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One Size Does *Not* Fit All: Extending the Transtheoretical Model to Energy Feedback Technology Design

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "One Size Does *Not* Fit All: Extending the Transtheoretical Model to Energy Feedback Technology Design" submitted by Helen Ai He in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

Global warming and climate change are urgent global issues. One remedy is to motivate sustainable energy consumption behaviours by people. One approach is the use of technologies that provide real-time, energy usage feedback. However, current technologies use a "one-size-fits-all" solution, providing the *same* feedback to *differently* motivated individuals at different stages of behavioural change.

I make four contributions. First, I frame motivational psychology literature as key notions for designers of technology that motivates sustainable energy behaviour. Second, I show how this motivational perspective can be used to assess existing feedback technologies. Third, I construct a motivational framework based on the Transtheoretical Model, where I offer strategies that target *individual* motivations at each *stage* of change. Fourth, I present two design scenarios as initial approaches to illustrate the application of the framework to inform energy feedback technology design. The first are textual examples illustrating one way to apply each of the framework's recommendations. The second revisits our implemented feedback system by providing initial, high-level, redesign ideas based on the framework's recommendations for each stage of change. Both scenarios are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design.

Publications

Some of the materials, ideas, and figures in this thesis have previously appeared in the following publications.

HE, H.A., GREENBERG, S., HUANG, E.M. 2010. One Size Does Not Fit All: Applying the Transtheoretical Model to Energy Feedback Technology Design, In *Proceedings of the ACM Conference on Human Factors in Computing Systems (ACM CHI' 2010),* ACM Press, 10 pages, April.

HE, H. A., AND GREENBERG, S. 2009. Motivating sustainable energy consumption in the home, In *ACM CHI Workshop on Defining the Role of HCI in the Challenges of Sustainability.* (Workshop held at the ACM CHI Conference), 5 Pages, April. Also in: ACM CSCW Workshop on Designing for Families (Workshop held at the ACM CSCW Conference), November, 2008.

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To my parents,

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Chapter 1. Introduction

This thesis concerns the design of energy feedback technologies, where the technology's aim is to motivate sustainable energy behaviors by people. In particular, I explore how the theories, techniques and models within motivational psychology literature can be leveraged to design such technologies.

In this chapter, I introduce the context and motivation behind my research. I first argue for the importance of sustainable energy consumption, discussing the impacts of human consumption as one of the major causes of global warming. Given global recognition of these problems, I then narrow onto two primary approaches advocated in the move towards more sustainable lifestyles. The first approach creates energy-efficient *technologies*. The second approach – and the focus of this thesis – motivates sustainable energy *behaviors* by people. I introduce my research constraints, followed by a succinct statement of the thesis problem, research questions and methodologies used to address these questions. I conclude with an organizational overview of this thesis.

1.1 The importance of sustainable energy consumption

Since the 1960's, there has been an increasing trend in world energy consumption, with oil, coal and gas as the leading sources of energy usage (BP Statistical Review of World Energy, 2009). This trend is accompanied by many harmful and long-term environmental costs, including ozone depletion, resource depletion, and global warming. While all of these consequences are detrimental to the Earth and our environment, I primarily focus on the issue of global warming: the cause, and the impacts it has on human, wildlife, and plant life.

1.1.1 Global warming: the impacts

Global warming occurs when light from the sun comes into the atmosphere, and greenhouse gases trap a portion of the outward-bound infrared radiation into the atmosphere, thereby warming up the air (Houghton, 1997). The result is an increase in the mean surface temperature of the earth (Climate Change 2001). While greenhouse gases include a variety of different chemical compounds (methane, nitrous oxide, and others), it is carbon dioxide (CO_2) that contributes to 80% of total greenhouse gases (Gore, 2006). Since the late 19th century and the beginning of the industrial revolution, the content of CO_2 in the air has increased by 27% (Hansen et al., 2008). These emissions are primarily caused by human activities, such as large-scale deforestation and the combustion of fossil fuels including oil, coal, and natural gas (US Department of Energy/Energy Information Administration, 2001). Global warming has serious impacts on climate change, glacier retreat, animal and plant extirpations and extinctions, and in turn, human, wildlife and plant life.

Climate change

The Intergovernmental Panel of Climate Change (IPCC) projected that global warming will induce global average surface temperatures to increase at a rate between 1.4 to 5.8 degrees over the period 1900 to 2100, a rate very likely to be without precedent in at least the last 10,000 years (Climate Change 2001). They also predicted with confidence that during the 21st century, these changes will lead to climate change: higher maximum temperatures and lower minimum temperatures over nearly all land areas, increased summer continental drying and associated risk of drought in mid-latitude continental interiors, and more intense precipitation events over many areas. US Climate Change Science Program (CCSP) models have predicted that intense precipitation events that used to occur every 20 years will now occur every 5 years (Eilperin, 2008). Indeed, in 2007, twelve of the thirteen major relief operations were climate-related (Borger, 2007), including Hurricane Katrina in 2005 and Cyclone Nargis in 2008. The United Nations predicts that within a decade, climate change disasters will cost the world's financial centers as much as $150 billion annually (Environmental Defense, 2007).

Climate change has detrimental impacts to human health (Gerberding, 2007). It allows for the increased emergence, resurgence and spread of infectious diseases, indicating a definite link between climate change and disease outbreaks (Epstein, 2000). The United States Center for Disease Control and Prevention (CDC) discusses serious public health concerns as direct or indirect results of climate change: extreme heat waves causing death, extreme weather events causing loss of life and acute trauma, air pollution related health effects, allergic diseases, water and food borne infectious diseases, vector-borne and zoonotic diseases (i.e. plague, Lyme disease, West Nile virus, malaria), and mental health problems in anticipating climate change and/or coping with its effects (Gerberding, 2007).

Glacier retreat

Global warming leads to the continued retreat of glaciers and icecaps around the world (Climate Change 2001). This raises the global mean sea level, which in turn, may cause major coastal flooding (Oppenheimer, 1998). Unstable ice sheets include the Arctic (Caldicott, 2009), Greenland (Caldicott, 2009), and West Antarctic (Oppenheimer, 1998). Some scientists predict that the Arctic could be ice-free in summertime as soon as 2010 (Spratt & Sutton, 2008). In the last 100 years, sea levels have risen 4-8 inches (Ross, 2005), and there is already enough carbon in the Earth's atmosphere to ensure an additional rise of several feet in sea levels (Hansen et al., 2008). The complete release of the already unstable West Antarctic ice sheet would raise global mean sea levels by four to six meters, causing major coastal flooding worldwide (Oppenheimer, 1998). Indeed, twenty-two of the world's largest cities are now threatened by flooding, including Tokyo, New York, Venice, Miami, London, St. Petersburg, Hong Kong, and Buenes Aires (Stern Review, 2006).

Animal and plant extirpations and extinctions

Last, but definitely not least, the significant impact of global warming is already discernible in animal and plant populations (Root et al., 2003). The synergism of rapid temperature rises and other stresses (in particular, habitat destruction due to fossil fuel exploration and mining) could lead to numerous extirpations and possibly extinctions (Root et al., 2003). As temperature changes are occurring very rapidly, most forests will die, and along with them will go numerous animal and bird species (Schneider, 1989). Recent calculations suggest that rates of species extinction are now on the order of 100 to 1000 times those before humanity's dominance of Earth (Lawton & May, 1995). Here, I must mention that while the growth of most plants is *enhanced* by elevated CO_2, the tissue chemistry of plants that respond to CO2 is altered in ways that *decrease* food quality for animals and microbes (Vitouseak et al., 1997).

1.1.2 Global warming: the causes

Carbon dioxide (CO_2) contributes to 80% of total greenhouse gases (Gore, 2006). These emissions are primarily caused by human activities, such as the combustion of fossil fuels (i.e. oil, coal, natural gas) and large-scale deforestation (US Department of Energy, 2006). The following discusses these causes in detail.

Increasing fossil fuel demand

The rising trend in global energy consumption indicates a growing demand for ever more fossil fuels, such as oil, coal and gas (Caldicott, 2009). Primary energy demands are expected to increase by 1.5 to 3 times by 2050 (Anon, 1995) – a rate which is unsustainable as fuel sources are depleted. Oil is the foremost energy resource in the world and is used primarily for transportation (Caldicott, 2009). As oil reserves deplete, high prices and real shortages of available oil will dramatically change and put national economies at risk (Heinberg, 2007). Coal is the largest reservoir of carbon, exceeding that of oil and gas (Caldicott, 2009). As the prices of oil and gas increase, more emphasis is placed on coal (Caldicott, 2009) to generate electricity, making it the largest contributor to the increase of CO_2 in the atmosphere (Caldicott, 2009).

Deforestation

Deforestation accounts for 20% of global warming (Caldicott, 2009). Each year, an area of tropical rain forest the size of Florida is cleared (Caldicott, 2009). Cattle ranching is the primary cause, occupying 72% of cleared forest areas, where most of the beef is used to supply fast food burger chains in the US, Central America and Europe (Caldicott, 2009). At the present rate, deforestation will destroy all the world's tropical forests within 25-50 years, along with 15 to 24 *million* species, thereby turning the land into a desert (Caldicott, 2009). As an aside, this has many negative impacts other than global warming: the loss of many crucial active ingredients derived from rain forest plants, including anaesthetics and contraceptives (Facts about the Rainforest, 2001-2005), and anticancer chemicals (Sting & Dutilleux, 1989). In addition, it has (and may continue to) lead to the disruption and displacement of many indigenous and Amazonian tribes that have peacefully coexisted with their environment for ten thousand years (Calidcott, 2009).

1.2 Sustainable development, sustainable consumption

The world is finally reaching consensus that urgent action needs to be taken, despite uncertainties regarding the accuracy of predictions of global warming causes and impacts (Houghton, 1997). From a scientific perspective, the effects of greenhouse gases on atmospheric composition and climate are long-lasting, and are projected to continue several centuries after even emissions have been stabilized (Climate Change 2001). Once stabilized, global mean surface temperatures would rise at a rate of only a few tenths of a degree per century rather than several degrees per century as projected for the 21^{st} century without stabilization (Climate Change 2001).

Developed nations should take the lead in this action (Houghton, 1997), as they are the largest consumers of energy resources (Key World Energy Statistics, 2006). For example, the US population represents only 4% of the global population, but uses 21% of world's energy (Caldicott, 2009). Indeed, if everyone lived like today's average North American, it would take at least *two* additional planets to sustain our level of living, produce the resources, absorb the wastes and otherwise maintain life-support (Wackernagel & Reeds, 1996). If present trends in the world's population continue, we may reach 14 billion by the end of this century (World Commission on Environment and Development, 1987) - a rate which cannot be sustained given our current rate of consumption (Caldicott, 2009).

The serious implications of global warming lead to the unmistakeable conclusion that humankind (and, in particular, developed nations) need to move towards a more sustainable way of life. Two approaches are sustainable development and sustainable consumption. *Sustainable development* is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Anon, 1987). I adapt this definition to define *sustainable consumption* as "energy consumption that meets the needs of the present without compromising the ability of future generations to meet their own needs". To achieve these goals, global, integrative and holistic solutions are needed (Houghton, 1997), as a large number of factors are important in determining the future level of a country's energy consumption and production, including population growth, economic performance, consumer tastes, technological developments, government policies concerning the energy sector, and developments on world energy markets (Dincer & Rosen, 1999).

Considering all possible solutions to sustainable consumption is clearly beyond the scope of an MSc thesis. Consequently, the following sections narrow the scope of this research considerably, where I investigate a partial approach to motivating sustainable energy consumption *behaviours* by household members.

1.3 The context: motivating sustainable energy behaviours by household residents

I now discuss two approaches to motivating sustainable energy consumption: the *technological* and the *people* perspective.

From the technological perspective, much focus has been on creating energy-efficient technology: homes, appliances, cars, etc. While this is an important and necessary step, it is only a *partial* solution (Yates & Aronson, 1983) as people do not always use this technology in energy-efficient ways (Shipworth, 2000). Specifically, energy-efficient appliances do not necessarily result in overall energy savings, as people may use these appliances more often (Abrahamse et al., 2005). Also, while improved energy efficiency slows the growth of energy use and carbon emissions, it will not reverse the trend towards increased energy use required to support economic growth (Dincer & Rosen, 1999).

