-13.	Ambient Canvas (Rodgers & Bartram, 2010)	32
Figure 3-1.	Sample screenshot for Google PowerMeter™	40
Figure 3-2.	Sample screenshot for Microsoft® Hohm™	40
Figure 4-1.	Example of Solarvis1. The screenshot was taken with synthetic data.....	47
Figure 4-2.	Example of SolarVis2. The screenshot was taken with synthetic data.....	49
Figure 4-3.	Example of Excel Charts. The screenshot was taken with synthetic data.	50

Figure 4-4.	Participant Demographics – Gender	54
Figure 4-5.	Participant Demographics – Age	54
Figure 4-6.	Accuracy by basic understanding question for each visualization.....	56
Figure 4-7.	Time by basic understanding question for each visualization	59
Figure 4-8.	Accuracy by comprehension question for each visualization	62
Figure 4-9.	Time by comprehension question for each visualization	64
Figure 4-10.	Rate by appeal for each visualization.....	66
Figure 4-11.	Rate by location for each visualization	67
Figure 5-1.	Web Interface of Energy Conservation Game	79
Figure 5-2.	Game Story Example	81
Figure 5-3.	Self-evaluation Example.....	81
Figure 5-4.	Abstract Tree with Berries to represent positive actions	82
Figure 5-5.	Abstract Tree without berries.....	84
Figure 5-6.	Bar Chart with embellishment.....	85
Figure 5-7.	Energy Conservation Game - System Architecture	87
Figure 5-8.	System Installations.....	88
Figure 5-9.	Participants demographics	89
Figure 5-10.	Conservation activities mentioned by participants, number of mentions stacked by grade.....	90
Figure 5-11.	User Actual Game Score by Participants	91
Figure 5-12.	User Perceived Game Score by Participants	92
Figure 5-13.	Delta (actual score – perceived score) by Participants	93
Figure 5-14.	User Actual Game Score by Tasks	94
Figure 5-15.	User Perceived Game Score by Tasks	94
Figure 5-16.	Delta (actual score – perceived score) by Tasks.....	95
Figure 5-17.	User Actual Game score by story.....	96

Figure 5-18.	User Perceived Game score by story	96
Figure 5-19.	Delta (actual score – perceived score) by story	96
Figure 5-20.	Game Score by visualizations	97
Figure 5-21.	Fridge Setting	99
Figure 5-22.	Room Temperature Control.....	99
Figure 5-23.	Lighting.....	99
Figure 5-24.	Turn Off Unused Appliances	100
Figure 5-25.	Unplug Unused Appliances	100
Figure 5-26.	Number of game logs by individual appliances	102
Figure 5-27.	Number of game logs by individual appliances separated by visualizations	103
Figure 5-28.	Number of logs by game story.....	104
Figure 5-29.	Number of logs by visualization.....	104
Figure 5-30.	Participant’s individual impression on visualization vs. their actual game scores	105
Figure 5-31.	Participants’ impressions on different visualizations	105
Figure 5-32.	Individual preferences of location at home	107
Figure 5-33.	General preferences on location at home across three visualizations	107
Figure 5-34.	Sample in-home placement of the display.....	109

List of Acronyms

Aml	Ambient Intelligence
EV	Eco-visualization
GHG	Green House Gas
HCI	Human Computer Interaction
Infographic	Information Graphic
NRCan	Natural Resources Canada
UI	User Interface

Glossary

Ambient Display	“Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user’s attention.” (Mankoff, Dey, Hsieh, Kientz, Lederer, & Ames, 2003)
Calm Technology	A type of information technology where the interaction between the technology and its user is designed to occur in the user’s periphery rather than constantly at the center of attention. “Calm technology engages both the center and the periphery of our attention, and in fact moves back and forth between the two.” (Weiser & Brown, The coming age of calm technology, 1997)
Consumer Energy Use	The use of electrical energy in support of daily activities. In this context, it particularly refers to: 1) charging of mobile devices at a solar charging station and 2) electricity use at home to power all sorts of home appliances.
Vampire Power	Vampire power refers to the electric power consumed by electronic and electrical appliances while they are switched off or in a standby mode.

1. Introduction

All people, everywhere, use energy. People use it for cooking, heating, lighting and powering all sorts of their electronics. They may use it economically or wastefully, consciously or blissfully unaware of how and where it is being consumed. However, energy use never occurs without side effects, it is at the cost of environmental degradation: global warming, climate change and water and soil pollution. With the large growth of energy demand, such impacts on deterioration of the environment have become prominent and significant. The situation requires immediate attention and action from policy makers, environmentalists, designers and citizens to improve energy performance, including raising energy efficiency and promoting energy conservation.

In Canada, great efforts have been made to reduce green house gas (GHG) emissions and to protect the environment with clean energy technologies. According to the recent annual Report to Parliament:

Natural Resources Canada (NRCan) promotes energy efficiency and the use of alternative energy as a means to reduce GHG emissions and save money. NRCan uses a broad range of policy instruments, including leadership; information; voluntary initiatives; financial incentives; research, development and demonstration; and regulation. (Natural Resources Canada, 2012)

In British Columbia, the provincial government has laid several plans addressing energy issues and strategies, which include the BC Energy Plan (B.C.'s Ministry of Energy, Mines and Petroleum Resources, 2009), BC Climate Action Plan (B.C.'s Ministry of Environment, 2009) and The Green Energy Advisory Task Force Report (B.C.'s Ministry of Environment, 2009). The government plans primarily target energy conservation and efficiency from a macroscopic view, such as making more investments in clean and renewable energy. From the consumers' end, the local utility company has carried out the Smart Metering Program, aimed at helping residential customers reduce

energy use and save money by providing them with timely information about their energy consumption with in-home feedback tools. As the company highlights,

Without specific and timely information about your consumption, it's difficult to make informed decisions to actively manage your electricity use. The introduction of smart meter enabled technology will give you the ability to track your power use and costs regularly, along with access to new tools to better understand and manage your electricity use. (BC Hydro, 2013)

Notably, information on energy use is an important instrument to be emphasized as it increases consumer awareness of the environmental impact of energy use and encourages them to become more energy efficient. It allows consumers to know their energy consumption and make more informed decisions to actively manage their energy use. More importantly, technology makes a difference in how we may effectively and successfully deliver the information. And this presents opportunities for designers, researchers and technologists to develop new information technology to bridge the gap between consumer awareness of energy use and their everyday activities and to contribute to a greener world.

1.1. The Problem

However, the problem here is: what, how and where should information on energy use be delivered to consumers to initiate changes towards energy conservation?

What is the right information? Individual consumers think of energy in three ways: as a commodity, a basic human need and an ecological resource (Darby, 2001). As a commodity, it is important for consumers to know the cost, how much energy they have consumed and where it has been consumed. As a basic human need, consumers need to be informed that energy is a scarcity that should be used appropriately. Information on energy shortage, availability and supply should be available to them. Finally, as an ecological resource, consumers should be educated as to where energy comes from, how its production affects the environment and how their actions with respect to consumption may lower the environmental impact. Therefore, information on energy consumption alone is inadequate for consumers to make informed decisions.

Supplementary information such as how energy consumption relates to GHG emissions and everyday activities may also be helpful.

How should consumers see the information? There are various ways for consumers to access the information discussed above. In British Columbia, the public utility company actively promotes the Smart Metering Program, which allows customers to track their power use and costs on a regular basis. The program intends to help consumers save energy and money by providing specific and timely information about their consumption (BC Hydro, 2013). The recent annual Report to Parliament mentions that “information activities include publications, exhibits, advertising, toll-free telephone lines, conferences, Web sites, workshops, training, building-design software and promotional products” (Natural Resources Canada, 2012). These activities communicate information that focuses on viewing energy as a basic human need and an ecological resource.

Where would it be appropriate for consumers to see the information? Information can be displayed either publicly or privately, depending on the content. For information that is for educational purposes, it should be distributed publicly via exhibits, advertising or Web sites so as to arouse wide public concern. Whereas for information related to personal energy consumption, people would prefer to keep it in private, to have it shown in their homes or through Web sites with user authentications. However, research also shows that energy consumption is a social behaviour, proper sharing of consumption information among communities, friends and/or families might lead to positive competitions towards energy conservation (Darby, 2010).

Taken together, what, how and where information should be delivered to raise consumer awareness of energy production and consumption and to bridge the gap between consumer activity and energy conservation is a complex problem. To date, much effort has been put into designing and developing feedback technologies to effectively distribute information of consumer energy use (Darby, 2001). And this is also the focus of our research discussed in this thesis.

1.2. Our Approach

To address the problem discussed above, we have explored the feedback tools that are currently available from paper bills to more recent web-based applications (Google PowerMeter™ and Microsoft® Hohm™). We point out that the problem with the former is that the information provided is inadequate for decision-making, lacking details of how energy is consumed relating to consumer activities. And the billing cycle is usually too long for the consumers to receive timely feedback. Whereas the latter, although detailed, precise and prompt, is not attractive and engaging; and does not integrate gracefully into the environment. As an alternative, we propose that aesthetic visualization may be a promising approach to the provision of feedback for consumer energy use.

1.2.1. *Why Aesthetic Visualization?*

We adopt Kosara's definition of aesthetic visualization as opposed to pragmatic visualization. It treats aesthetics as an important value and has the advantage of applying various depictive and narrative-related forms of representation to communicate a concern about the underlying information (Kosara, 2007). Besides aesthetics, another primary property of aesthetic visualization is periphery. It can remain peripheral to people's attention while sustaining interest over time (Ljungblad, Skog, & Holmquist, 2004). Forms of aesthetic visualization include ambient and artistic visualization (or informative art) and infographics.

We argue that the aesthetic visualization approach to consumer energy use feedback offers promise over pragmatic visualization for the following reasons. First, we can explore more engaging representations to make it more attractive, especially to children. Enhanced engagement adds potential to make it an educational tool to inform people of energy use and conservation. Second, it supports at-a-glance awareness. This requires less effort for people to notice and interpret the data. Finally, considering the aesthetics of both the visualization and the context as an explicit factor makes the display part of daily life and activities, and integrate better into the environment. Pragmatic visualizations are not preferred in places such as people's homes simply because their serious looks do not fit with the environment. Taken together, we believe

that the aesthetic visualization approach has great potential because it engages people more with its interesting display, remains peripheral to people's attention while sustaining interest over time; and has better integration into the environment with high aesthetic value.

1.2.2. Research Overview

Our research is to explore whether the aesthetic visualization as an approach to consumer energy use feedback is able to inform and ultimately lead consumers to use energy in an ecological fashion. The research begins with a thorough literature review of the problem to establish the theoretical background and situate the work into the broader research field of Sustainable Human Computer Interaction (HCI).

To explore the effectiveness and utility of this approach, we make experimental investigations in two stages. In the first stage, we intend to prove that aesthetic visualization has the advantage of engaging people with a visually compelling display while maintaining comprehensibility and supporting at-a-glance awareness. We quantify comprehensibility into two statistical measures: accuracy of user interpretation and time required for the interpretation. We present the results with a quantitative method and confirm our hypotheses. Following this, we extend the research with a second user study to evaluate various forms of aesthetic visualizations targeted at school-age children through real usage via a game that simulates a real-life environment. This age group is chosen because: 1) energy forms a major part of the school curriculum during the middle school years (grade 5-8) (Ministry of Education, 2010); 2) the impact of children's awareness on parental behaviour is known to have an influence on the adults in their homes (Evans S. M., 1996; Mandel, 2013); 3) these represent our future generations: we were interested in understanding how best to enhance and sustain their learning about energy and conservation. As a result, we suggest that aesthetic visualization should be considered a promising approach to energy feedback that enables informed decision-making. Moreover, another finding that is not quite anticipated in our hypotheses is that the game turns out to be a helpful tool to tease out and elicit where people do not understand or remember about energy consumption in their homes.

As a by-product of evaluating the approach, we draw some design implications in this design space. First, it is important to choose the right data for display. Information of high relevancy and consumer interest should be presented to better support understanding and decision-making. Second, aesthetics is a key issue to be considered provided that comprehensibility is well maintained. Our experience shows that graphical representations that are conceptually related lead to better comprehension. Finally, the design of aesthetic visualization is a process of trial and error. Sketches and software prototypes are fast and useful ways to try out different design ideas. Also user preferences and opinions should be highly valued.

This work makes three primary contributions to research in developing novel ways of effective energy feedback. First, we demonstrate that aesthetic visualization is able to maintain its comprehensibility while better engaging people with its richer and more visually appealing representations. Second, we show that aesthetic and depictive visualization has the potential to support decision-making and learning. Finally, we examine the promise and viability of its utility in real-life settings through two user studies.

As a limitation, this research considers only the design aspects of the approach but does not address whether it has an impact on user behaviour change. Although it is an important aspect to be considered in evaluating feedback technology, it is not part of our intention due to limitations of sample size, study duration and physical contexts. As will be discussed, to fully evaluate aesthetic visualization as feedback for energy use, especially to find out whether it has an effect on behaviour change towards energy conservation, further long-term in-situ studies are required and necessary (Skog, 2006).

1.3. Methodology

We take a design-oriented research perspective with mixed methods throughout our research process. Design-oriented research (Figure 1-1), as opposed to research-oriented design (Figure 1-2), seeks to reveal new knowledge through design, during which research is the main objective and design is the means; whereas for research-

oriented design, the focus is on the creation of the products while research is used to facilitate the design (Fallman, 2007).

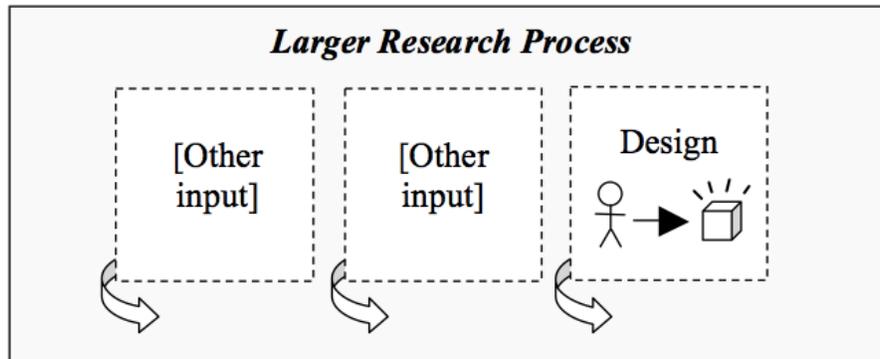


Figure 1-1. Design-oriented Research (Fallman, 2007)

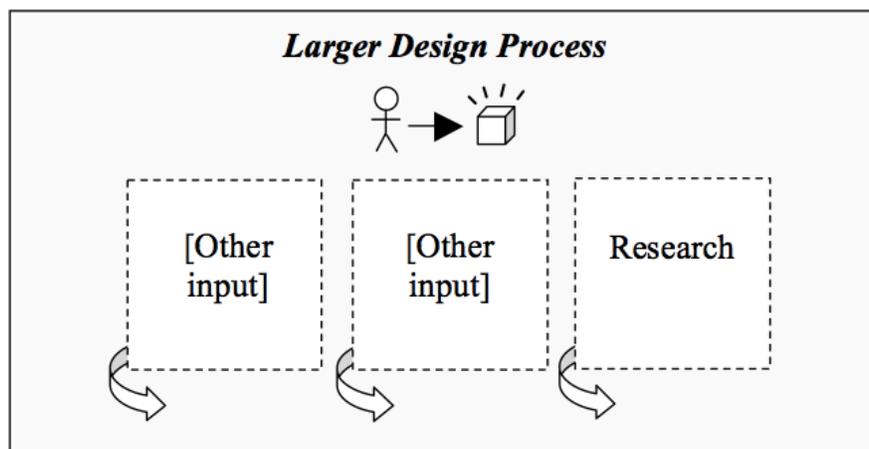


Figure 1-2. Research-oriented Design (Fallman, 2007)

More specifically,

In design-oriented research, the knowledge that comes from studying the designed artefact in use or from the process of bringing the product into being should be seen as the main contribution—the 'result'—while the artefact that has been developed becomes more of a means than an end. (Fallman, 2007)

We situate our work into the discipline of design-oriented research because our primary goal is to explore a new approach to consumer energy use feedback and we achieve that through studies of our prototype designs.

To study the visualization prototypes as a means to this exploratory research, we conducted two user studies. User studies are essential in design-oriented research, as Fallman points out:

Studying an artefact to gain some new knowledge is hence as much a question of understanding people, context, and 'now'—i.e. looking into and trying to grasp the complex interplay between people, technologies, and society and how this 'now' changes when a new artefact is introduced—as it is to develop and study technology. (Fallman, 2007)

Additionally, user studies are important in evaluating visualization techniques because “user studies offer a scientifically sound method to measure a visualization’s performance” (Kosara, Healey, Interrante, Laidlaw, & Ware, 2003). According to Kosara et al. (2003), the importance of conducting user studies includes “to evaluate the strengths and weaknesses of different visualization techniques”, “to show that a new visualization technique is useful in a practical sense”, “to seek insight into why a particular technique is effective” and “to show that an abstract theory applies under certain practical conditions”.

This design-oriented research discipline has also influenced our selection of methods. Our studies focus on user experience of several prototype designs, which involves both statistics and interviews. Therefore, we choose mixed-methods because it “involves collecting, analyzing, and mixing qualitative and quantitative approaches at many phases in the research process”, “focuses on collecting, analyzing, and mixing quantitative and qualitative data in a single study or series of studies” and “provides a better understanding of research problems than either approach alone” (Creswell & Plano Clark, 2011). In this thesis research, both quantitative and qualitative data are collected and analyzed as evidence to reflect on the research questions and as implications to assist future work in the related field.

1.4. Thesis Organization

This thesis document consists of six chapters including this *Introduction* chapter. The rest of the document is organized as follows:

Chapter 2: Background presents a literature review of the problem and establishes the theoretical background to our research with focuses on three main areas. First, consumer perception on energy conservation as related to decision-making is discussed and strategies and theoretical studies on interventions to motivate sustainable behaviours are explored. Second, a survey of interactive research in the domain of Sustainable HCI is conducted to expand our knowledge to better situate the research discussed in this thesis into this field. Finally, the approach of aesthetic visualization with ambient displays is reviewed with highlights on design requirements and evaluation methods followed by examples of existing work.

Chapter 3: Motivation and Goals begins with a review of current available energy feedback technologies. Their drawbacks have motivated us to explore a novel way of using aesthetic visualization as feedback on energy use. The chapter further describes the research goals we aim to achieve with our two-staged studies addressed in this thesis and outlines the scopes and limitations of our research.

In *Chapter 4: Study 1: Effectiveness of Aesthetic Visualization*, we present our first experimental investigation of exploring the effectiveness of using aesthetic visualization as feedback for power and energy use. The study addresses effectiveness on user comprehension. The results of the study are analyzed using a quantitative method and the implications of these preliminary results are discussed.

In *Chapter 5: Study 2: Energy Conservation Game*, we present the second study extending the previous one to further explore the effectiveness of aesthetic visualization as feedback for energy use in terms of “decision-making”, with more realistically representative simulations – a game, and an ambient display. The study takes a design-oriented research perspective with mixed evaluation methods. The chapter covers descriptions of planning and details of the user study, introductions of design and implementation of the study installations and analysis and discussions of the study results.

Finally, *Chapter 6: Conclusion and Future Work* summarizes the findings of this research by revisiting the research questions. Conclusions are made to detail the contributions this research has made towards the broader area of Sustainable HCI. Also opportunities and paths to future work are outlined.

2. Background

This chapter explores and discusses literature that provides context for over-viewing existing research and projects in energy conservation and establishes the theoretical background to our research. The literature review addresses on three main areas. First, current strategies of promoting consumer energy conservation are explored, with special attention to intervention studies that focus on providing effective feedback to motivate behaviour change. Second, a survey of recent interactive research projects on sustainability is conducted to expand our knowledge in the related area. The extensive past works also help us to situate our research into the field and to locate areas for contribution and improvement. Finally, various research works on aesthetic visualization techniques and ambient displays are reviewed. Especially, design requirements and evaluation methods are discussed for this approach with examples of existing applications.

2.1. Raising Awareness – Initial Step to Energy Conservation

One major challenge in promoting energy conservation is to inform consumers of the link between their energy use and the environmental consequences and how their inconspicuous efforts may contribute significantly to higher energy efficiency. In this section, findings of consumer perceptions on energy consumption and conservation are reviewed and theoretical studies on interventions are addressed. Additionally, previous research on how feedback affects decision-making and further leads to behaviour change is discussed.

2.1.1. *Importance of Consumer Energy Conservation*

The importance of consumer energy conservation is obvious as a recent report reveals that in Canada, residential energy use accounts for 17 percent of the total

national energy use (Figure 2-1) and 15 percent of greenhouse gas emissions (Figure 2-2). The report also shows that with energy efficiency measures taken such as more energy-efficient appliances, Canadian households have made 31 percent improvement in energy efficiency between 1990 and 2008 (Natural Resources Canada, 2012). This suggests that research into promoting energy conservation from the consumers' end is valuable and will result in a significant contribution to a sustainable environment.

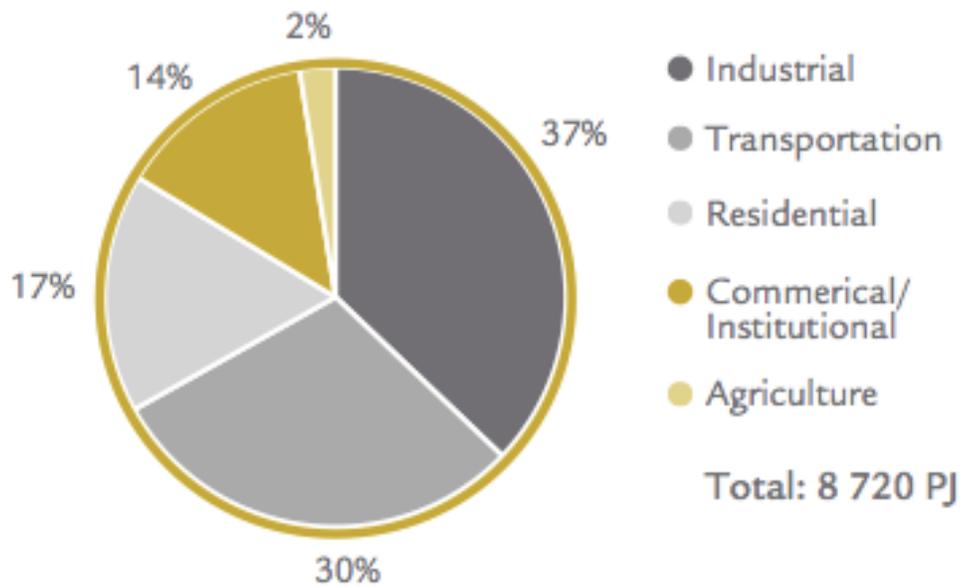


Figure 2-1. Secondary Energy Use by Sector, 2008 (Natural Resources Canada, 2012)

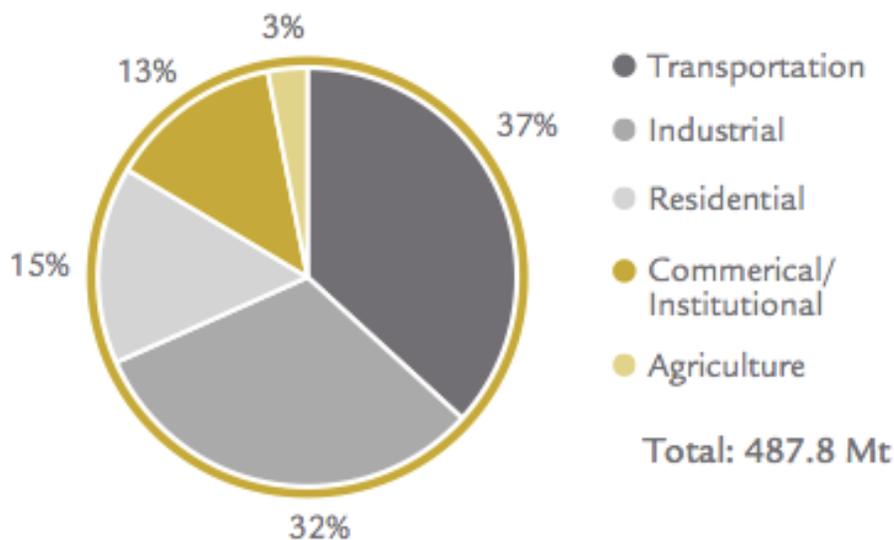


Figure 2-2. GHG Emissions From Secondary Energy Use by Sector, 2008 (Natural Resources Canada, 2012)

Consumer Perceptions

Prior to considering strategies to encourage consumers to take actions on energy conservation, it is important to understand their opinions on the issue and their preferences in energy efficiency. Accenture (2010) conducts an online survey of 9108 individuals across 17 countries on their perspectives toward electricity management programs. The survey closes with five major findings (Table 2-1).

Table 2-1. Key Findings of consumer opinions and preferences toward electricity management programs (Accenture, 2010)

Finding #1	There is a significant contradiction between consumer perceptions and their actual knowledge of energy efficiency.
Finding #2	Consumers' first instinct is to contact utilities/electricity providers for energy-efficiency activities, but providers still need to build trust and credibility.
Finding #3	While price remains a key factor to adoption, the extent of the utilities' electricity providers' control over energy use has emerged as a potential barrier.
Finding #4	Channels and contact points for utilities/electricity providers to communicate with consumers are diverse.
Finding #5	Adoption of electricity management programs is influenced by fragmented and non-traditional consumer preferences.

These findings yield further insights for utilities/electricity providers to develop more effective conservation strategies. One of such strategies is to educate consumers and raise their awareness of the interconnection between their energy usage behaviour and the impact on the environment (Accenture, 2010).

Consumer Energy Research

In fact, vast growth in conservation-related consumer research can be traced back to 1970s. Gordon et al. (1981) review 645 studies in this domain between 1974 and 1980 and categorize them into two primary streams: first, research that centers on understanding consumers; and second, research that focuses on the impact of conservation initiatives.

The first stream has four subcategories: (1) opinion research, (2) self-reported conservation, (3) adoption/diffusion research and (4) modelling energy consumption. The authors find that the major problem existed in this stream of studies is the lack of association between energy consumption and consumers' views and attitudes towards conservation. Consumers' life styles "account for 20-30 percent of the variance in consumption" (Lundstrom, 1980; Sonderegger, 1978; Gordon, John, J.R., & C., 1981).

The second stream concerns four types of primary conservation initiatives: information, incentive, disincentive and restriction. In assessing these studies, the authors recognize that the negligence of cost-effectiveness has been the major failure in developing programs for encouraging consumer conservation actions (Gordon, John, J.R., & C., 1981).

2.1.2. *Intervention Studies*

The next step is to develop interventions to help consumers reduce energy consumption. The goal is to affect decision-making and ultimately motivate sustainable behaviours. Over the past few decades, various social and environmental studies have embarked on designing and implementing intervention plans and testing the effectiveness of intervention strategies. The following section elaborates on different types of interventions, their success and shortcomings. Also methods and criteria for evaluating the effectiveness of an intervention are discussed.

Intervention Types

According to Darby (2010), intervention strategies can be categorized into five main types: enhanced billing, financial incentives, written tips and advice on energy saving, in-home displays and community programmes. Each has been employed with varying degrees of success.

A utility bill is a form of feedback informing consumers of their energy use with monetary consequences. The problem with a standard bill is its low billing frequency (Gaskell, Ellis, & Pike, 1982) and lack of advice (Wilhite & Rich, 1995). However, even with enhanced billing, i.e. bills with more frequent billing rate and more informative data, the result in reduction of energy use is low as shown in a few studies (Garay & Lindholm, 1995; Henderson, Staniaszek, Anderson, & Phillipson, 2003).

Various financial incentive strategies have been made to motivate energy savings, and they mainly fall into two categories: incentives to reduce consumption and incentives to shift consumption (Darby, 2010). Successful incentive strategies of the former include rebates, grants and loans (Shipworth, 2000). However, the positive effect is short-lived and only lasts as long as the incentive lasts (Abrahamse, Linda, Charles, & Talib, 2005). Incentives to shift consumption aim at encouraging consumers to use electricity at low demand times by applying time-of-use rates. Studies have indicated that this has resulted 20 percent in bill savings (Isaacson, Kotewa, Star, & Ozog, 2006) and 4 percent conservation impact (King & Delurey, 2005).

Few studies have shown whether written tips or advice is effective in promoting energy conservation (Darby, 2010). However, advice by home audits has proved to be effective, especially when the information is tailored for a specific family (Abrahamse, Linda, Charles, & Talib, 2005).

In-home display refers to a range of display monitors that provide real-time, historical or predictive feedback of energy consumption. Examples include Smart Meter, Power Cost Monitor (PCM) and various web-based displays. Darby (2010) concludes from various in-home display studies that they only work for people who are already motivated and know how to use these devices. She also states that the design of the displays needs to be aesthetically pleasing and self-explanatory so as to engage more

people to use them. Besides, the cost-effectiveness should be well taken into consideration, i.e., the price for the display should be carefully decided (Gordon, John, J.R., & C., 1981).

Social influence constitutes an important impact on consumer energy conservation and community programmes can be very effective in addressing this issue (Darby, 2010). One main form of such programme is to set up competition between households with similar settings. Studies have shown that people are more concerned with information from their friends or families and comparative social feedback can lead up to 10 percent energy reduction (Shipworth, 2000).

Effectiveness Evaluation

The effectiveness of the interventions needs to be carefully evaluated to improve our understanding and knowledge for carrying out more valid future intervention plans. Abrahamse et al. (2005) review 38 studies to assess the effectiveness of interventions based on four criteria: (1) measure of energy saving and/or change in behaviour the intervention has caused; (2) to what degree these changes have been caused by the intervention as compared to a control group; (3) how/why the intervention leads to these changes; and (4) whether the intervention has carry on effect in energy conservation. To examine the studies, the authors classify them into two groups based on when and how interventions are employed to affect behaviour change: antecedent and consequence.

Antecedent strategies include commitment, goal setting, information, and modeling. Studies in this category have shown that all these strategies result in energy reduction in varying degrees. Commitment has a long-term effect in energy saving. Goal setting is effective when combined with feedback. Information is successful especially when it is tailored and used with other interventions. Modelling has a positive effect on spreading the knowledge but no statistical findings have been found to show whether it has led to energy reduction (Abrahamse, Linda, Charles, & Talib, 2005).

Consequence strategies are mainly feedback and rewards. Feedback is considered to be a crucial intervention in most conservation studies and the focuses have been on both the feedback frequency and the feedback content. Abrahamse et al.

(2005) conclude that feedback is effective when it is provided on a frequent basis and combined with other interventions such as reward. However, there's no indication whether feedback in a particular type of content is more effective than the others (Abrahamse, Linda, Charles, & Talib, 2005).

Multiple Interventions

Both Abrahamse et al. (2005) and Darby's (2010) studies show that interventions to promote energy conservation are successful especially when they are employed in combinations. In particular, the feedback intervention contributes success to most other interventions. For instance, both Becker (1978) and McCalley & Midden's (2002) experiments prove that combining goal setting with feedback receives a positive effect on reducing electricity use. Another example is the EcoTeam Program that provides households with their own energy saving information as well as others'. The program results in 20 percent of gas savings and 5 percent of electricity savings (Staats, Harland, & Wilke, 2004). Also the Energy-Smart Pricing Plan, which applies a web-based display to show real-time electricity pricing, results in a shift of consumption to off-peak hours and savings in energy bills (Isaacson, Kotewa, Star, & Ozog, 2006).

2.1.3. From Feedback to Behaviour Change

The ultimate goal of promoting energy feedback is to motivate consumer behaviour change. To achieve a lasting effect, such conservational behaviours ought to be finally formed as habits. However, getting people to develop and maintain more sustainable lifestyles requires proper motivation. As discussed above, one effective way to motivate change is to provide real-time, continuous feedback of one's energy use. According to Darby (2010), feedback plays an important role in decision-making based on four theories: sociological, economic, educational and psychological.

Sociological Theory

The sociological theory basically suggests that with the timely and accurate feedback, people can get a better understanding of their energy consumption, which in turn affects their behaviours.

Economic Theory

The most direct way to affect energy usage is pricing. Based on the economic theory, feedback on real-time pricing can help consumers shift energy usage and make savings in their energy bills (Isaacson, Kotewa, Star, & Ozog, 2006).

Educational Theory

The educational theory states that consumers learn to use energy more efficiently and effectively through increased awareness and experience. And feedback has the role of providing such knowledge and helping people realize that they can control their energy consumption in a more sustainable way (Darby, 2010).

Psychological Theory

Psychologically, both “stimulus-response mechanisms and engaging attention” can have an impact on energy consumption (Darby, 2010). With changes in one’s understanding, perception and motivation towards energy conservation, changes in their behaviour will also follow (Linda, 2008). From this point of view, Fischer (2008) concludes from five review studies and 21 papers on the effectiveness of energy feedback that “the most successful feedback combines the following features: it is given frequently and over a long time, provides an appliance-specific breakdown, is presented in a clear and appealing way, and uses computerized and interactive tools”.

Transtheoretical Model

Another important work within the perspective of motivational psychology is the “motivational framework” based on the Transtheoretical model (He, Greenberg, & Huang, 2010). Rather than have a “one-size-fits-all” solution targeted at behaviour change, the authors address that behaviour change occurs as a process in a series of stages, within each stage, specific feedback should be given to motivate people to move to the next stage. Details of progress for each stage are presented in Table 2-2 below.

Table 2-2. The Transtheoretical Model of behaviour change stages progress (He, Greenberg, & Huang, 2010).

Precontemplation	The individual may be unaware, uninformed, unwilling or discouraged to change the problem behavior. They do not believe the negative aspects of the current behavior outweigh the positive.
Contemplation	The individual acknowledges that their behavior is a problem and begins to <i>think</i> seriously about solving it. While they can be open to information about the problem behavior, they still may feel ambivalent, and as such, may be far from making an actual commitment.
Preparation	The individual is ready to change. They aim to develop a plan they can commit to in the near future.
Action	The individual takes action by overtly modifying their behavior.
Maintenance, Relapse, Recycling	The individual works to sustain the behavior change, and struggles to prevent relapse. If relapse occurs, individuals regress to an earlier stage and begin to progress through the stages again.