Given these factors, we must also focus on a *people* solution. In particular, we need to understand the fundamentals of how and why people use energy (Shipworth, 2000) so we can develop technologies that can truly motivate sustainable energy behaviour. The value of this approach has been supported by consistent findings that targeting human behaviour can result in significant energy savings due to differences in individual energy usage behaviours (Froehlich, 2009). For example, energy use can differ by two to three times in identical homes, occupied by people with similar demographics (Socolow, 1978), (Winett et al, 1979). As such, intervention strategies promoting sustainable behaviours could potentially result in significant energy savings (Froehlich, 2009).

The next sections will discuss some constraints that I have chosen in my approach to motivating sustainable energy behaviour: a *psychological* focus, a target audience of the *household resident*, and using *energy feedback technologies* as the vehicle to motivate behavioural change.

1.3.1 A psychological focus

Motivating behaviour change (within the context of sustainable energy consumption or otherwise) is a *psychologically*, *socially*, and *culturally* complex problem (Shipworth, 2000). While all perspectives offer valuable and important insights, I approach this problem primarily from the *psychological* perspective, where *psychology* is defined as "the scientific study of behaviour and mental processes" (Hockenbury & Hockenbury, 2003). To understand how to motivate sustainable energy behaviours, I draw upon literature from a variety of subfields and schools of thought within psychology, including motivation theories, learning theories, social psychology, environmental psychology, and behaviour change theories and therapies. Throughout this thesis, when I refer to "motivational psychology", I refer to my usage of this combined literature. In contrast, I do *not* consider the social (societal) or cultural (traditions, rituals) aspects that influence energy behaviour. Rather, I only consider the North American culture (of developed, affluent nations) that surrounds energy usage.

1.3.2 The household resident

Households are major contributors to the emission of greenhouse gases, and consequently, global warming (Abrahamse et al., 2005). In the US, the residential sector accounts for 21% of the nation's energy use, where the average American household spends nearly 2000 USD annually on energy bills (US Department of Energy, 2006). In this thesis, I target motivation of sustainable consumption behaviours by *household residents* (as opposed to governmental policy-makers, businesses, etc.). Even within this narrowing, I consider household residents from North American cultures, who are moderately high energy users, who are technically proficient (at least to the point that they would know how to use energy feedback technologies), and have reasonable income (where they would be able to afford such technologies). In particular, I target household residents between approximately 18 to 65 years of age, ensuring a certain cognitive maturity, and normal eyesight, hearing and mobility.

1.3.3 Energy feedback technologies

An *"energy feedback technology"* is any technology that presents a consumer with feedback of their energy usage. A decade ago, the *only* form of energy feedback household residents received was a monthly paper-based utility bill, or by reading the electric meter. This is ineffective feedback. Kempton and Layne (1994) drew the analogy that this would be like shopping at a grocery store where the goods are not marked with individual prices and the only feedback received about purchasing is through a monthly bill which provides one, aggregate total cost. Studies showed that in 1982, only a small percentage (1-2%) of household residents knew the amount of kilowatthours (kWh) they used per day or month, and many did not know where the electricity meter was even located (Geller et al., 1982). While recent years have seen the development of feedback technologies providing real-time feedback of one's energy usage (discussed shortly), in practice, most households still receive energy feedback via their utility bill. In this regard, to provide the reader with a general understanding of the major sources of household electricity consumption, Table 1.1 (next page) lists average electricity consumption values for heating, cooling, and major appliance usage in the household. Please note that these values only provide a ballpark view of what appliances consume when "on", where values may vary across households, seasons, location of the appliance, energy-efficiency of the appliance, among many other factors.

To address this problem, in the last decade or so, industry and research have developed a wide variety of technologies that provide real-time, continuous feedback of one's energy usage. This feedback is often presented as raw energy use (e.g., watts), as personal cost (e.g., money), or as environmental impact (e.g., CO_2). However, their use is still fairly limited. Chapter 2 of this thesis will detail several technologies that provide such feedback.

Yet, feedback alone is not enough. While feedback technologies have been shown to be one of the most effective strategies in reducing energy consumption in the home (Geller et al., 1982), there is one important problem. Unless the individual *already* holds a strong goal to use energy in a sustainable way (McCalley & Midden, 2002), feedback only *informs*, but does not necessarily *motivate* any sustainable energy action. The issue is that current technologies tend to use a "one-size-fits-all" solution, providing the *same* feedback to *differently* motivated individuals, at different stages of willingness, ableness and readiness for change.

Heating	
26,500 watts	Elec. furnace, 2000sf, cold climate
7941 watts	Elec. furnace, 1000sf, warm climate
1440 watts	Electric space heater (high)
900 watts	Electric space heater (medium)
600 watts	Electric space heater (low)
750 watts	Gas furnace (for the blower)
1100 watts	Waterbed heater
450 watts	Waterbed heater (avg. 10 hrs./day)
Cooling	
3500 watts	Central Air Conditioner (2.5 tons)
1440 watts	Window unit AC, huge
900 watts	Window unit AC, medium
Televisions & Videogames	
340 watts	50-56" Plasma television
260 watts	50-56" LCD television
170 watts	50-56" DLP television
270 watts	42" Plasma television
210 watts	42" LCD television
125 watts	32" LCD television
55-90 watts	19" CRT television
45 watts	HD cable box
194 watts	PS3
185 watts	Xbox 360
70 watts	Xbox
30 watts	PS2
18 watts	Nintendo Wii (source)
More efficient cooling	
400 watts	Evaporative cooler
350 watts	Whole-house fan
100 watts	Floor or box fan (high speed)
90 watts	52" ceiling fan (high speed)
75 watts	48" ceiling fan (high speed)
55 watts	36" ceiling fan (high speed)
24 watts	42" ceiling fan (low speed)
Major appliances	
4400 watts	Clothes dryer (electric)
see sep. page	Washing machine
3800 watts	Water heater (electric)
200-700 watts	Refrigerator (compressor)
57-160 watts	Refrigerator (average)
3600 watts	Dishwasher (washer heats water)
2000 watts	Electric oven, 350°F
1178 watts	Electric oven, self-cleaning mode (takes 4.5 hrs, 5.3 kWh total)
1200 watts	Dishwasher (washer doesn't heat water)
Other	
1440 watts	Microwave oven or 4-slot Toaster
900 watts	Coffee maker
800 watts	Range burner
4 watts	Clock radio
Lighting	
60 watts	60-watt light bulb (incandescent)
18 watts	CFL light bulb (60-watt equivalent)
5	Night light
0.5	LED night light

Figure 1.1: Major sources of household electricity consumption. Retrieved March 10, 2010 from: http://michaelbluejay.com/electricity/howmuch.html

1.4 Research questions and methodologies

This thesis explores how energy feedback technology design can leverage the techniques, theories and therapies found within the motivational psychology literature to motivate sustainable energy usage behaviours by household residents. I now present my research questions and methodologies. Particular emphasis is placed on the process by which I came to address these questions (i.e. where findings from a previous question led to the phrasing of the next question).

Research question #1: What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?

While there are many different kinds of energy feedback technologies, their producers rarely speak of them in terms of how their designs are premised on psychological motivation theories of behaviour change. This question reconsiders these technologies and technology design from that perspective. To address this question, I take three approaches:

a) In Chapter 2, I review related work in energy feedback technologies that aim to motivate sustainable energy behaviour.

b) In Chapter 4, I review selected motivational psychology literature, which later chapters will show to be relevant in the context of motivating sustainable energy behaviour.

From these reviews, I argue that feedback technology designers need to consider two important points when motivating sustainable energy behaviour:

1) Different people hold different *attitudes, beliefs* and *values* (Beebe et al., 1999), and are motivated by different things. As such, designers need to develop a *range* of strategies in order to account for the complexity of human behaviour (Shipworth, 2000).

2) Intentional behaviour change does not occur as an event, but rather, as a *process* in a series of stages as defined by the Transtheoretical Model (Miller & Rollnick, 2002). Individuals move from being unaware or unwilling to acknowledge the problem, to considering the possibility of change, to preparing to make the change, to taking action, and finally, to maintaining the desired behaviour over time (Miller & Rollnick, 2002).

Given these points, I take approach c) to finish answering this question:

c) In Chapter 5, I assess energy feedback technologies (presented in Chapter 2) from a motivational psychology lens. That is, I evaluate and critique their potential effectiveness in *motivating* sustainable energy behaviour. Specifically, I use the primary lens of the stages of change (proposed in the Transtheoretical Model), and the secondary lens of other relevant motivational psychology literature.

From this assessment, I identified three shortcomings of current energy feedback technology design:

1. While feedback technologies aim to motivate sustainable energy behaviour, their designs could benefit significantly by explicitly incorporating aspects of motivational psychology literature.
2. Motivational psychology literature is fragmented among different psychological subfields and schools of thought, making it difficult to apply to energy feedback technology design in a cohesive and meaningful way.
3. Feedback technologies tend to design for "one-size-fits-all", providing the same feedback to differently motivated individuals at different stages of behavioural change.

The identification of these shortcomings led me to ask the next question:

Research question #2: Can we develop a framework that encompasses relevant motivational psychology literature to apply to energy feedback technology design in a way that addresses individual motivations at different stages of behavioural change?

In Chapter 6, I synthesize various motivational psychology literature to propose a motivational framework based on the Transtheoretical Model to consider individual motivations at each stage of behavioural change. Specifically, I propose intervention strategies that may be most effective to target individuals at each stage of change. For each stage, I present the motivational *goal(s),* and *recommendation(s)* for how technologies may reach these goals. Each goal and recommendation is supported by a *rationale* (based on motivational psychology literature).

Research question #3: Can we use this framework to inform the design of energy feedback technologies?

I take two initial approaches to illustrate the application of the framework to inform energy feedback technology design. Both approaches are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design. As such, I do *not* fully answer this question within this thesis.

First, to make the recommendations in the motivation framework more vivid, Chapter 6 presents a scenario of a particular energy user named Mary, who holds specific attitudes, beliefs and values. I simplify this scenario to focus on motivating the sustainable energy usage of one appliance – the desktop computer. I draw upon the details presented in the scenario to provide a simple *textual example* for each of the framework's recommendations. I do not claim the examples I provide are ideally presented; rather, they illustrate *one* way (and perhaps, not the best way) to realize a recommendation.

Second, Chapter 3 presents our concept of a feedback system that uses augmented reality to provide real-time energy feedback in context. Following this, Chapter 3 presents our limited instantiation (implementation) of this concept – a feedback system called 'AREnergyViewer'. However, despite the novelty of this concept, AREnergyViewer's design did not consider the issue of motivation – that is, whether the user is even interested or motivated to use such a feedback device. To address this, Chapter 6 revisits 'AREnergyViewer' by providing initial, high-level, *redesign* ideas based on the framework's recommendations for each stage of change.

1.5 Thesis contributions

The contributions in this thesis are to Human-Computer Interaction (HCI) and design, not psychology. I am not a psychologist but rather aim to apply motivational psychology to HCI design: specifically, energy feedback technology design. I make the following contributions.

Primary:

1. Chapters 4 and 5 frame motivational psychology literature as *key notions* for designers of energy feedback technologies that aim to motivate sustainable energy behavior change.
2. Chapter 5 demonstrates how these notions can be used to *assess* existing feedback technologies from a motivational perspective.
3. Chapter 6 constructs a *motivational framework* based on the Transtheoretical Model in which I propose specific motivational interventions to target individual attitudes, beliefs and values held at each stage of behavioral change.

Secondary:

4. Chapter 6 presents two *design scenarios* as initial approaches to illustrate the application of the motivational framework to inform energy feedback technology design. The first are textual examples based on a scenario of a particular energy user named "Mary". These examples illustrate *one* way to apply each of the framework's recommendations. The second revisits our limited instantiation of an augmented reality feedback system, 'AREnergyViewer', by providing initial, high-level, redesign ideas based on the framework's recommendations for each stage of change. Both approaches are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design.