According to Table 2-2, the goal for each stage of the behaviour change should vary and the feedback should be specifically designed with proper information targeted at each stage. As for design recommendations, He et al. (2010) further suggest five motivational models that are commonly employed in current feedback technologies: Attitude, Rational-Economic, Information, Positive Reinforcement, and Elaboration Likelihood Model.

The Emergent Dialogue Model

The final model of behaviour change we look at is the Emergent Dialogue Model within the sustainability research (Robinson, 2004). Robinson (2004) argues that information alone is not sufficient enough to raise awareness and motivate behaviour change. Instead, it is more important to engage people in the process of exploring the sustainable issues and become active participants to promote and carry out sustainable actions. This model suggests that an effective design of the feedback tools should take user engagement into consideration. In other words, it is less for a feedback tool to provide information to educate people, but rather to motivate them to generate their own views of the problem and recognize how their behaviours would contribute to the consequence.

In summary, feedback plays an important role in motivating behaviour change essentially due to its duty of raising consumer awareness both of their consumption and

of how to control their usage. Besides, it makes energy consumption more visible as a commercial product in terms of pricing and helps consumers make more savings in their energy bills.

2.2. Review of Interactive Research on Sustainability

In recent years, there have been increasing interests among researchers in the notion of “Sustainable HCI”. In this section, a review of recent interactive research projects on sustainability is conducted to expand our knowledge in this area. Our main focus is on ambient awareness and feedback technologies that are closely related to the research discussed in this document.

2.2.1. *Sustainable HCI: an Overview*

With the explosive growth in sustainable HCI, many different approaches, methods and orientations have emerged in the field, key topics covering ubiquitous computing (discussed in section 2.2.2) and specifically energy feedback technologies (discussed in section 2.2.3). To analyze and catalogue tons of research works in this area, several researchers have made great effort to review and categorize the literature and map out their intellectual similarities, differences and emerging issues.

In her review of 120 papers on the subject of HCI related to “nature”, “the environment” or “sustainability”, Goodman (2009) identifies three environmental discourses in human-computer interaction: sustainable interaction design, re-visioning consumption and citizen sensing. Sustainable interaction design encourages environmental decision-making in terms of manufacturing, use and disposal practices through persuasive technological interventions (Goodman, 2009). An example of this is to use aesthetic visualizations as feedback for resource consumption to engage consumers and induce behaviour change (Holmes, 2007). Notably, our research also fits into this discourse, as our primary focus is to motivate better decision-making through more effective feedback. Re-visioning consumption focuses on how people perceive their relationship towards the environment and treats consumption as a shared experience instead of individual decisions. The resulting product is some belief system

that affects people's feelings towards the environment rather than force interventions (Goodman, 2009). Finally, citizen sensing attempts to treat people as "civic actors" to collect data for creating environmental information systems (Goodman, 2009).

Similarly, DiSalvo et al. review 157 papers related to sustainability and provide a more precise and meticulous categorizations. In their analysis, research in sustainable HCI is separated into five genres: persuasive technology, ambient awareness, sustainable interaction design, formative user studies and persuasive and participatory design (DiSalvo, Sengers, & Brynjarsdóttir, 2010). The major approach within persuasive technology is to provide information to consumers of their unsustainable behaviour and persuade them to behave in a more sustainable way. Ambient awareness systems take advantage of calm technology and ambient displays to inform consumers of the sustainable aspect of their behaviour. Often, it is applied in combination with persuasive systems to improve decision-making (DiSalvo, Sengers, & Brynjarsdóttir, 2010). Our work lies within these two genres and will be discussed in detail in later sections. Sustainable interaction design defined by DiSalvo et al. aligns with that of Goodman but more precisely describes sustainability as a "critical lens" for design. Formative user studies draw attention to users as opposed to designers in terms of their attitudes towards sustainability. Persuasive and participatory design is the same as citizen sensing described by Goodman (DiSalvo, Sengers, & Brynjarsdóttir, 2010).

2.2.2. *Ubiquitous Computing*

Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives. Alan Kay of Apple calls this "Third Paradigm" computing. (Weiser, 1996)

Ubiquitous computing is now widely applied in sustainable HCI research with two main aspects: persuasive technology and ambient awareness. Examples are discussed in the following sections.

Persuasive Technology

Persuasion is “an attempt to change attitudes or behaviours or both (without using coercion or deception)” (Fogg, 2002). Persuasive technology is a primary research focus in sustainable HCI. As analyzed by DiSalvo et al., it accounts for 45% of their entire corpus of research concerning sustainable HCI. The major approach is to design systems that persuade people to behave more sustainably. Based on this design strategy, there are two streams of such systems: system with strong persuasion and system with passive persuasion (DiSalvo, Sengers, & Brynjarsdóttir, 2010).

The first stream informs people of the degree to which their behaviour is or is not sustainable. One example of this is the PowerHouse, which is a persuasive computer game aimed at raising players’ awareness of domestic energy consumption and influencing their behaviours associated with energy use (Bang, Torstensson, & Katzeff, 2006). Several persuasive methods are adopted in the game: first, the PowerHouse itself is a simulated environment that models energy use in a home; second, operant conditioning is applied in that players get direct feedback on their actions through praise and getting bonus points; finally, intervening strategy is employed - during the play, players are advised with hints before they make a decision (Bang, Torstensson, & Katzeff, 2006). Another example is Yun’s web-based application designed to use persuasive technology to promote awareness and encourage energy conservation in the workplace. The prototype applies three main intervention techniques: 1) Self-monitoring, which tracks real-time and historical energy use for individual device; 2) Advice: both long-term and short-term suggestions are provided to inform users to behave in a more sustainable way; and 3) Control, which lets users control their items with the web-based application (Yun, 2013).

The second stream implicitly provides users with information related to sustainability such as how consumption might affect the environment. An example reviewed by DiSalvo et al. (2010) is the iParrot, a social persuasive agent that provides energy conservation advice in a user-friendly way and is rated as more trustworthy compared to an unfriendly agent (Mahmud, Dadlani, Mubin, Shahid, Midden, & Moran, 2007).

Ambient Awareness

The concept of Ambient Intelligence (Aml) provides a vision of the Information Society where the emphasis is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions. People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way. (IST Advisory Group, 2001)

In the scope of sustainable HCI, systems providing ambient awareness often make use of calm technology and ambient displays to engage the periphery of users' attention and make them aware of the issues related to their behaviour and sustainability (DiSalvo, Sengers, & Brynjarsdóttir, 2010). A typical example of ambient awareness system is the Power-Aware Cord (Figure 2-3), which visualizes electricity use through dynamically glowing patterns of the electrical power strip (Gustafsson & Gyllenswärd, 2005). Another example similar to this is the Element (Figure 2-4) – an electrical radiator that emits heat from light bulbs and uses the light to indicate energy use (Gyllenswärd, Gustafsson, & Bang, 2006). Both applications are a re-designing of existing domestic device to incorporate means of visualizing energy consumption in an engaging way to promote awareness.

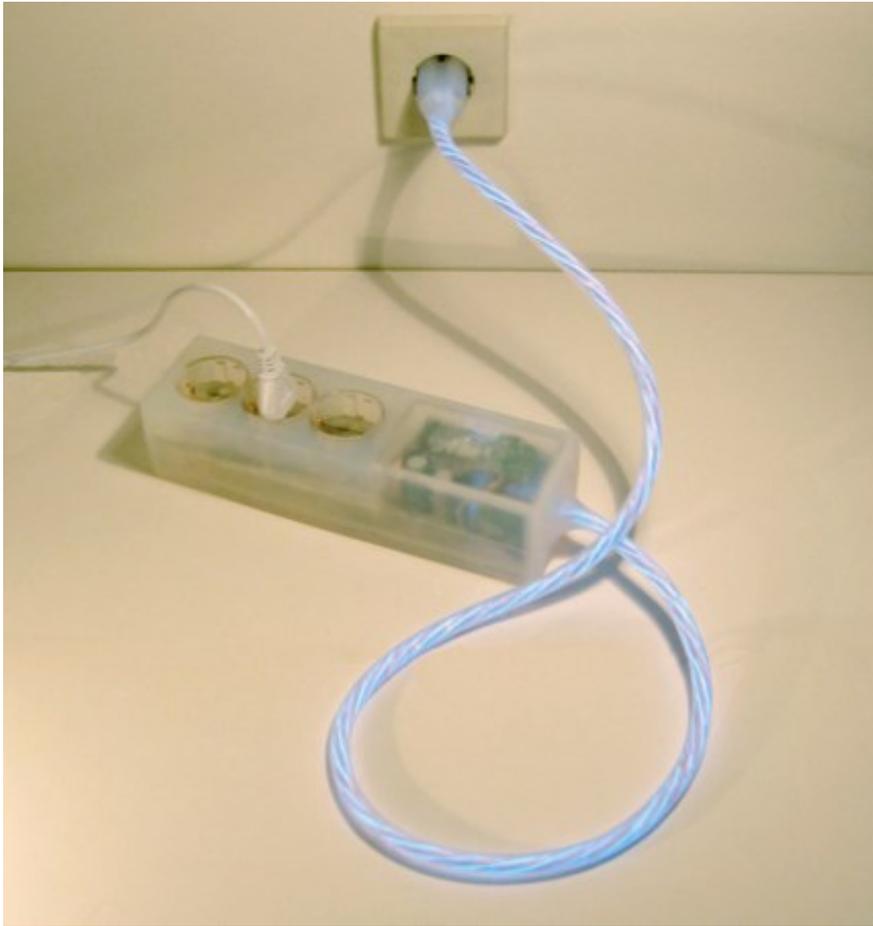


Figure 2-3. *Power-Aware Cord (Gustafsson & Gyllenswärd, 2005)*

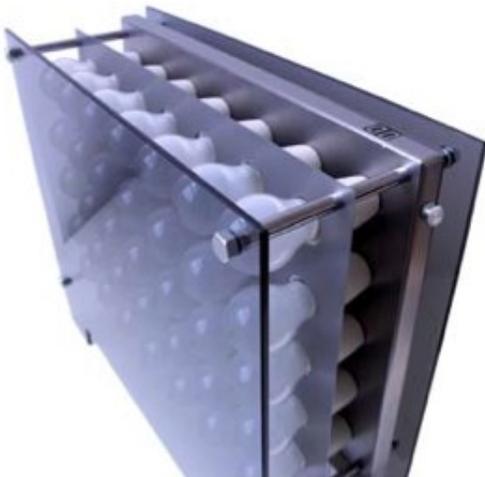


Figure 2-4. *The Element (Gyllenswärd, Gustafsson, & Bang, 2006)*

In DiSalvo et al.'s (2010) findings, systems supporting ambient awareness can also be persuasive. The idea behind this is that providing information in an ambient way is more likely to convince people to behave sustainably. One application of this is the Firefly Stairway (Figure 2-5), which uses wire firefly sculptures that are attached to LED lights to decorate the stairway and makes the stairs more interesting to use than a nearby elevator (Miller, Rich, & Davis, 2009). The Living and Robotic Plants, as shown in Figure 2-6 is another example. Designed by Holstius et al. (2005), the plants are an interactive ambient display that aim to encourage recycling behaviour in a cafeteria and their experiment results show that apparent increase of recycling does occur with the presence of the display. A further study led by Maan et al. (2011), which compares the effectiveness of using ambient lighting as feedback for space heating energy consumption to a numerical feedback, indicates that ambient feedback costs less cognitive load and has stronger persuasive effects leading to lower energy consumption (Maan, Merkus, Ham, & Midden, 2011).



Figure 2-5. The Firefly Stairway (Miller, Rich, & Davis, 2009)



Figure 2-6. Living and Robotic Plants (Holstius, Kembel, Hurst, Wan, & Forlizzi, 2005)

2.2.3. Survey of Eco-Feedback Technology

Eco-feedback technology or Eco-visualization is an important and popular form of research within sustainable HCI. An Eco-visualization (EV) is defined as “any kind of interactive device targeted at revealing energy use in order to promote sustainable behaviours or foster positive attitudes towards sustainable practices” (Pierce, Odom, & Blevis, 2008). According to Holmes, Eco-visualization denotes “a novel approach to display the real time consumption statistics of key environmental resources for the goal of promoting ecological literacy” (Holmes, 2007). In their survey, Pierce et al. review various interesting, creative and informative EVs that adopt diverse feedback technologies and target at different places and audiences.

Feedback Types

Feedback plays an important role in bridging the “environmental literacy gap”, which refers to the fact that people lack the awareness of how their everyday activities might have impact on the environment, by providing related information (Froehlich, Findlater, & Landay, 2010). In the context of eco-visualization, feedback is categorized by the type of data being displayed and by the type of visualization presenting those data (Pierce, Odom, & Blevis, 2008).

The type of data being discussed here is actually a matter of “scale”. For example, the Power-Aware cord (Figure 2-3) (Gustafsson & Gyllenswärd, 2005) and the Ténéré (Figure 2-7) (Kim, Kim, & Nam, 2009) represent relatively small scale of data that is limited to power use of a single outlet as compared to Nuage Vert (Figure 2-8), a large-scale artwork that makes use of light to draw in real time the outline of the cloud emitted from an industrial power plant so as to reflect power consumed by the city’s inhabitants (Evans, Hansen, & Hagedorn, 2009).



Figure 2-7. *The Ténéré (Kim, Kim, & Nam, 2009)*



Figure 2-8. Nuage Vert (Evans, Hansen, & Hagedorn, 2009)

Primarily, there are two types of visualizations employed by EVs: pragmatic visualization and artistic visualization. The former refers to “the technical application of visualization techniques to analyze data” (Kosara, 2007). An example of EV using such type of visualization is the Google PowerMeter™, which uses standard scientific charts as feedback for real-time home electricity use (Google.org, 2011). The latter uses an aesthetic approach to communicating a concern instead of showing numeric data (Kosara, 2007). Artistic visualization is widely used in EVs because it is aesthetically appealing and rich in context. Examples are the 7000 Oaks and Counting (Holmes, 2007) and the Ambient Canvas (Rodgers & Bartram, 2010).

Use-context

Another way to classify EVs is by use-context, which considers the location the visualization is to be implemented and the audience it targets at (Pierce, Odom, & Blevis, 2008). According to Pierce et al. (2008), two dimensions are being considered: dweller control and third-party control. Dweller control refers to the control the dweller has over how much energy to consume within the use-context, while third-party control refers to the control imposed by others (e.g. building managers) and the technology available within the use-context to support EVs (Pierce, Odom, & Blevis, 2008). Figure 2-9

illustrates some examples of use-contexts with different degrees of dweller control and third-party control. Currently, most EVs are designed for residential homes that monitor real-time home energy consumption and provide feedback in a way to engage dwellers with the information, for example, the Adaptive Living Interface System (ALIS) (Bartram, Rodgers, & Muise, 2010) and the WattBot (Petersen, Steele, & Wilkerson, 2009); whereas few are aimed at office buildings (Yun, 2013), outdoor public spaces (Evans, Hansen, & Hagedorn, 2009), and dormitories (Petersen, Shunturov, Janda, Platt, & Weinberger, 2007).

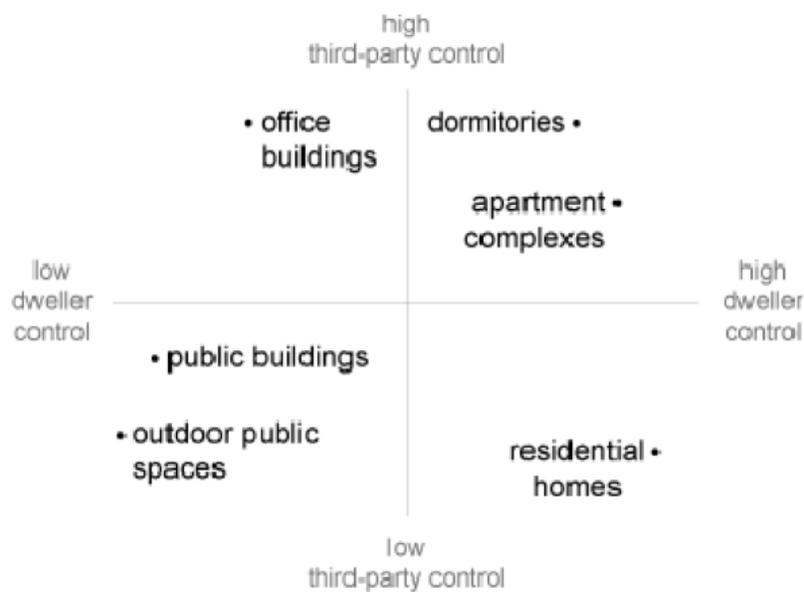


Figure 2-9. *Use-contexts plotted according to dimensions of dweller control and third-party control (Pierce, Odom, & Blevins, 2008)*

Strategies

To summarize, Pierce et al. (2008) highlight eight strategies for designing effective EVs through their critical analysis and evaluation of numerous works in the area (Table 2-3). Similarly, Liikkanen (2009) also points out in his paper that successful EVs must meet the needs of the dwellers and be designed in an engaging and useful way to promote long-term energy conservation.

Table 2-3. Design Strategies for Effective EV (Pierce, Odom, & Blevis, 2008)

Design Strategies for Effective EV	Focus
1. Offering behavioural cues and indicators	Supporting conservation goals with feedback
2. Providing tools for analysis	
3. Creating social incentive to conserve	Creating incentive to conserve
4. Connecting behaviour to material impacts of consumption	
5. Encouraging playful engagement and exploration with energy	Making consumption more visible to support conservation goals
6. Projecting and cultivating sustainable lifestyles and values	
7. Raising public awareness and facilitating discussion	
8. Simulating critical reflection	

In addition, Pierce et al. (2008) also reveal some design challenges and opportunities through those strategies. One important concern is the selection of data to visualize. As discussed above, the scale of the data significantly affects the use of EV and the conservation goal it is to achieve. Another concern is how to design effective EVs to fit different use-contexts as different locations involve different design challenges. For residential homes, challenges exist in how to encourage dwellers to use EVs and how to evaluate whether those tools are useful over time. As to public use-contexts, it is critical to design EVs that make energy visible in an interesting and meaningful way so as to get people engaged with the information to promote conservation. Finally, for dormitories, office buildings and apartments, effective EVs may take advantage of adopting competition as incentives or promoting cooperative goals. Also it is important to design EVs with aesthetic concerns that would make them well integrated with the building environment (Pierce, Odom, & Blevis, 2008).

2.3. The Approach of Aesthetic Visualization with Ambient Displays

Aesthetic visualization is defined as opposed to the traditional visualization that mainly consists of pragmatic charts (Kosara, 2007). Aesthetic visualization treats aesthetics as an important value and takes the advantage of applying various depictive and narrative-related forms of representation to communicate a concern of the information. Forms of aesthetic visualization include ambient and artistic visualization (or informative art) and infographics. And it is considered as one of the promising approaches to creating effective EVs. In this section, advantages of aesthetic visualization as opposed to pragmatic visualization are discussed, design requirements for such visualizations are highlighted and means to evaluate them are addressed.

2.3.1. Artistic vs. Pragmatic visualization

The distinction between artistic and pragmatic visualization is a measure of “sublimity” (Kosara, 2007). As shown in Figure 2-10, pragmatic and artistic visualization lie on the two extremes of the gamut with the former being entirely anti-sublime and latter being primarily sublime. According to Kosara (2007), the sublimity also decides the characteristics of the visualizations: the pragmatic visualization is recognizable and readable and is often used to explore and analyze the data for which visual efficiency is considered as an important criterion; whereas the artistic visualization might not be readily recognizable and readable, but the sublime quality makes it visible and interesting to communicate a concern of the underlying data.

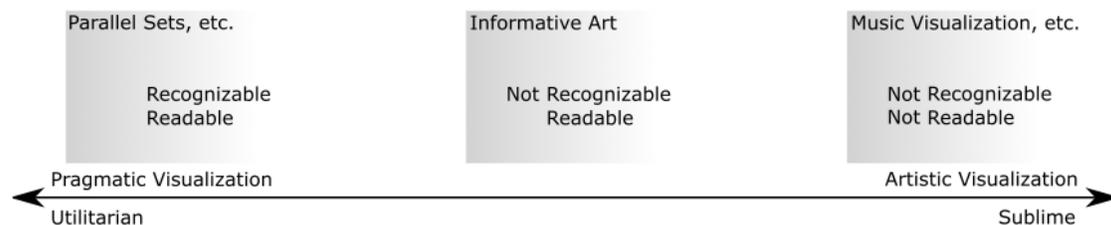


Figure 2-10. The gamut of data-based visualization (Kosara, 2007)

Kosara’s justification also indicates an approach that lies in the middle of the gamut - the Informative Art. Informative art treats aesthetics as a key factor to make it

not only visually pleasing and engaging but also readable to allow easy understanding of what is being visualized. This is also noted by Ljungblad et al. (2004) that “an informative art visualization looks like a piece of abstract art at first glance, but instead of merely presenting a static image, its visual appearance is continuously updated to reflect some dynamically changing information”. Besides aesthetics, another primary property of informative art is periphery, “it is necessary to make the presentation blend into the surroundings, or the amount of information calling for attention will be overwhelming” (Ljungblad, Skog, & Holmquist, 2004).

Examples of informative art include the Weather Composition (Figure 2-11), which maps worldwide weather information to the size and color of six squares (Ljungblad, Skog, & Holmquist, 2004), the InfoCanvas (Figure 2-12), which displays personalized information through an ambient and artistic display (Miller & Stasko, 2001), and the Ambient Canvas (Figure 2-13) that conveys information of resource use in the home through an ambient display that embeds in the kitchen backsplash (Rodgers & Bartram, 2010).

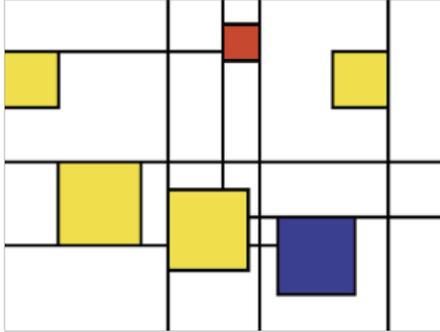


Figure 2-11. Weather Composition (Ljungblad, Skog, & Holmquist, 2004)

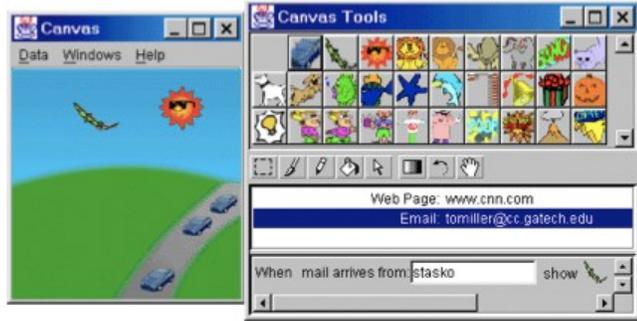


Figure 2-12. InfoCanvas (Miller & Stasko, 2001)



Figure 2-13. Ambient Canvas (Rodgers & Bartram, 2010)

2.3.2. Infographics

Infographics are graphical visual representations of information intended to present the underlying data more easily and concisely. “An infographic is handcrafted to bundle related data sets into a unified, visually compelling representation” (Krauss, 2012). More formally, “an infographic is defined as a visualization of data or ideas that tries to convey complex information to an audience in a manner that can be quickly consumed and easily understood” (Smiciklas, 2012). The strengths of infographics are that they are easy to digest, cool to look at and they catch people’s attention (Smiciklas, 2012). Infographics are just another form of aesthetic visualization and are now widely used by people to communicate a concern of the energy use and the environment.

Numerous examples can be found on the Internet, such as visual.ly (<http://visual.ly/>), which contains a large collection of infographics under the topic of “environment”. The problem with those works is that they are static and the data being represented can be out of date quickly. However, their rich and appealing way of data representation does inspire our research in designing engaging feedback for consumer energy use.

2.3.3. Design requirements

Information visualization is concerned with exploiting the cognitive capabilities of human visual perception in order to convey meaningful patterns and trends hidden in abstract datasets. (Moere, Tomitsch, Wimmer, Boesch, & Grechenig, 2012)

Summarized from various papers related to this topic, three features are considered essential and special in designing aesthetic visualizations beyond normal design criteria that are for pragmatic visualizations. They are aesthetics, real-time and ambient. And our focus here is particularly on aesthetic visualization for energy use feedback.

Aesthetics

Aesthetics is addressed by many researchers in this field (Skog, Ljungblad, & Erik, 2003; Cawthon & Moere, 2007; Rodgers & Bartram, 2010). As mentioned earlier, Kosara (2007) considers aesthetics as one of the critical criteria in classifying between artistic and pragmatic information visualization. As Cawthon and Moere note “Ranging from historical buildings to modern software applications, the integration of aesthetics typically aims to stimulate the desire, positively influence the first impression, encourage repeated usage or even overwhelm its audience” (Cawthon & Moere, 2007).

Skog et al. (2003) state that aesthetics is a major concern when visualization is embedded into the environment because in such situation, not only utility is an important issue to consider; it is also necessary that the work is visually appealing so as to naturally become part of its surroundings. In their study of an ambient information visualization of bus departure times, they conclude that aesthetics is more than an added bonus to enhance visual appearance; it is a primary property in design and during

use to support the readability and comprehension of such installation (Skog, Ljungblad, & Erik, 2003).

Similarly, Cawthon and Moere (2007) conduct a study to correlate aesthetics and usability measures in the context of data visualization. The researchers investigate the results of an online survey of 285 participants based on 11 different data visualization techniques of an identical hierarchical dataset. Their findings show that usability measures such as task abandonment and erroneous response are in correlation to aesthetic preference as users tend to have more patience and spend more time with more attractive visualizations. This also suggests that aesthetics should be considered as one of the design issues of data visualization as it affects usability (Cawthon & Moere, 2007).

In their framework for designing residential resource use feedback tools, Rogers and Bartram (2010) address that “aesthetics is an important factor as it expands the realm of visualization beyond analytical concerns toward a broader spectrum of representation and communication”. Additionally, they note that: “Aesthetic factors will be closely enmeshed with design decisions regarding the binding of a feedback instance, and will affect the expressive potential of an interface” (Rodgers & Bartram, 2010).

Real-time

Several papers on feedback technologies suggest that providing real-time information is critical to effectively and successfully induce behaviour change (Liikkanen, 2009; Darby, 2010; Pacific Northwest National Laboratory, 2011). This is particularly true for energy use feedback visualizations because it enables users to link their behaviour to energy use by connecting causes and effects (Pierce, Odom, & Blevis, 2008). Similarly, Fischer (2008) states “feedback is more effective, the more directly after an action it is given”.

However, translated into design requirement of an aesthetic visualization, real-time is achieved by properly defining the rate of change and the update rate. Skog et al. (2003) discover that a suitable update rate of the display should allow users to perceive the changes while not finding it to be too distractible. They suggest that “the rate of

change in the information should be frequent enough to promote relevance, but the developer can affect the visual appearance by slowing down the changes or adding a small amount of animation” (Skog, Ljungblad, & Erik, 2003).

Ambient

Ambient is another characteristic that is special to aesthetic visualization for energy use feedback. This requires the visualization to be designed to present information in the periphery of the user’s attention (Skog, Ljungblad, & Erik, 2003). In other words, aesthetic visualization is designed to blend into its surroundings, thus factors like information source, context and audience should be carefully considered. With their visualization of bus departure times, Skog et al. find that informative art visualizations should be designed so that the scope of the information is relevant to the location where it is placed and possible users of the display (Skog, Ljungblad, & Erik, 2003). Rodgers and Bartram also include context as an important dimension in their framework for designing energy use feedback tools. The context dimension shows that when the representation of the feedback is tightly bound to the context in which it is delivered, it is easier to be perceived and comprehended by the users (Rodgers & Bartram, 2010).

Taken together, aesthetic visualization is a means of presenting and providing awareness of dynamic changes in a data set in a particular place. It is designed to blend into its surroundings with high aesthetic concerns, display relevant scope of information and update on a suitable rate.

2.3.4. Evaluation

A critical aspect of the design and development of an aesthetic visualization is the evaluation. The exclusive features of it being aesthetically pleasing and ambient make its evaluation more difficult than a pragmatic visualization because these requirements are hard to define in measurable terms (Mankoff, Dey, Hsieh, Kientz, Lederer, & Ames, 2003). However, whether it is aesthetic visualization or pragmatic visualization, user studies offer a scientifically sound method to measure its performance (Kosara, Healey, Interrante, Laidlaw, & Ware, 2003).

Approaches

The idea of evaluating an aesthetic visualization is not new, several approaches have been proposed in the recent literature. Mankoff et al. (2003) have adapted a low-cost heuristic evaluation method from Nielsen's heuristic for usability to test with ambient displays. Through working with experts in designing ambient displays, the researchers have defined a set of ambient heuristics that have proved to be useful in identifying usability issues with ambient displays. Although results from their user studies imply that heuristic evaluation is an effective and inexpensive technique, the problem remains in that the method is only useful in the early stages of design with professionals but not applicable to "everyday" users to test their use in real-life settings.

With more focus on user comprehension, Holmquist introduces an evaluation framework for ambient displays. The framework addresses three levels of comprehension over time: 1) that information is visualized; 2) what kind of information is visualized and 3) how the information is visualized (Holmquist, 2004). As opposed to heuristic evaluation, Holmquist's framework is more effective in evaluating ambient displays in actual use.

Skog argues that the evaluation of an informative art is inseparable from the context it is placed because it is designed to serve as an integrated part of the users' surroundings. He further insists that getting usage data from real-life installation is crucial in evaluating such systems (Skog, 2006). Skog et al. evaluate their Bus Departure Time visualization with an on-site interview with actual users in the area. The interview is taken after the system has been installed in the university for 15 days. The results of the interview facilitate the researchers to yield four lessons that are important in designing ambient information visualization (Skog, Ljungblad, & Erik, 2003). The four lessons are summarized in Table 2-4 below:

Table 2-4. Lessons learned from designing several generations of ambient information visualizations (Skog, Ljungblad, & Erik, 2003)

Lesson 1	By finding information that is relevant to the place where the ambient display is located, every person spending time at that place becomes a potential user.
Lesson 2	The rate of change in the information should be frequent enough to promote relevance, but the developer can affect the visual appearance by slowing down the changes or adding a small amount of animation.
Lesson 3	Basing a visualization on an artistic style need not hinder – and might even support – the readability and comprehension of an ambient infovis installation.
Lesson 4	Letting features of the information source affect the visual encoding, thus providing a mnemonic to remember the mapping, is a good way to support the comprehension of the display.

Rodgers and Bartram (2011) adopt a mixed methods approach to evaluate their design of three different ambient visualizations of point-of-consumption energy use feedback. In their study, users are situated in a simulated real-life environment and data are collected through interviews, questionnaires, in-study observations and system logs. The mixed methods take advantage of both qualitative and quantitative methods to help researchers explore the viability of using ambient and artistic visualization for residential energy use feedback based on four design requirements: pragmatic, aesthetic, ambient, and ecological. Such method has greatly informed and inspired the evaluation mechanism in our research.

2.4. Discussion

The above literature review establishes the theoretical background to our research. From this review, we conclude that a feedback tool is very much needed to promote consumer energy conservation as it helps raise consumer awareness that motivates informed decision-making. And aesthetic visualization is a promising approach to the provision of such feedback tool because it is engaging, supports at-a-glance awareness and has better integration into the environment. We have seen various research and applications of using aesthetic or artistic visualizations as feedback for energy use, including their design and evaluation. However, there is still a lot to be explored in this research space. For example, how well do aesthetic visualizations as feedback for energy use support comprehensibility and informed decision-making? How

effective are they as compared to pragmatic visualizations? And how do people like this kind of feedback tool and have it in real use? Additionally, more general and complete design solutions need to be explored for this kind of feedback. For instance, what are the key features to be included in this kind of feedback design? The above questions present opportunities for us to carry out the research discussed in this thesis to further contribute to the broader subject of sustainable HCI.

3. Motivation and Goals

As discussed in chapter 2, providing effective feedback on energy use helps raise consumers' awareness of the link between their daily activities and the results of energy consumption, and ultimately allows them to better control their consumption to improve energy conservation. Currently, consumers receive energy feedback mainly through monthly energy bills sent out by their utility company. The major problem with it is that the information provided is inadequate for decision-making, lacking details of how energy is consumed in relationship to consumer activity. Also billing cycles are usually too long for the consumers to receive timely feedback that would give them immediate reflection upon their energy consumption.

Another feedback tool that is now available and deployed to household consumers is the Smart Meter, which has the advantage of providing more direct and prompt information about how much energy is used and when it is used. However, the smart meter alone is not enough for informed feedback on energy use. As a result, a few web-based applications (Google PowerMeter™ and Microsoft® Hohm™) based on its data have been developed to provide more comprehensive information to enhance consumer awareness of energy consumption. Both of these tools are able to track near real-time and historical electricity usage, allow precise analysis of the tracking data and present the data with nice charts through an interactive dashboard. Unfortunately, both applications have discontinued their services due to lack of user adoption. Anecdotally, people report that they put them “out of the way” after a short period of use. As shown in Figure 3-1 and Figure 3-2, both applications use pragmatic charts with precise numbers to visualize consumption data. The advantage of these charts is that they are precise and detailed, however, they are typically unattractive and unengaging, especially to children. Besides, they do not integrate gracefully with the domestic environment nor do they support at-a-glance awareness of the data. Much attention and great effort are required for people to interpret those charts.



Figure 3-1. Sample screenshot for Google PowerMeter™

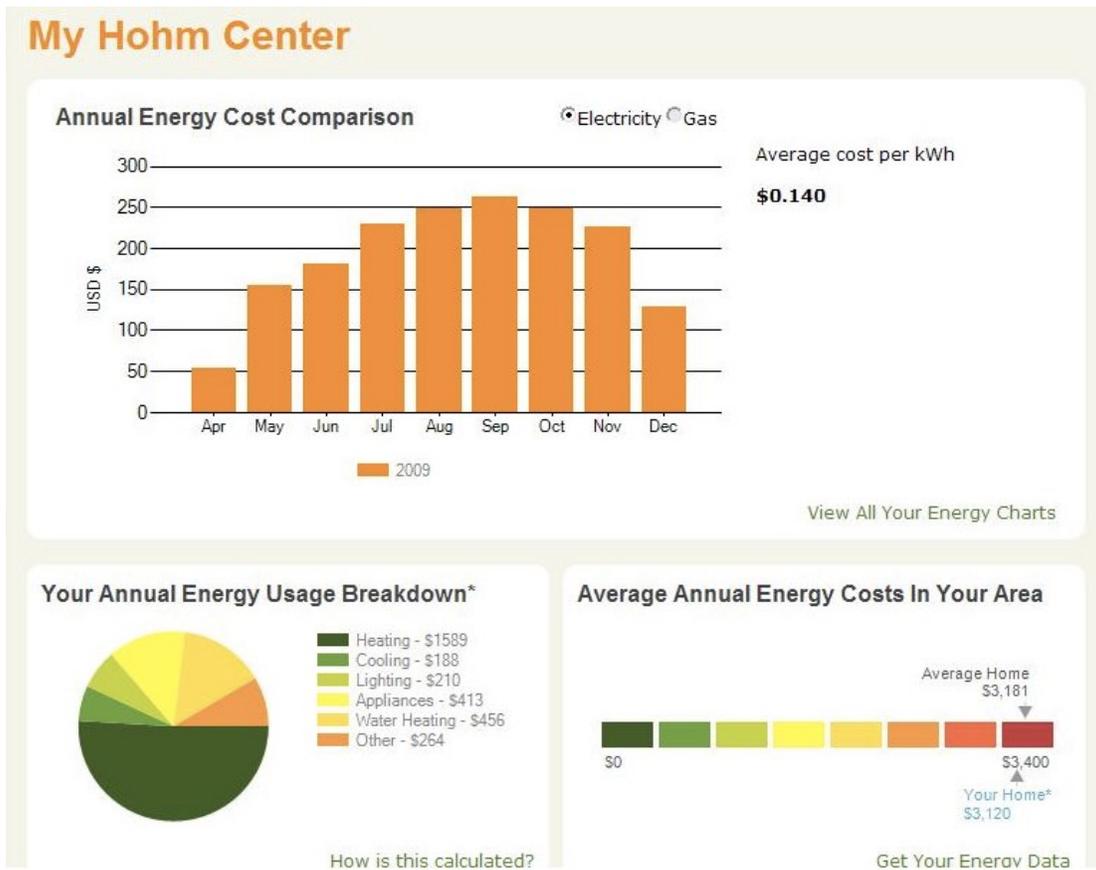


Figure 3-2. Sample screenshot for Microsoft® Hohm™

3.1. Motivation

Based on Fischer's review and analysis of the vast research in this field, successful feedback should take into account of the frequency, content, breakdown, presentation, inclusion of comparisons, and combination with additional information and other instruments (Fischer, 2008). With this in mind and motivated by various existing feedback technologies reviewed in Section 2.2.3, we decided to explore this novel way of using aesthetic visualization as feedback for energy use. As reviewed in Section 2.3, the strength of aesthetic visualization has made it a good candidate for displaying energy use data.

Comparing to traditional feedback tools with pragmatic visualizations (standard charts) with respect to the features outlined by Fischer, feedback with aesthetic visualization has more flexibility and superiority in medium and mode of presentation. The way information is presented is crucial for its adoption, as according to Fischer, "the information needs to capture attention and be understood before it can become effective" (Fischer, 2008). Aesthetic visualization uses electronic media and is flexible in showing different kinds of information upon user request when compared to paper-based bills. And it can achieve real-time to provide immediate feedback when an action is taken. As Fischer states "quick feedback would improve the link between action and effect, and therefore, increase consciousness about the action's consequences" (Fischer, 2008). Additionally, it is able to maintain its comprehensibility while showing information with various graphic components that are aesthetically appealing. In contrast to digital and interactive tools that use standard charts as discussed above (Google PowerMeterTM and Microsoft® HohmTM), this novel and interesting way of data presentation is more visually compelling and attractive. Also it is able to communicate and emphasize concerns about energy consumption with at-a-glance awareness rather than showing numbers that may make no sense to some users.

Previous research suggests that ambient and artistic visualization is a viable way to provide resource use feedback in the domestic environment (Rodgers & Bartram, 2011). In particular, the researchers address the importance of aesthetics and context of use in this design space. Four design requirements are emphasized in their research as criteria for the feedback to be effective, which are: pragmatic, aesthetic, ambient, and

ecological (Rodgers & Bartram, 2011). Their findings and evidence encouraged us to study the feasibility of this approach to a greater extent. However, we needed to ensure that the approach did not compromise the effectiveness and utility offered by traditionally validated visualizations. More specifically, we wanted to draw out what made them effective and in which way and whether they made a difference in real practice. In addition, the previous research only looked at the design aspects of the visualization, but did not explore whether it had support for informed decision-making and learning. And this formed an interesting research question for us to explore and we aimed to investigate its effectiveness and utility through real use.

In summary, we believed that feedback using the aesthetic visualization approach would engage people more with its rich and interesting display and remain peripheral to one's attention while sustaining interest over time. With this motivation, we aimed to empirically validate the potential application of this approach with our own aesthetic visualization designs and experimental investigations in different energy use contexts. During the process, we would also like to gain valuable design experience and establish some basic design guidelines and tips for future reference within this field.

3.2. Goals

To explore the effectiveness and utility of using aesthetic visualization as an approach to providing energy use feedback, two separate studies were carried out to emphasize different aspects of the research goals. The first focused more on user understanding of the feedback. With statistical measures of how correctly users were able to interpret the feedback content and the time they spent interpreting the information, the study intended to verify that the aesthetic visualization had the same or better comprehensibility than the pragmatic visualization. While the second study explored whether feedback designed with various aesthetic visualizations affected decision-making. By putting the feedback into actual use in a simulated environment, the study provided a more detailed analysis on the design components to find out what worked and what didn't.

3.2.1. Study 1

An initial step to explore the effectiveness of an aesthetic visualization is to test its comprehensibility. The reason is that information must be understood before it can be effective (Fischer, 2008). In our first study, we designed two different aesthetic visualizations in the context of a solar charging station for mobile devices and compared them to a pragmatic visualization (Excel charts). Comprehensibility was addressed as the major evaluation criteria and was measured in terms of how accurately users were able to interpret the information and how long it took them to do so. In short, could those visualizations be understood and how much effort was needed? Our primary goal was to find out whether the aesthetic visualization, with its more abstract form of data presentation, was the same or easier to understand than the pragmatic visualization.

Further, we aimed to know whether this abstract form of representation appealed to users. In other words, whether users rated the aesthetic visualization to be more attractive than the pragmatic visualization. Also, we wanted to get a sense of whether users preferred this novel way of representation and where they thought would be the potential sites to place the visualizations. User opinions were crucial in this research because if users showed no interest in this aesthetic visualization approach, then it would be meaningless to continue the exploration.

The first study established the basis for us to further examine the potential of putting the visualizations into actual use. Essentially, the feedback information needs to be understood before it can activate other motives conducive to electricity conservation. Besides, user preference and interest are also important. This includes not only the content of the feedback: What kind of data they would like to see? Historical or real-time or both? Personal or comparison with others? but also the way the information is displayed: Is this abstract form of representation more engaging than the pragmatic chart? Is it more useful to communicate a concern with at-a-glance awareness than to show detailed analysis with precise numbers?

3.2.2. Study 2

With preliminary results gathered from the first study, the aesthetic visualization proved to be a promising approach to energy use feedback. As an extension, our

second study sought to further explore its effectiveness and utility by integrating it with an ambient display and a simulation game. The game was chosen as the testing environment because it offered more realistically representative simulations and was more attractive to our participants, especially children. Meanwhile, the game itself served as an experiment through which we would like to understand where people were weak in their knowledge and understanding of home energy use at both conceptual and operational levels.

In this study, two aesthetic visualizations along with a standard bar chart were designed for residential electricity use feedback. The visualizations were shown via an ambient display that looked like a framed artwork and applied in the context of a simulation game that mimicked real home environment. As opposed to the first study, the effectiveness being studied here was more than comprehensibility. Our goal was to see whether different forms of feedback would result in different decision-making. With the simulation game, we were able to mimic different real life settings in which various options were given and users were able to act in the way they normally did in everyday life to achieve the game goal – saving energy. By comparing the game performances of people seeing different feedback, we attempted to find out whether aesthetic visualization displays had better support for positive decision-making towards energy conservation than the pragmatic visualization. Specifically, we intended to see if the explicit representation of positive actions applied in one of our visualizations affected decision-making: would it encourage more positive actions and how did users like this rewarding component in the feedback?

In addition, we wanted to elicit user impressions on these different feedback tools in terms of their comprehensibility, visual interest, attractiveness and aesthetic appeal. And more importantly, we purposed to know if people would like to use them in their everyday life and where exactly they would like to place them in their homes. In contrast to our first study, we believed that results gathered in this one would lead to more profound insights because the simulated real-life use would add more validity to the experiment.

A secondary goal of this study was to test the usefulness of the simulation game itself. The game was more than a simulation environment. We wanted to know whether

it could provide us with more convincing information about participants' knowledge of energy conservation and their actual actions than a pure interview.

3.3. Limitations

Both studies considered only the design aspects of the approach and were merely a proof of concept due to limitations of sample size, study duration and physical contexts. According to Skog, users' habits, attitudes and physical context all affect their perception of an informative art display (Skog, 2006). Thus, to fully evaluate an aesthetic visualization as feedback for energy use, especially to find out whether it affects behaviour change towards energy conservation, further long-term in-situ studies are required and necessary.

4. Study 1: the Effectiveness of Aesthetic Visualization

This chapter describes the prototype study of our research towards exploring the effectiveness of using aesthetic visualization as feedback for power and energy use. In this study, we examined the utility and appeal of three different visualizations in the context of a solar charging station, where the power comes from the solar generation and the consumption goes out to mobile devices being charged at the station. The results of the study were analyzed using a quantitative method and the implications of these preliminary results were discussed as a reference for designing similar visualizations for energy use feedback in our second study.

4.1. Design of Three Visualizations

We began our investigation of visualizing energy use feedback with the design of three different visualizations: a graphic abstraction of solar panels as calendar entries (SolarVis1), a non-photorealistic rendering of an apple tree (SolarVis2) and a set of standard information visualization charts (Excel Charts). The first two were categorized as aesthetic visualization and the third was considered as pragmatic visualization. However, both SolarVis1 and SolarVis2 had pragmatic components on them so as to allow them to show the historical data. All three designs were capable of displaying both real-time power (W) and cumulative energy (Wh) values simultaneously. SolarVis1 and SolarVis2 were developed using Processing and various open-source Java libraries. The set of standard charts were generated with Excel. The following sections discuss the three designs in detail.

4.1.1. SolarVis1: A Graphic Abstraction of Solar Panels as Calendar Entries

Our first design (SolarVis1) uses a graphical abstraction of solar panels as calendar entries. An example of it is shown in Figure 4-1. The top view shows the current weather and temperature to give people a sense of how solar energy is being produced with respect to these two factors. The main view (middle part) visualizes how many devices have been charged daily for the current month by the number of green sprouts popping up on a series of solar panels as calendar entries. It also shows the status of how much energy is left in the station by the end of each day with the color of the solar panels: green for a lot, yellow for medium and red for little. The bottom part adopts a standard bar/line chart to show power production and consumption for the same days as shown in the main view. In addition, a solar panel and a battery are displayed in the bottom left and right to show real-time input/output power status of the station and how much energy is currently available for charging.

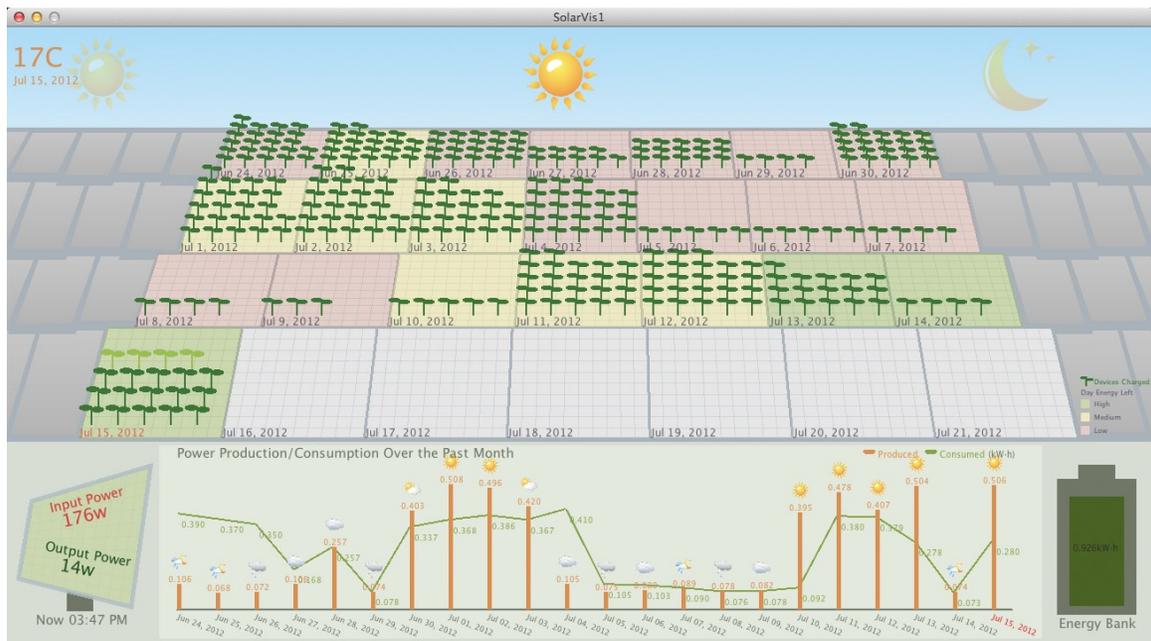


Figure 4-1. Example of Solarvis1. The screenshot was taken with synthetic data.

The aesthetic choice of using green sprouts and solar panels is based on the idea that they are conceptually related to clean energy and environmental sustainability. The geometrical layout of solar panels is very similar to a digital calendar, and we take

that analogy to make it as a monthly view to show historical data. And the sprouts easily make people think of green environment. And with that, we hope to encourage people to use the station. As people plug their devices into the station, a green sprout will pop up as a reward to people indicating that they have contributed to protecting the environment by using solar energy.

4.1.2. *SolarVis2: A Non-photorealistic Rendering of an Apple Tree*

SolarVis2 chooses a non-photorealistic rendering of an apple tree as the main graphical element to interpret the data. As shown in Figure 4-2, the green leaves of the tree represent the energy production of the day; the apples on the tree are the mobile devices that are charged or currently being charged at the station; and the trunk of the tree indicates how much energy is currently available for charging at the station just like the battery in SolarVis1. Also, the visualization uses different colors to distinguish between real-time and historical data: dark green leaves represent real-time power generation and light green ones reflect the cumulative energy production; yellow apples are devices currently being charged at the station and red apples are devices that have been charged on that day. To show energy production/consumption over time, a stacked bar chart is applied at the bottom of the visualization and it is designed as the roots of the tree to make the whole picture look more correlated and aesthetically appealing. Similar to SolarVis1, the background reflects the real-time weather and temperature information to show how these two factors relate to solar energy production. Additionally, a yellow tag is displayed in the top right corner to show the real-time input/output power status of the station.

The design rationale behind this tree representation is that it can be easily related to the usage of green energy such as solar. The tree leaves grow as there is more solar energy is produced and becomes more fruitful as more energy is consumed. We want to use this analogy to encourage people to use solar energy. And we choose a non-photorealistic rendering of the tree not just for aesthetic reasons but we also hope that it will draw more attention from the younger generation. The design is aimed to inform and engage more people including children to learn and to use solar energy.

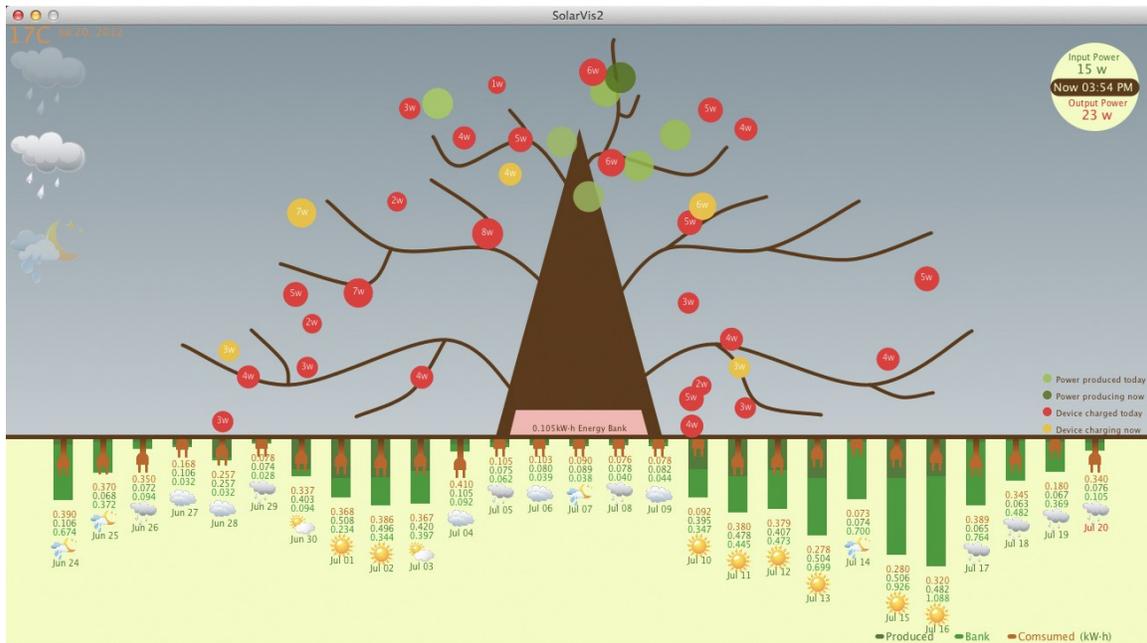


Figure 4-2. Example of SolarVis2. The screenshot was taken with synthetic data.

4.1.3. Excel Charts: Example of Pragmatic Visualization

The Excel charts include a set of five standard bar/line charts as shown in Figure 4-3. The bar/line chart is chosen over other types of standard charts because it is easy to read and can be easily understood due to its widespread use in people's everyday life. In addition, the bar/line chart clarifies the historical energy use trends and it is easy for people to make comparisons.

The purpose of having Excel charts as our third design is to allow us to make comparisons to see if the aesthetic visualization is as effective as the pragmatic visualization. And we want to explore if standard charts have a prominent advantage as feedback for energy use.

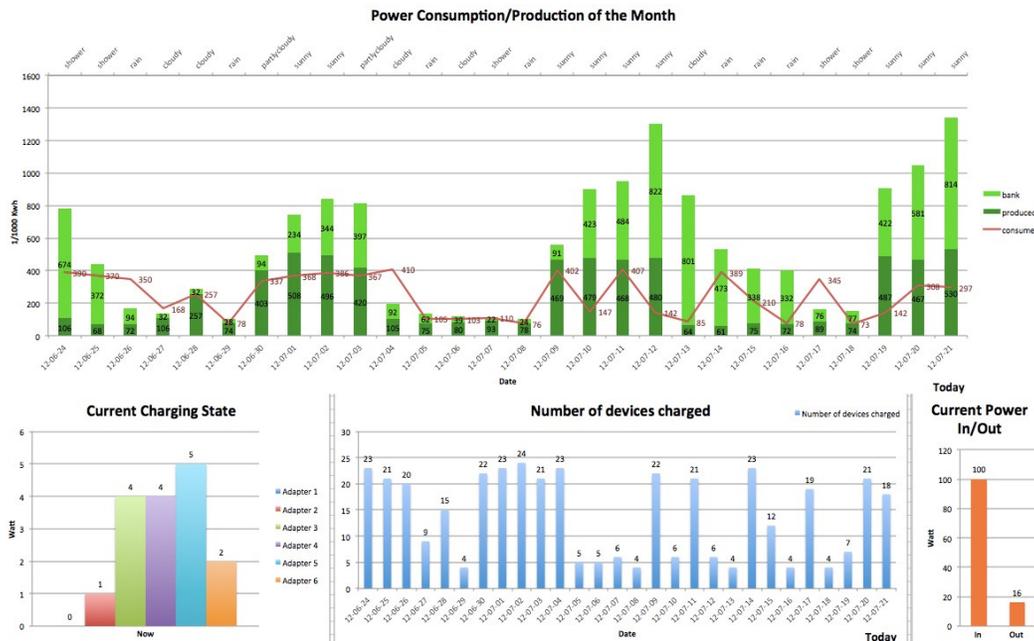


Figure 4-3. Example of Excel Charts. The screenshot was taken with synthetic data.

Note. From top to bottom, left to right, we have: 1) a combined bar/line chart showing energy production/consumption (kwh) over time; 2) a bar chart showing current charging status of the six adapters at the charging station; 3) a bar chart of number of devices charged for the past month; 4) and a bar chart of real-time input and output power (kw) status of the station.

4.2. User Study

The purpose of this study was to explore the appeal and utility of the above three visualizations as feedback for solar energy use. We compared and evaluated these three visualizations based on three main factors: comprehension, appeal and relationship to locations. Comprehension was assessed for both real-time (power/my use of power) and historical scenarios (energy/how the system worked/how much we charged). It was evaluated by accuracy and completion time of participants' interpretation of the data and their comprehension of power/energy from the three visualizations. Appeal looked at the readability, at-a-glance awareness and attractiveness of the visualization and it was evaluated based on scores of user preference ratings. Readability referred how easy the participants felt about to read and understand the visualizations; at-a-glance awareness referred whether these visualizations could be understood immediately without much effort; and attractiveness

was how attractive or interesting the visualizations were to the participants. Finally, all three visualizations were rated by participants to find out where they would most like to see them in different given locations (Community Center, Company, Elementary School, Secondary School, Public Library and University). Table 4-1 summarizes the research questions and how they are measured and analyzed in this study.

Table 4-1. Study1: Alignment Chart

Research Questions	Constructs	Measure	Log Files	Questionnaire
1. Are aesthetic visualizations more comprehensible than pragmatic one?	Effectiveness	Time, accuracy	Answers to test questions 1-11, and time used for each question.	N/A
2. Are aesthetic visualizations more appealing (readability, at-a-glance awareness and attractiveness) than pragmatic one?	Effectiveness	User ratings	N/A	Q1 (a, b, c)
3. Are aesthetic visualizations more preferred in the provided locations (Community Center, Company, Elementary School, Secondary School, Public Library and University) than pragmatic one?	Utility	User ratings	N/A	Q2 (a, b, c)

4.2.1. Hypotheses

Our principal interest in this study was to examine the effectiveness of the two aesthetic visualizations (SolarVis1 and SolarVis2) as feedback for energy use as compared to the pragmatic visualization (Excel Charts). We expected that the aesthetic visualizations would be as effective as standard charts for conveying the information but would be more appealing and engaging due to their richer contexts and more aesthetically appealing displays.

In summary, the study tested the following hypotheses:

- **H1:** SolarVis1 and SolarVis2 have scores on accuracy no lower than Excel chart for basic content understanding questions.
- **H2:** SolarVis1 and SolarVis2 take less completion time than Excel chart for basic content understanding questions.

- **H3:** SolarVis1 and SolarVis2 have scores on accuracy no lower than Excel chart for power/energy comprehension questions.
- **H4:** SolarVis1 and SolarVis2 take less completion time than Excel chart for power/energy comprehension questions.
- **H5:** SolarVis1 and SolarVis2 are considered to be more appealing than Excel chart.
- **H6:** SolarVis1 and SolarVis2 are more preferred in given locations than Excel chart.

4.2.2. Participants

A pilot study with 4 participants (2 female) was followed by a full study of 13 participants (7 female) recruited through personal contacts from colleagues and friends of the researchers and through SFU student participant databases maintained by the School of Interactive Arts and Technology.

4.2.3. Procedure

Participants were tested individually in a study session of about 60 minutes with three related activities. All three activities were performed using an online website which automatically logged user entries and calculated completion time. An example of it is available at: <http://sr-hercules03.iat.sfu.ca/msun/SolarVis/test01/index.html>.

First, a brief pre-session interview (Appendix A-1) was conducted to determine if and how participants understood power and energy use by giving them a typical BC Hydro bill (Appendix A-2) and asking them to explain it. Then the participants were given a short tutorial on how solar energy production works.

Second, the participants were shown six different visualization screenshots (two for each visualization type) on a standard computer monitor. In this study, only screenshots of the visualizations were provided and participants did not directly interact with the visualizations. The screenshots were generated with three sets of synthetic data that were randomly assigned to each type of the visualization. The six screenshots were separated into three test blocks with two different scenarios for each type of the visualization, for which the participants were asked to answer 16 questions (Appendix A-3). The first 11 questions were about the basic understanding of the visualization

content based on the first scenario and the questions were in the form of multiple choices; The last 5 were short answer questions related to comprehension of power/energy consumption and production with solar energy based on the second scenario.

Finally, the study concluded with a questionnaire (Appendix A-4) and a semi-structured interview around user preferences for the three visualizations, regarding their appeal and the locations where they would most like to be seen. The appeal of the visualizations was assessed by three criteria: readability, at-a-glance awareness and attractiveness. And the locations provided for ratings were Community Center, Company, Elementary School, Secondary School, Public Library and University. Before they were asked to rate for their preferred locations, they were explicitly told by the researcher that the visualizations would be run on a standard monitor placed on a desk or hanging on a wall. In each of the questionnaire questions, participants were asked to give a score from 1 to 5 for each visualization, with 1 being the most preferable and 5 being the least preferable.

4.2.4. Results

Participant Demographics

Of the 13 participants (7 female), nine were between 19 and 25, two between 26 and 35, one between 36 and 45 and one was over 50 (Figure 4-4 and Figure 4-5). All of them had a basic understanding of electricity usage in their home but only 6 of them paid for their electricity and read their monthly energy bills. Notably, only 7 of the participants could tell the differences between power and energy well.

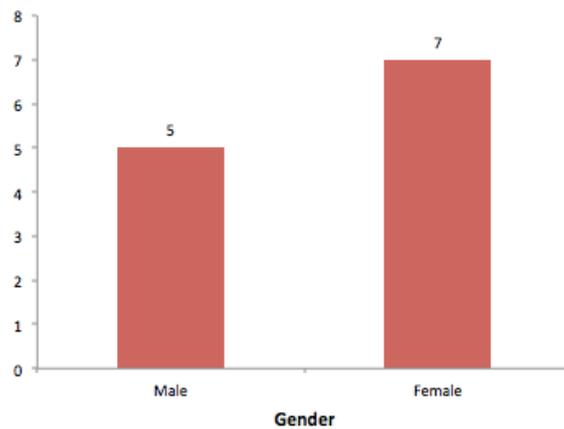


Figure 4-4. Participant Demographics – Gender

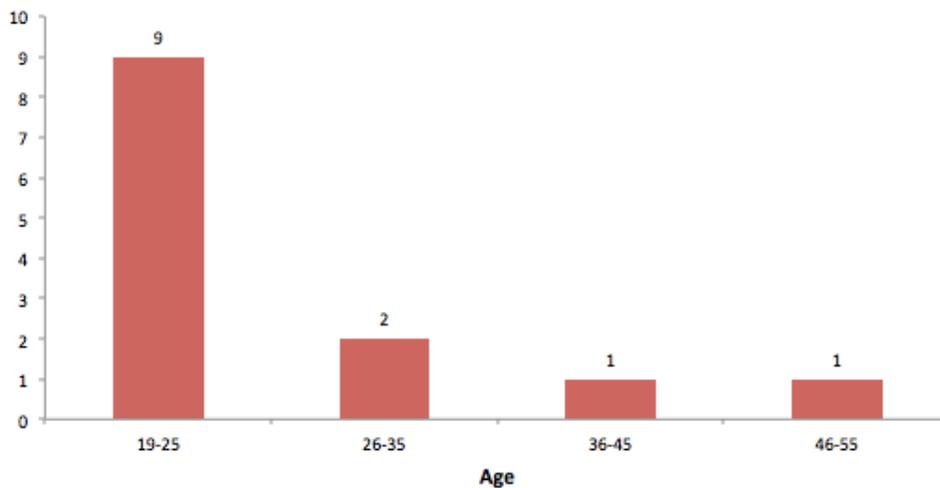


Figure 4-5. Participant Demographics – Age

Comprehension

Accuracy and completion time were analyzed separately for the first 11 multiple choice questions on basic understanding of the visualization content and the following 5 short answer questions on comprehension of solar power/energy consumption and production. All results were analyzed using two-way analysis of variance, with two between group factors.

Accuracy of Basic Understanding of Visualization Content

Table 4-2 reveals a significant main effect for type of questions and a significant type of visualizations by type of questions interaction. Details of how the three

visualizations scored for each individual question are presented in Figure 4-6 and analyzed reasons leading to these results are described in Table 4-3.

Table 4-2. Statistical result for Two-Way ANOVA test (accuracy, basic understanding question)

Tests of Between-Subjects Effects

Dependent Variable: Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9.305 ^a	32	.291	2.512	.000
Intercept	308.848	1	308.848	2667.705	.000
Vis	.284	2	.142	1.228	.294
Question	4.126	10	.413	3.564	.000
Vis * Question	4.895	20	.245	2.114	.004
Error	45.846	396	.116		
Total	364.000	429			
Corrected Total	55.152	428			

a. R Squared = .169 (Adjusted R Squared = .102)

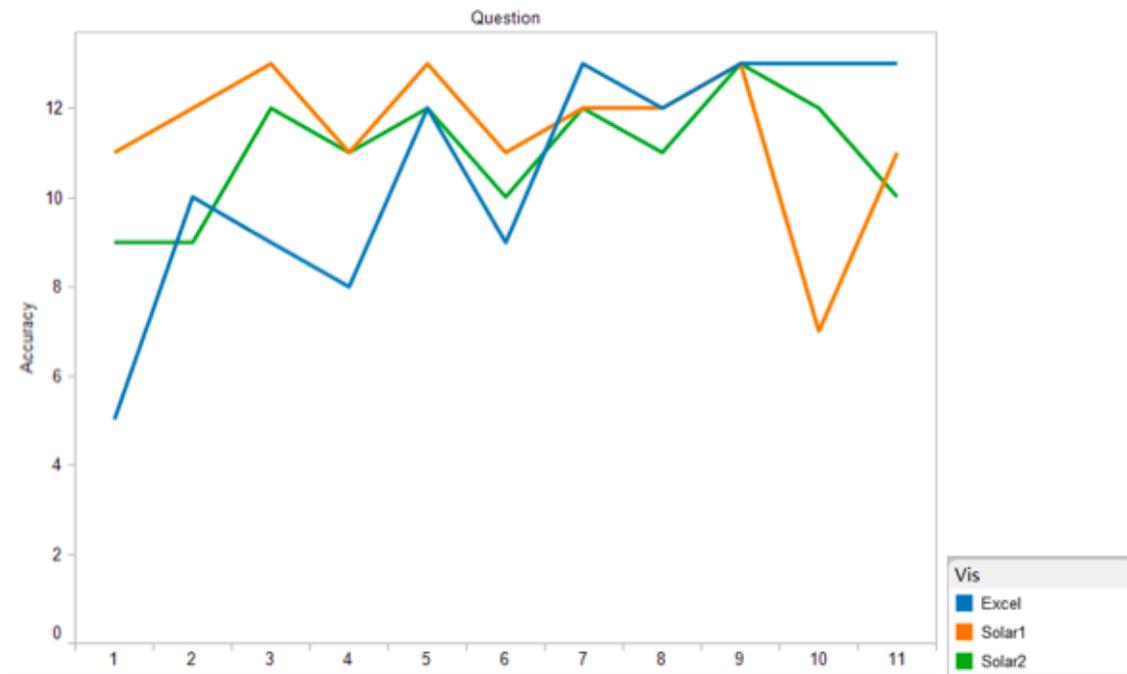


Figure 4-6. Accuracy by basic understanding question for each visualization

Table 4-3. Detailed results for basic understanding questions and analyzed reasons

Question	Information	Result	Reason
1. How many devices are currently being charged?	Real-time	SolarVis1 and SolarVis2 scored much higher than Excel.	Both SolarVis1 and SolarVis2 used icon to represent device and color to differentiate its status (whether charged or currently being charged), which was clear at-a-glance. While Excel used a bar chart of current usage status of adapters to indirectly reflect this same information and was not understood by most participants.
2. How many different devices are currently being charged?	Real-time	Close scores for SolarVis2 and Excel. SolarVis 1 didn't provide the corresponding information.	

Question	Information	Result	Reason
3. How much energy is currently available in the bank?	Real-time	SolarVis1 and SolarVis2 scored much higher than Excel.	The battery icon of SolarVis1 and the tree trunk of SolarVis2 that represent the energy bank were more effective than bar chart in Excel as participants were able to tell the current status of the energy bank by color at-a-glance.
4. How much power is coming in?	Real-time	SolarVis1 and SolarVis2 scored much higher than Excel.	Both SolarVis1 and SolarVis2 used large texts to show incoming power and could be easily picked up by viewers. Excel used bar chart and was less straightforward.
5. Is any power being saved to the energy bank?	Real-time	SolarVis1 scored slightly higher than the other two.	
6. Will there be a lot of power saved today?	Real-time	SolarVis1 scored slightly higher than the other two.	
7. How many devices have been charged today?	Historical	Excel scored slightly higher than the other two.	
8. Which of the following days had most energy produced?	Historical	Excel scored slightly higher than the other two.	
9. Which of the following days had most energy consumed?	Historical	Same score for all three visualizations.	
10. Which of the following days had most energy left in the bank?	Historical	SolarVis1 scored much lower than the other two.	SolarVis1 used color to show energy level and was not understood by most test participants, while the other two visualizations used stacked bars with labels of numbers which were more straightforward.
11. Which of the following days had most devices charged?	Historical	Excel chart performed much better than both SolarVis1 and SolarVis2.	Excel used simple bar chart which was clear at-a-glance. SolarVis1 and SolarVis2 required more effort to get this information as they required participants to count the number of icons that represent the devices.