1.6 Thesis overview

The remainder of this thesis describes in detail the research outlined above.

Chapter 2 reviews related work in energy feedback technologies.

Chapter 3 presents our concept of a feedback system that uses augmented reality to provide real-time, energy feedback in context, as well as our limited instantiation (implementation) of this concept, called "AREnergyViewer".

Chapter 4 reviews selected motivational psychology literature. Later chapters show this literature to be relevant to motivating sustainable energy behaviour.

Chapter 5 assesses selected energy feedback technologies in terms of their potential effectiveness to motivate sustainable energy behaviour, using the primary lens of the Transtheoretical Model's stages of behaviour change and the secondary lens of other relevant motivational psychology literature.

Chapter 6 constructs a motivational framework based on the Transtheoretical Model's stages of behavioral change to propose specific interventions for each stage of change. To illustrate the application of the framework to guide energy feedback technology design, Chapter 6 offers two designs scenarios as initial probes into future directions of research. The first are textual examples based on a particular energy user named "Mary", and the second revisits 'AREnergyViewer' (presented in Chapter 3) to provide initial, high-level, redesign ideas based on the framework's recommendations for each stage of change.

Chapter 7 discusses the motivational framework and future directions of exploration. I then restate my research questions, approaches, and contributions and conclude this work.

Chapter 2. The landscape of energy feedback technologies

Research question #1 asked: "What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?". This chapter partially addresses this question by reviewing energy feedback technologies that aim to motivate sustainable energy behaviour.

I first introduce the notion of designing value-sensitive technology; in particular, designing for the specific value of environmental sustainability. I then review the landscape of energy feedback systems that aim to motivate sustainable energy behaviour. To understand the diversity of feedback technology characteristics, I propose 19 design dimensions (listed in Table 2.1). Using design dimension #1: "context of target audience", I present energy feedback technologies in two broad audience contexts: 1) those that aim to motivate the individual, and 2) those that aim to motivate the individual within a social group. Within this broad categorization, I choose two additional design dimensions to guide the order in which I present these feedback systems. These dimensions are used for literary convenience, and the reader should not interpret them as a taxonomy or the key dimensions for design.

2.1 Research Context: Value-Sensitive Design (VSD)

The last few years has seen a growing interest in the Human-Computer Interaction (HCI) community in designing systems that support enduring human values. One approach is that of *Value-Sensitive Design (VSD)*, defined as "a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process" (Friedman et al., 2006).

In this thesis, I explore how feedback technologies can be designed to consider the specific value of environmental sustainability. This value is supported by the foundational work of Blevis (2007), who defines *Sustainable Interaction Design (SID)* as "the perspective that sustainability can and should be a central focus of interaction design". He argues that interaction designers need to consider: (a) the potential effects of their design on the environment, and (b) the sustainability of the behaviors induced by designed interactions. It is this latter *behavioral* portion that is the focus of my thesis. Specifically, my premise is that interaction designers can actively promote conservation in use by taking human behaviors into account (Pierce & Roedl, 2008). One approach to motivating conservation behaviours is through technologies that provide real-time feedback of one's energy usage. The following reviews the landscape of energy feedback technologies that aim to motivate energy conservation behaviour.

2.2 Energy feedback technologies

Feedback is defined as "information about the result of a process of action that can be used in modification or control of a process of system…especially by noting the difference between a desired and actual result" (Oxford English Dictionary). Feedback can facilitate performance in several ways, by providing information about the type, extent and direction of errors so that they may be corrected (Becker, 1978). Within the context of energy consumption, feedback has two important benefits. First, studies have shown that feedback of one's energy usage is essential to increasing personal awareness on the ecological impact of one's daily actions (Darby, 2001), (Holmes, 2007). Second, direct feedback (feedback that is available on demand) in the form of an interactive computer display, has been shown to contribute to reducing household energy consumption by 20 percent (Darby, 2001).

Feedback is most effective when it is continuous (Abrahamse et al., 2005) and immediate (Geller, 2002). Several studies show that computerized feedback is more effective than paper-based feedback due to their immediate responsiveness, flexibility in reacting to user's demands, and their interactive component (Fischer, 2008). Within computerized feedback, multiple feedback options (e.g. consumption over various time periods, comparisons, additional information such as cost or environmental saving tips), user interaction (where the user can explore and interact with the data), and detailed, appliance-specific breakdowns of energy usage have shown to be most effective (Fischer, 2008).

2.3 A review of energy feedback technologies

I now review energy feedback technologies that try to motivate sustainable energy behaviour. This review is not exhaustive. Rather, it defines a general landscape of work in this area.

Design Dimension	**Approach(es)**	**Example systems**
d1. Context of target audience	• *The individual* • *The individual within a social group*	Individual – e.g. Kill-A-Watt Individual within a social group – e.g. CarbonRally
d2. Attention level	• *Foreground* (central) • *Background* (peripheral)	Foreground – e.g. Cent-A-Meter Background – e.g. Energy Orb
d3. Interaction level	• *Active* (i.e. specific user input or decision-making is required in order to display the desired feedback) • *Passive* (i.e. feedback is displayed without requiring user input or decision-making)	Active – e.g. A Future-Proofed Power Meter Passive – e.g. Ecomagination
d4. Feedback medium	• *Screen display* • *Physical form* • *Other*	Screen display – e.g. Ecomagination Physical form – e.g. Flower Lamp Other – e.g. Nuage Vert (projection onto the sky)
d5. Method of feedback visualization	• *Text* (e.g. numbers, words) • *Charts* (e.g. bar or line graphs) • *Graphics* (e.g. icons, images) • *Animation*	Text – e.g. Kill-A-Watt Charts – e.g. PowerNab Graphics – e.g. Ecomagination Animation – e.g. GreenLite Dartmouth
d6. Temporal feedback	• *History* • *Real-time* (now) • *Projected*	History – e.g. Google PowerMeter Real-time – e.g. Watts Up Projected – e.g. StepGreen
d7. Periodic summaries	• *Daily* • *Weekly* • *Monthly* • *Yearly*	Daily – e.g. PowerNab Weekly – e.g. Google PowerMeter Monthly – e.g. Ecomagination Yearly – e.g. Ecomagination
d8. Comparative feedback	• *With yourself* (e.g. with your own previous or average usage) • *With others*	With yourself – e.g. Google PowerMeter With others – e.g. Google PowerMeter

d9. Level of feedback processing	• *Raw* (e.g. watts, amps, hertz, volt-amperes) • *Processed* (e.g. kWh, monetary cost, CO_2 emissions, water usage compared to equivalent number of bathtubs)	Raw – e.g. Kill-A-Watt Processed – e.g. 7000 Oaks and Counting, Ecomagination
d10. Persuasive strategies	• *Instructions for sustainable usage* • *Commitment to energy goals* • *Reinforcement or rewards* • *Value-added design* • *Prompts* • *Social validation* • *Adaptive interfaces* • *Emotional connection* • *Recognition* • *Competition*	Instructions – e.g. Energy Tree Commitment – e.g. StepGreen Reinforcement – e.g. Waterbot Value-added design – e.g. Waterbot Prompts – e.g. Waterbot Social validation – e.g. Waterbot Adaptive interfaces – e.g. Waterbot Emotional connection – e.g. Ubigreen Recognition – e.g. CarbonRally Competition – e.g. GreenLite Dartmouth
d11. Granularity of measure	• *Appliance* • *Plug outlet* • *Room* • *House*	Appliance – e.g. Energy Tree Plug outlet – e.g. Watts Up Room – e.g. PowerNab House – e.g. Wattson
d12. Number of input mediums	• *Single* • *Multiple*	Single – e.g. Power Conscience Multiple – e.g. Energy Tree
d13. Visualization integration	• *Integrated* (e.g. one device for visualization) • *Distributed* (e.g. includes standalone software for external visualization)	Integrated – e.g. Power-Aware Cord Distributed – e.g. Wattson, Watts Up
d14. Appliance control	• *Remote* • *Manual*	Remote – e.g. Energy Tree Manual – e.g. Power-Aware Cord
d15. Non-energy usage feedback	• *Weather* • *Humidity* • *Other*	Weather – e.g. PowerNab Humidity – e.g. Cent-A-Meter Other – e.g. Energy Tree (recycling)
d16. Type of feedback	• *Electricity* • *Water* • *Gas* • *Solar* • *Other*	Electricity – e.g. Power-Aware Cord Water – e.g. Waterbot Gas – none Solar – e.g. PowerNab Other – e.g. Ubigreen (transportation)
d17. Development sector	• *Commercial* • *Research*	Commercial – e.g. Cent-A-Meter Research – e.g. Ubigreen Other – e.g. Nuage Vert (art

	• *Other*	installation)
d18. Level of abstraction	• *Literal* • *Abstract*	Literal – e.g. Power Cost Monitor Abstract – e.g. Nuage Vert
d19. Interface navigation	• *Mode-switching* (e.g. must switch modes to view different types of feedback) • *Parallel* (e.g. one screen shows multiple types of feedback)	Mode-switching – e.g. Kill-A-Watt Parallel – e.g. PowerNab

Table 2.1: Design dimensions of energy feedback systems

To understand the diversity of energy feedback technology characteristics, I propose 19 design dimensions and approaches used within these dimensions, listed in Table 2.1. For each dimension, the approaches used are not necessarily mutually exclusive. I use design dimension #1: "context of target audience" to present energy feedback technologies in two broad audience contexts: 1) those that aim to motivate the individual, and 2) those that aim to motivate the individual within a social group. I choose this as the primary categorization as there are significant design differences between these two approaches.

Within this broad categorization, and for purposes of literary convenience, I choose two additional design dimensions to guide the order in which I present feedback systems: design dimension #2 – "attention level" and design dimension #3 – "interaction level". Again, I stress that the reader should not take this organization as a taxonomy assumed by my research, or that the dimensions along which I divide the systems are necessarily the key ones for design. Throughout my description of these systems, I also refer to other design dimensions listed in Table 2.1, using the following naming convention (e.g. "d8" to refer to design dimension #8).

Finally, in presenting the systems, I focus primarily on the design of the user interface, as this is the portion that aims to motivate sustainable energy behaviour change. I do not discuss the technical or implementation details of the system (e.g. programming language, hardware, wireless protocols, sensor setup, and so on), except in passing.

2.3.1 Motivating the individual

I begin with energy feedback systems geared towards motivating the individual. I further divide these systems using design dimensions "d2. attention level" and "d3. interaction level", as listed in Table 2.1.

Foreground attention, passive interaction

I first present displays that require an individual's foreground attention (d2) to maintain awareness of the visualization, and allow passive interaction (d3), where specific user input or decision-making is not required to display the desired feedback.

These include commercial (d17) energy feedback technologies that present electricity feedback (d16) on small, LCD displays using only numbers and text (d5) (Figure 2.1). Some devices present feedback for the entire household (d11) by measuring the main electric panel (e.g. Cent-A-Meter, The Energy Detective, Power Cost Monitor), while others measure a group of appliances at the plug outlet level (d11) (e.g. Kill-A-Watt, Watts Up).

Navigation through the interface is achieved through mode-switching (d19) by pressing buttons. Modes of feedback include raw data (d9), such as watts, volts, amps, hertz (Figure 2.1a, b), processed feedback (d9) such as kilowatt hours (kWh) (Figure 2.1a, b, c, e), and temporal feedback (d6) including the actual and projected monetary cost based on household energy usage patterns (Figure 2.1c, e). For example, Cent-A-Meter (Figure 2.1d) is currently showing a cost of 51.3 cents per hour. To view a different mode of feedback, the user can press the leftmost button labelled "Mode".

Due to the small display size and textual form of provided feedback, foreground attention (d2) is required to maintain awareness of energy feedback. Some devices also offer extra features (d15) such as outside temperature, humidity, or alarms that sound when one exceeds the expected usage (e.g. Cent-A-Meter). A few devices (e.g. Watts Up, The Energy Detective) provide external, standalone software (d13) that visualizes a history (d6) of energy

a) Kill-A-Watt b) Watts Up Pro c) The Energy Detective (TED) d) Cent-a-Meter e) Power-Cost Monitor

Figure 2.1: Commercial devices providing textual and numerical feedback of electricity consumption.