As expected, SolarVis1 and SolarVis2 had close or higher accuracy than Excel charts in most content understanding questions except for questions 10 and 11. SolarVis1 had a much lower score on Question 10, which asked about the status of

energy left in the bank. The reason might be that it used color to show energy level that was not recognized by most test participants and was not as straightforward as stacked bars used in the other two visualizations. Excel performed much better in Question 11, which asked about the number of devices charged for the day. This showed that the bar chart used in Excel was clearer at-a-glance while the icons used in SolarVis1 and SolarVis2 required more effort for the participants to interpret this information though they looked more interesting.

In general, for all three visualizations, participants were able to answer the questions with fair scores. This indicated that the aesthetic visualizations were as comprehensible as the pragmatic one.

Completion Time of Basic Understanding of Visualization Content

Table 4-4 reveals a significant main effect for type of questions and a significant type of visualizations by type of questions interaction. Details of how much time the three visualizations took for each individual questions are presented in Figure 4-7 and possible reasons of the results are described in Table 4-5.

Table 4-4. Statistical result for Two-Way ANOVA test (time, basic understanding question)

Tests of Between-Subjects Effects

Dependent Variable: Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	76081.389 ^a	32	2377.543	4.542	.000
Intercept	332590.566	1	332590.566	635.430	.000
Vis	700.171	2	350.085	.669	.513
Question	51086.931	10	5108.693	9.760	.000
Vis * Question	24294.287	20	1214.714	2.321	.001
Error	207270.310	396	523.410		
Total	615942.265	429			
Corrected Total	283351.699	428			

a. R Squared = .269 (Adjusted R Squared = .209)

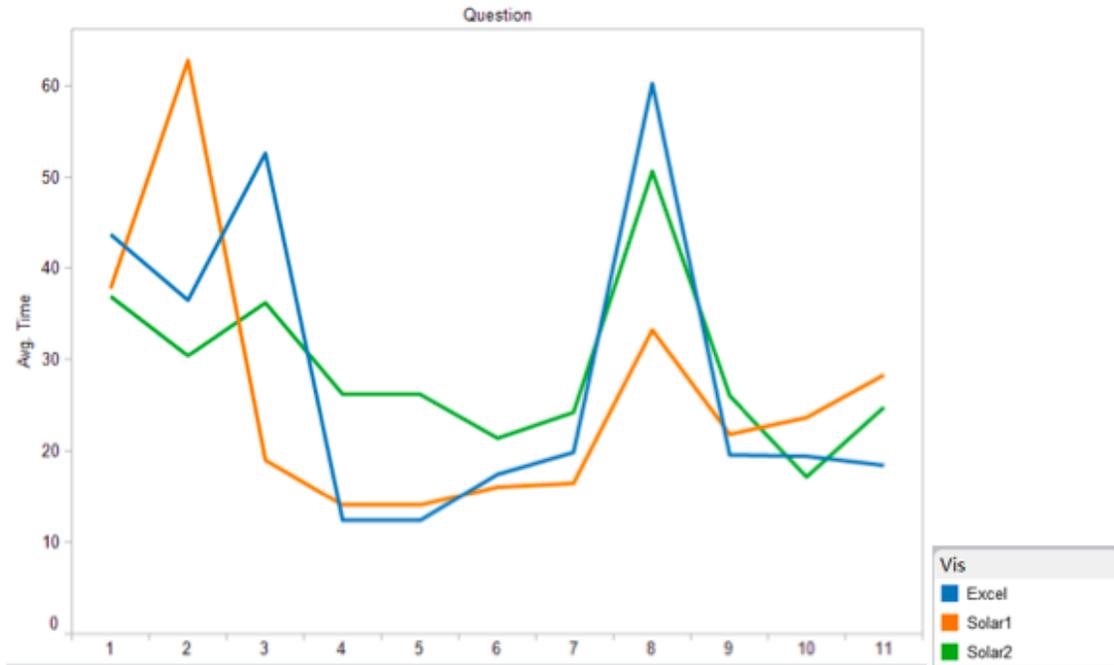


Figure 4-7. Time by basic understanding question for each visualization

Table 4-5. Detailed results for basic understanding questions and analyzed reasons

Question	Information	Result	Reason
1. How many devices are currently being charged?	Real-time	Excel took slightly more time than the other two.	
2. How many different devices are currently being charged?	Real-time	Close completion time for SolarVis 2 and Excel. SolarVis1 didn't provide the corresponding information.	
3. How much energy is currently available in the bank?	Real-time	SolarVis1 took least completion time while Excel took the most.	The battery icon of SolarVis1 and the tree trunk of SolarVis2 that represent the energy bank were more effective than bar chart in Excel as participants were able to tell the current status of the energy bank by color at-a-glance.
4. How much power is coming in?	Real-time	SolarVis2 took more time than other two.	The text showing incoming power information of SolarVis2 located in upper right corner which might take some time for participants to find out.

Question	Information	Result	Reason
5. Is any power being saved to the energy bank?	Real-time	SolarVis2 took more time than other two.	The text showing incoming power information of SolarVis2 located in upper right corner which might take some time for participants to find out.
6. Will there be a lot of power saved today?	Real-time	All three visualizations took similar completion time.	
7. How many devices have been charged today?	Historical	All three visualizations took similar completion time.	
8. Which of the following days had most energy produced?	Historical	SolarVis1 took much less time than the other two.	SolarVis1 used simple bar chart which was easier to read than the stacked bar chart displayed in the other two.
9. Which of the following days had most energy consumed?	Historical	All three visualizations took similar completion time.	
10. Which of the following days had most energy left in the bank?	Historical	All three visualizations took similar completion time.	
11. Which of the following days had most devices charged?	Historical	Excel took less time than SolarVis1 and SolarVis2.	Excel used simple bar chart which was clear at-a-glance. SolarVis1 and SolarVis2 required more effort to get this information as they required participants to count the number of icons that represent the devices.

For the completion time, SolarVis1 and SolarVis2 did not take less completion time than Excel chart as we expected. In fact, the completion time varied significantly depending on the questions asked. SolarVis1 was fast for most questions except for questions 10 and 11. SolarVis2 took less time for questions 2 and 10 but more on questions 4, 5 and 8. Excel was fast for questions 4, 5 and 11 but slow for questions 3 and 8. By looking at the individual questions, we saw that: 1) the battery icon of SolarVis1 and the tree trunk of SolarVis2 that represented the energy bank were more effective than the bar chart in Excel; 2) The simple bar chart used in SolarVis1 to show historical energy production/consumption information was easier to read than the

stacked bar chart displayed in the other two; 3) The bar chart showing the number of devices charged in Excel was clearer than the icons used in SolarVis1 and SolarVis2.

Accuracy of Comprehension of Power/Energy Consumption and Production with Solar

Table 4-6 reveals a significant main effect for type of questions but no significant type of visualizations by type of questions interaction. Details of how the three visualizations scored for each individual question are presented in Figure 4-8 and possible reasons for the results are described in Table 4-7. From Figure 4-8, we see that the three visualizations have very close scores for the five comprehension questions.

Table 4-6. Statistical result for Two-Way ANOVA test (accuracy, comprehension question)

Tests of Between-Subjects Effects

Dependent Variable: Accuracy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.758 ^a	14	.411	4.272	.000
Intercept	96.603	1	96.603	1003.555	.000
Vis	.094	2	.047	.489	.614
Question	5.158	4	1.290	13.397	.000
Vis * Question	.505	8	.063	.656	.730
Error	17.327	180	.096		
Total	119.688	195			
Corrected Total	23.085	194			

a. R Squared = .249 (Adjusted R Squared = .191)

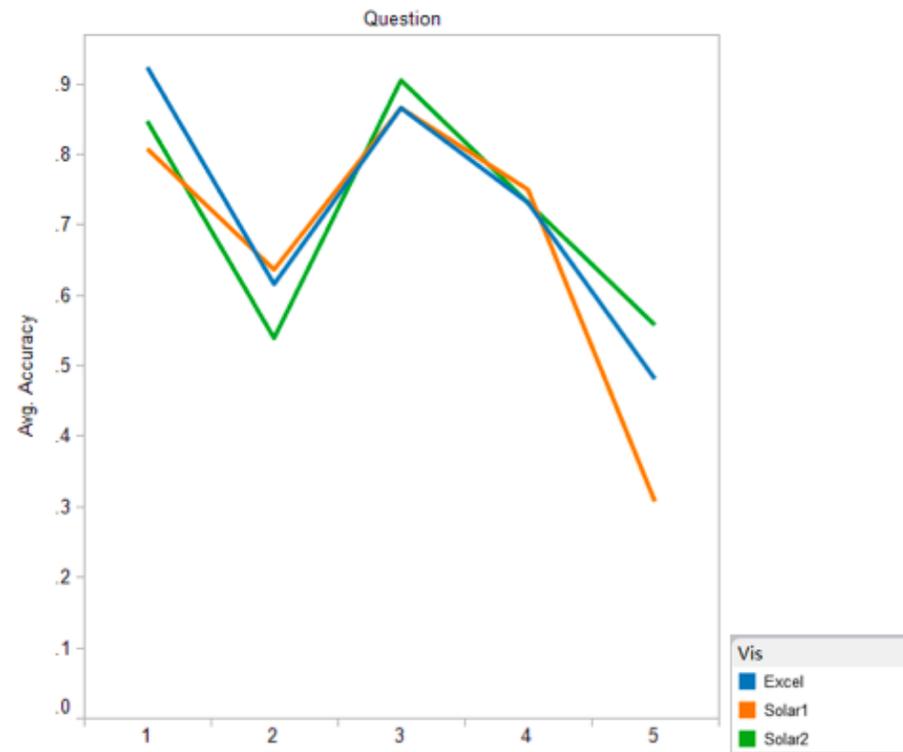


Figure 4-8. Accuracy by comprehension question for each visualization

Table 4-7. Detailed results for comprehension questions and analyzed reasons

Question	Result	Reason
1. How much power is going out? Where do you think it is going?	Close scores for all three visualizations.	Lower scores of question 2 & 5 showed that participants did not fully understand the notion of "Energy Left"
2. What is the level of energy left today (low/medium/high)? Why?		
3. Can I charge my laptop now? Why or why not? If not, when?		
4. Is there a day that had more energy consumed than produced? If yes, choose one, and explain how could that happen? If not, why?		
5. Could there be a lot energy left on a cloudy/rainy day? If yes, choose one, and explain how could that happen? If not, why?		

In general, for all three visualizations, participants were able to answer the questions with fair scores. This indicated that the aesthetic visualizations supported

participants' understanding of solar production and consumption as well as the pragmatic one.

Completion Time of Comprehension of Power/Energy Consumption and Production with Solar

Table 4-8 reveals a significant main effect for type of questions but no significant type of visualizations by type of questions interaction. Details of how much time the three visualizations took for each individual question are presented in Figure 4-9 and possible reasons for the results are described in Table 4-9.

Table 4-8. Statistical result for Two-Way ANOVA test (time, comprehension question)

Tests of Between-Subjects Effects

Dependent Variable: Time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	58002.998 ^a	14	4143.071	2.822	.001
Intercept	730305.476	1	730305.476	497.358	.000
Vis	4281.243	2	2140.621	1.458	.235
Question	40213.073	4	10053.268	6.847	.000
Vis * Question	13508.682	8	1688.585	1.150	.332
Error	264306.504	180	1468.369		
Total	1052614.978	195			
Corrected Total	322309.502	194			

a. R Squared = .180 (Adjusted R Squared = .116)

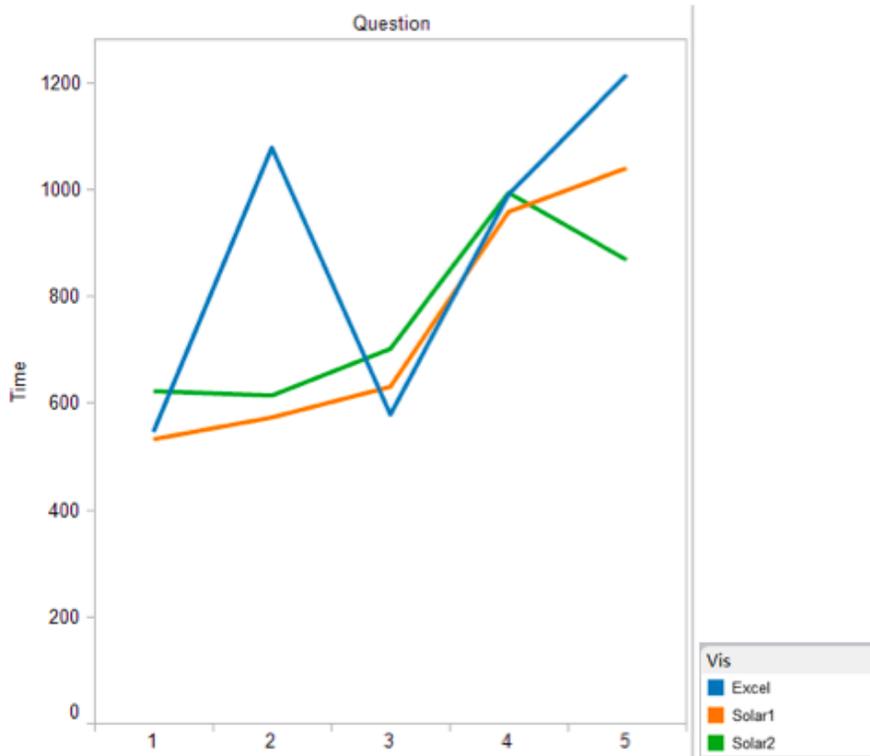


Figure 4-9. Time by comprehension question for each visualization

Table 4-9. Detailed results for comprehension questions and analyzed reasons

Question	Result	Reason
1. How much power is going out? Where do you think it is going?	All three visualizations took similar completion time.	
2. What is the level of energy left today (low/medium/high)? Why?	Excel took much more time than SolarVis1 and SolarVis2.	The battery icon of SolarVis1 and the tree trunk of SolarVis2 that represent the energy bank were more eye-catching than the bar chart in Excel and could be easily seen by the participants.
3. Can I charge my laptop now? Why or why not? If not, when?	All three visualizations took similar completion time.	
4. Is there a day that had more energy consumed than produced? If yes, choose one, and explain how could that happen? If not, why?	All three visualizations took similar completion time.	

Question	Result	Reason
5. Could there be a lot energy left on a cloudy/rainy day? If yes, choose one, and explain how could that happen? If not, why?	SolarVis2 took least completion time while Excel took the most.	Both SolarVis1 and SolarVis2 had weather displayed as an icon, which was clearer than texts displayed in Excel.

As expected, though not for all five questions, SolarVis1 and SolarVis2 took much less completion time than Excel for questions 2 and 5. This proved that the graphical elements (the energy bank icon and the weather icon) we used in SolarVis1 and SolarVis2 did help making the displayed information more eye-catching and more easily to be picked up by the audience.

Appeal

Results of the user ratings for appeal of the three visualizations were analyzed using two-way analysis of variance, with two between group factors. Table 4-10 indicates that the type of visualization variable produced a significant difference and significant type of visualizations by type of appeal criteria interaction was present.

Table 4-10. Statistical result for Two-Way ANOVA test (appeal)

Tests of Between-Subjects Effects

Dependent Variable:Rate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	27.197 ^a	8	3.400	3.221	.003
Intercept	743.803	1	743.803	704.656	.000
Vis	6.889	2	3.444	3.263	.042
Criteria	3.709	2	1.855	1.757	.177
Vis * Criteria	16.598	4	4.150	3.931	.005
Error	114.000	108	1.056		
Total	885.000	117			
Corrected Total	141.197	116			

a. R Squared = .193 (Adjusted R Squared = .133)

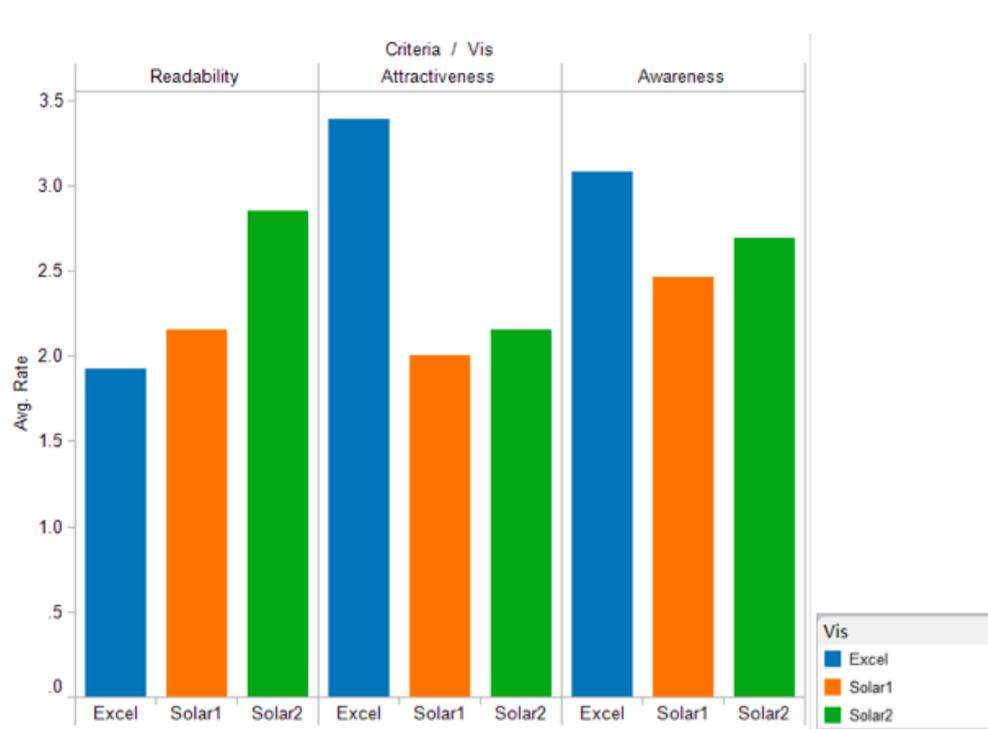


Figure 4-10. Rate by appeal for each visualization

Details of the ratings for the three criteria across all visualizations are presented in Figure 4-10. The ratings for readability and at-a-glance awareness were very close across all three visualizations. However, SolarVis1 and SolarVis2 were rated as much more attractive than Excel charts because of their richer representations and more aesthetic appeals.

Relationship to locations

Again, results of the scores were analyzed using two-way analysis of variance, with two between group factors as shown in Table 4-11. This indicated that both the visualization and location variables produced a significant difference and significant type of visualizations by type of location interaction was present.

Table 4-11. Statistical result for Two-Way ANOVA test (location)

Tests of Between-Subjects Effects

Dependent Variable:Rate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	74.769 ^a	17	4.398	3.114	.000
Intercept	1632.154	1	1632.154	1155.595	.000
Vis	16.179	2	8.090	5.728	.004
Location	17.179	5	3.436	2.433	.036
Vis * Location	41.410	10	4.141	2.932	.002
Error	305.077	216	1.412		
Total	2012.000	234			
Corrected Total	379.846	233			

a. R Squared = .197 (Adjusted R Squared = .134)

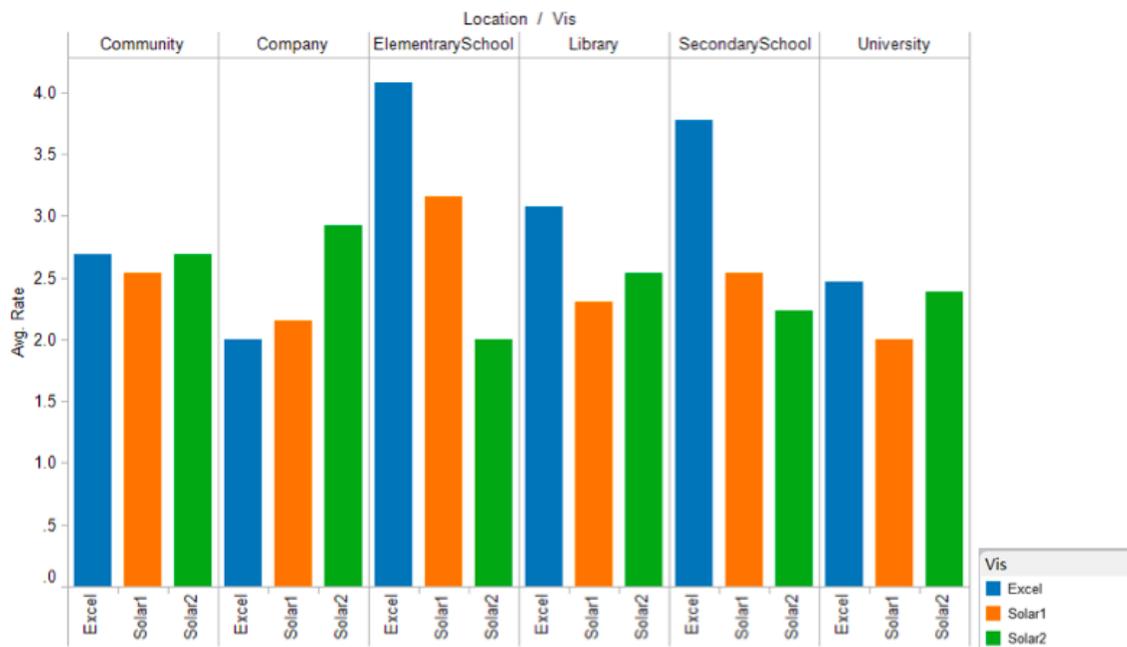


Figure 4-11. Rate by location for each visualization

As shown in Figure 4-11, people would more like to see SolarVis1 and SolarVis2 than the Excel chart in most public locations except for the company as some participants said that it was a more serious place where the Excel chart might look more

professional. Ratings for SolarVis1 and SolarVis2 were pretty close in most locations except for the company and the elementary school. People would not like to see SolarVis2 in a company because the tree representation looked very childish but it was most welcomed in an elementary school, as younger kids might be very interested in seeing the growth of an apple tree.

Other Comments

8 of 13 participants stated that they preferred SolarVis1 because they liked the graphical representation of solar panels and they thought it was easy to read and understand. 3 participants liked SolarVis2 the most because it was interesting and clear. Other notable comments were: 1) 3 participants stated that the visualizations had too much information displayed at the same time and they suggested adding user interactions so that they could filter the information they would like to see; 2) 4 participants expressed that the lower part of SolarVis2 was hard to read because the stacked bars used similar colors for two different variables and they overlapped; 3) 1 participant pointed out that it would be nicer if the upper and lower part of SolarVis1 could have more connections in context as in SolarVis2.

4.2.5. Discussion

Our findings showed that the three visualizations had their own strengths and weaknesses depending on the questions asked. In other words, this revealed that some of the design elements in our visualizations were successful while others were not.

SolarVis1 had high accuracy for almost all basic data interpretation questions (Question 1 to 11) except for question 10 and it required much less time for the participants to understand those data. Such results indicated that SolarVis1 was successful in displaying both real-time and historical information. However, its failure in question 10 that asked about day energy left in the bank reflected that the color coding of the solar panels representing the energy levels was not understood by most participants and definitely needed to be redesigned and improved. SolarVis2 was supposed to be more “Day View” oriented than SolarVis1, but unexpectedly, it had lower scores for questions of real-time information than SolarVis1 and no obvious superiority in completion time. As some participants pointed out that the tree abstraction was hard to

understand at first sight, but as they got more familiar with the idea they admitted that the real-time information displayed with the tree was clearer at-a-glance. In general, the results of the first 11 questions showed both SolarVis1 and SolarVis2 performed better than Excel charts for the basic content understanding questions. Though the difference was not significant, we could still conclude that our first two hypotheses were confirmed.

The results also showed that there was no significant difference in accuracy for the five comprehension questions among SolarVis1, SolarVis2 and Excel Charts, which indicated that the aesthetic visualizations were able to help people understand solar through their displayed information just as well as standard charts did. Additionally, the fact that SolarVis1 and SolarVis2 took much less time than Excel Charts for the participants to answer questions 2 and 5 was not only a proof to our third hypothesis, it also confirmed that the graphical elements we designed in those aesthetic visualizations, especially the battery and the tree trunk that represented the energy bank, did help participants understand the concepts more quickly and easily.

As proof to our last two hypotheses, the user preference ratings showed that SolarVis1 and SolarVis2 were rated as much more attractive than Excel charts due to their richer representations and more aesthetic appeals. People would more like to see them than Excel charts in most locations except for the company. However, they were not rated as readable as Excel charts because they didn't have clear headings, legends and numbers for the information displayed.

In conclusion, SolarVis1 and SolarVis2, in the form of aesthetic visualization were as effective as pragmatic visualization tools (Excel charts) in conveying energy usage information to the consumers. In addition, they were more attractive than Excel charts because of their richer representations and more visually compelling appeals and they were more likely to engage people and lead them to think about using the solar energy.

4.3. Summary

Our goal in this user study was to explore the effectiveness of using the aesthetic visualization as feedback for power and energy use as compared to the pragmatic

visualization. Our preliminary results showed that the approach had good potential. However, as we discovered in the user study, there were some design flaws that affected how people perceived and understood the information that was embedded in the aesthetic displays. And this led us to the question of how to balance the aesthetic interest and the readability. Theoretically, aesthetic visualization and pragmatic visualization are two different types of visualizations that sit on opposite ends of the “sublimity” scale: the former is less readable and recognizable for the data as it is aimed to transfer the basic concern from the data; while the latter is designed to aid in data analysis but is less visible and interesting for people to see the underlying problem the data implies (Kosara, 2007). In our case, we were not sacrificing the readability of our aesthetic visualizations for aesthetic reasons. Although our main goal was to provide at-a-glance awareness of energy use and to inform and engage people with richer and more interesting displays, we still wanted to maintain the details of the data as some of our audience might be interested to see exactly how much energy was produced or consumed. One solution to this, as some of our participants pointed out, was to add interaction so as to enable the users to customize what they wanted to see.

The study results indicated that the aesthetic visualizations did help people better understand solar power and energy and were more engaging and welcomed than the pragmatic one. Based on this, our next avenue is to explore how they work with ambient displays and whether they will affect sustainable decision-making with more realistically representative simulations.

5. Study 2: Energy Conservation Game

As an extension to our previous study, this research explores the effectiveness of using different aesthetic visualizations as feedback for residential energy use by integrating them with ambient displays and a simulation game. The game is chosen as a testing context because it offers more realistically representative simulations and is more attractive to our test participants. Particularly in this research, school-age children are considered as our primary participants because we hope to find out if these feedback tools help enhance their learning of energy and conservation. Two things motivate this decision: 1) in BC, energy forms part of the science curriculum in grades 5-7 (Ministry of Education, 2010) and 2) children's awareness and behaviour often have a great impact on the adults at home (Evans S. M., 1996; Mandel, 2013). Meanwhile, we would also like to understand where people are weak in their knowledge and understanding of home energy use at both conceptual and operational levels. In this chapter, the planning and the details of the research study are described; the design and the implementation of the study installations are introduced; the study results are presented with mixed data analysis techniques; and implications of the results are addressed.

5.1. Research Design

In this study, we took a design-oriented research perspective with mixed evaluation methods. As Fallman (2007) states, the main objective of a design-oriented research is to reveal the knowledge that comes from studying user behaviour and user experience of a design artefact. In this context, we would like to explore the potential of different depictive and narrative-related aesthetic visualizations as an approach to energy use feedback. Also we aimed to both understand the potential benefits and caveats of this approach, and to tease out where people's comprehension was weak regarding energy conservation at home.

5.1.1. Research Questions

Three different visualizations were developed in this design research, among which two were designed using an aesthetic visualization approach and one was a standard bar chart with embellishment. Notably, one of the two aesthetic visualizations employed an explicit representation of positive actions. These design artefacts were studied as means rather than end products to explore the potential of using depictive visualizations as effective feedback for residential energy use. The following research questions were examined to qualify this approach.

Research Question 1: What are the implications of using these visualizations in an applied learning context (the game)?

Following this question, we wish to know whether users are able to understand these visualizations and whether that understanding affects their decision-making. In other words, do these visualizations help users perform better or make better self-evaluations in the simulation game? Additionally, we want to answer: are feedback tools designed using the aesthetic visualization more effective than using standard charts? How do participants describe their impressions of the visualizations: is there one easier to understand or more interesting or attractive or aesthetically appealing than the others?

Research Question 2: What are the affordances, benefits and caveats of providing explicit action representation as motivations?

Sub questions following this one are: Does explicit representation of positive actions make a difference? Are users able to understand this representation? How do users like the rewarding mechanism in the visualization? Does it help users to realize what is good for energy conservation? Does it help to encourage positive actions?

Research Question 3: Where might people use this (if at all) in their homes?

This question is the key to this design research that aims to find out whether users would like to have those visualizations in their homes, and more specifically, which room they would like to put them in. Also we wish to know whether users think having those visualizations in their homes would have a positive effect on their daily activities, i.e. are they helpful?

Research Question 4: What does this simulation game suggest about people's understanding of how to use energy efficiently in their homes?

More specifically, the question is to elicit what children and families understand, don't understand or "forget" about operating their homes more efficiently. And we wish to know whether this simulation game is useful in providing us with more information regarding users understanding of home energy conservation than the early interview.

5.1.2. User Study

As Fallman addresses on design-oriented research:

Studying an artefact to gain some new knowledge is hence as much a question of understanding people, context, and 'now'—i.e. looking into and trying to grasp the complex interplay between people, technologies, and society and how this 'now' changes when a new artefact is introduced—as it is to develop and study technology. (Fallman, 2007)

Thus, conducting user studies is important and necessary in this research to get valuable insights into the visualization design and its potential use.

The user study started with a pilot study of 2 participants and followed by a study of 24 participants recruited through personal contacts from colleagues and friends of the researchers. All participants were school-age children. Some participated in the study individually, some with their parents and some with their friends. This age group was chosen because: 1) energy forms a major part of the school curriculum during the middle school years (grade 5-8) (Ministry of Education, 2010); 2) the impact of children's awareness on parental behaviour is known to have an influence on the adults in their homes (Evans S. M., 1996; Mandel, 2013); 3) these represent our future generations: we were interested in understanding how best to enhance and sustain their learning about energy and conservation. Most of the study sessions were done in participants' homes with two exceptions in coffee shops due to privacy concerns of the participants. The participants' homes were chosen as the primary study place because they were the intended locations where the visualizations were to be placed. As mentioned in our survey of evaluation approaches (2.3.4: Evaluation), the evaluation of an aesthetic

visualization was inseparable from its context and we attempted to take the advantage of collecting data from real-life installation.

The study took around 30~45 minutes, which included three major related activities plus a casual conversation at the end. First, a pre-session interview was conducted to determine whether and how participants knew about energy usage in their homes. Then the participants were asked to complete the energy conservation game, during which they were randomly assigned to see one of the three visualizations (8 for each visualization). Details of the game are described in the next Section (5.2: Energy Conservation Game). After the game, the participants were required to fill in a questionnaire on their impressions of the visualization they saw and their preferences of whether they would like to have it in their homes. Finally at the end of the study session, all three types of visualizations were shown to the participants, and the researcher took a casual conversation with the participants to get an idea of how they thought about all those visualizations and which they liked the most.

5.1.3. *Data Collection and Analysis*

The study data were collected and analyzed with several methods (

Table 5-1 summarizes the research questions and how they are measured and analyzed in this study). First, a pre-session interview for around 5 minutes was taken to elicit participants' knowledge of their home energy use. Three questions were asked, including total energy cost of the house, energy use of a particular household appliance and conservation actions that might be taken at home to save energy (Appendix B-1). The interviews were audio-recorded and then transcribed and analyzed with a qualitative approach. As a limitation, only one coder was involved in transcribing the data. But the interview was short and the questions were structured, therefore, the coding was very straightforward.

Second, a game session varying in length from 20 to 30 minutes was performed. Before starting with the game, a short tutorial of the control of the dollhouse interface was given and free exploration of the game installation was allowed till participants felt comfortable to start the game. The game included four stories and participants were asked to complete all of them in the same order. Without counterbalancing, limitation existed with such kind of experiment design as learning effect would affect participants' performance. On the other hand, the learning effect itself was something we would like to explore in this study. In each game story, participants needed to complete a few tasks first and then evaluate their own actions. The game data were digitally logged by the system itself, which contained basic information of the participant (user name and school grade), game scores for each story task (actual score and self-evaluated score) and a log of all interactions participants made during the game. The data were analyzed using descriptive statistics and visualized using Tableau®. Interesting findings were found and discussed in Section 5.3 and 5.4.

After the game, a post-session questionnaire collected participants' impression of the visualization they saw and response of whether they would like to have the visualization in their homes (Appendix B-2). Impression questions included whether the visualization was: easy to understand, interesting, attractive and good-looking. And participants were asked to rate them on a 5-point scale from strongly disagree, disagree, neutral, agree to strongly agree. The location preference question provided a list of seven rooms (e.g. living room, bedroom and etc.) for the participants to choose. Participants were also allowed to specify rooms that were not on the list or choose "would not like it in their house". The questionnaire concluded with an open question

that allowed participants to leave any comment they had about the visualization. The questionnaire data was collected electronically via a web interface and analyzed quantitatively to make comparisons among all three visualizations. A link to it is available at: <http://energyvis.iat.sfu.ca/energy-game-v3/house/index.html?session=11111>.

Finally, all three visualizations were presented to the participants and the researcher led a short discussion with the participants around their general impression and preference of them. The answers were recorded with researcher notes and reviewed qualitatively.