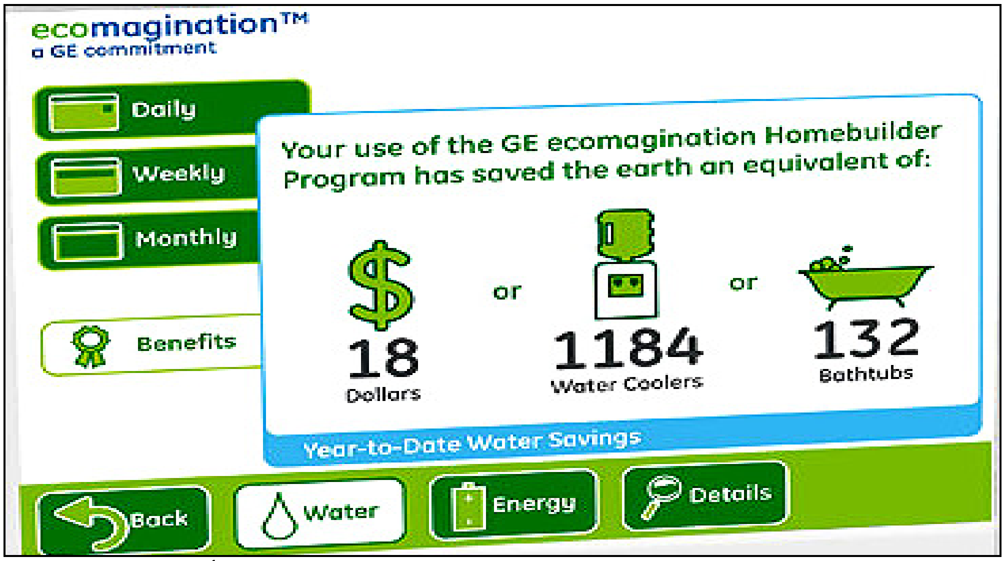
usage patterns using simple bar or line charts (d5). In general, navigation through both the actual device and standalone software interface is complicated and unintuitive, and often provides extraneous raw feedback information that the average household owner may not need or understand (e.g. hertz, amperes, volt-amperes, etc).

I now present a newer generation of feedback devices that provide much the same information as the previous group, but use charts and graphical visualizations (d5), in addition to text and numbers, and have a focus on more aesthetically-pleasing interfaces. Figure 2.2 (next page) shows examples of commercial tools (d17) including ‘Ecomagination’, ‘PowerNab’, and ‘Google PowerMeter’.

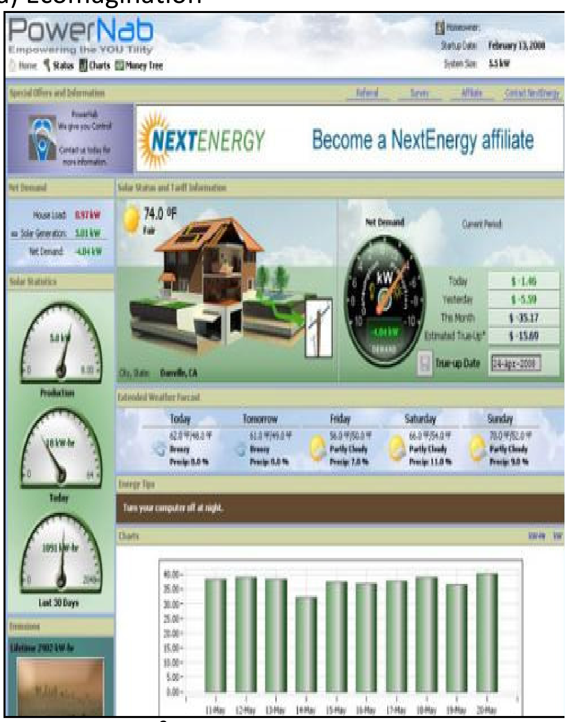
‘Ecomagination’ (Figure 2.2a) is a home energy visualization and control system that provides feedback of one’s electricity and water usage (d16) in terms of processed feedback (d9), such as monetary cost, and other equivalent and consumer-understandable comparisons (e.g. water usage compared to number of water coolers or bathtubs). As shown on its left, consumers can explore their daily, weekly or monthly consumption patterns (d7) (by selecting the “Daily, Weekly, Monthly” tabs), as well as benefits of their energy savings (by selecting the “Benefits” tab).

‘PowerNab’ (Figure 2.2b) is a commercial (d17) home energy feedback and monitoring system for solar-powered (d16) homes. Unlike ‘Ecomagination’, raw feedback of household energy consumption is represented through bar and line charts (d5), graphical visualizations (d5), and daily summary statistics of usage (d7). ‘PowerNab’ states that it will eventually provide household residents with other types of energy feedback, such as electricity, water and gas (d16).

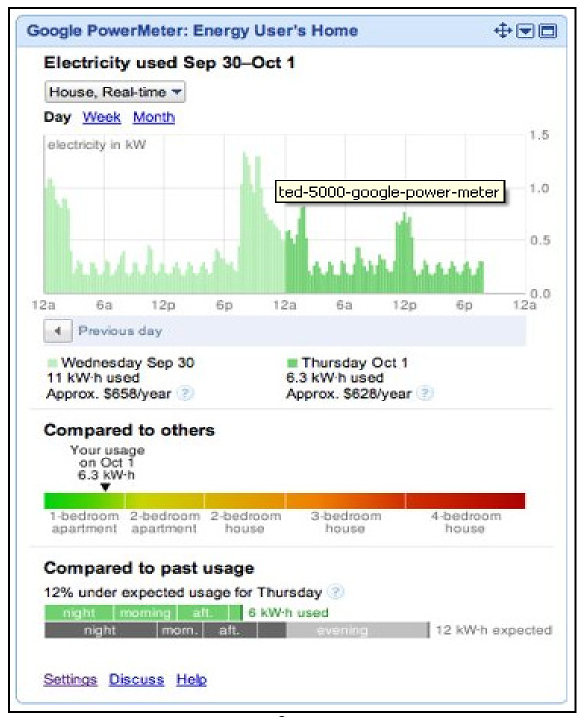
‘Google PowerMeter’ (Figure 2.2c) is an electricity usage (d16) monitoring tool that visualizes real-time (d6) feedback of household consumption. What is different from the above is that comparative feedback (d8), visualized through bar charts, line charts and



a) Ecomagination[1]



b) PowerNab[2]



c) Google PowerMeter[3]

Figure 2.2: Commercial home energy visualization tools: a) **Ecomagination** provides feedback of home electricity and water usage, b) **PowerNab** is a feedback and monitoring system for solar-powered homes, c) **Google PowerMeter** visualizes real-time feedback of household energy usage.

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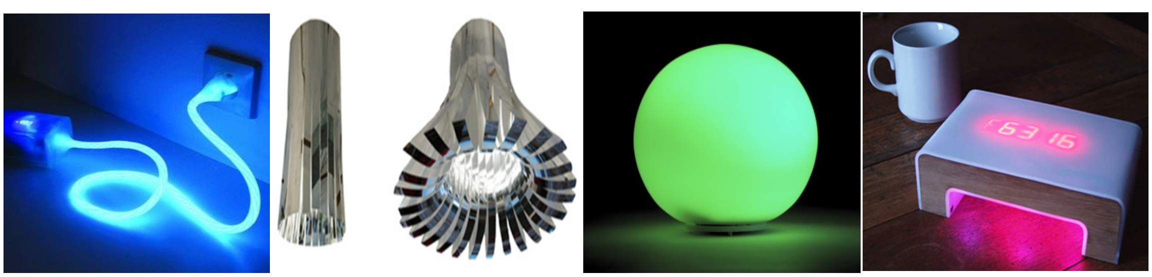
[1] http://news.cnet.com/2300-13842_3-6240513-6.html?tag=mncol. Retrieved Jan.2, 2009.
[2] http://news.cnet.com/2300-13842_3-6240513-5.html?tag=mncol. Retrieved Jan 18, 2009.
[3] http://fivepercent.us/2009/10/05/ted-5000-and-google-power-meter-who-needs-smart-meters/. Retrieved Jan 16. 2009.

progress bars (d5), shows one's own energy usage trend over time (top of the interface), compared to past and average expected usage ("Compared to past usage" in interface). Household residents can also compare their usage with the average consumption of similar-sized houses ("Compare to others" in interface).

Background attention, passive interaction

I now turn to energy feedback systems that appeal to an individual's background (peripheral) attention (d2) and allow passive interaction (d3), where feedback is provided without requiring user input or decision-making. These systems are primarily *ambient information systems (AIS)* - physical devices or graphical displays that present important, but non-crucial information to the periphery of a person's attention in a calm and non-disruptive way (Weiser, 1991). These systems make use of human beings' natural ability to attune to many pieces of information at the same time in the periphery of our attention, while focusing on a primary task in the center of our attention. When information in the periphery becomes of interest, we are able to easily switch it to the center of our attention and then back again without much conscious effort (Weiser, 1991).

I first present systems that are *physical* devices – that is, they use physical changes in form (d4) to visualize feedback. As shown in Figure 2.3, examples include the 'Power-Aware Cord', 'Flower Lamp', 'Energy Orb', and 'Wattson'.



a) Power-Aware Cord b) Flower Lamp c) Energy Orb d) Wattson

Figure 2.3: Physical ambient feedback systems: a) **Power-Aware Cord** (from Gustafsson & Gyllenswärd, 2005): changes in cord illumination provide electricity feedback, b) **Flower Lamp** (from Lagerkvist et al., 2006): the lamp "blooms" when household energy usage has been low for some time, c) **Energy Orb**[4]: color changes indicate current energy prices, d) **Wattson**[5]: the color of the glow indicates current household energy usage.

[4] http://www.inhabitat.com/wp-content/uploads/greenorb_onblack.jpg. Retrieved Dec.1, 2009.
[5] http://www.inhabitat.com/images/wattson.jpg. Retrieved Dec 3, 2009.

First, the 'Power-Aware Cord' (Gustafsson & Gyllensward, 2005) (Figure 2.3a) is a common electrical cord that uses three electroluminescent wires to visualize the amount of electricity (d16) it is consuming by varying the pulses, flow, and intensities of light (d5). It aims to invoke reflection of one's energy usage. Second, 'Flower Lamp' (Lagerkvist et al., 2006) (Figure 2.3b) changes shape to reward (d10) low household energy usage behaviour. When household energy consumption has been low for some time, the lamp 'blooms', changing to a more aesthetically-pleasing shape (d5), and in turn, increasing the amount of light it provides. In this way, 'Flower Lamp' reflects the rhythms and cycles of household energy usage over time (d6). Third, 'Energy Orb' (Figure 2.3c) is a glass orb linked to the Pacific Gas and Electric Company (PG&E) demand-response energy saving program. The orb's color changes (d5) to reflect current energy prices (d9): green when low, yellow when fair, and red when high. The idea is to encourage off-peak hour usage to save energy and monetary cost. Finally, 'Wattson' (Figure 2.3d) is a wireless device that glows different colors based on current (d6) household (d11) electricity (d16) consumption: blue for low usage, purple for average and red for high usage. The 'Wattson' also provides a real-time numerical reading of monetary cost (d9) per year (d7). In addition, household residents can purchase the 'Holmes' software to connect to the 'Wattson' (d13). 'Holmes' provides graphical visualizations (d5) of energy usage history (d6), costs (d9), and carbon emissions (d9) over days, weeks, and months (d7).

Another set of ambient information systems are *screen* displays (d4) which provide feedback using visualizations and/or animations (d5). Examples include 'Ubigreen', 'Power Conscience', and '7000 Oaks and Counting'.

'Ubigreen' (Froehlich et al., 2009) (Figure 2.4, top left and bottom) is an ambient, mobile phone visualization that uses semi-automatic sensing technologies to provide feedback of transportation behaviors (d16). 'Ubigreen' uses a series of emotionally persuasive (d10) icons (d5) of polar bears (Figure 2.4, bottom) or a tree. The more "green" one's transportation behaviors, the further one gets in the progression of icons. For example, in the polar bear visualization, the iceberg grows and the ecosystem improves until one reaches the final stage - the sun sets and Northern Lights appear (Figure 2.4, bottom). Feedback icons representing "auxiliary benefits" (d9) are also provided (Figure 2.4, top left):

Figure 2.4: Ubigreen (from Froehlich et al., 2009): (Top left): using polar bear icons to motivate "green" transportation behaviours. Auxiliary icons are shown on the bottom. (Bottom): Sequence of polar bear images (from left to right) as one's transportation behaviour becomes more "green". **Power-Conscience** (from Dennisur, 2007) (Top right): visualizes household energy usage using differently colored trees.

a piggy bank to represent money savings, a person meditating to represent relaxation, a book representing the opportunity to read, and a weightlifter to represent exercise (Froehlich et al., 2009).

'Power Conscience' (Figure 2.4, top right) is a small, outlet device that visualizes household (d11) energy usage using color change animations (d5) of graphical trees. When energy use is low, the tree is coloured a gradient of dark to light green. When energy use is average, the gradient is green to yellow. When usage is high, the gradient is yellow to red.

'7000 Oaks and Counting' (Holmes, 2007) (Figure 2.5) is a public artwork (d17) that visualizes the carbon footprint of a building by equating energy used with number of trees required to offset carbon emissions (d9). The lower the energy usage, the more trees shown (d5) (Figure 2.5, bottom, early in the day). The higher the energy usage, the more buildings and appliances shown (d5) (Figure 2.5, bottom, later in the day). This work also links to a website inviting building residents to make individual public commitments to reduce their carbon footprint (d10). After the individual fills out a web form, their name is incorporated into the visualization's animation sequence (d5), and the proposed carbon offset is applied immediately to the building's total. Whether or not individuals follow through on their commitment is based on trust.

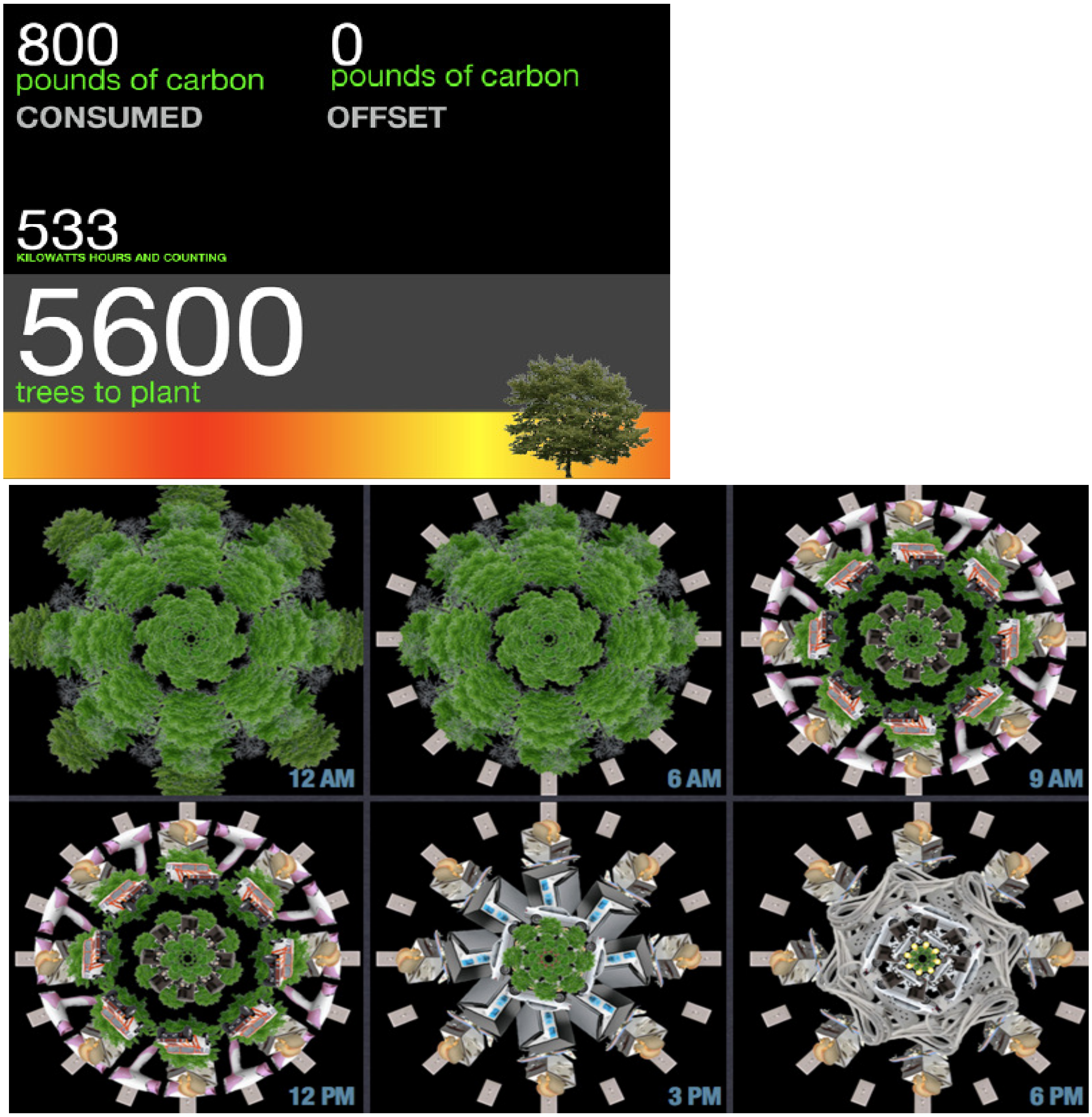


Figure 2.5: 7000 Oaks and Counting (from Holmes, 2007) (Top): visualizes a building's kWh, emissions, trees required to offset emissions, and completed carbon offsets. (Bottom): Visualizations throughout the day - more trees represent low usage, more appliances represent high usage.

Background or foreground attention, passive interaction

I now present feedback systems, which, depending on the situation, appeal to an individual's background or foreground attention (2) to maintain awareness of the visualization. These systems also allow passive interaction (d3), where feedback is provided without requiring specific input or decision-making from the individual. Examples include 'Nuage Vert', 'Infotropism', 'Waterbot' and 'Energy Tree'.

a) Nuage Vert b) Infotropism c) Waterbot

Figure 2.6: a) **Nuage Vert** (Evans and Hansen, 2009) (Left): a projected cloud represents the city's power plant consumption. (Right): a sequence of images showing high (leftmost) to low (rightmost) energy usage, b) **Infotropism** (from Holstius et al., 2004): a plant leans towards the direction where motion is most frequently sensed – in this case, the trash bin (not the recycling bin), c) **Waterbot** (from Arroyo et al, 2005): motivating sustainable tap usage using color-illumination to add to the perceived value of water.

'Nuage Vert' (Evans and Hansen, 2009) (Figure 2.6a,b) was a week-long, city-scale art light installation (d17) in Helsinki, Finland. It visualized the energy consumption of the city's coal-burning (d16) power plant by projecting green lasers (d5) onto the smoke emitted from the plant (Figure 2.6a). The green illumination adjusts its shape and size to the contours of the smoke, where the *more* energy city residents consumed, the *smaller* the projected cloud (Figure 2.6b). During the installation, residents were asked to reduce their energy consumption, where their actions would be rewarded (d10) by a bigger projected cloud.

'Infotropism' (Holstius et al., 2004) (Figure 2.6b) is an interactive research (d17) work that uses lights, sensors, and robotics to provide feedback of waste behavior and to motivate recycling. It is placed between a recycling bin and a trash bin. A motion sensor gives light to the side where motion is most frequently detected. Then, phototropic behaviour is simulated by manipulating the plant such that it grows and leans toward the side with the most light (d5). In the location where 'Infotropism' was set up, it communicated the idea that people throw away more than they recycle.

'Waterbot' (Arroyo et al., 2005) (Figure 2.6c) is an augmented physical interface installed at the sink to provide feedback of one's water (tap) (d16) consumption. It aims to motivate water conservation behaviours using persuasive strategies (d10), such as: "value-added design" - the use of color-illumination to add to the perceived value of flowing water (Figure 2.6c), visual and auditory "just-in-time prompts" which act as reminders and "positive reinforcement" to encourage sustainable water behavior at the point of usage, "adaptive interfaces" that provide reinforcement at varying intervals before gradually withdrawing, and "social validation" (d10) through the use of a bar chart visualization (d5) that compares (d8) an individual's water usage to the household average usage.

'Energy Tree' (Arent, 2007) (Figure 2.7) receives input from sensors and recycling bins (d12) to provide feedback of household appliance (d11) usage and recycling behaviors (d15) using chart and graphical visualizations (d5). In addition, a real tree (d4) (Figure 2.7, left) responds to the individual's level of energy efficient appliance usage and recycling behaviours, where the more energy-efficient one is, the healthier the tree will grow. The less efficient, the more likely the tree will acquire disease and die. Energy efficiency is represented as a percentage (Figure 2.7, right) and is determined by two factors. First, intelligent recycling bins communicate the weight and fullness of the bins to 'Energy Tree', indicating the amount that household residents recycle (Figure 2.7 (right) shows bins for "glass", "paper", "food", "plastic", and "dangerous"). Second, household residents can view and control (d14) appliance usage through 'Energy Tree's graphical interface. Figure 2.7 (right) shows appliance usage for the "living room TV", "bedroom PC", "microwave", and "hifi", where efficiency level of appliance usage is communicated to the tree. Additional features include instructions for specific energy actions and their potential savings (d10)

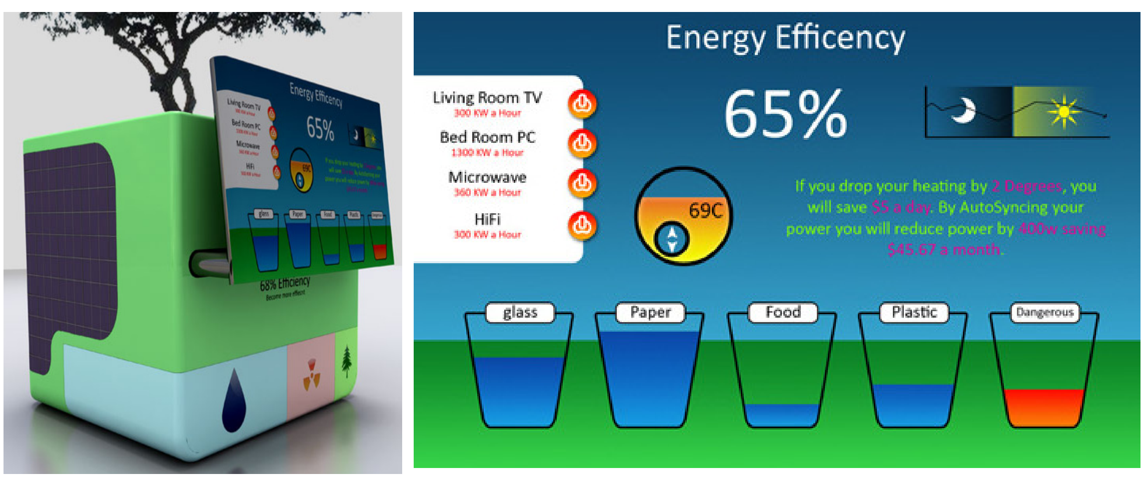


Figure 2.7: Energy Tree (from Arent, 2007): (Left) - A real tree responds to the level of energy-efficient appliance usage and recycling behaviour. (Right) – The interface showing feedback of one's recycling and energy consumption behaviours.

Figure 2.8: Energy Curtain (from Ernevi et al., 2006): The curtain's glowing pattern represents collected sunlight during the daytime

(Figure 2.7 (right): "If you drop your heating by…"), and a line chart indicating total household consumption trend throughout the day (d6) (Figure 2.7 (right), moon and sun chart).