Table 5-1. Study 2: Alignment Chart

Research Questions	Constructs	Measure	Log Files	Questionnaire
1. What are the implications of using these visualizations in an applied learning context (the game)?				
1a. Do these visualizations help users perform better or make better self-evaluations in the simulation game?	Effectiveness	User interactions / game scores	User interactions / game scores	N/A
1b. How do participants describe their impressions of the visualizations: is there one easier to understand or more interesting or attractive or aesthetically appealing than the others?		User ratings	N/A	Q1
2. What are the affordances, benefits and caveats of providing explicit action representation as motivations?				
2a. Does explicit representation of positive actions make a difference?	Effectiveness	User interactions / game scores	User interactions / game scores	N/A
2b. How do users like the rewarding mechanism in the visualization?		User ratings	N/A	Q1
3. Where might people use this (if at all) in their homes?	Utility	User ratings	N/A	Q2
4. What does this simulation game suggest about people's understanding of how to use energy efficiently in their homes?	N/A	Perceived game score vs. actual game score	Game scores	N/A

5.2. Energy Conservation Game

Gamification techniques that use simulation, hands-on experience, and explicit rewards are often cited as important in educational contexts (Schifter, 2013) and have shown to be successful in engaging students in exploring large-scale ecological outcomes (Antle, Tanenbaum, & Macaranas, 2013), but they have not been applied to enhancing energy awareness and comprehension of actual home use. As Lawley (2012) states “Games can be powerful experiences, leveraging both motivation and engagement”.

To achieve more realistically representative simulations, we created this energy conservation game as a testing environment for the visualizations. We defined it as a game rather than a simple simulation because it employed basic game techniques. For example, it had scores for the user performance and allowed users to compete against each other (but this was not tested in the user study). The game also intended to make the study session a more interesting process to engage children in the activity of “using energy” in this research. Additionally, the game was an experiment in the usefulness itself, through which we would like to explore what people understood and didn’t understand about energy conservation in their homes.

5.2.1. Game Design

In the game, a dollhouse UI (Figure 5-1, left) is used to simulate the home environment and drive the three visualizations (Figure 5-1, right). The dollhouse has six rooms: mechanics, kitchen, living room, laundry, bedroom and washroom, each of which contains household appliances that users may turn on/off/unplug to simulate their daily activities.

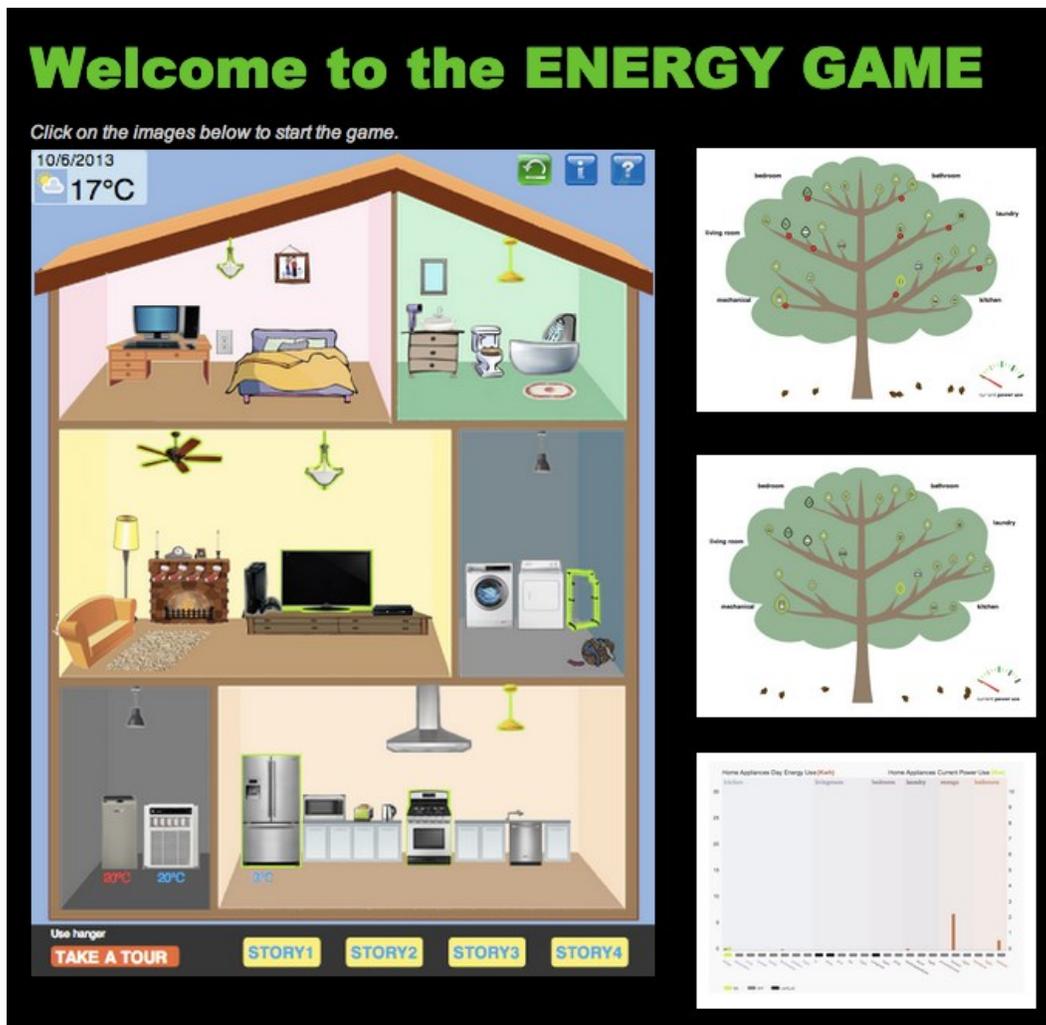


Figure 5-1. Web Interface of Energy Conservation Game

The game consists of four stories (Table 5-2) that mimic people’s everyday lives. In each story, participants are asked to imagine themselves in the described scenario and complete tasks accordingly (Figure 5-2). The tasks are designed to have special focus on activities that people may do to save energy in their home, for example, turning off the light when leaving a room, unplugging unused appliances to stop “vampire” power, washing clothes with cold water and taking a shower instead of bath. But participants are not explicitly given a list of energy-related tasks to carry out (for example, they are not told to turn off the light when leaving a room). Instead, we instruct them to do things as “energy efficiently as possible”. After finishing the tasks, participants will be asked to evaluate their own actions in terms of whether they think they have done things energy efficiently. And feedback regarding their actions will be

provided (Figure 5-3). Additionally, a score (out of 10, 2 per task) will be given and participants may compare their scores with their friends or the best players of the day.

Table 5-2. Game Stories

Game Story	Description	Tasks
1. Entertainment	On a hot summer night, you invite your friends to your home. First cool your house, bring iced drinks to your friends (Make sure your fridge is running efficiently). Then play games and watch movies with them. After your friends leave, tidy up the room and go to bed.	<ol style="list-style-type: none"> 1. Room Temperature Control 2. Fridge Setting 3. Watch Movies 4. Play Games 5. Lighting
2. Laundry	Wash yourself completely, including your hair. And then do laundry. Wash and dry your clothes. After all these are done, go out and meet your friends.	<ol style="list-style-type: none"> 1. Wash Yourself 2. Dry Your Hair 3. Wash Clothes 4. Dry Clothes 5. Lighting
3. Cooking	On a Sunday morning, help your mom prepare breakfast for your family, including heating the milk with the microwave, making toast and fried eggs. Then wash the dishes and leave the kitchen.	<ol style="list-style-type: none"> 1. Heat Milk 2. Make Toast 3. Make Fried Eggs 4. Wash Dishes 5. Lighting
4. General Efficiency	Some things have to either stay on or run automatically in your house, like your fridge; some could remain off while not in use; other things run automatically to control temperature. Make your house run as energy efficiently as possible before you go to bed.	<ol style="list-style-type: none"> 1. Fridge Setting 2. Turn Off Unused Appliances 3. Unplug Unused Appliances 4. Room Temperature Control 5. Lighting



Figure 5-2. Game Story Example

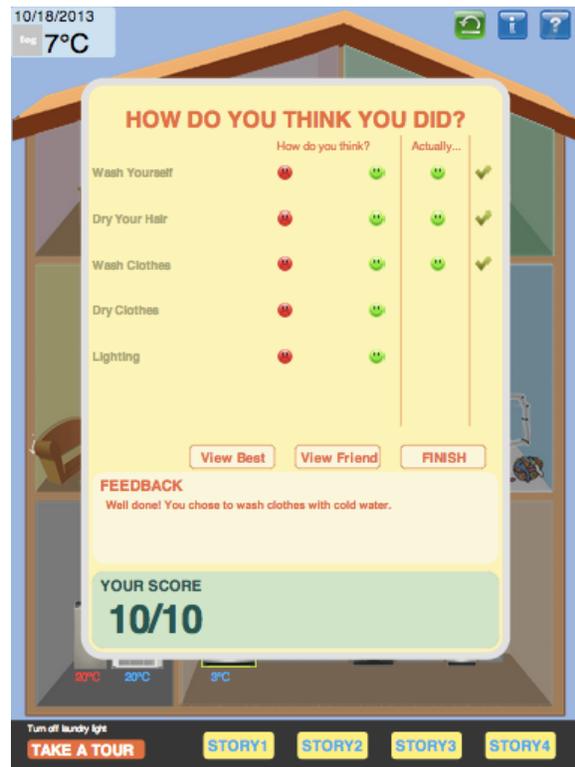


Figure 5-3. Self-evaluation Example

5.2.2. Visualization Design

Three different visualizations were studied in this design research. Two were designed with an abstract tree representation and one was a standard bar chart with embellishment. All three visualizations are for residential energy use feedback, which include real-time reflection of individual household appliance's status (on/off/unplug), power and energy usage and cumulative house's energy cost (energy is a measure of how much fuel is contained within something, or used by something over a specific period of time, and it is measure in kWh; power is the rate at which energy is generated or used and is measure in kW). Based on Fischer's model for successful feedback, providing breakdown for specific rooms and appliances is essential for creating direct links between action and effect and raising consciousness of individual activities (Fischer, 2008). And we take that into consideration in all three visualizations: energy use for individual appliance is visualized and separated by rooms.

Abstract Tree with Berries

Inspired from the previous study (Section 4), we continued to use the abstract tree representation as the design for our aesthetic visualization because it was thought to be visually attractive, related to “green” thinking and interesting to children. Besides, the tree was chosen because it could be conceptually related to energy conservation and the green environment.

Several versions of tree designs were considered (Appendix C), including different tree types (apple, berry), layouts (horizontal, vertical) and graphic styles (abstract, realistic). A variety of color palettes, icon designs, data mappings and degrees of animation and interactivity were also explored. The ideas were fleshed out with sketches on paper and software prototypes.

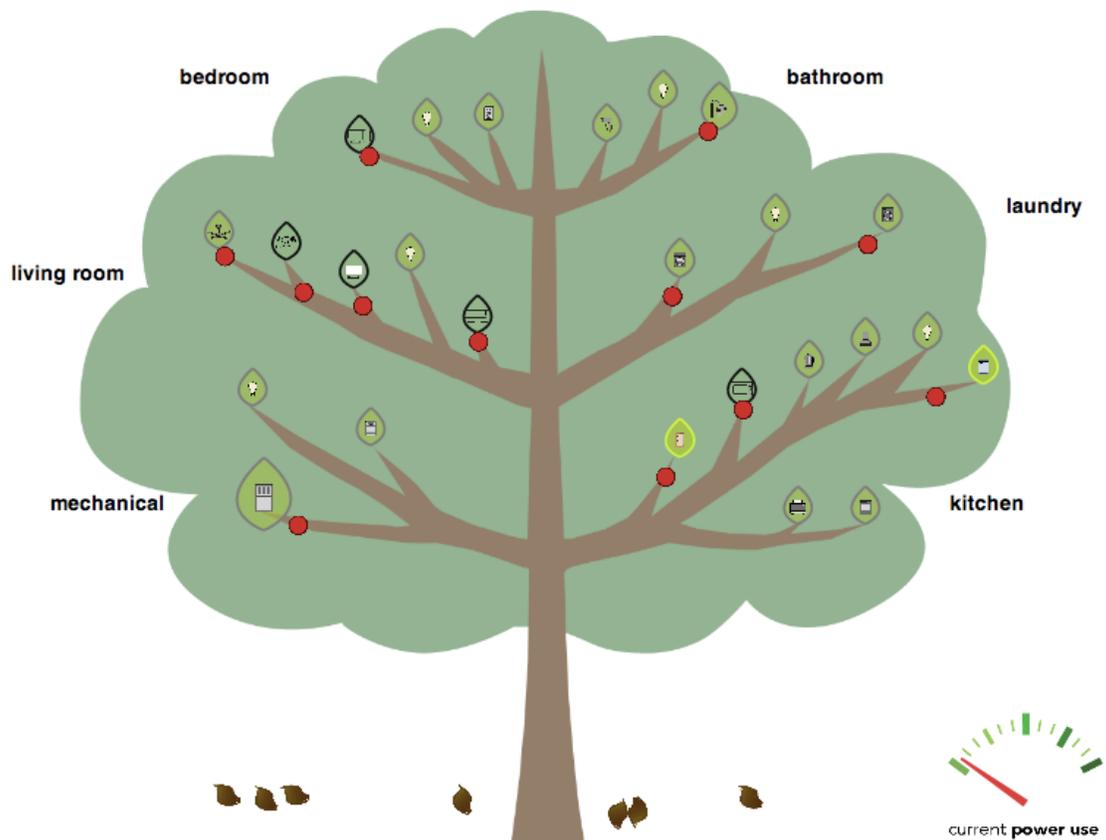


Figure 5-4. *Abstract Tree with Berries to represent positive actions*

After a period of collaboration with professional designers, the final design for the study is a non-photorealistic rendering of a berry tree as shown in Figure 5-4. The

branches in the tree represent different rooms in a house. For this study, it is mapped to the dollhouse interface. On each tree branch, there are leaves representing household appliances in the room that the branch is mapped to. Each individual appliance is mapped to a single leaf with its icon displayed. The outline color of the leaf shows the current status of the appliance: green for on, grey for off and black for unplugged. The size of the leaf is mapped to the total energy the appliance costs (kwh): the larger the leaf, the more energy it uses. The berries on the tree represent positive actions towards energy conservation, for example, unplugging unused appliance, washing clothes in cold water and turning up the fridge temperature. The yellow leaves piling up at the bottom of the tree indicate the accumulative energy used in the house: the more leaves, the more energy is consumed. The meter at the bottom right corner shows the current power use (kw) in the house, which is self-explanatory.

Though the above tree visualization was decided and chosen for the study, there were issues and conflict ideas around the design. First, several alternative ways of displaying the appliances had been discussed in the design phase, including using icons without the leaves and using icons with explanatory texts. For aesthetic reasons, the current one was considered the best, though the icons for the appliances were thought to be a bit too small to recognize. Second, the power meter didn't go with the tree design and looked abrupt in the picture. Unfortunately we hadn't found a better way to represent the current power use.

Abstract Tree without Berries

As a variation to the berry tree design, we also included a tree visualization without the berries (Figure 5-5) in our study for the purpose of finding out whether the explicit representation of positive actions would make a difference in engaging children and encouraging more energy conservation behaviour. The data mapping to the tree is identical to the one discussed above except positive actions are not displayed. In other words, the berries are omitted.

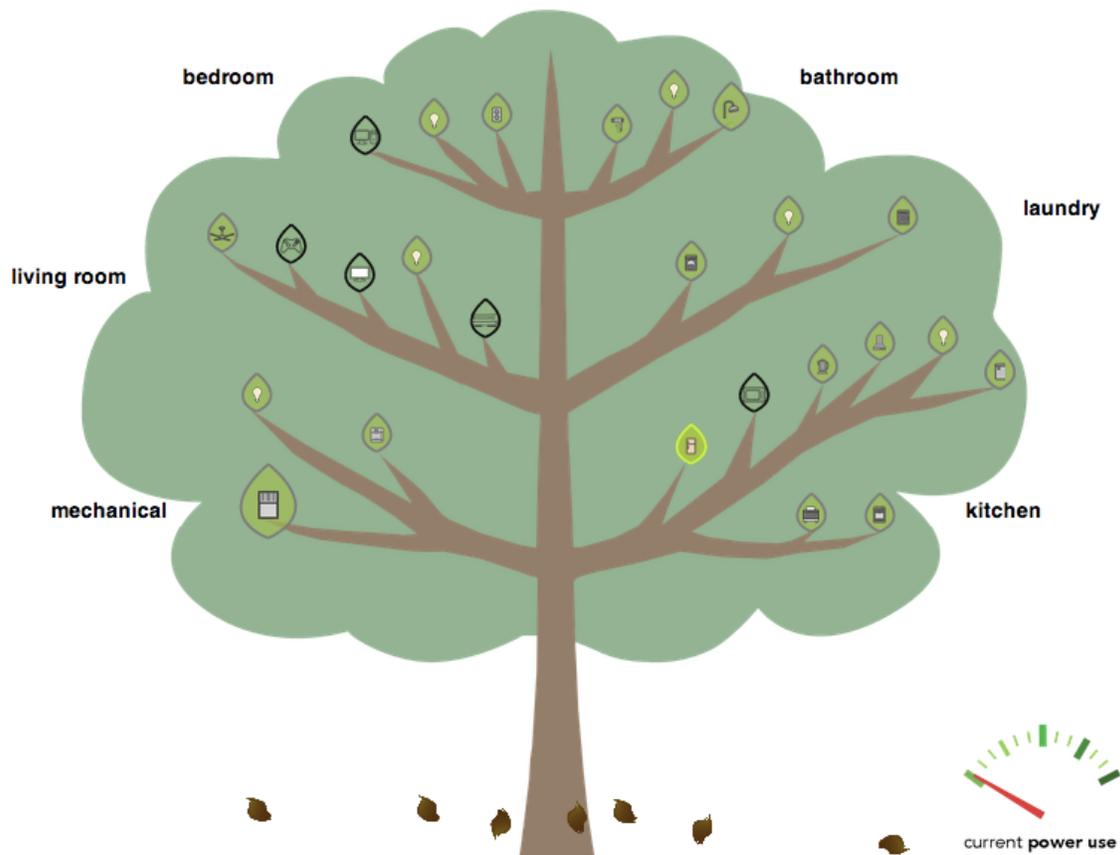


Figure 5-5. Abstract Tree without berries

Bar Chart

The bar chart was included for the study as a representation of the pragmatic visualization to make comparison with the aesthetic visualization solutions. It was chosen because people even children were familiar with it in their everyday lives and it allowed easy comparison among the data.

As shown in Figure 5-6, the x-axis is a list of household appliances grouped by the rooms in the house. The color of the little square on top of the appliance's name indicates the status of the corresponding appliance: green for on, grey for off and black for unplugged. The left y-axis shows the total energy each appliance costs for the day in kwh and the right y-axis represents the current power use of each appliance in kw. The color and layout of the bar chart are specially designed for aesthetic reasons.

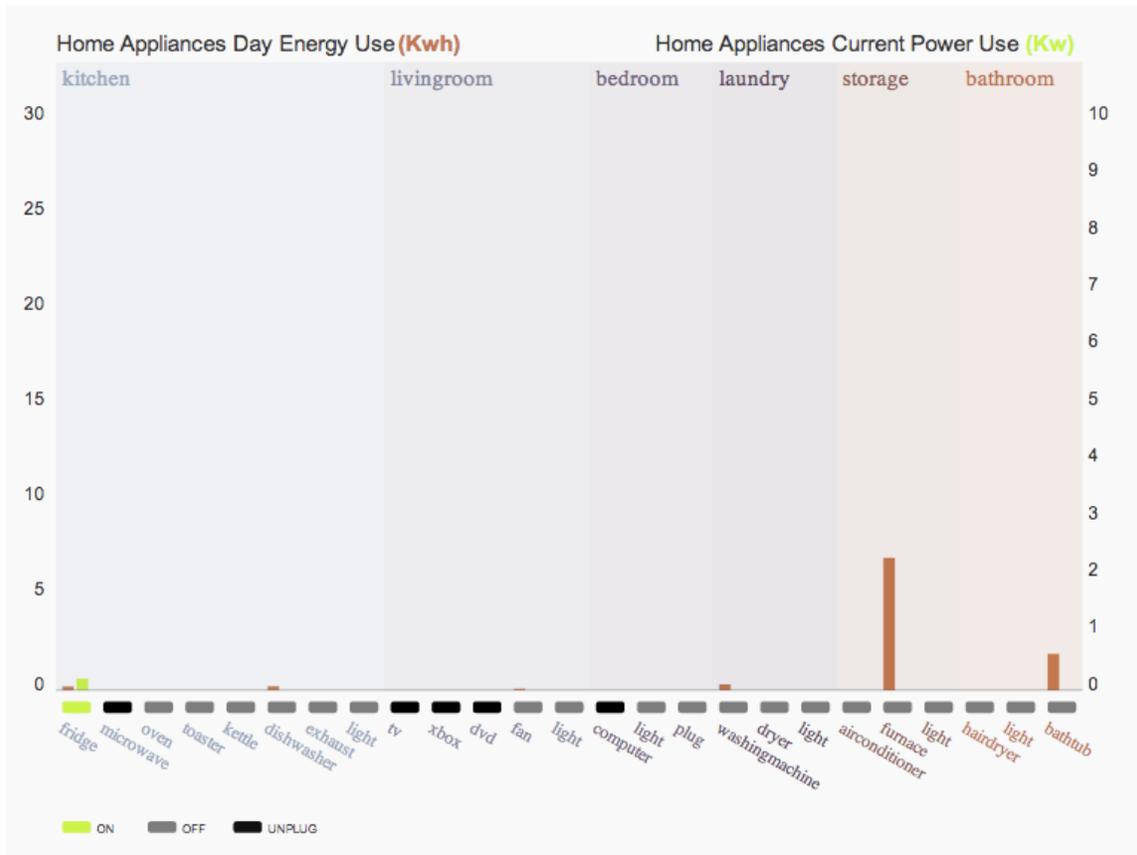


Figure 5-6. Bar Chart with embellishment

Table 5-3 summarizes the data features of the above three visualizations. Again, all three visualizations were considered as research instruments in this design study rather than final products. The goal was to explore their potential of practical use and gain knowledge and inspiration for further related designs.

Table 5-3. Summary of data features of all three visualizations

Note: “X” for having the specified feature, “-” for not.

Data Feature	TreeVisWithBerries	TreeVisWithoutBerries	BarChart
Status of individual appliance	X	X	X
Energy cost of individual appliance	X	X	X
Energy cost of all appliances	X	X	-

Data Feature	TreeVisWithBerries	TreeVisWithoutBerries	BarChart
Power use of individual appliance	-	-	×
Power use of all appliances	×	×	-
Number of positive actions	×	-	-

5.2.3. System Implementation

The system (including the dollhouse and the visualizations) was developed a web application using JavaScript (with D3 library) for the flexibility that it would be run on different platforms and the data were kept in a MySQL database secured on the SIAT lab server. The system was compatible with most web browsers (link: <http://energyvis.iat.sfu.ca/energy-game-v3/>).

The system architecture is illustrated in Figure 5-7 below. The basic power (watt) information for household appliances shown in the dollhouse is taken from the website SavingElectricity (link: <http://michaelbluejay.com/electricity/howmuch.html>) and hard coded into the MySQL database. The dollhouse interface loads the appliance power data from the database on initiation and uses the information to calculate the appliance's actual energy cost (Energy Cost (kw·h) = Power (kw) * Time(h)). The time in the system is simulated in a way that every 20 seconds is treated as an hour. The dollhouse then sends the energy information back to the MySQL database along with the appliance status (on/off/unplug) information. The dollhouse also has a real-time display of the weather information, which is acquired from the World Weather API (Link: <http://www.worldweatheronline.com/>) and updated on an hourly basis. On the visualization side, all data required by the display including individual appliance status, energy cost, etc., are pulled from the MySQL database and updated every 0.5-second to achieve real-time effect.

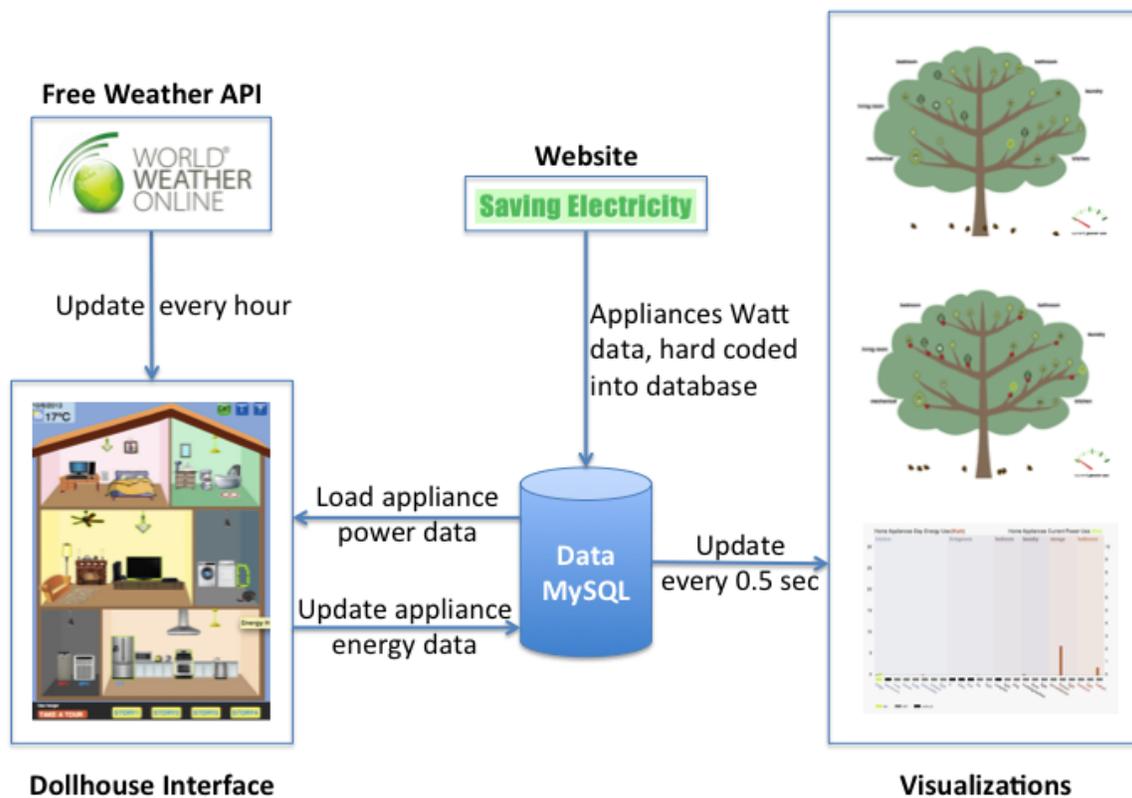


Figure 5-7. Energy Conservation Game - System Architecture

Figure 5-8 shows the system installation for the user study. The dollhouse is shown on a 10-inch tablet (running Android), via which users can touch on the appliances to turn them on, off or unplug. The visualization is displayed full-screen on a framed iPad. The wooden frame adds aesthetic value to the visualization to make it look more like a piece of art and also to meet the ambient requirement.



Figure 5-8. System Installations

To allow concurrent instantiations of the system, a unique session code is required for each paired instance of the visualization and the dollhouse interface. The session code is entered manually on initiation of the system. Also for research purpose, every user input is logged into the database for further analysis.

5.3. Results

5.3.1. Participants and Their Energy Understanding

All 24 participants (including the 2 pilots) were school-age children with the youngest in grade 4 and the oldest in 12. Most of them were in grade 12 (9 participants) and grade 8 (5 participants) as shown in Figure 5-9. Notably, 11 were between grade 5 and grade 8 as highlighted in Figure 5-9. This grade group was of particular interest

because it was when children started to learn about power and energy in school. (Ministry of Education, 2010)

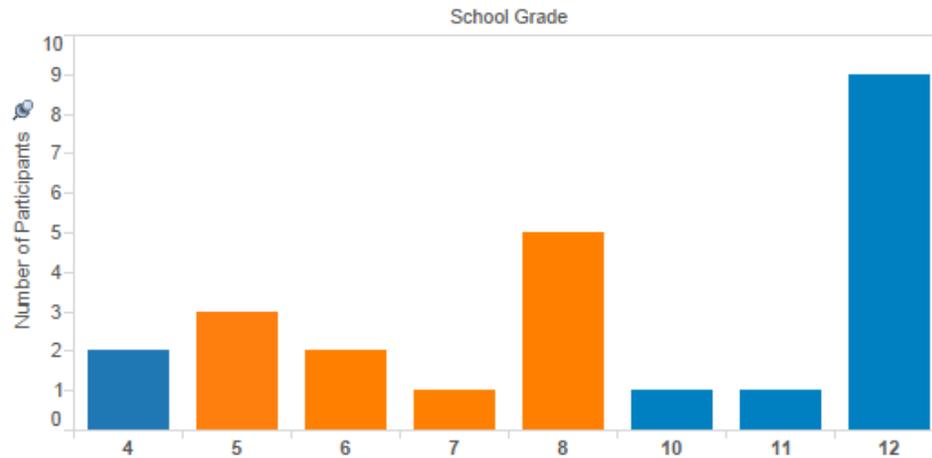


Figure 5-9. Participants demographics

All participants admitted they had no idea about their family monthly energy cost. They didn't care about their family electricity bills and they never thought about discussing the issue with their parents. All participants had a sense of which appliance in their homes used the most energy, though a few of them were unsure about their guesses. Of the 24 participants, 8 answered with "fridge" and 8 mentioned room temperature control devices (heater/air-conditioner). Almost all participants thought that appliances that they used most cost the most energy. All participants were able to name 2-3 actions that they might take at home to save energy (Figure 5-10). Among all the positive actions, the most commonly answered were: "turning off lights when leaving the room or when the daylight is bright enough", which was mentioned by almost all participants except one, and "unplugging appliances not in use", which was brought up by 9 participants. Other conservation actions mentioned included "washing with cold water", "turning off unused appliances", "watching less TV", "using less heater", etc.

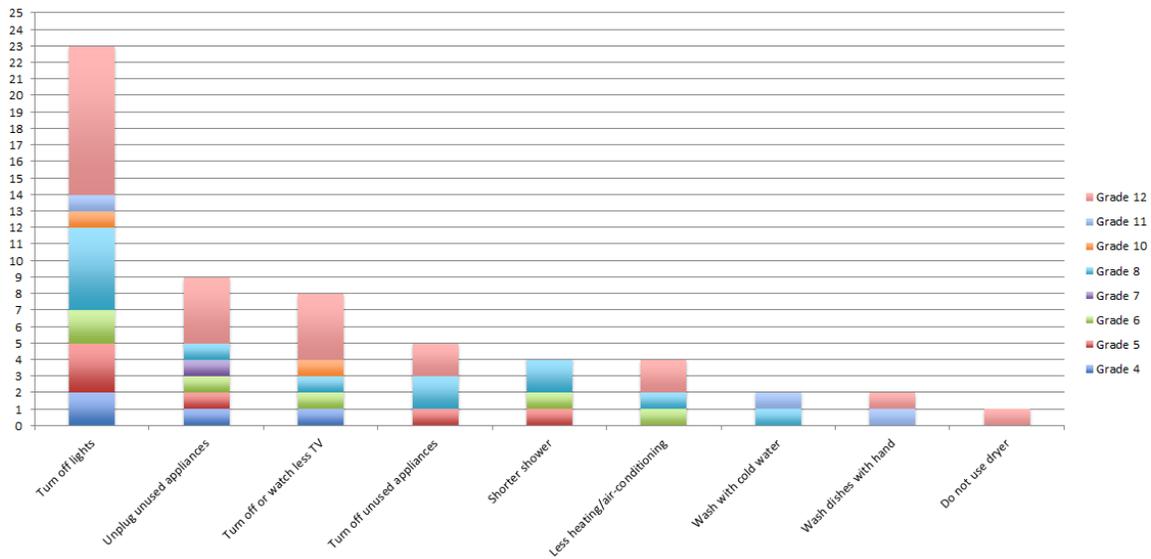


Figure 5-10. Conservation activities mentioned by participants, number of mentions stacked by grade

5.3.2. Game Performance

Participants

Figure 5-17, Figure 5-18 and Figure 5-19 below illustrate game performance for each game story by the individual participant in terms of the actual game score, user perceived game score and the difference between the two (delta). The figures show that variance exists among participants for all three types of data, but the data is still roughly considered as normally distributed (see Appendix B-3 for detailed statistical distribution analysis).