Active interaction

I now present feedback systems that require active interaction (d3) on part of the user – that is, in order to display the desired feedback, specific user input or decision-making is required. Examples of systems in this subcategory include 'Energy Curtain' and 'A future-proofed power meter'.

'Energy Curtain' (Ernevi et al, 2006) (Figure 2.8) is a window shade woven from a combination of textile, solar-collection and light-emitting materials (d4). Household residents must make an active decision (d3) as to whether they wish to 1) open the curtain during daytime to let sunlight in, or 2) close the curtain during daytime to collect sunlight, where the collected energy is expressed as a glowing pattern on the inside of the shade in the evening (d5).

'A future-proofed power meter' (Jeremijenko, 2001) – not shown - relies on human intelligence to display energy feedback data. The meter's natural state is a blank screen. To display one's energy data, the person must take action (d3) by speaking into the meter's speech recognition system and provide a guess (within the correct range) of the kilowatt hours (kWh) currently being used (d3). If correct, the meter will display (using numbers and text) the person's current and past energy usage (d6). The goal is that over time, the individual will become familiar enough with their usage patterns that the device will become obsolete. From there, the designer envisioned that the meter can be passed to a friend or neighbour. No image is available for this work.

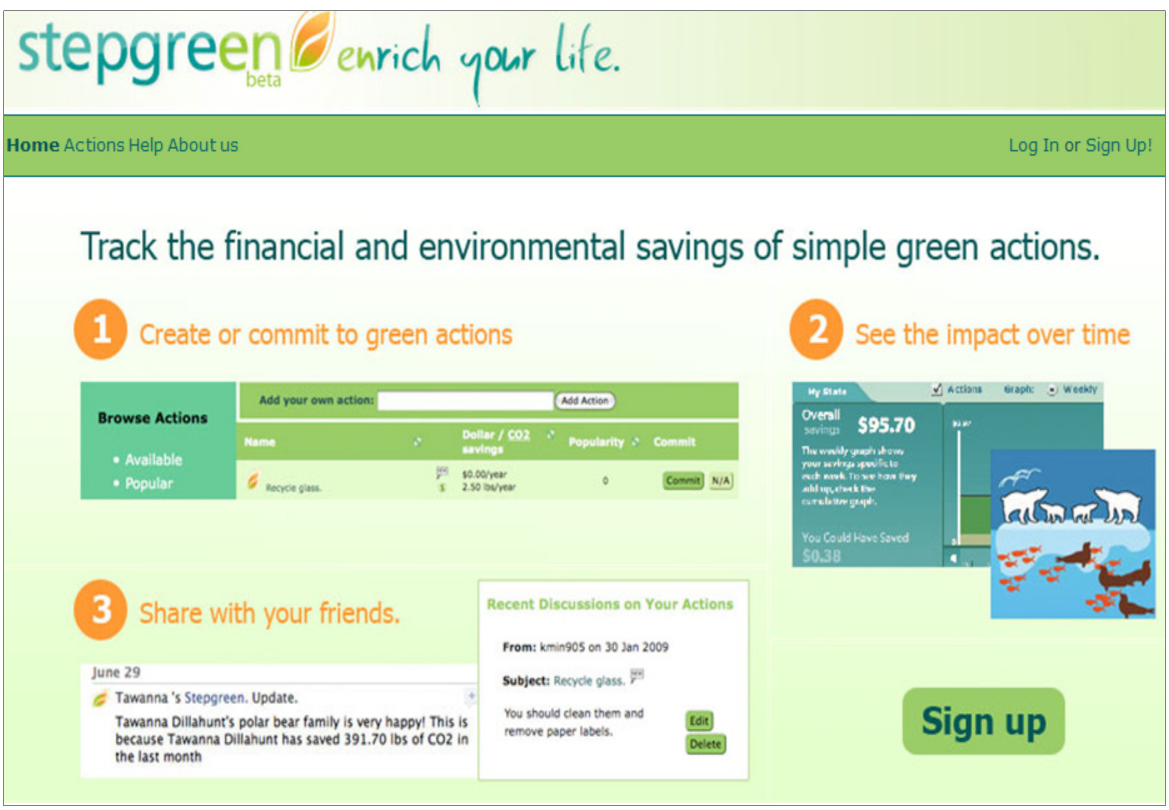
2.3.2 Motivating the individual within a social group

I now present feedback technologies in the second broad audience context - systems that aim to motivate the individual within a social group. These systems differ in design from the previous audience context as they consider the interactions between individuals and social groups.

Foreground attention, passive interaction

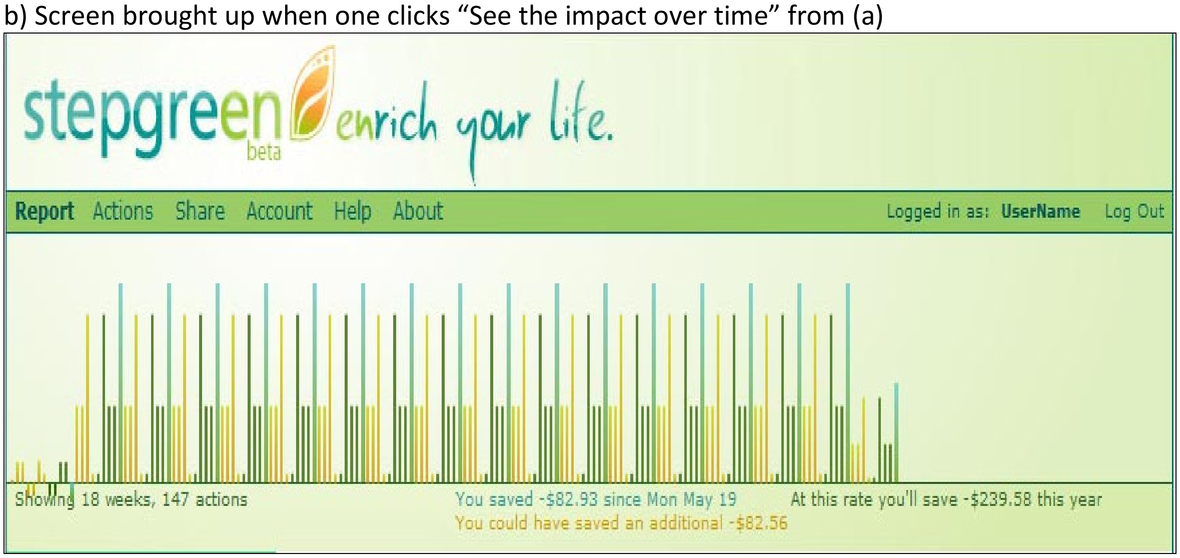
I now present feedback systems that require foreground attention (d2) to maintain awareness of the visualization and allow passive interaction (d3), where feedback is provided without requiring specific user input or decision-making. Examples include 'StepGreen', 'CarbonRally' and 'GreenLite Dartmouth'.

'StepGreen' (www.stepgreen.org)(Figure 2.9) is a web-based, social network (d1) tool that allows individuals to monitor energy usage and chart their energy savings over time. Three features are available. First, individuals can set goals (d10) to commit to energy actions by selecting from a pre-existing list, or create new actions (Figure 2.9a). For each committed action, feedback is provided (based on average appliance consumption values) of the money and CO_2 emissions savings over a year (d9) (Figure 2.9c). Whether the individual completes the committed action is based on trust. Second, after taking energy actions, a visualization shows the impact of actions over time (d6) (Figure 2.9b). Third, individuals can share their StepGreen actions or results with friends (d1), by joining a MySpace or Facebook page (Figure 2.9a, "Share with your friends").



a) Homepage showing three actions

b) Screen brought up when one clicks “See the impact over time” from (a)



c) Screen brought up when one clicks “Create or commit to green actions” from (a)

Figure 2.9: StepGreen (from www.stepgreen.org).

'CarbonRally' (Figure 2.10) is a web-based, social network tool (d1) where individuals can commit to small energy actions over time. The rally's objective is to motivate personal energy behavior changes, through challenges (d10), public commitments (d10), and by providing information (d10) of energy problems. 'CarbonRally' provides six tools. First, individuals can commit to existing challenges (d10), or create and post new challenges. Whether or not commitments are followed through is based on trust. Individuals can cancel a commitment within 21 days and try again another time. Second, individuals can create a new team, join an existing team, or become a team leader (d1). Third, individuals can see projections of the result of their potential actions (d6), and the collective impacts of actions that their team, or other teams across the country have taken (d8). Fourth, a message board provides the opportunity for individuals to chat with other Rally members or teams (d1). Fifth, a LeaderBoard displays the top cities, teams and individuals, and highlights occasional prizes (e.g. recognizing the top recruiters to 'CarbonRally') (d10). Finally, individuals who do not wish to join the rally can still contribute by becoming recruiters, building teams, or offering new ideas to the project.

a) The homepage.

b) The screen brought up when one clicks "Take a challenge" (from the homepage).

Figure 2.10: CarbonRally (from www.carbonrally.com).

Finally, 'GreenLite Dartmouth: Unplug or the polar bear gets it!' (Tice et al., 2009) (Figure 2.11) provides real-time electricity (d16) feedback of student dorms within Dartmouth College, as part of a college-wide dorm competition (d10) to motivate energy-efficient behaviour. Using animations of a mother and child polar bear in their Arctic habitat, the goal of this visualization is to motivate sustainable energy behaviours by creating an emotional connection (d10) between one's energy usage and the well-being of animated polar bears. When dorm usage is low, the polar bears are happy and playful. As usage goes up, the polar bears become distressed and their well-being is threatened. Specifically, a sequence of events happens: first, the iceberg that mother and child polar bear are on, breaks

Figure 2.11: GreenLite DartMouth: Unplug or the polar bear gets it! (screenshots from their video)[6]: (Left to right): a) opening screen, b) scene when dorm energy usage is high, c) bears on gold, silver and bronze platforms representing winners of the competition

into two pieces, separating the child from the mother. Both bears roar in panic while the child polar bear breaks away (Figure 2.11b). At the end of the competition, the top three dorm winners receive a monetary reward, along with an animation of three bears standing on gold, silver and bronze platforms (Figure 2.11c). Additionally, 'GreenLite Dartmouth' provides line chart visualizations (d5) representing the dorm's energy usage history (d6).

2.4 Summary

This chapter reviewed the landscape of energy feedback technologies that try to motivate sustainable energy behaviour. To understand the diversity of energy feedback technologies, I proposed 19 design dimensions and approaches used within these dimensions (listed in Table 2.1). I referred to these design dimensions throughout my description of these systems. Specifically, I presented feedback systems in two broad audience contexts (based on "d1. context of target audience"): 1) those that aim to motivate the individual, and 2) those that aim to motivate the individual within a social group. Within this broad categorization, for purposes of literary convenience, I further divided feedback systems based on "d2. attention level" and "d3. interaction level".

[6] http://www.youtube.com/watch?v=gRnOVzetQmc. Retrieved Jan 3, 2010.

Chapter 3. An augmented reality energy feedback system

This chapter presents our concept of a feedback system that uses augmented reality to visualize real-time energy feedback in context of the physical appliances being measured. In particular, we present our limited instantiation (implementation) of this concept – a feedback system called "AREnergyViewer".

I begin by defining augmented reality. Next, I present our motivation and concept of an augmented reality feedback system, and provide a scenario to more vividly demonstrate this concept. I then present our limited instantiation of this concept - a feedback system that we implemented called "AREnergyViewer" [7]. Specifically, I discuss AREnergyViewer's interface design and interaction, the appliances we measured, and the network architecture. I conclude with a discussion of AREnergyViewer as a "proof-of-concept" system and discuss future work.

3.1 Defining "Augmented Reality" (AR)

Augmented Reality (AR) can be best understood as a variation of Virtual Reality (VR). Virtual Reality technologies completely immerse the user inside a synthetic environment, where the user cannot see the real world around them (Azufma, 1997). In contrast, augmented reality allows the user to see the real world, with virtual objects superimposed upon, or composited with the real world (Azuma, 1997). Figure 3.1 illustrates two examples of augmented reality usage.

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[7] This work was inspired by the initial system developed by Lapides et al. (2009). It was done in collaboration with Saul Greenberg, Xin Wang, and Elaine Huang between mid-June and August, 2009. My part was the implementation of the back-end, including the network architecture, data capturing, the MySQL database setup, calculations of energy data, and the design concept of AREnergyViewer's interface and interaction. Xin Wang implemented the front-end of AREnergyViewer's interface and interaction.

Figure 3.1: Examples of Augmented Reality usage. (Left)[8]: Virtual text is superimposed on a real world scene. (Right)[9]: A real hand holds a baseball card with a virtual player standing on it.

AR systems have three characteristics (Azuma, 1997): 1) they combine the real and virtual world, 2) they are interactive in real-time, and 3) they are registered in 3D. When AR works ideally, the user should perceive that virtual and real world objects coexist in the same space (Azuma, 1997). The use of AR has been applied to many real world applications, including medical simulations, robot path planning, and entertainment, to name a few.

3.2 A scenario

I now present our concept of a feedback system that uses augmented reality to visualize real-time, energy feedback in the context of the physical appliances being measured. To more vividly demonstrate this concept, I draw upon a scenario of a person named "Dave". Dave wants to learn how his family can be more efficient in their energy usage, but does not know enough about how the devices in his home consume energy. Using a combination of semantic zooming based on proximity to support both high-level and detailed information display, a variety of real-time feedback visualizations, in-depth snapshot browsing capabilities and alternate views by manipulating physical phidgets, the feedback system allows Dave to explore energy usage and energy usage patterns in his home in a naturalistic fashion. I begin this scenario with Dave using the feedback device to view energy consumption of individual rooms in a particular hallway of his house.

As Dave walks down the hallway, he points the feedback device such that it pans across each doorway in the hallway. For each recognized doorway, the feedback device presents Dave with an overview visualization showing the current, total consumption of all

[8] http://www.uwplatt.edu/web/presentations/ar/heweb09/pix/augmented-reality-hud.jpg. Retrieved Dec 10, 2009.
[9] http://www.crispbranding.com/v1/images/stories/blog/Nam/Generic/09topps450.jpeg. Retrieved Dec 10, 2009.

appliances in the room beyond the doorway. After passing the master bedroom and the bathroom (which currently use a low amount of energy), Dave stops with interest as the feedback device shows a high consumption overview visualization of his teenage son Cody's closed door. While pointing the feedback device at Cody's doorway, Dave opens the door, and enters Cody's room. Immediately, the overview visualization changes to be enhanced with detailed feedback of appliance-specific consumption in the room. Dave looks around, and notices that no one is in the room, although the overhead lights, TV, laptop and alarm clock radio are all on, with random items and clothes strewn on Cody's floor. Dave guesses that his son probably left in a rush to meet his friends and forgot to turn everything off before leaving. Dave believes this happens quite frequently, and while thinking of how to get across to Cody when he comes home, moves the feedback device closer to the TV and laptop out of curiosity to see further details of what these frequently "on" appliances use. Dave then wonders how long these appliances have been on for, and moves a physical slider phidget (representing the time interval of visualized feedback) from "now" to "the last 12 hours". Dave notices that usage in the last 12 hours is high, and proceeds to change a rotation dial phidget (representing the current mode) to the "efficiency" mode to see how much of that usage was energy-efficient (i.e. used while Cody was actually in the room). Suddenly, Dave's cell phone rings. Dave presses the button phidget to take a "snapshot" of the visualization, before setting it down on the table and answering his phone. After a quick chat with his colleague, Dave returns to the feedback device as it lies on the table, this time, exploring very detailed appliance feedback using GUI interaction (e.g. scrolling, clicking, etc). After viewing several detailed, long-term visualizations of appliance consumption in Cody's room, Dave saves three particularly interesting screenshots to show Cody when he gets home. Dave presses the "snapshot" button phidget again to return to the real-time augmented reality view. Dave sighs, and manually turns off the TV, radio, lights, and closes the laptop lid, noting the immediate change in the feedback visualization. Dave turns and points the feedback device towards the hallway, walks out of Cody's room, hoping that this time, the screenshots he saved are enough to motivate Cody to be more environmentally-conscious in the future.

3.3 Motivation and concept

I now discuss the motivation and concept behind the augmented reality feedback system presented in the scenario. Topics include: 1) mobile, in-context viewing, 2) no on-screen spatial configuration, 3) real-time (immediate) feedback, 4) overview to detail by semantic zooming, 5) snapshot feature, 6) alternate views using phidgets, and 7) personal activity in relation to energy consumption. The following discusses these in detail.

Mobile, in-context viewing

Feedback of one's energy usage can be viewed by walking around a physical space (e.g. a house, a warehouse, a store, etc.) while pointing a webcam mounted on top of the feedback device towards the desired physical appliance(s) that the individual wishes to receive feedback for. Upon recognition of the appliance(s), the feedback device will visualize appliance-specific consumption feedback, using augmented reality to superimpose the visualization overtop the physical appliances. In this way, individuals can view real-time, energy feedback in context of the physical appliances being measured.

This has several benefits. First, being in context offers a high level of manual appliance control, making it easy for individuals to take energy action as they are already in the same physical space as the appliance. Second, being in context provides the individual with valuable contextual and situational information that could otherwise not be discerned, such as who is in the physical space, what they are doing, and the context and situation in which appliances are being used. Third, viewing energy feedback in context allows the individual to easily share the feedback visualization with others in the same physical space. In this way, the feedback visualization may serve as a conversation starter regarding activities relating to appliance usage in that space.

No on-screen spatial configuration

Viewing energy feedback in context eliminates the need for on-screen spatial (map) configuration, such as specifying which visualized (on-screen) appliance represents which physical appliance, and configuring the visualized space to look the same as the physical (real) space. Instead, individuals can specify appliance profile information in context by pointing the webcam mounted on top of the feedback device towards the desired appliance.

This has two benefits. First, it reduces the need for individuals to cognitively synchronize on-screen appliances with their counterpart in the physical space. Second, as individuals are viewing energy feedback in the same physical space as the measured appliances, there is no need for a re-configuration of the visualized spatial (map) layout if new appliances are added, existing appliances are removed, or existing appliances change location. Rather, individuals only need to specify (or re-specify) appliance profile information by pointing the webcam at the new (or modified) appliance.

Real-time (immediate) feedback

As mentioned in Section 3.1, augmented reality systems are interactive in real-time. Thus, our concept of an augmented reality feedback system provides real-time (immediate) feedback of appliance consumption.

This has two benefits. First, feedback is most effective when it is continuous (Abrahamse et al., 2005) and immediate (Geller, 2002). Second, receiving real-time feedback, in conjunction with viewing energy feedback in context, allows individuals to easily explore "what if" questions of energy usage, for example by manually trying out energy actions on a physical appliance and receiving immediate feedback of the impact of those actions within the visualization. This type of immediate cause and effect interplay may encourage more explorative types of interaction between the individual and the physical appliance.

Overview to detail by semantic zooming

In our concept of an augmented reality feedback system, the individual can move from overview to detail using semantic zooming. In comparison to *spatial zooming*, where the detailed view is "just an enlarged version of the overview" (Card et al., 1999), in *semantic zooming,* the content stays the same, but the appearance of the content changes (Bederson & Hollan, 1994). For example, an object in the overview would initially appear as a small point. As the user zooms in, it would turn into a square, and with further zooming, a labelled square and finally, a page of text.

To move from overview to detail by semantic zooming, the individual can manually change the proximity (distance) between the feedback device and the object(s) of interest (e.g. whether it be the energy consumption of a room, a group of appliances, or one appliance). When far from the object(s) of interest, an overview of energy consumption feedback will be displayed, with minimal to no detail. As the proximity between the feedback device and the object(s) of interest becomes smaller, the far view visualization is enhanced to provide further detail, which in the previous view, was not provided.

A significant advantage of using semantic zooming by proximity manipulation is that it mimics the natural interaction process of someone who, from a wide array of information, physically moves closer to an object of interest in order to explore it in more detail. In other words, when people stand at a far proximity from something, they typically wish to see a sense of the overview, rather than the details. From this overview, if specific objects capture their attention, people typically tend to move physically closer to the object of interest in order to examine or explore it more carefully. Here, I draw upon the example of a painter who occasionally stands back from her work to gain a sense of the overall picture, before delving back into the details of areas that require her attention.

Snapshot feature

At any proximity between the feedback device and the object(s) of interest, the individual can employ the "snapshot" feature. This freezes the current visualization and overlays options on top for viewing detailed energy consumption feedback. This allows individuals to set down the feedback device and interact with it using traditional graphical user interface (GUI) methods.

This has two benefits. First, the "snapshot" feature allows individuals to immediately access detailed feedback information on demand, without requiring manual manipulation of proximity to change the level of detail in the provided feedback. Second, as the "snapshot" feature freezes the current visualization, it may be useful in situations when the feedback device is difficult to view while holding (e.g. at certain distances, angles or positions) or when hand-shake is an issue (i.e. when the device is difficult to hold with still hands).

Alternate views using phidgets

A *phidget* is a "physical representation and/or implementation of a GUI widget"[10]. At any proximity (e.g. far, middle, near), phidgets can be used to filter or change to alternate views of the provided feedback. For example, a slider phidget can be used to change the time interval of the visualized feedback, a rotation (dial) phidget can be used to change the type (mode) of visualized feedback, and a button phidget can be used to take a "snapshot" of the visualization. This type of *physical* interface manipulation works well with the active nature of interaction required by the feedback device. Specifically, as the user is required to 1) hold and point the feedback device towards the physical objects(s) of interest in order to receive feedback for it, and 2) manually manipulate proximity in order to change the level of detail in the provided feedback, the active interaction required by the feedback device makes it difficult to use graphical user interface (GUI) methods to interact with the system. Thus, a physical approach to interface manipulation is a practical solution.

Personal activity in relation to energy consumption

While viewing energy feedback in context provides the individual with contextual and situational information for appliances located in current physical space at the current point in time, it may also be valuable to provide the contextual and usage *history* for appliances in the entire household. To achieve this, phidget sensors (e.g. a motion sensor to detect activity in a room) can be used to capture personal activity information in conjunction with appliance consumption feedback.

This has several benefits. First, personal activity information in conjunction with appliance consumption feedback can indicate the level of energy-efficient appliance usage. For example, in a living room consisting of a TV and a couch, personal activity information such as a force sensor on the seat of the couch can be used to detect presence, while a motion sensor facing towards the doorway entry can be used to detect activity in the room. Depending on the appliance, sensor information could be further extended to consider the time threshold for what is considered "energy-efficient" usage. For example, while the TV is on and presence and movement have been detected in the last 10 minutes, the feedback device may infer that the person is sitting on the couch and watching TV, making the TV's

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[10] http://en.wikipedia.org/wiki/Phidget. Retrieved Jan 10, 2010.

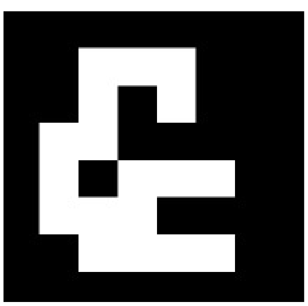
usage in the last 10 minutes "energy-efficient". In comparison, while the TV was on, presence was detected on the couch for the last 30 minutes, but motion was not detected for the last 15 minutes, the feedback device may infer that the person may have fallen asleep in the last 15 minutes while watching TV, making the TV's usage in the last 15 minutes "not energy-efficient". Second, personal activity information in conjunction with appliance consumption feedback can also be used to detect general patterns of energy usage behaviour over time. Using the same example, the individual may discern a pattern that on weekdays, he tends to start watching TV around 7pm, but seems to fall asleep between 7:30pm and 7:45pm while the TV is on. Third, capturing and visualizing personal activity information can benefit awareness and coordination of household residents. For example, Adam, upstairs in his bedroom, waiting to do laundry, notices that the washing machine, previously in an "on" state, has just turned off. He then looks at the feedback visualization of his roommate Jack's room, and notices that no motion has been detected for over an hour. This indicates to Adam that Jack has probably left the house, and the washing machine is currently free. In this way, appliance consumption feedback in conjunction with personal activity information can benefit the awareness and coordination of household residents.