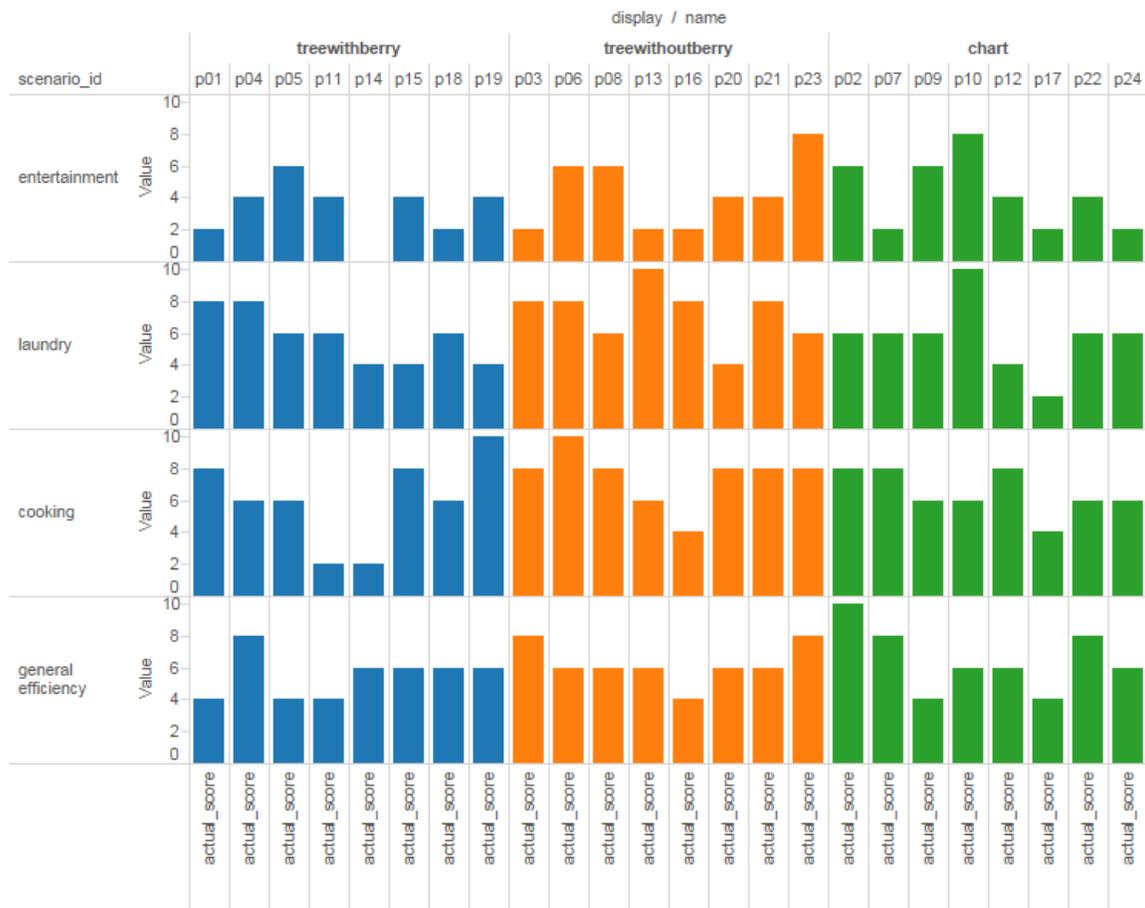


Figure 5-11. User Actual Game Score by Participants

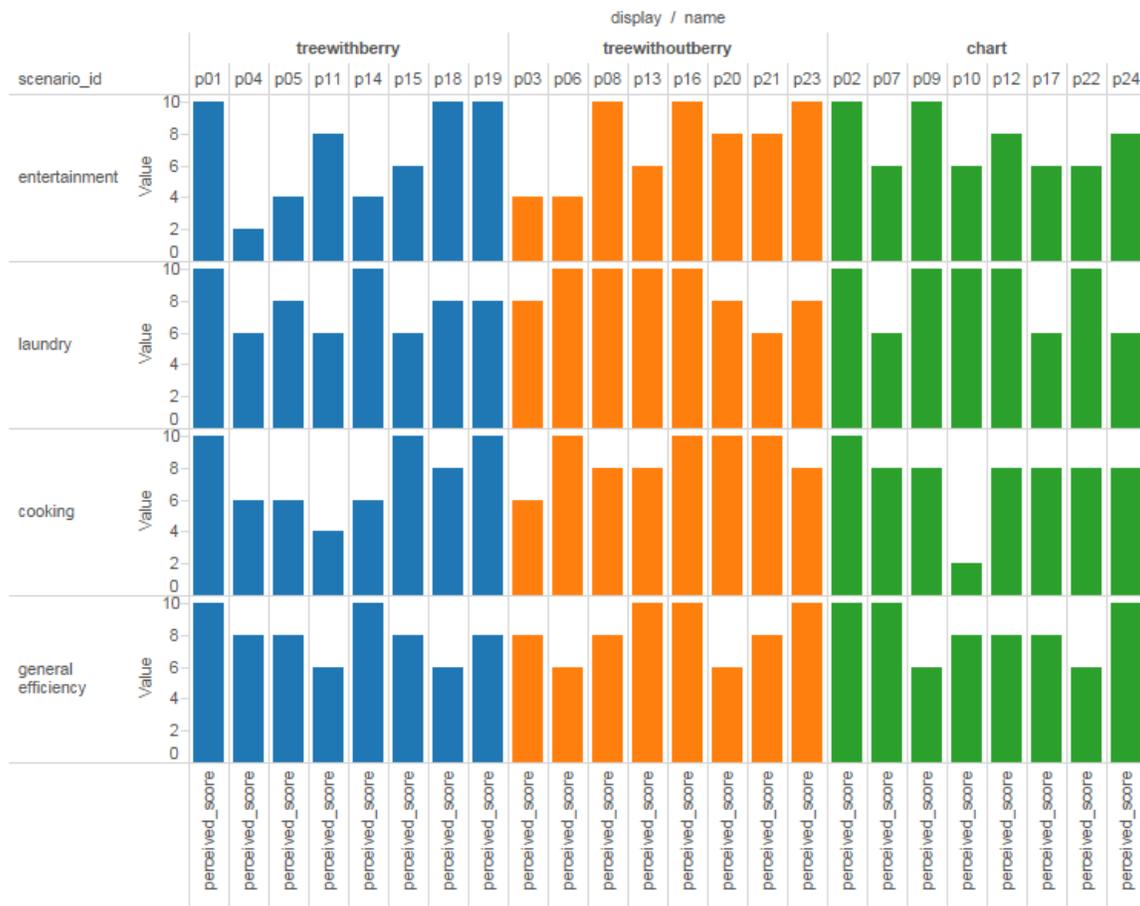


Figure 5-12. User Perceived Game Score by Participants

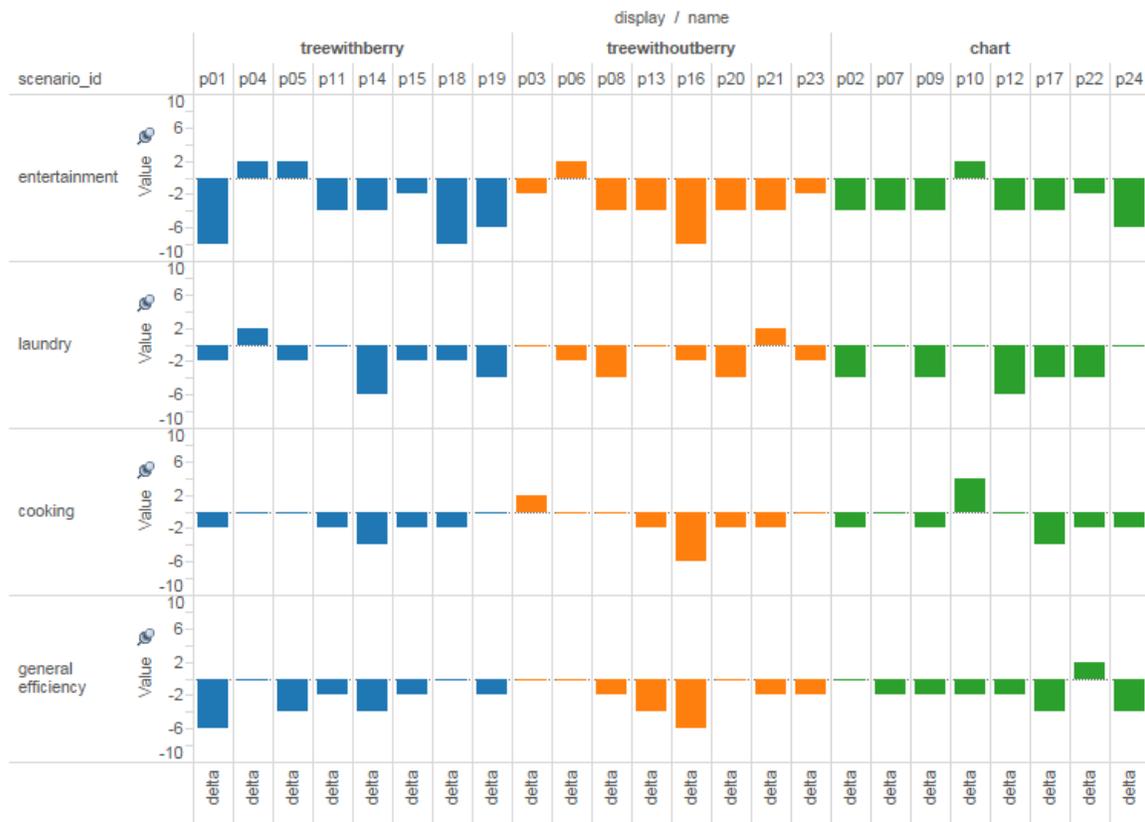


Figure 5-13. Delta (actual score – perceived score) by Participants

Tasks

Scores (both actual and perceived) varied greatly for each game task. Figure 5-14, Figure 5-15 and Figure 5-16 show that participants did best with “lighting” “turn off unused appliances” and “wash yourself” and they also perceived themselves to have done best in those tasks too. This result indicated that participants had firm knowledge of saving energy with those actions. Participants’ actual scores were low in “unplug unused appliances” (including “Heat milk”, “play games” and “watch movies”) and “fridge setting”. However, they didn’t seem to realize their poor performance in those tasks as they rated themselves to be much higher (large negative delta values shown in green). Relating to our last pre-session interview question, although “unplug” was mentioned by many participants as one way towards energy conservation, it wasn’t done in practice in this simulation game. As for “fridge setting”, most children were unfamiliar with it and they said that it wasn’t something they would normally consider.

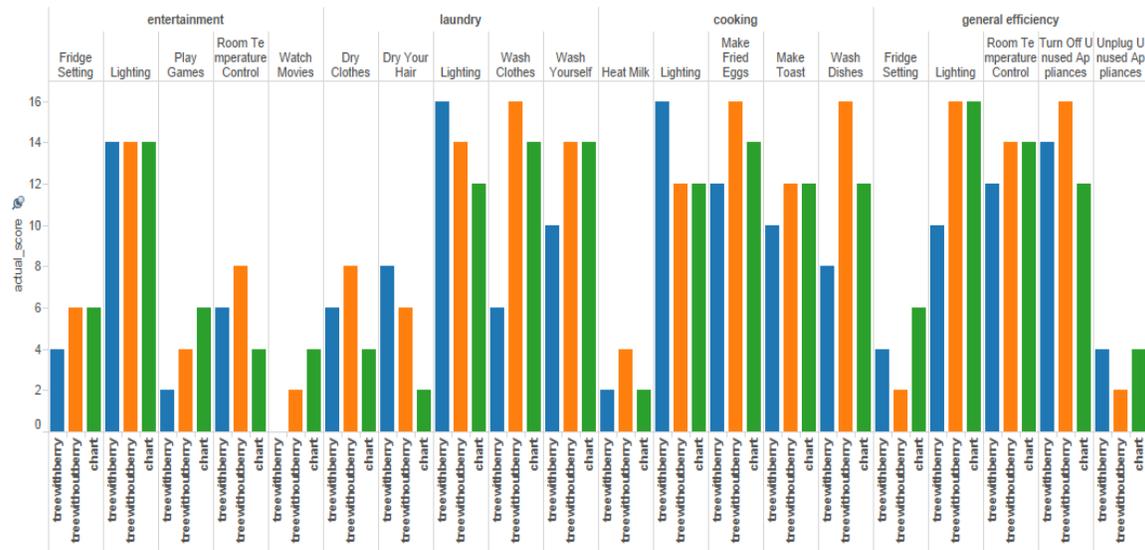


Figure 5-14. User Actual Game Score by Tasks

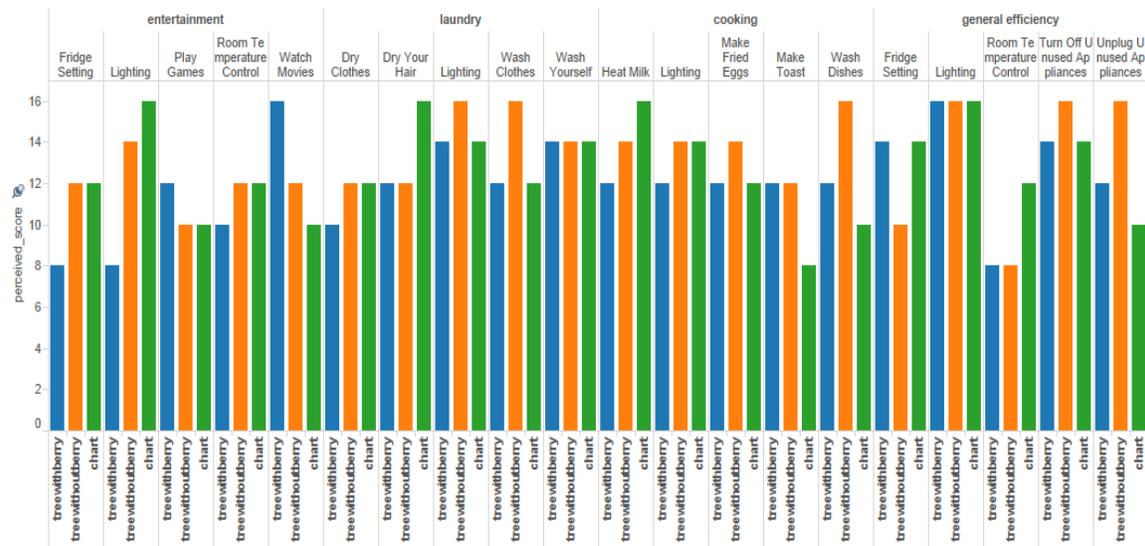


Figure 5-15. User Perceived Game Score by Tasks

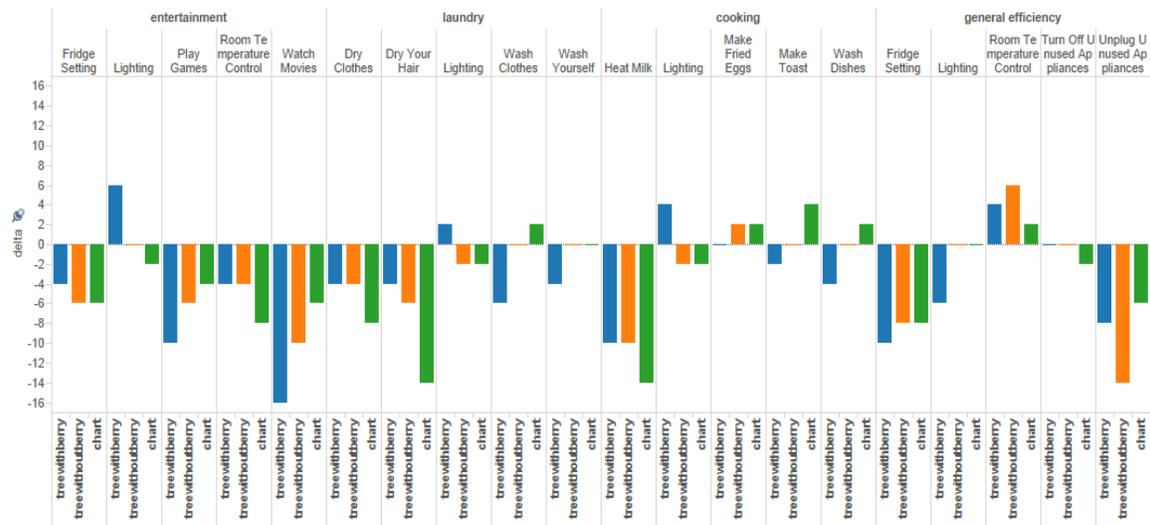


Figure 5-16. Delta (actual score – perceived score) by Tasks

In general, participants were able to correctly complete most of the game tasks and they always considered themselves to have done better than they actually did. The gap here offered a great opportunity for the participants to learn what was the right thing to do from the game feedback. Figure 5-14, Figure 5-15 and Figure 5-16 also reveal that there wasn't much difference among the different visualizations, as scores (both actual and perceived) for each game task was pretty similar across the three.

Game Stories

Figure 5-17, Figure 5-18 and Figure 5-19 show the scores for each game story in the same order participants were asked to complete them (from left to right). The actual score showed that participants did better as they progressed through the stories except the last one, for which a few of them had difficulty understanding the story description. Similarly, although for all stories, participants perceived themselves to have done better than they actually did, the differences got smaller as they progressed through the stories except the last one. This trend suggested that participants tend to have better understanding of the game as they progressed through and think more about energy conservation while completing the tasks.

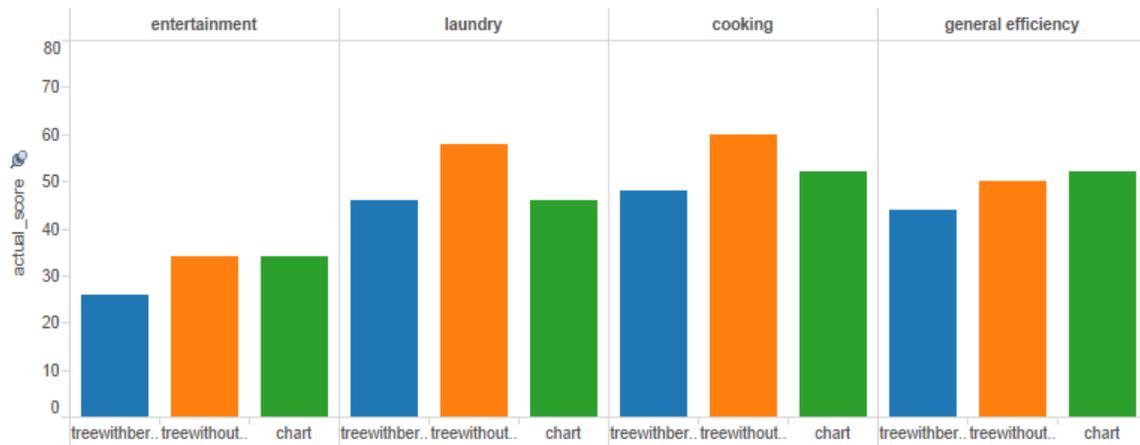


Figure 5-17. User Actual Game score by story



Figure 5-18. User Perceived Game score by story

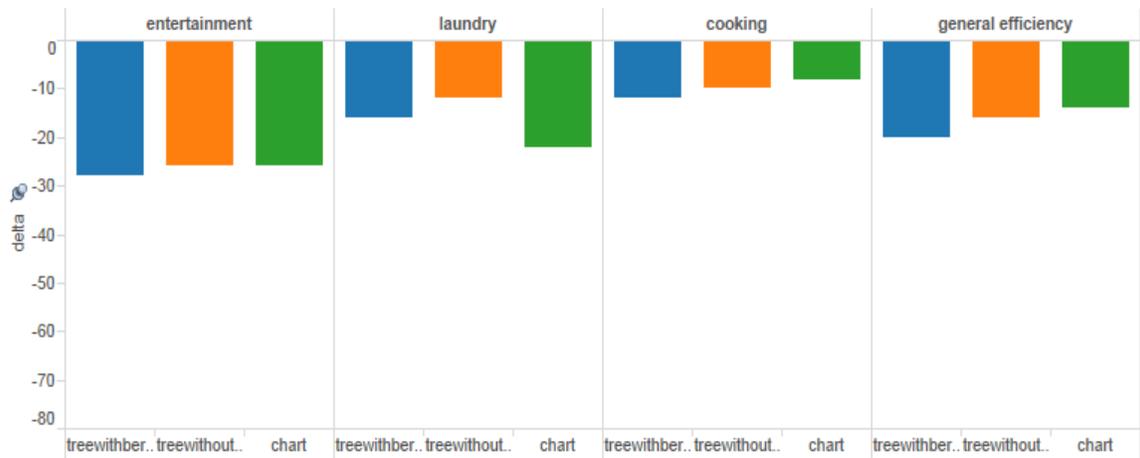


Figure 5-19. Delta (actual score – perceived score) by story

Visualizations

One of our major interests in this research was to find out if there existed any difference among participant groups. Unexpectedly, the results were relatively even. As illustrated in Figure 5-20, participants who saw the “TreeWithoutBerry” display scored highest in the game, but the difference was small across all three visualizations.

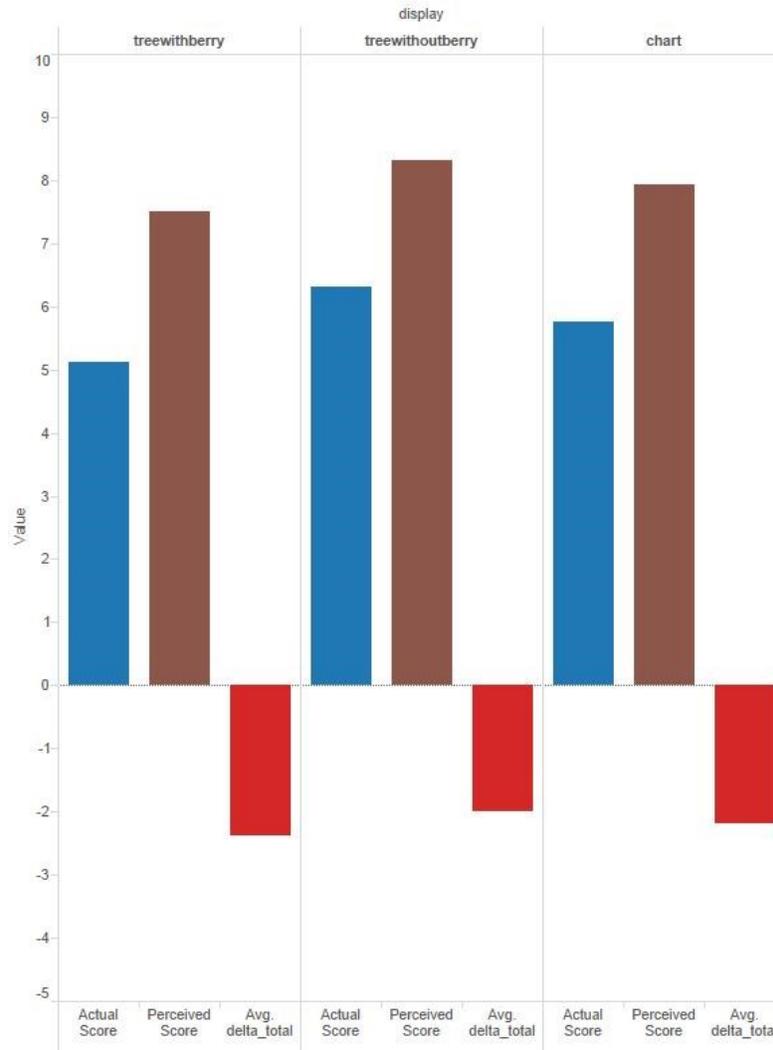


Figure 5-20. Game Score by visualizations

Learning Effect

As mentioned, all participants were asked to complete the game stories in the same order: Entertainment → Laundry → Cooking → general Efficiency. This was a limitation from the perspective of experiment design because participants tended to

exhibit better performance as they went through and it would be unfair to compare the difficulty among tasks or game stories. The technique of counterbalancing could have been applied to compensate this issue, however, the learning effect was what we expected and were interested in examining in this study. As presented in the previous section (Section - Game Stories), participants performed better as they progressed through the stories. This in a way showed that the explicit feedback provided in the game did help participants reflect on their actions and make better decisions. Such learning effect was more evident in tasks that got repeated across multiple game stories (see Figure 5-21, Figure 5-22, Figure 5-23, Figure 5-24 and Figure 5-25). The figures showed that for all three visualizations, participants did better when they encountered the same task they had done before (only with few exceptions). And this was particularly true for the task “Room Temperature Control”.

Another factor that affected the learning effect was the imbalance in showing the types of data. Summarized in Table 5-3, both tree visualizations showed only the energy data for individual appliance while the bar chart showed both power and energy data for each appliance. The more adequate data had clearly made a difference in improving participants’ understanding. As illustrated in Figure 5-17, participants who saw the bar chart visualization had scored slightly higher in some game stories (entertainment and general efficiency) than those who saw the tree visualizations. Also in Figure 5-21, Figure 5-22 and Figure 5-25, we saw that participants had better performance in repeated tasks, indicating better learning results.

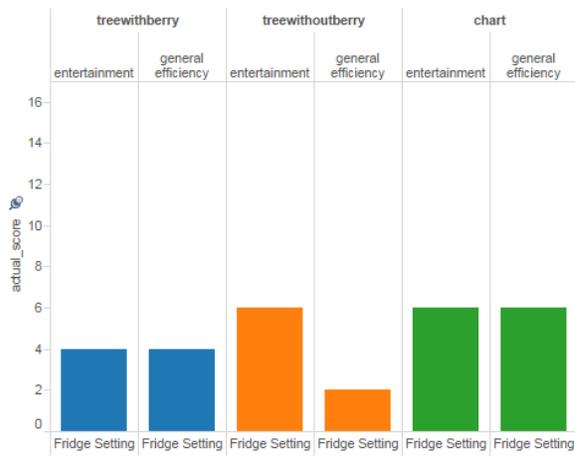


Figure 5-21. Fridge Setting

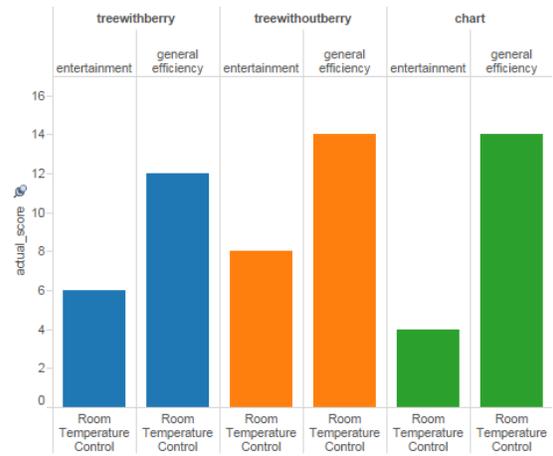


Figure 5-22. Room Temperature Control



Figure 5-23. Lighting

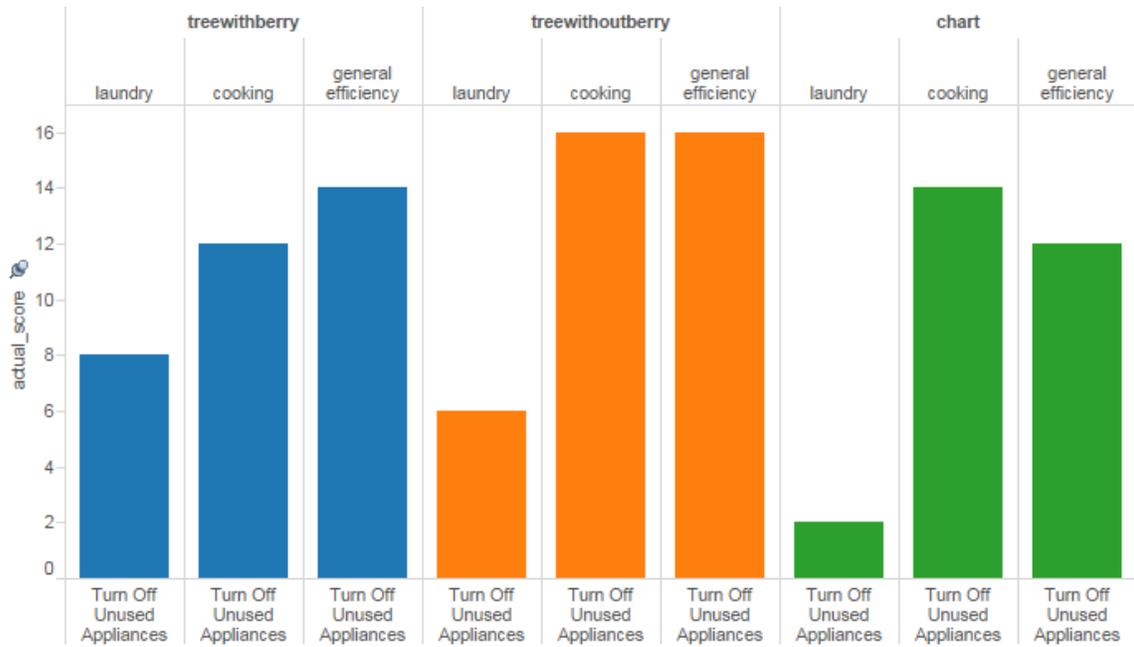


Figure 5-24. Turn Off Unused Appliances

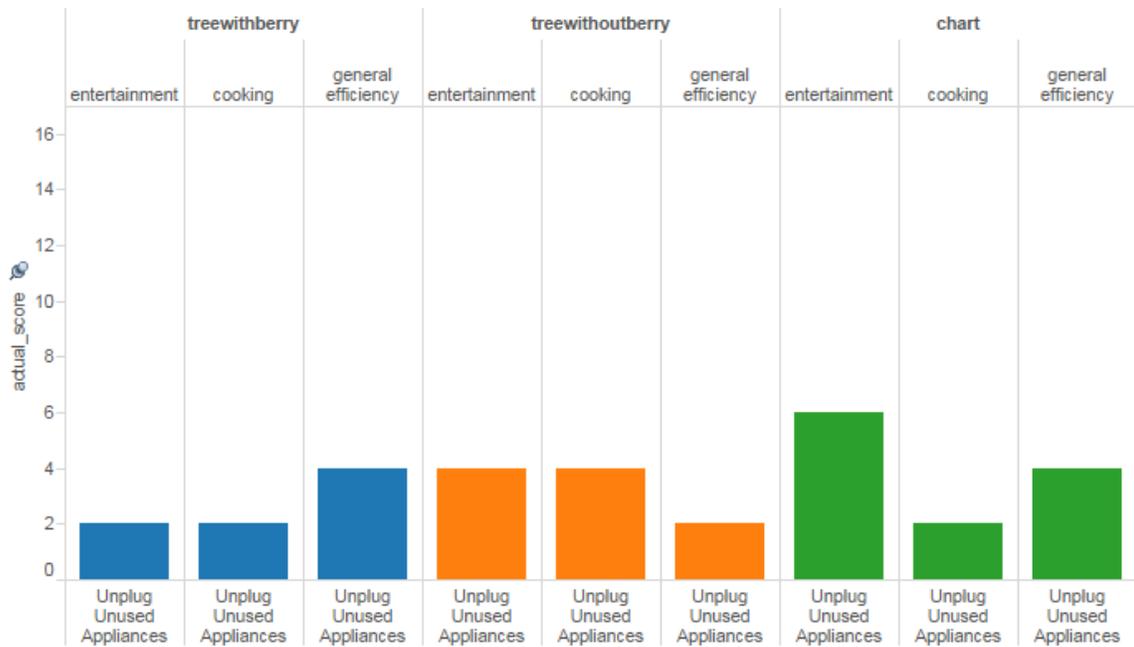


Figure 5-25. Unplug Unused Appliances

5.3.3. Game Logs

A game log is a record of a participant's interaction with the game interface, i.e., an action on a certain appliance to turn it on, off, or unplug. The number of the game logs was an important aspect to be analyzed in this study as it indirectly indicated how much effort participants spent on the game or how much interest participants had with the game installations (the dollhouse and the corresponding visualization). The more logs showed the more trials participants did during the game, which was either caused by more effort participants needed to complete the game tasks or by more curiosity that participants had to explore the game.

Appliances

The game logs showed significant difference among the number of times participants interacted on different appliances (Figure 5-26). The lights were the most clicked appliances. Unsurprisingly, they were required in all four game stories. Other appliances with higher clicks were the dryer, fridge, oven, air-conditioner, TV and Xbox. Two possible reasons were concluded from this finding: first, appliances such as the light, dryer, oven and air-conditioner that had more obvious changing effects upon interaction either in the dollhouse (light) or in the display (larger leaves or higher bars), tended to cause the interest of the participants to explore them more; second, participants were more interested in appliances that were familiar to them in real life such as the TV and Xbox and were curious to know how they appeared in the dollhouse and the visualizations. A more concrete example to this was the computer, which had a lot of clicks even though it was not asked in any of the game stories.

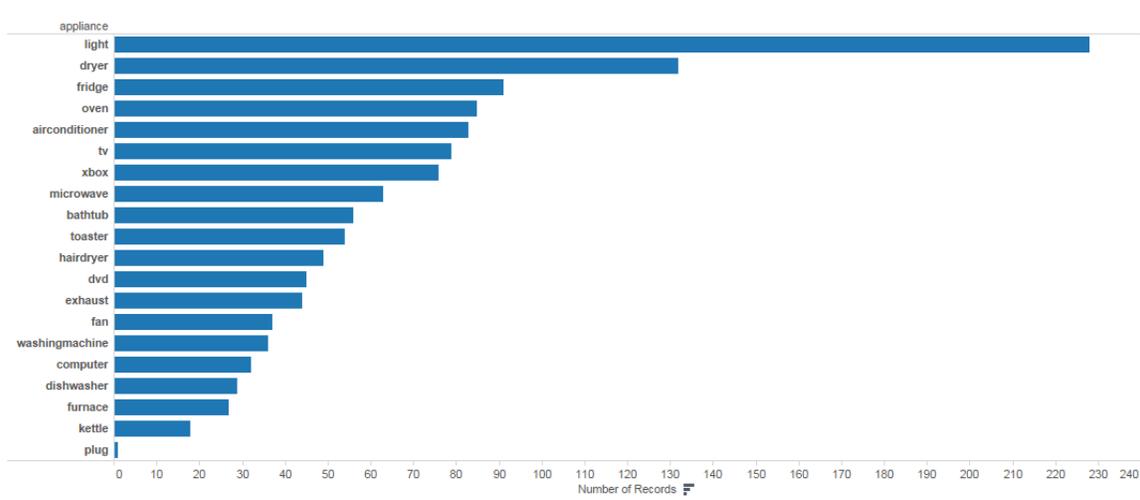


Figure 5-26. Number of game logs by individual appliances

Figure 5-27 takes a more detailed look at the number of game logs on individual appliances by the type of the visualizations. Notably, Participants who saw the “TreeWithBerry” display had higher clicks on the dryer, bathtub, air-conditioner and fan, probably because these appliances gave them the opportunities to get berries in the tree. As a result, the berry representation did cause interest of the participants, engage them more and have the potential to encourage more energy conservation actions.

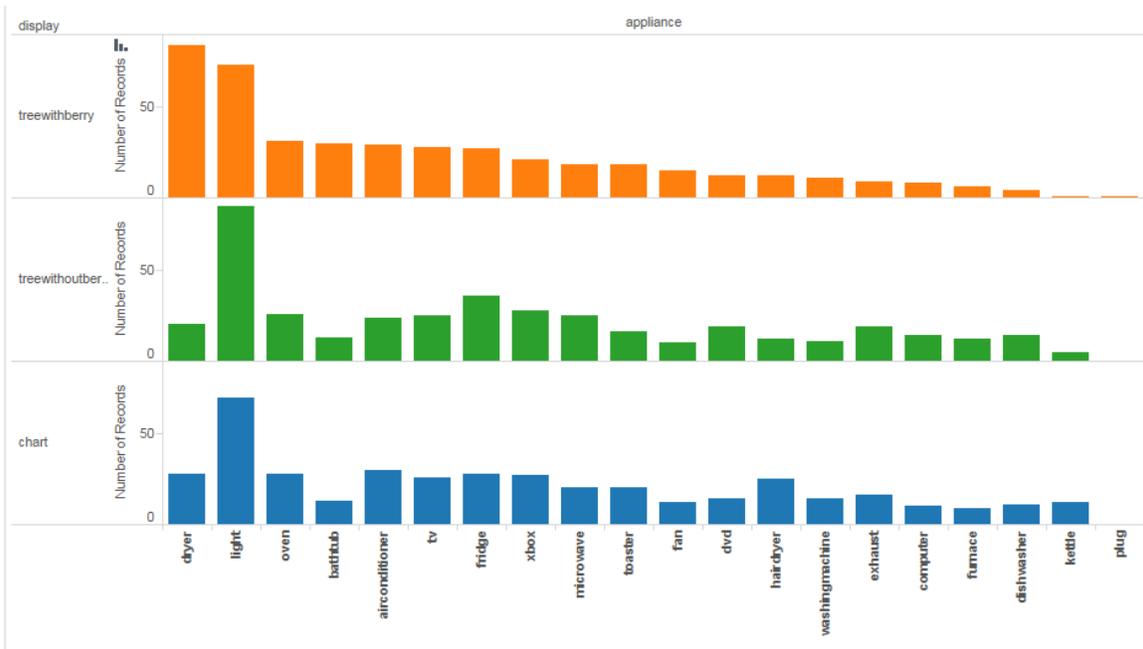


Figure 5-27. Number of game logs by individual appliances separated by visualizations

Logs in General

More logs were found in the first game story than the others (Figure 5-28). As expected, when participants first started the game, they would spend more effort figuring out how to complete the game tasks, which resulted in more trials. Also this was when they were most curious about the game installations and would click on various appliances to discover what might happen even if those appliances were not asked in the game story. Additionally, participants who saw the “TreeWithBerry” visualization had most clicks on the appliances (Figure 5-29), but the difference was not significant across all three visualizations.

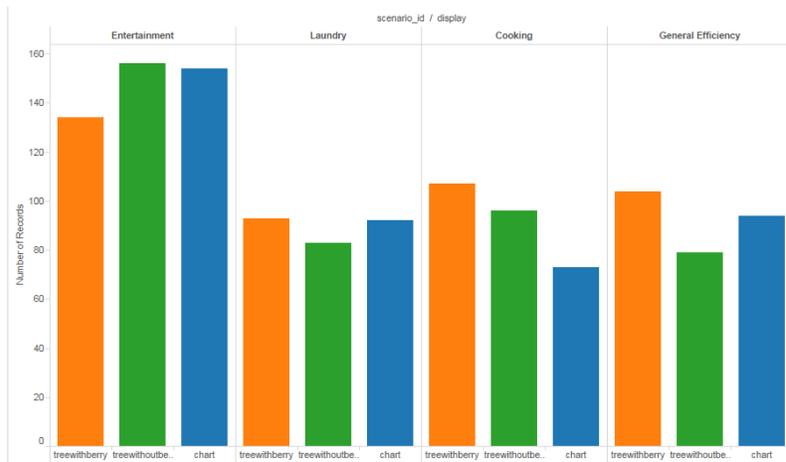


Figure 5-28. Number of logs by game story

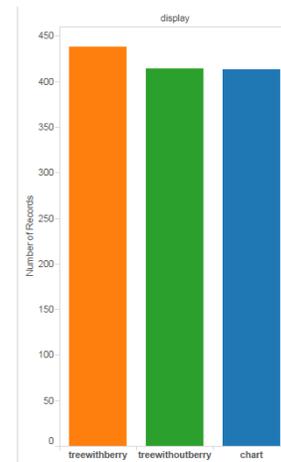


Figure 5-29. Number of logs by visualization

5.3.4. Impressions on Visualization Design

Participants rated the visualization they were exposed to on four different criteria (appealing, attractive, interesting and easy to understand) on a 5-point scale as shown in Figure 5-30. Over half of the participants (15 of 24) agreed or strongly agreed that the visualizations was appealing, 4 of the 24 participants rated it as Neutral, and 5 of them disagreed or strongly disagreed that the visualizations was good-looking. Of those who disagreed on the criteria, 3 were assigned to the Bar Chart visualization. Half of the participants (12 of 24) agreed or strongly agreed the visualization they saw was attractive, among which 9 of them were exposed to the Tree one. Accordingly, most of the neural and negative voices lied in the Bar Chart group. The majority of the participants thought the visualizations were interesting (4 Neutral and 2 Disagree). Similarly, 18 of 24 agreed or strongly agreed the visualizations were easy to understand. Others chose Neutral and only one in the Bar Chart group disagreed with the criteria. Interestingly, as illustrated in Figure 5-30, participants' performance in the game didn't affect how they rated their impressions on the visualizations. For example, one participant (p14) scored low in the game but still rated the visualization as appealing, attractive, interesting and easy to understand, whereas another participant (p02) had

high score in the game but disagreed that the visualization was appealing, attractive or interesting.

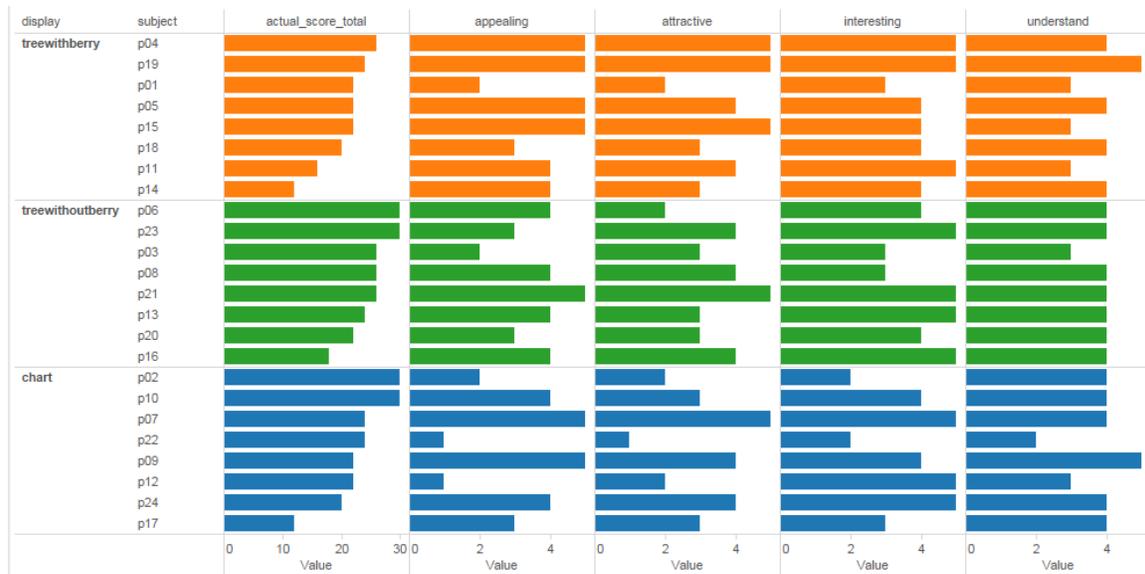


Figure 5-30. Participant's individual impression on visualization vs. their actual game scores

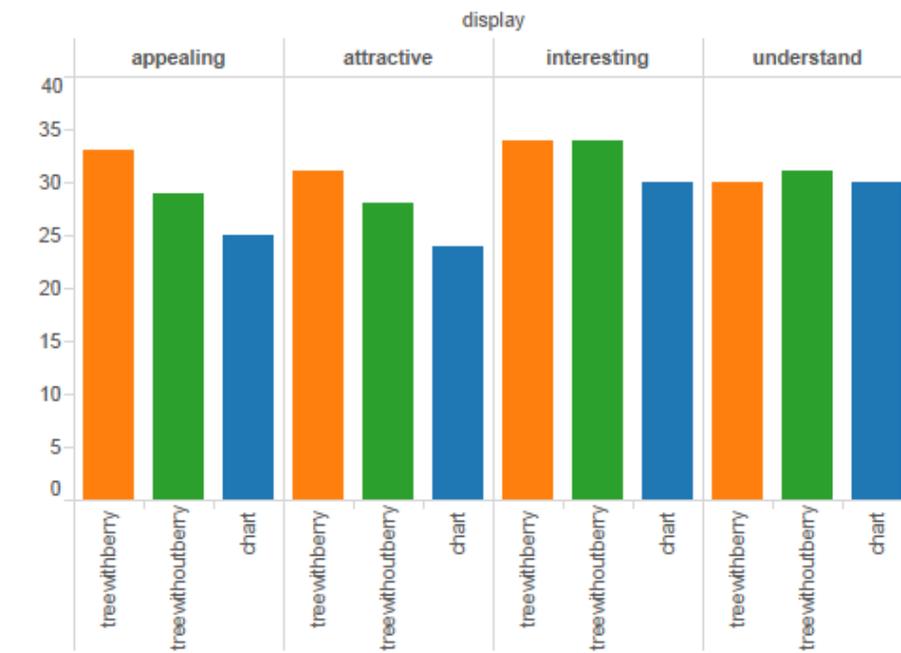


Figure 5-31. Participants' impressions on different visualizations

Figure 5-31 gave a more general perspective of the participants' impressions on the three visualizations across all four criteria. The aesthetic visualizations ("TreeWithBerry" and "TreeWithoutBerry") were thought to be more appealing, interesting and attractive than the pragmatic one (Bar Chart). Particularly, the berry made the tree visualization even more interesting and appealing. In terms of comprehension, all three visualizations were thought to be somewhat easy to understand with a similar average score around 3.5, which was between Neutral and Agree.

5.3.5. Preferences of Location at Home

All participants would like to have the visualization in their homes as all of them selected at least one room as their preferred location to place the visualization (Figure 5-32). The most common rooms indicated as locations for the visualization were the living room (16 of 24) and the kitchen (12 of 24). The bedroom and mechanic room were also preferred by a few participants as sites to place the visualization. Interestingly, all rooms provided on the questionnaire were chosen by at least one participant and many participants were willing to place the visualization in multiple rooms at home (9 of 24 selected more than one room).

As a further analysis on comparisons of the three visualizations in terms of location preference, Figure 5-33 indicates that all visualizations were preferred in a variety of rooms in the home. The Living room and the kitchen were most preferred for all three visualizations. Especially, almost all participants would like to have it in their living room except the one who saw the "TreeWithBerry" visualization.

This finding was very similar to what Rodgers and Bartram (2010) found with their ambient and artistic visualizations of point-of-consumption energy use feedback. Both showed that people had the desire for having some sort of energy use feedback in their homes to keep them informed, regardless of its form. And they preferred to have them in high-traffic places where they spent the most time and used the most energy, especially the living room and the kitchen. They also would like to have them in multiple rooms in their homes.

display	subject	bathroom	bedroom	kitchen	laundry	livingroom	mechanics	outdoors
treewithberry	p01					■		
	p04		■	■	■	■	■	
	p05		■	■	■	■	■	
	p11			■		■		
	p14			■		■		
	p15		■	■		■		
	p18		■	■		■		
	p19					■		
treewithoutberry	p03			■		■		
	p06			■				
	p08			■				
	p13			■		■		
	p16			■		■		
	p20							
	p21	■	■	■	■	■	■	
	p23						■	
chart	p02							■
	p07					■	■	
	p09			■				
	p10		■	■		■		
	p12		■	■		■		
	p17					■		
	p22					■		
	p24	■		■	■		■	

Figure 5-32. Individual preferences of location at home

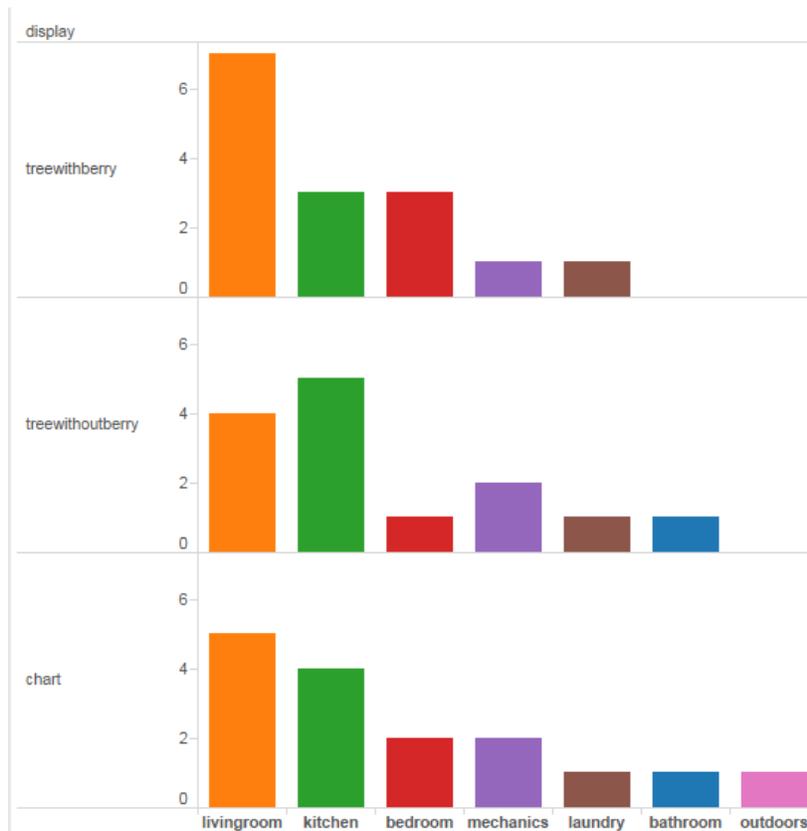


Figure 5-33. General preferences on location at home across three visualizations

5.4. Discussion

Our findings, to various extents, directly or indirectly referred to our research questions. We have explored the utility of the visualizations in the context of a simulated game environment and collected data of the participants' game performance, impressions on visualization design and preferences of integrating the visualization tool into their homes. The energy conservation game turned out to be quite fun and engaging. Participants got very focused during the game session and tried hard to explore everything that might cause changes in the game installations. Most of the times, participants tended to over rate their performance in the game and the provided feedback and conservation advice offered them a chance to reflect on their own actions.

In terms of our first research question, all three visualizations proved to be effective as feedback for home energy use. This was indicated by the game performance results that participants seeing different visualizations were all able to complete the game tasks with moderate scores and there was no significant difference among the three groups. The real-time feedback of the visualizations helped participants immediately link the effects to their actions and let them give a thought on what they should and should not do the next to score higher. As a matter of fact, this was what we expected as effects on decision-making. Additionally in the follow-up questionnaire, all three visualizations were rated as easy to understand. Comprehensibility was the key to visualization design regardless of its form and was the basis for it to serve its function. However, the aesthetic visualizations ("TreeWithBerry" and "TreeWithoutBerry") were considered to be more appealing, interesting and attractive than the pragmatic one (Bar Chart). When participants were shown all three visualizations at the end of the study, almost all of them expressed preference on the "TreeWithBerry" one as they thought "getting berries" was an interesting feedback to their positive actions and the berries made the tree more aesthetically appealing. Only one participant preferred the Bar Chart the most, but no specific reason was given.

Much to our unexpectation, the explicit representation of positive actions (the berries) didn't affect participants' performance in the game. Although, our results showed that the "berry" was preferred by most participants and indeed drew more attention during the game (with more game logs than others), it didn't make a difference

in leading to more energy conservation actions. However, our study design was very limited to fully answer this question because research on people's behaviour change would require longitudinal studies in real-life settings (Skog, 2006).

Our results also indicated the viability of the visualizations, especially those designed using the aesthetic visualization approach, to serve as feedback for residential energy use. All participants were willing to have it somewhere in their homes, and many of them would even like to have them in multiple rooms (Figure 5-34). Back to our first pre-session interview question, all our participants had no idea about their family electricity use and had no intention to read the energy bills. In other words, they were not exposed to any form of energy feedback in their house, nor were they ever interested in any existing feedback that was available to them. This made our approach to energy feedback a promising method to bring home energy information to our children and help them get a sense of how energy was consumed in their everyday life and what they might do to contribute to energy conservation.



Figure 5-34. Sample in-home placement of the display

Referring to our last research question, the simulation game proved to be useful both as a testing platform and an experiment itself to help us gain more insightful

findings of how people understood energy conservation in their homes. With this realistically representative simulation, we were able to draw more information than a pure interview and discover the great gap between participants' self-perceived understandings of energy conservation at home and their actual performance. For example, quite a few participants mentioned "unplugging appliances not in use" as one way to save energy, but in the simulation game, few of them actually did that. The game turned out to be a useful tool to help them realize and bridge this gap as we saw apparent improvement as they progressed through the game stories. This also led to another finding that was not quite anticipated in our hypotheses - the game could be a helpful tool to tease out and elicit where people did not understand or remember about energy consumption in their homes.

To summarize, all three visualizations proved to be effective as feedback for residential energy use. Particularly, the two aesthetic visualizations appeared to be more engaging and attractive to children. It is very promising that it will be an interesting tool to help our future generation raise their awareness of home energy use and promote more behaviours towards energy conservation. However, this requires future studies that involve long-term evaluations within real-life settings. Besides, the game itself proves to be a useful experiment to elicit participants' perceived understandings of energy conservation as compared to their actual performance. Such findings are valuable in the future design practice as they serve as references for what the visualization should address on.

Finally, in terms of design hints, although the above three visualizations are merely conceived as research instruments rather than final products to be evaluated, their design process shares us with valuable experience and inspirations. Showing the right data is important in helping people better understand the situation. For example in this research, both power and energy data should be addressed to improve participants' knowledge of energy use for each household appliance. Aesthetics is a key issue to be considered in such kind of visualization provided that comprehensibility is well maintained. The design of aesthetic visualization is a process of trial and error, during which sketches and software prototypes are useful to explore various design ideas and alternatives. Sketching is important because it "works as a tool or technique useful for communicating with other designers and with customers as it provides a shared

language which has no equivalent in ordinary, spoken language, but which allows designers to express themselves” and it is “a way of shaping new ideas” (Fallman, 2003). Finally, the abstract art makes an important source of inspiration because they are visually fascinating and can remain peripheral to one’s attention while sustaining interest over time.

6. Conclusion and Future Work

In this research, we have discovered the preliminary evidence that the aesthetic visualization approach is a promising alternative to the provision of feedback for consumer energy use. With two experimental investigations, we explored the effectiveness and utility of the approach focusing on different aspects. In the first study, we laid the groundwork for proving that aesthetic visualization had the advantage of engaging people with visually fascinating displays while maintaining comprehensibility and supporting at-a-glance awareness. We quantified comprehensibility into two statistical measures: accuracy of user interpretation and time required for the interpretation. And we evaluated it using a quantitative method. We further reported that aesthetic visualization was effective as an approach to energy feedback because it had the potential to affect sustainable decision-making. This was evidenced by our second study in which visualizations were tested through real usage via a simulated real-life environment. We took a design-oriented research perspective (Fallman, 2007) with mixed evaluation methods. In both studies, we compared aesthetic visualization to pragmatic visualization (standard bar chart) and proved that aesthetic visualization had slightly better performance than pragmatic visualization in terms of basic functionality. However, the aesthetic visualization was much more favoured by the users (especially children) and considered to be more interesting and engaging. We suggest that aesthetic visualization should be considered a promising approach to consumer energy feedback that enables informed decision-making. With regard to design issues in this space, we address on balancing aesthetic interest with usefulness and transferring user attention from highly attentive to peripheral (Skog, 2006).

6.1. Research Questions Revisited

As a review to our research discussed in this thesis, this section summarizes the research questions in the two studies separately and concludes with implications and recommendations these studies have established for future reference.

6.1.1. Study 1

A feedback tool needs to be understood before it can be effective to serve any other purpose. Our major research question in this study is to explore - whether aesthetic visualization, with its aesthetic appeal, still maintains comprehensibility and whether this added aesthetic value assists users better understand the information. We compared two aesthetic visualizations in different styles to a pragmatic visualization and confirmed our hypothesis that they were as easy or slightly easier to comprehend than pragmatic visualization with statistical measures. Specifically, we took a detailed analysis at each individual graphical element in the visualization to find out which one worked or did not work. Our findings showed that graphical representations, which were conceptually related to the information represented, did add ease to the comprehensibility. For example, the “battery” representing the energy level well supported at-a-glance awareness as users were able to quickly and accurately tell how much energy was currently left in the bank. Whereas the color coding of the solar panel, also representing the energy level, failed to serve its purpose as most users didn’t get its meaning. This suggests that for the graphical representation to be useful and provide insights, not only aesthetics should be concerned, but also the way information is represented.

In addition, we questioned in the study whether users would have higher ratings for aesthetic visualizations with respect to readability, attractiveness and at-a-glance awareness based on their general impression. Our assumption was partially approved that the superiority in attractiveness and support for at-a-glance awareness somehow made aesthetic visualizations lose readability as compared to pragmatic visualization because details such as headings, legends and numbers were omitted for aesthetic reasons. This leads to the dilemma: whether it is more important to communicate a concern or focus more on detailed analysis. Finally, we collected user polls on where

they would like to place those visualizations. The results varied for different visualizations and indicated that designs for such kind of feedback was context-sensitive, but overall people liked the idea to have them in their everyday lives.

6.1.2. Study 2

We extended the research to further examine the effectiveness of aesthetic visualization in practical use within a simulated real-life environment. Research questions around “effectiveness” transferred its focus from comprehensibility to whether it had the promise to lead to sustainable decision-making. Again, we compared that to a pragmatic visualization. The results of our simulation game in which users were asked to make decisions didn’t show significant difference between aesthetic visualization and pragmatic visualization. While the game logs revealed that users who saw the aesthetic visualizations showed more interest in trying out things with sustainable options, especially those who saw the one with explicit representations for positive actions. In addition to this, we reported the effectiveness of aesthetic visualizations based on higher user preferences in the criteria of easy to understand, appealing, interesting and attractive. However, the evidence wasn’t strong enough to fully answer our research question in terms of decision-making. According to Skog (2006), this requires longitudinal in-situ studies for more comprehensive and valid evaluation.

Similar to our previous study, we also collected user preferences on where they would like to have those feedback tools in their life, particularly in their homes. In contrast, we believed user decisions in this study to be more mature and justifiable because users had real use experience with them and the visualization designs were specifically targeted at users in their age group. The positive results indicated the viability of using aesthetic visualization as feedback for residential energy use.

Additionally, the simulated testing environment - the Energy Conservation Game itself turned out to be a useful tool to help us better understand participants’ knowledge of home energy conservation. It exposed the gap between participants’ self-perceived understandings of energy conservation at home and their actual performance. Participants always over rated themselves to have done better than they actually did, indicating missing knowledge of their own behaviours. For example, quite a few

participants mentioned “unplugging appliances not in use” as one way to save energy, but in the simulation game, few of them actually did that. These findings may not directly link to issues discussed in this research, but they are important hints to be considered in future feedback designs in this space.

6.1.3. Design Implications

The two studies verified the effectiveness and utility of aesthetic visualization as an approach to energy feedback in two stages. Our preliminary results showed that the approach had good potential within two specific use contexts, inferring more general design considerations for this type of feedback to be effective from these two instances.

First, showing the right data is important in helping people better understand the situation. The right data refers to not only the preciseness of the data, but also the relevance of the data – what should be presented and to which degree. For example in our visualization design for residential energy use, both instant power and cumulative energy data should be addressed for each household appliance to improve participants’ knowledge of their energy use. More generally, the data should be relevant to consumer understanding and perception of energy. As mentioned in introduction (The Problem1.1), individual consumers think of energy in three ways: as a commodity, a basic human need and an ecological resource (Darby, 2001). Therefore, when representing energy data to consumers, it should fit in one of their expectations of what energy is to them. For example, it is good idea to visualize the energy price, how it powers household appliances and how it relates to GHG emissions, but it might be pointless to present energy to them in physics illustrations.

Second, aesthetics is a key issue to be considered provided that comprehensibility is well maintained. This includes how we balance aesthetic interest and readability concern, as Kosara (2007) states they lie on the opposite ends of the “sublimity” scale. Our main goal is to provide at-a-glance awareness of energy use and to inform and engage people with rich and interesting display. To achieve that, special thoughts should be put on what kind of graphical elements to choose and how to map them to the underlying data. Our experience shows that graphical representations that are conceptually related lead to better comprehension. More importantly, it should be

appropriate to the targeted audience and context. For example, children are interested in more abstract and cartoon-looking representations like our tree design and standard charts look too serious to be integrated into the home environment.

Finally, the design of the aesthetic visualization is a process of trial and error. Software prototypes are fast and useful ways to try out different design ideas. Their flexibility allows us to quickly generate various alternatives and compare them in parallel. There's no absolute answer to issues like color choices and size mappings, all have to be tested out with comparisons. Besides, all user opinions and preferences are valuable, however, they may be diverse and conflicting. Thus, the design should consider and satisfy the taste of the majority of the audience.

6.1.4. Summary

Both study 1 and study 2 have provided positive answers to the research questions explored. And we conclude that the aesthetic visualization is able to maintain comprehensibility while better engaging people with its rich and interesting display and has the potential to support decision-making and learning. More importantly, we have received positive feedback from our test participants that they would like to have such visualization tool in real use. This suggests that the aesthetic visualization may be a promising and engaging tool to help raise consumer awareness of energy use and promote more behaviour towards energy conservation.

6.2. Contributions

We situate this work within the broader subject of sustainable HCI discussed in Section 2.2.1. Particularly, our research fits into the discourse described as sustainable interaction design (Goodman, 2009) and lies within the two genres of “persuasive technology” and “ambient awareness” (DiSalvo, Sengers, & Brynjarsdóttir, 2010). Inspired and motivated by various works within this field (Rodgers & Bartram, 2011; Bartram, Rodgers, & Muise, 2010; Holmes, 2007), our primary focus of this research is to motivate better decision-making through more effective feedback. As a result, this work makes contribution to evolving the exploration on Eco-visualization (Pierce, Odom,

& Blevis, 2008) and diversifying the trials on developing new eco-feedback technologies (Froehlich, Findlater, & Landay, 2010).

More specifically, this work leads to three critical outcomes in validating the effectiveness and utility of aesthetic visualization as a novel approach to the provision of consumer energy feedback. First, we have demonstrated that aesthetic visualization is able to maintain its comprehensibility while better engaging people with its richer and more appealing representations. Second, we have shown that aesthetic and depictive visualization has the potential to support decision-making and learning. Although the proof here is quite preliminary, it is evident enough to foster long-term field studies to further evaluate its feasibility. Finally, we have unveiled the promise and viability of its utility in real-life settings through two mixed methods user studies. We have received high user preference ratings, positive attitudes and comments towards having the aesthetic visualization feedback in everyday use.

Furthermore, the work contributes to design concerns of developing effective energy feedback tools with detailed examinations of several of our prototypes. We have arrived at a conclusion that aesthetics is an important issue to consider in this design space because it draws user interest and assists at-a-glance awareness. Aesthetic visualization is flexible in its content with inspirations from various art works, however, it is context-sensitive and the selection of its visual representation should take serious concern of its working environment and audiences. Besides, we have drawn several key factors in this design space: first, the data being displayed should be relevant to people's understanding of the underlying problem and sufficient information should be provided to support people's awareness; and second, the displayed information should reveal real-time change so as to allow people to immediately relate their behaviours to energy use effects.

6.3. Future Work

We have emphasized several times in this thesis that our findings are preliminary and our work has laid only the groundwork for the provision of aesthetic visualization as feedback for consumer energy use. Thus, numerous opportunities are available for

future work to evolve exploration within this field, including long-term in-situ evaluation of its feasibility, further exploration of more general and completed design concerns within this space and development of variations or improvements to the approach.

Our work has revealed the promise of aesthetic visualization as an approach to energy feedback. With limitations in time and context, the current work is insufficient in reaching our ultimate goal of exploring whether this approach affects sustainable decision-making that results in behavioural change. Therefore, our next avenue is to conduct longitudinal field studies that will enable us to make more valid evaluations of these factors over time.

With detailed examination of our prototypes, we have drawn a few basic design implications within this space, but additional work is required to make that more comprehensive and completed as general design guidelines for developing such kind of feedback. Future work will expand current focus on balancing aesthetic and usability to embracing aesthetic as a required quality to supplement effectiveness and visual efficiency. We wish to arrive at some framework that will help identify the proper representation to be used in designing this kind of feedback based on use-context, from general graphical styles to more detailed features such as color choices.

With respect to design hints, we also want to explore what is the right data to represent to better support informed decision-making. For example, in this research, we saw that both power and energy information for individual appliance were important in improving consumer knowledge whereas the explicit representation of positive actions made little difference. Future work will continue to explore what information is important and how to effectively show it. As reviewed in the background study (Section 2.1.2 and Section 2.1.3), various interventions have proved to be useful in motivating behaviour change such as social influence. This opens possibilities for future research to explore whether integrating these different types of data into feedback design will add to its effectiveness.

Finally, our prototype design of aesthetic visualizations mainly followed the design requirements proposed by Rodgers & Bartram (2011). However, according to our interviews with users, variations or improvements may be made to the current design. For example, use of animations may be considered to add to the vividness of

the visualization and adding interactions may allow preference settings of the display to better customize individual user needs. This may conflict with the “ambient” requirement, but it is in fact a matter of how we control the “use of degree” and it can only be verified through trial and error.

References

- Abrahamse, W., Linda, S., Charles, V., & Talib, R. (2005 йил 12). A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology* , 25 (3), pp. 273-291.
- Accenture. (2010). Understanding Consumer Preferences in Energy Efficiency - Accenture end-consumer observatoryon electricity management 2010.
- Antle, A. N., Tanenbaum, J., & Macaranas, A. (2013). Games for change: Looking at models of persuasion through the lens of design. In A. Nijholt (Ed.), *Playful User Interfaces: Interfaces that Invite Social and Physical Interaction*. Springer.
- B.C.'s Ministry of Energy, Mines and Petroleum Resources. (2009). *The BC Energy Plan - A Vision for Clean Energy Leadership*.
- B.C.'s Ministry of Environment. (2009). *BC Climate Action Plan*.
- B.C.'s Ministry of Environment. (2009). *The Green Energy Advisory Task Force Report*.
- Bang, M., Torstensson, C., & Katzeff, C. (2006). The PowerHouse: a persuasive computer game designed to raise awareness of domestic energy consumption. *PERSUASIVE'06 Proceedings of the First international conference on Persuasive technology for human well-being* (pp. 123-132). Berlin, Heidelberg: Springer-Verlag.
- Bartram, L., Rodgers, J., & Muise, K. (2010). Chasing the Negawatt: Visualization for Sustainable Living. *IEEE Computer Graphics and Applications* , 30 (3), 8-14.
- BC Hydro. (2013). Smart Meters, Smart Choice. Retrieved 2013 йил 27-11 from BC Hydro: https://www.bchydro.com/energy-in-bc/projects/smart_metering_infrastructure_program/smart_meter_and_grid_technology/future_with_smart_meters.html
- Becker, L. J. (1978, 8). Joint effect of feedback and goal setting on performance: A field study of residential energy conservation. *Journal of Applied Psychology* , 63 (4), p. 428.
- Cawthon, N., & Moere, A. V. (2007). The Effect of Aesthetic on the Usability of Data Visualization. *Information Visualization, IV '07. 11th International Conference*, (pp. 637 - 648). Zurich.

- Creswell, J. W., & Plano Clark, V. L. (2011). Understanding Mixed Methods Research. In J. W. Creswell, & V. L. Plano Clark, *Designing and Conducting Mixed Methods Research* (pp. 1-19). SAGE Publications, Inc.
- Darby, S. (2001). Making it obvious: designing feedback into energy consumption. In *Energy Efficiency in Household Appliances and Lighting* (pp. 685-696). Springer Berlin Heidelberg.
- Darby, S. (2010 йил 8-12). Literature Review for Energy Demand Research Project.
- DiSalvo, C., Sengers, P., & Brynjarsdóttir, H. (2010). Mapping the landscape of sustainable HCI. CHI '10 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems , pp. 1975-1984.
- Evans, H., Hansen, H., & Hagedorn, J. (2009). Artful Media: Nuage Vert. *IEEE MultiMedia* , 16 (3), 13-15.
- Evans, S. M. (1996). Schoolchildren as educators: the indirect influence of environmental education in schools on parents' attitudes towards the environment. *Journal of Biological Education* , 30 (4), 243-248.
- Fallman, D. (2003). Design-oriented Human—Computer Interaction. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 225-232). New York, NY: ACM.
- Fallman, D. (2007). Why Research-oriented Design Isn't Design-oriented Research. *Knowledge, Technology & Policy* , 20 (3), 193-200.
- Fischer, C. (2008 йил 2). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency* , 1 (1), pp. 79-104.
- Fogg, B. J. (2002). *Persuasive technology: using computers to change what we think and do*. Morgan Kaufmann.
- Froehlich, J., Findlater, L., & Landay, J. (2010). The design of eco-feedback technology. CHI '10 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 1999-2008). New York, NY: ACM.
- Garay, J., & Lindholm, P. (1995 йил 8). Statistics on the energy bill: better control for the customer.
- Gaskell, G., Ellis, P., & Pike, R. (1982). The energy literate consumer: the effects of consumption feedback and information on beliefs, knowledge and behaviour.
- Goodman, E. (2009). Three environmental discourses in human-computer interaction. CHI EA '09 CHI '09 Extended Abstracts on Human Factors in Computing Systems , pp. 2535-2544.
- Google.org. (2011). Google PowerMeter: A Google.org Project. Retrieved 2013 йил 8-8 from Google: <http://www.google.com/powermeter/about/>

- Gordon, M. H., John, C. D., J.R., R. B., & C., A. D. (1981 йил 12). Consumer Energy Research: A Review. *Journal of Consumer Research* , 8 (3), pp. 343-354.
- Gustafsson, A., & Gyllenswärd, M. (2005). The Power-Aware Cord: Energy Awareness through Ambient Information Display. *CHI '05 Extended Abstracts on Human Factors in Computing Systems* (pp. 1423-1426). New York, NY: ACM.
- Gyllensward, M., Gustafsson, A., & Bang, M. (2006). Visualizing energy consumption of radiators. *PERSUASIVE'06 Proceedings of the First international conference on Persuasive technology for human well-being* (pp. 167-170). Berlin, Heidelberg: Springer-Verlag.
- He, H. A., Greenberg, S., & Huang, E. M. (2010). One size does not fit all: applying the transtheoretical model to energy feedback technology design. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* , pp. 927-936.
- Henderson, G., Staniaszek, D., Anderson, B., & Phillipson, M. (2003). Energy savings from insulation improvements in electrically heated dwellings in the UK. *Proceedings, European Council for an Energy-Efficient Economy summer study* , pp. 325-334.
- Holmes, T. G. (2007). Eco-visualization: combining art and technology to reduce energy consumption. *C&C '07 Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition* , pp. 153 - 162.
- Holmquist, L. E. (2004). Evaluating the Comprehension of Ambient Displays. *CHI '04 Extended Abstracts on Human Factors in Computing Systems* (pp. 1545-1545). New York, NY: ACM.
- Holstius, D., Kembel, J., Hurst, A., Wan, P.-H., & Forlizzi, J. (2005). Infotropism: living and robotic plants as interactive displays. *DIS '04 Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 215-221). New York, NY: ACM.
- Isaacson, M., Kotewa, L., Star, A., & Ozog, M. (2006). Changing How People Think About Energy. *Proceedings, American Council for an Energy-Efficient Economy summer study* .
- IST Advisory Group. (2001). *Scenarios for Ambient Intelligence in 2010*. IPTS (Institute for Prospective Technological Studies).
- Kim, J.-W., Kim, Y.-K., & Nam, T.-J. (2009). The Ténére: Design for Supporting Energy Conservation Behaviors. *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (pp. 2643-2646). New York, NY: ACM.
- King, C., & Delurey, D. (2005 йил 3). Twins, siblings or cousins? Analyzing the conservation effects of demand response programs. *Public Utilities Fortnightly* .

- Kosara, R. (2007). Visualization Criticism - The Missing Link Between Information Visualization and Art. IV '07 Proceedings of the 11th International Conference Information Visualization (pp. 631-636). Washington, DC, USA: IEEE Computer Society.
- Kosara, R., Healey, C. G., Interrante, V., Laidlaw, D. H., & Ware, C. (2003). Thoughts on User Studies: Why, How, and When. *Computer Graphics and Applications* , 23 (4), 20-25.
- Krauss, J. (2012). Infographics: More than Words Can Say. *Learning & Leading with Technology* , 39, 10-14.
- Lawley, E. (2012). Games as an Alternate Lens for Design. *Interactions* , 19 (4), 16.
- Liikkanen, L. A. (2009). Extreme-user approach and the design of energy feedback systems. *Energy Efficiency in Domestic Appliances and Lighting EEDAL 2009*. Berlin, Germany.
- Linda, S. (2008 йил 12). Promoting household energy conservation. *Energy Policy* , 36 (12), pp. 4449-4453.
- Ljungblad, S., Skog, T., & Holmquist, L. E. (2004). From usable to enjoyable information displays. In *Funology* (pp. 213-221). Norwell, MA, USA: Kluwer Academic Publishers.
- Lundstrom, E. (1980). *Energy Consumption in Single-Family Houses-Influence of the Occupants*.
- Maan, S., Merkus, B., Ham, J., & Midden, C. (2011). Making it not too obvious: the effect of ambient light feedback on space heating energy consumption. *Energy Efficiency* , 4 (2), 175-183.
- Mahmud, A. A., Dadlani, P., Mubin, O., Shahid, S., Midden, C., & Moran, O. (2007). iParrot: towards designing a persuasive agent for energy conservation. *PERSUASIVE'07 Proceedings of the 2nd international conference on Persuasive technology* (pp. 64-67). Berlin, Heidelberg: Springer-Verlag.
- Mandel, P. (2013). *Children as Change Agents: The Influence of Integrating Environmental Education into Home Learning Projects on Families and Community Members*. South Florida Education Research Conference.
- Mankoff, J., Dey, A. K., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Heuristic evaluation of ambient displays. *CHI '03 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 169-176). New York, NY: ACM.
- McCalley, L. T., & Midden, C. H. (2002 йил 10). Energy conservation through product-integrated feedback: The roles of goal-setting and social orientation. *Journal of Economic Psychology* , 23 (5), pp. 589-603.

- Miller, T. M., Rich, P., & Davis, J. (2009). ADAPT: audience design of ambient persuasive technology. CHI '09 Extended Abstracts on Human Factors in Computing Systems (pp. 4165-4170). New York, NY: ACM.
- Miller, T., & Stasko, J. (2001). The InfoCanvas: information conveyance through personalized, expressive art. CHI '01 Extended Abstracts on Human Factors in Computing Systems (pp. 305-306). New York, NY: ACM.
- Ministry of Education. (2010). British Columbia Curriculum Package Grade 5.
- Moere, A. V., Tomitsch, M., Wimmer, C., Boesch, C., & Grechenig, T. (2012). Evaluating the Effect of Style in Information Visualization. IEEE Transactions on Visualization and Computer Graphics , 18 (12), 2739-2748.
- Natural Resources Canada. (2012). Improving Energy Performance in Canada – Report to Parliament Under the Energy Efficiency Act For the Fiscal Year 2010-2011.
- Pacific Northwest National Laboratory. (2011). Achieving Energy Efficiency Through Real-Time Feedback. U.S. Department of Energy, Richland, WA.
- Petersen, D., Steele, J., & Wilkerson, J. (2009). WattBot: a residential electricity monitoring and feedback system. CHI '09 Extended Abstracts on Human Factors in Computing Systems (pp. 2847-2852). New York, NY: ACM.
- Petersen, J. E., Shunturov, V., Janda, K., Platt, G., & Weinberger, K. (2007). Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives. International Journal of Sustainability in Higher Education , 8 (6), 16 - 33.
- Pierce, J., Odom, W., & Blevins, E. (2008). Energy Aware Dwelling: A Critical Survey of Interaction Design for Eco-Visualizations. OZCHI '08 Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat (pp. 1-8). New York, NY: ACM.
- Rodgers, J., & Bartram, L. (2010). Ambient and Artistic Visualization of Residential Resource Use. Graphics Interface Poster Session (GI 2010). 588, pp. 17-19. Ottawa, On, Ca: CEUR-WS.org.
- Rodgers, J., & Bartram, L. (2010). Residential Resource Use Feedback Technology: A Framework for Design. IEEE Information Visualization Conference. IEEE.
- Rodgers, J., & Bartram, L. (2011). Exploring Ambient and Artistic Visualization for Residential Energy Use Feedback. Visualization and Computer Graphics , 17 (12), 2489 - 2497.
- Schifter, C. c. (2013). Games in Learning, Design and Motivation. Handbook on innovations in learning , 149-164.
- Shipworth, M. (2000). Motivating Home Energy Action - A handbook of what works.

- Skog, T. (2006). Ambient Information Visualization. Göteborg, Sweden: Unpublished doctoral dissertation.
- Skog, T., Ljungblad, D., & Erik, L. (2003). Between aesthetics and utility: designing ambient information visualizations. IEEE Symposium on Information Visualization, (pp. 233 - 240). Seattle, WA.
- Smiciklas, M. (2012). ThePower of Infographics- Using Pictures to Communicate and Connect with Your Audience. Que Publishing.
- Sonderegger, R. C. (1978). Movers and Stayers: The Resident's Contribution to Variation Across Houses in Energy Consumption in Space Heating. Energy and Buildings , 1, pp. 313-24.
- Staats, H., Harland, P., & Wilke, H. A. (2004 йил May). Effecting durable change. A team approach to improve environmental behavior in the household. Environment and Behaviour , 36 (3), pp. 341-367.
- Weiser, M. (1996, 3 17). Ubiquitous Computing. Retrieved 2 12, 2014 from <http://www.ubiq.com/hypertext/weiser/UbiHome.html>
- Weiser, M., & Brown, J. S. (1997). The coming age of calm technology. In Beyond calculation (pp. 75-85).
- Wilhite, H., & Rich, L. (1995). Measured energy savings from a more informative energy bill. Energy and Buildings , 22 (2), pp. 145-155.
- Yun, R. (2013). The Design of Persuasive System for Sustainability in the Workplace. Doctoral Consortium and BCSS Workshop at PERSUASIVE-2013. Sydney, Australia: Adjunct Proceedings of the 8th International Conference on Persuasive Technology.

Appendices

Appendix A. Study 1 Documents

1. Pre-session Interview Script
2. Sample BC Hydro Bill
3. Test Sets and Questions
4. Post-session Questionnaire

Pre-Interview Guide

The purpose of this pre-session interview is to elicit information about whether and how each participant is aware of power and energy use. Additionally, it is to give participants some background knowledge on how alternative energy production works.

Topics to cover are:

1. Do you ever read your BC Hydro bill in detail? How much do you understand?
 - a) How much energy did you use in this bill? Do you know why and how?
 - b) Where do you think you use most energy?
 - c) What times of the day/week/month?
2. Do you know how energy is being produced and consumed?
3. Do you know the difference between power and energy?

Sample BC Hydro Bill



Prepared For

JOHN DOE
1234 ANYNAME ST
ANYTOWN BC V5V 1X1

Invoice Number:
15000000004

Billing Date	Account Number
Jun 14, 2012	1011 0101 001
Pay By	Please Pay
Jul 05, 2012	\$145.77

Meter Reading Information

Electric:
Meter # ABC1234
Apr 18 5341
Jun 14 6981
58 days 1640

Next meter reading on or about Aug 14

kWh Daily Average Usage per Billing Period

Jun 2011	20 kWh
Jun 2012	28 kWh

Take action to save electricity and money. Call 604 431 9463 or visit bchydro.com/powersmart

Other questions? Call the numbers displayed in the Customer Service area at the top of this bill.

Customer Service

Phone: (604) 224-9376 **Power Out?** 1-888-769-3766
Mail to: BC Hydro, PO Box 9501 Stn Terminal, Vancouver BC, V6B 4N1

Balance payable from your previous bill 153.00
Thank you for your payment Apr 25, 2012 153.00CR

Previous Bill

Balance from your previous bill \$0.00

BC Hydro

Electric Charges

Apr 18 to Jun 14 (Residential Conservation Rate 1101)
Basic Charge: 58 days @ \$0.15050 /day 8.73*
Usage Charge¹
Step 1: 1287 kW.h @ \$0.06800 /kW.h 87.52*
Step 2: 353 kW.h @ \$0.10190 /kW.h 35.97*
Rate Rider at 5.0% 6.61*
* HST 16.66
BC HST Residential Energy Credit 9.72CR

\$145.77

Your total consumption for the billing period is 1640 kW.h and your Conservation Rate breakdown is as follows:



¹For more information on the Conservation Rate visit bchydro.com/conservationrate

Taxes

The following is a summary of taxes billed to your account since your last invoice:
HST at 12 % on 138.83 16.66

Balance payable \$145.77

Customer Service

Phone: (604) 224-9376 **Power Out?** 1-888-769-3766 or *49376
Fax: (604) 528-2297 **Web:** www.bchydro.com/contact
Hours: Mon-Fri 7 a.m. to 8 p.m. and Sat 9 a.m. to 5 p.m. Pacific Time

Test Scenarios

No.	Time	Weather	Devices Charged	Energy Bank	No.	Time	Weather	Devices Charged	Energy Bank
1	AM	Sunny	Few	Low	13	AM	Sunny	Many	Medium
	PM	Sunny				PM	Sunny		
2	AM	Sunny	Few	Low	14	AM	Sunny	Many	Medium
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
3	AM	Rainy/Cloudy	Few	Low	15	AM	Rainy/Cloudy	Many	Medium
	PM	Sunny				PM	Sunny		
4	AM	Rainy/Cloudy	Few	Low	16	AM	Rainy/Cloudy	Many	Medium
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
5	AM	Sunny	Many	Low	17	AM	Sunny	Few	High
	PM	Sunny				PM	Sunny		
6	AM	Sunny	Many	Low	18	AM	Sunny	Few	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
7	AM	Rainy/Cloudy	Many	Low	19	AM	Rainy/Cloudy	Few	High
	PM	Sunny				PM	Sunny		
8	AM	Rainy/Cloudy	Many	Low	20	AM	Rainy/Cloudy	Few	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
9	AM	Sunny	Few	Medium	21	AM	Sunny	Many	High
	PM	Sunny				PM	Sunny		
10	AM	Sunny	Few	Medium	22	AM	Sunny	Many	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
11	AM	Rainy/Cloudy	Few	Medium	23	AM	Rainy/Cloudy	Many	High
	PM	Sunny				PM	Sunny		
12	AM	Rainy/Cloudy	Few	Medium	24	AM	Rainy/Cloudy	Many	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		

No.	Time	Weather	Devices Charged	Energy Bank	No.	Time	Weather	Devices Charged	Energy Bank
1	AM	Sunny	Few	Low	13	AM	Sunny	Many	Medium
	PM	Sunny				PM	Sunny		
2	AM	Sunny	Few	Low	14	AM	Sunny	Many	Medium
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
3	AM	Rainy/Cloudy	Few	Low	15	AM	Rainy/Cloudy	Many	Medium
	PM	Sunny				PM	Sunny		
4	AM	Rainy/Cloudy	Few	Low	16	AM	Rainy/Cloudy	Many	Medium
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
5	AM	Sunny	Many	Low	17	AM	Sunny	Few	High
	PM	Sunny				PM	Sunny		
6	AM	Sunny	Many	Low	18	AM	Sunny	Few	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
7	AM	Rainy/Cloudy	Many	Low	19	AM	Rainy/Cloudy	Few	High
	PM	Sunny				PM	Sunny		
8	AM	Rainy/Cloudy	Many	Low	20	AM	Rainy/Cloudy	Few	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
9	AM	Sunny	Few	Medium	21	AM	Sunny	Many	High
	PM	Sunny				PM	Sunny		
10	AM	Sunny	Few	Medium	22	AM	Sunny	Many	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		
11	AM	Rainy/Cloudy	Few	Medium	23	AM	Rainy/Cloudy	Many	High
	PM	Sunny				PM	Sunny		
12	AM	Rainy/Cloudy	Few	Medium	24	AM	Rainy/Cloudy	Many	High
	PM	Rainy/Cloudy				PM	Rainy/Cloudy		

Test Questions

Basic Content Understanding Questions

1. How many devices are currently being charged?

Devices currently being charged

Cannot tell from the provided visualization

2. How many different devices are currently being charged?

Devices with power load(≤ 5 w)

Devices with power load(> 5 w)

Cannot tell from the provided visualization

3. How much energy is currently available in the bank?

A lot (≥ 0.5 kwh)

Medium (< 0.5 kwh, ≥ 0.3 kwh)

Low (< 0.3 kwh)

Cannot tell from the provided visualization

4. How much power is coming in? Is any power being saved to the energy bank?

Power:

Yes

No

I don't know

5. Will there be a lot of power saved today?

Yes

No

I don't know

7. Which of the following days had most energy produced?

- Jun 24
- Jun 25
- Jun 26
- Cannot tell from the provided visualization

Next

8. Which of the following days had most energy consumed?

- Jun 24
- Jun 25
- Jun 26
- Cannot tell from the provided visualization

Next

9. Which of the following days had most energy left in the bank?

- Jun 24
- Jun 25
- Jun 26
- Cannot tell from the provided visualization

Next

10. Which of the following days had most devices charged?

- Jun 24
- Jun 25
- Jun 26
- Cannot tell from the provided visualization

Submit

Solar Comprehension Questions

Start

1. How much power is going out? Where do you think it is going?

Next

2. What is the level of energy left today (low/medium/high)? Why?

Next

3. Can I charge my laptop now? Why or why not? If not, when?

Next

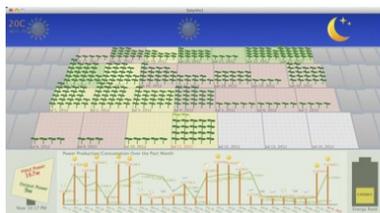
4. Is there a day that had more energy consumed than produced? If yes, choose one, and explain how could that happen? If not, why?

Next

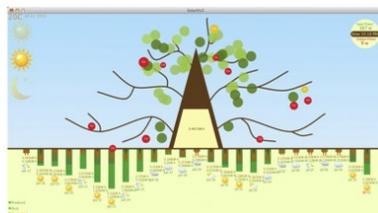
5. Could there be a lot energy left on a cloudy/rainy day? If yes, choose one, and explain how could that happen? If not, why?

Submit

Post-Session Questionnaire



SolarVis1



SolarVis2



Excel Chart

1. Please rate the following visualizations in terms of:

a) Readability

	Very easy to read		Medium	Very hard to read	
	1	2	3	4	5
SolarVis1	<input type="radio"/>				
SolarVis2	<input type="radio"/>				
Excel Chart	<input type="radio"/>				

b) At-a-glance Awareness

	Very easy to understand		Medium	Very hard to understand	
	1	2	3	4	5
SolarVis1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
SolarVis2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Excel Chart	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

c) Attractiveness

	Very attractive		Medium	Not at all	
	1	2	3	4	5
SolarVis1	<input type="radio"/>				
SolarVis2	<input type="radio"/>				
Excel Chart	<input type="radio"/>				

2. Many institutions are considering providing some solar energy to their users. If this service were to be available to the people in an organization, which, if any, of these visualizations would be suitable? On a scale of 1 to 5, rate each visualization on how appropriate it is for the particular use.

a) SolarVis1

	Would really like to see			Would not like to see at all	
	1	2	3	4	5
Elementary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Secondary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
University	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public Library	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Community Centre	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Corporation/Company	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Others, please specify: <input type="text"/>					

b) SolarVis2

	Would really like to see			Would not like to see at all	
	1	2	3	4	5
Elementary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Secondary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
University	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public Library	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Community Centre	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Corporation/Company	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Others, please specify:	<input type="text"/>				

c) Excel Chart

	Would really like to see			Would not like to see at all	
	1	2	3	4	5
Elementary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Secondary School	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
University	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public Library	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Community Centre	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Corporation/Company	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Others, please specify:	<input type="text"/>				

3. If you could choose your own representation, what kind of representation would you prefer?

Appendix B. Study 2 Documents

1. Pre-session Interview Script
2. Post-session Questionnaire
3. Statistical Distribution of Participants Game Score

Pre-Interview Guide

The purpose of this semi-structured pre-session interview is to elicit information about whether and how each participant is aware of power and energy use in their homes.

Topics to cover are:

1. Do you know how much you or your family pay for your home electricity use every month and how much you use?
2. Do you know which appliance costs most energy in your home?
3. Can you name three activities that you may do to save your home energy?

Post-session Questionnaire

What Do You Think of the Display?

Age:

School Grade (If applicable):

The display I saw:

- Tree with berries
- Tree without berries
- Bar Chart

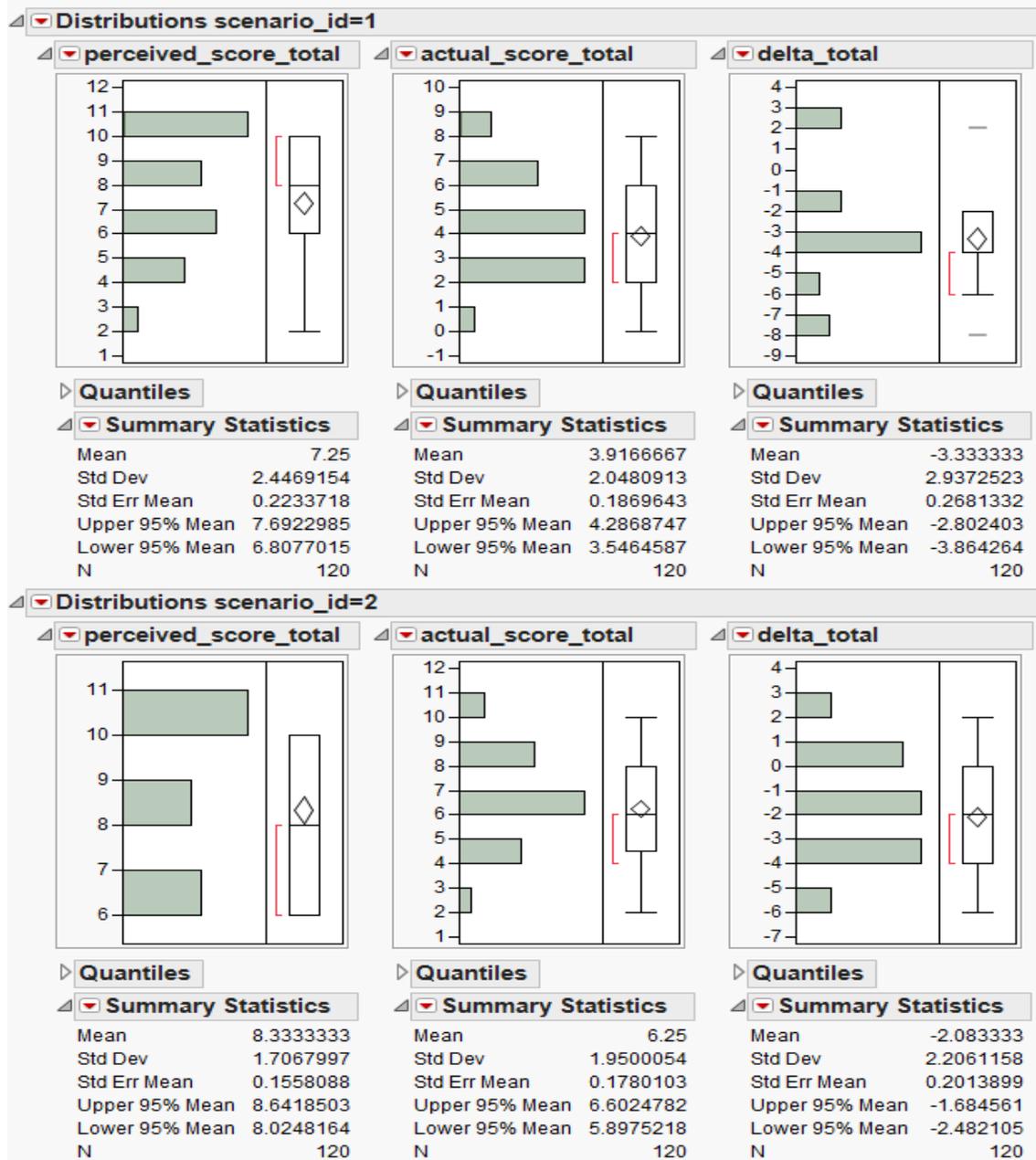
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The display is easy to understand.	<input type="radio"/>				
The display is interesting.	<input type="radio"/>				
The display is attractive.	<input type="radio"/>				
The display is good looking.	<input type="radio"/>				

If you were to have a display like this in your home, where would you put it? Check all that apply.

- Kitchen
- Bathroom
- Bedroom
- Living Room
- Laundry
- Mechanics
- Outdoors
- Other, please specify
- Would not want it in my home

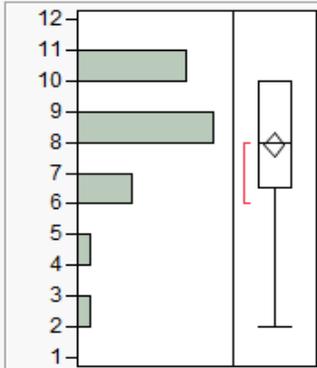
Other comments? (e.g. Is the display helpful? Did you learn anything about energy conservation? How do you like the display? the colors? the symbols? Any other idea for the design of the display? or any improvements that could be done? etc.)

Statistical Distribution of Participants Game Score



▾ Distributions scenario_id=3

▾ perceived_score_total

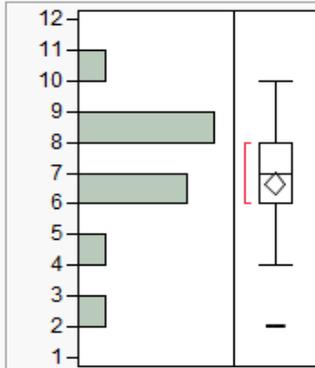


▾ Quantiles

▾ Summary Statistics

Mean	7.9166667
Std Dev	2.0480913
Std Err Mean	0.1869643
Upper 95% Mean	8.2868747
Lower 95% Mean	7.5464587
N	120

▾ actual_score_total

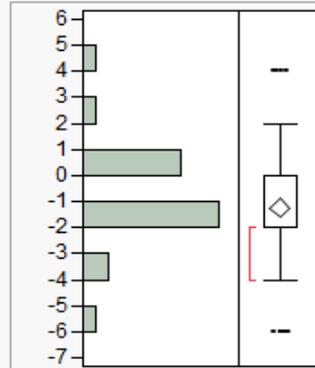


▾ Quantiles

▾ Summary Statistics

Mean	6.6666667
Std Dev	2.0634202
Std Err Mean	0.1883636
Upper 95% Mean	7.0396455
Lower 95% Mean	6.2936879
N	120

▾ delta_total



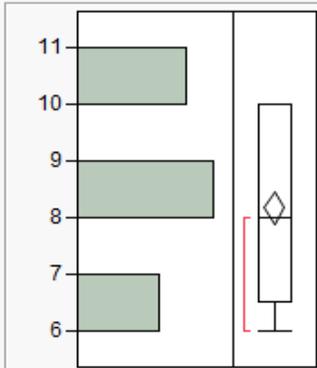
▾ Quantiles

▾ Summary Statistics

Mean	-1.25
Std Dev	1.9926335
Std Err Mean	0.1819017
Upper 95% Mean	-0.889816
Lower 95% Mean	-1.610184
N	120

▾ Distributions scenario_id=4

▾ perceived_score_total

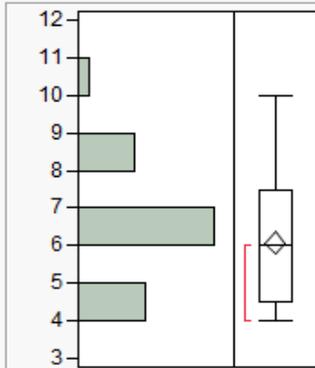


▾ Quantiles

▾ Summary Statistics

Mean	8.1666667
Std Dev	1.5247721
Std Err Mean	0.139192
Upper 95% Mean	8.4422808
Lower 95% Mean	7.8910526
N	120

▾ actual_score_total

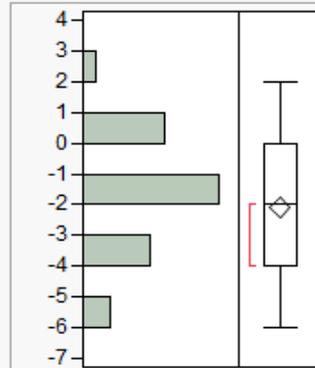


▾ Quantiles

▾ Summary Statistics

Mean	6.0833333
Std Dev	1.5855616
Std Err Mean	0.1447413
Upper 95% Mean	6.3699356
Lower 95% Mean	5.7967311
N	120

▾ delta_total



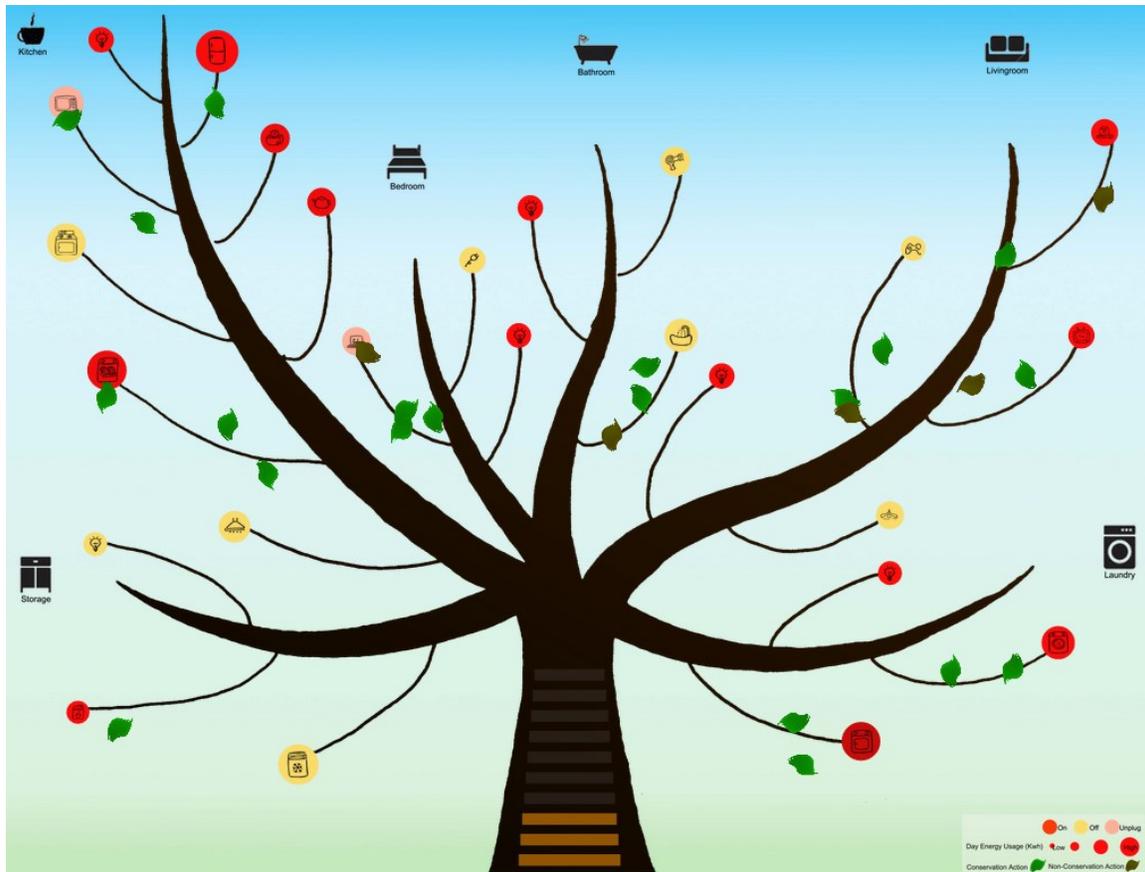
▾ Quantiles

▾ Summary Statistics

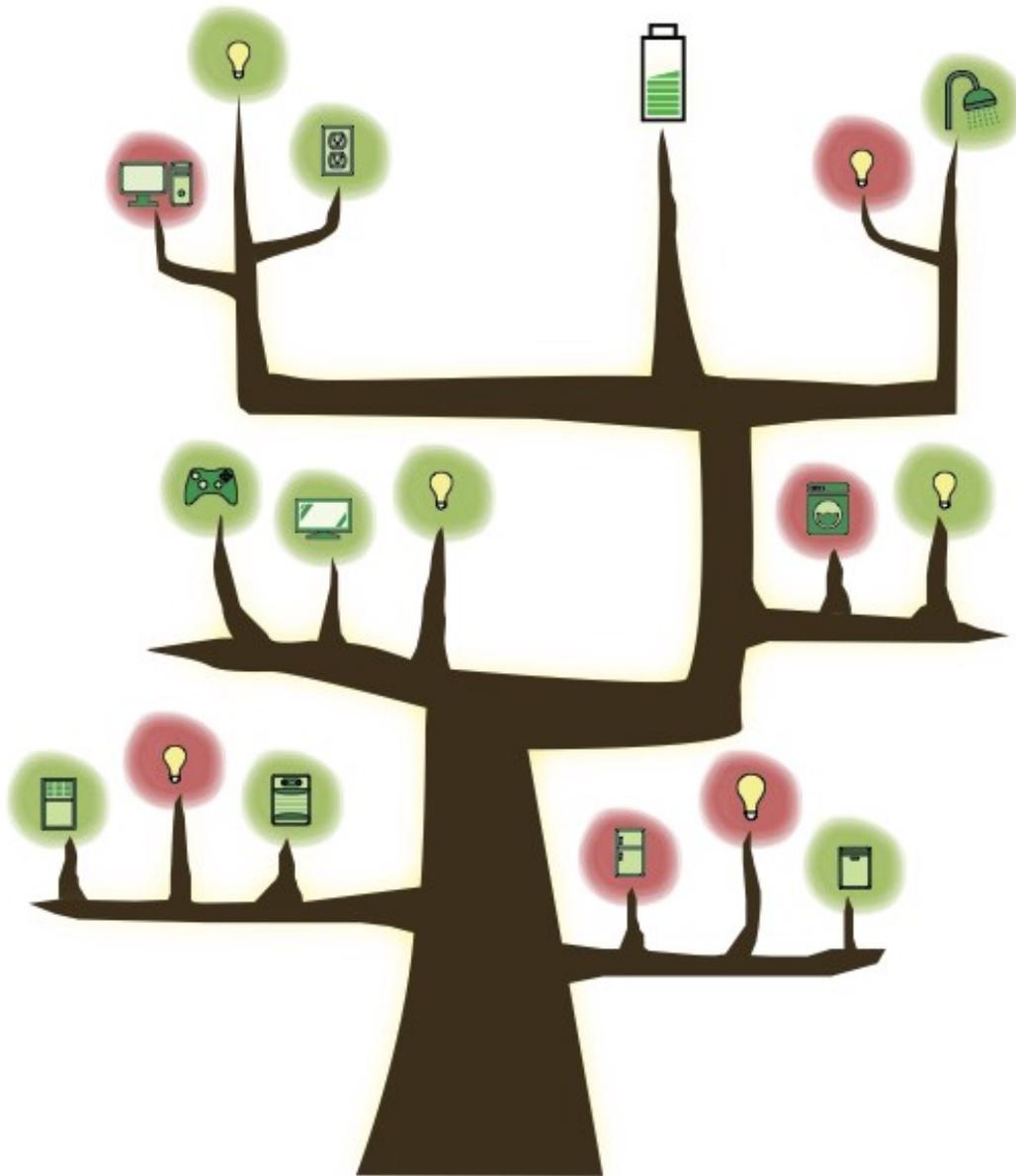
Mean	-2.083333
Std Dev	1.9643175
Std Err Mean	0.1793168
Upper 95% Mean	-1.728268
Lower 95% Mean	-2.438399
N	120

Appendix C. Design Exploration – Past Versions of Tree Visualization Design

Version 1



Version 2



Version 3



Version 4