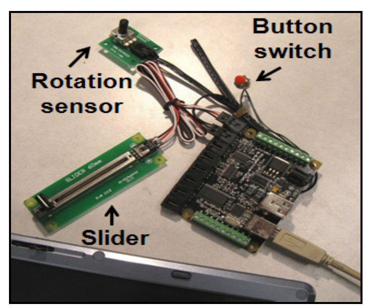
However, given the potential of the above benefits, there are also several costs to this approach. First, the capturing of personal activity information (such as time-based movements and activities of household residents) can be a serious invasion of privacy. Second, using a feedback device to infer the level of energy-efficient appliance usage implicitly assigns a value judgement where "energy-efficient" is "good" and "not energy-efficient" is "bad". However, such value judgements should, at least, be partially determined by the user and the specific situations and contexts in which they use their appliances.

3.4 AREnergyViewer: A "proof-of-concept" feedback system

I now present our limited instantiation of this concept – an augmented reality feedback system that we developed called "AREnergyViewer". While the methods we use for capturing appliance feedback and augmented reality appliance recognition are quite limited, AREnergyViewer is a "proof-of-concept" system that aims to demonstrate the motivation and concepts discussed in the previous section. I begin with a discussion of the physical components that AREnergyViewer is comprised of, followed by details of interface design

a) An overview of AREnergyViewer's physical components.





b) An AR marker c) AREnergyViewer's webcam d) AREnergyViewer's phidgets

Figure 3.2: AREnergyViewer physical components.

and interaction. I then discuss the appliances we measured, and finally, the network architecture.

3.4.1 Physical components

AREnergyViewer is comprised of the following physical components (Figure 3.2):

- *Tablet computer* (Figure 3.2a)*:* AREnergyViewer was developed on a 9" by 11.5", LifeBook T Series tablet computer.
- *AR markers* (Figure 3.2b)*:* Markers are black and white checkerboards. One marker represents one appliance, where the marker is placed in front of the physical appliance that the individual wishes to receive feedback for. In this way, markers act as unique appliance identifiers, and provide information to AREnergyViewer about the position and orientation of the physical appliance.
- *Webcam* (Figure 3.2c*)*: A webcam mounted on top of AREnergyViewer's tablet can be pointed towards the AR marker(s) representing the physical appliance(s) that the viewer wishes to receive appliance-specific energy usage feedback for.
- *Phidgets* (Figure 3.2d)*:* To change the content of visualized feedback, the user can manipulate physical phidgets, including a slider, a rotation dial, and a button. The slider phidget controls the time interval of the visualized feedback. The rotation phidget changes the type (mode) of visualized feedback. The button phidget invokes the "snapshot" feature, and freezes the current visualization. Phidget sensor feedback is captured using the Shared Phidgets Toolkit[11].

3.4.2 Interface design and interaction

I now present details of interface design and interaction. Topics include: 1) modes of feedback, 2) legend text and color scheme, 3) time interval of feedback, 4) overview to detail by semantic zooming, and 5) snapshot view.

Modes of feedback

AREnergyViewer uses mode-switching to provide different types of feedback. The current mode is displayed in the bottom right of the screen (Figure 3.4, next page). Modes can be changed by turning the rotation (dial) phidget. Modes include wattage, kilowatt-hours (kWh), monetary cost ($), CO_2 emissions (kg), and percentage of energy-efficient usage (%). Details of calculations are discussed in Appendix A.

[11] http://grouplab.cpsc.ucalgary.ca/cookbook/index.php/Toolkits/SharedPhidgets. Retrieved June 20, 2008.

Legend text and color scheme

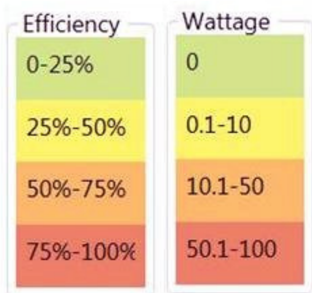


Figure 3.3: Comparison of legend text and color scheme in two modes.

The legend is located in the top right corner of the screen (Figure 3.4, next page). When the mode changes, the legend color scheme stays the same, while the legend text changes to reflect the appropriate numeric range and unit for the current mode. Figure 3.3 compares the legend text and color scheme for the "Efficiency" and "Wattage" modes.

Time interval of feedback

The time interval (period) of visualized feedback can be changed by manipulating the phidget slider. The current time interval is shown on the bottom left of the screen (Figure 3.4). When the slider control is at the top, feedback is visualized for the current point in time ("Now"). As the slider control shifts down, the time interval of the visualized feedback increases. From top to bottom, the time intervals include "Now", "Last 30 minutes", "Last 1 hour", "Last 12 hours", "Last 1 day", "Last 1 week", "Last 1 month". Of particular note is manipulation of the time interval in the "Wattage" mode - as the slider control moves from top to bottom, the visualized feedback changes from 'Now' to 'average wattage per second' over the specified time interval.

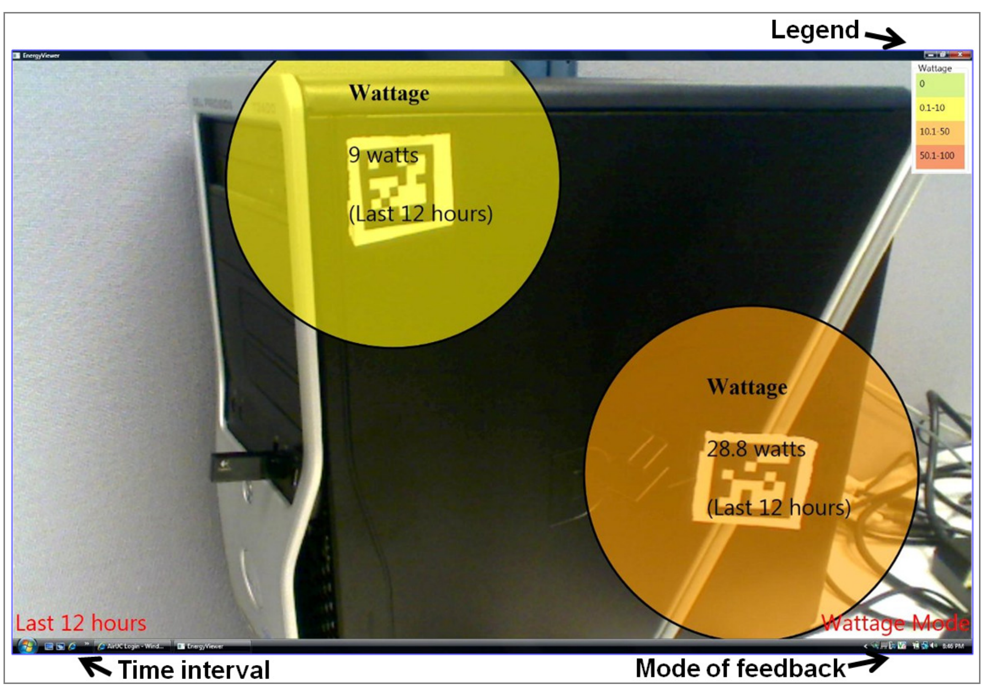
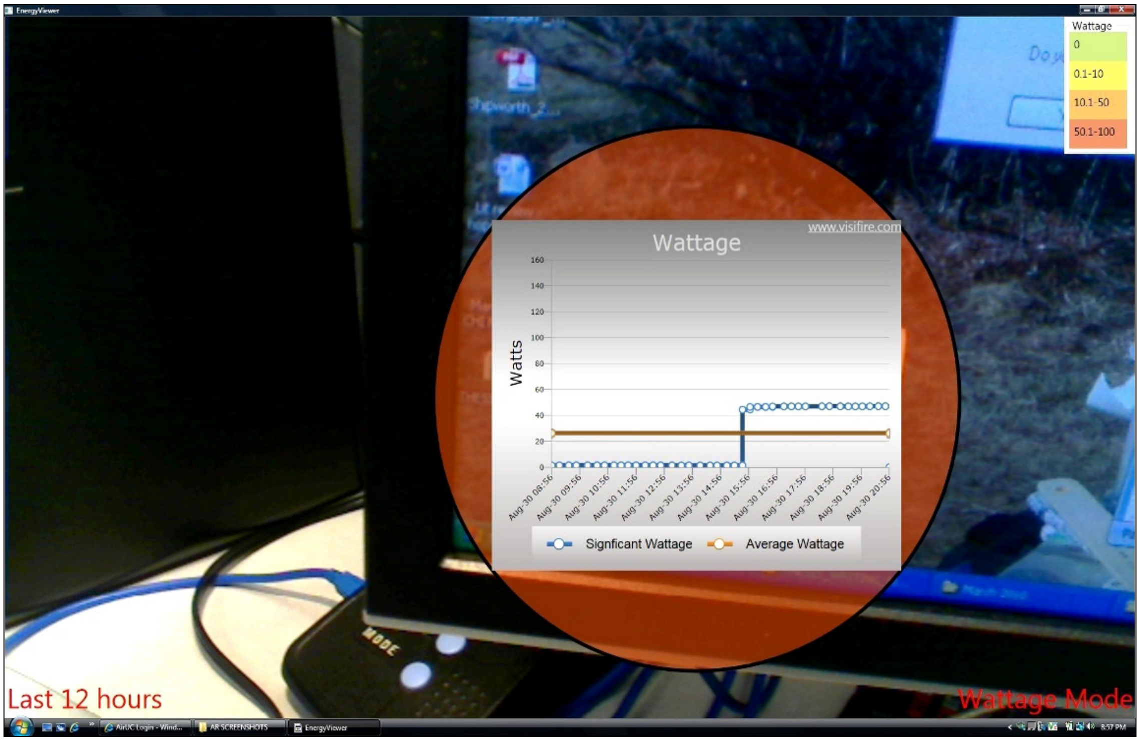


Figure 3.4: Interface showing legend, current mode of feedback and time interval of feedback.

a) Far view

b) Middle view



c) Near view

Figure 3.5: AREnergyViewer's three recognized proximities in "Wattage" mode for the "Last 12 hours".

Overview to detail by semantic zooming

To change the level of detail in the provided feedback, individuals can manipulate the proximity (distance) between AREnergyViewer and the measured physical appliance. AREnergyViewer recognizes three proximities: far, middle and near. Figure 3.5 shows AREnergyViewer's visualizations for all three proximities in "Wattage" mode for the "Last 12 hours". Details of each proximity are discussed below.

The far view provides the least detail of the three proximities. It assumes the individual is interested in several appliances, and aims to provide an overview of appliance consumption feedback using same-sized, colored circles (Figure 3.5a), where the color of the circle represents the numeric *range* of feedback, depending on the current mode and time interval. Due to limitations in AR marker recognition, the far view recognizes a maximum distance of approximately 1.2 meters from the measured appliance.

The middle view provides slightly more detail than the far view. It assumes that the individual is interested in a smaller number of appliances, and uses smooth animation to enhance the far view's colored circle with additional details of the numerical value and unit of energy feedback (Figure 3.5b). The current mode and time interval are also shown in the circle, though this information is always reflected in the bottom of the screen.

The near view provides the most detail of the three proximities. It assumes that the individual is interested in feedback of only one or two appliances. Depending on the current mode, the near view uses smooth animation to replace the text shown in the colored circle of the middle view with detailed numerical and graphical visualizations (i.e. bar and line charts) of appliance consumption feedback. Figure 3.5c shows the near view visualization for the "Wattage" mode over a 12 hour time period, where two line charts visualize "significant" and "average" wattage.

Snapshot view

At any proximity (i.e. far, middle, near), the individual can take a "snapshot" of the visualization by pressing the button phidget. As shown in Figure 3.6, this "freezes" the current visualization and overlays two buttons on top of each colored circle: 1) options to view detailed appliance usage over a specified time period ("Show calendar") and 2) options to configure appliance profile information ("Configure device").

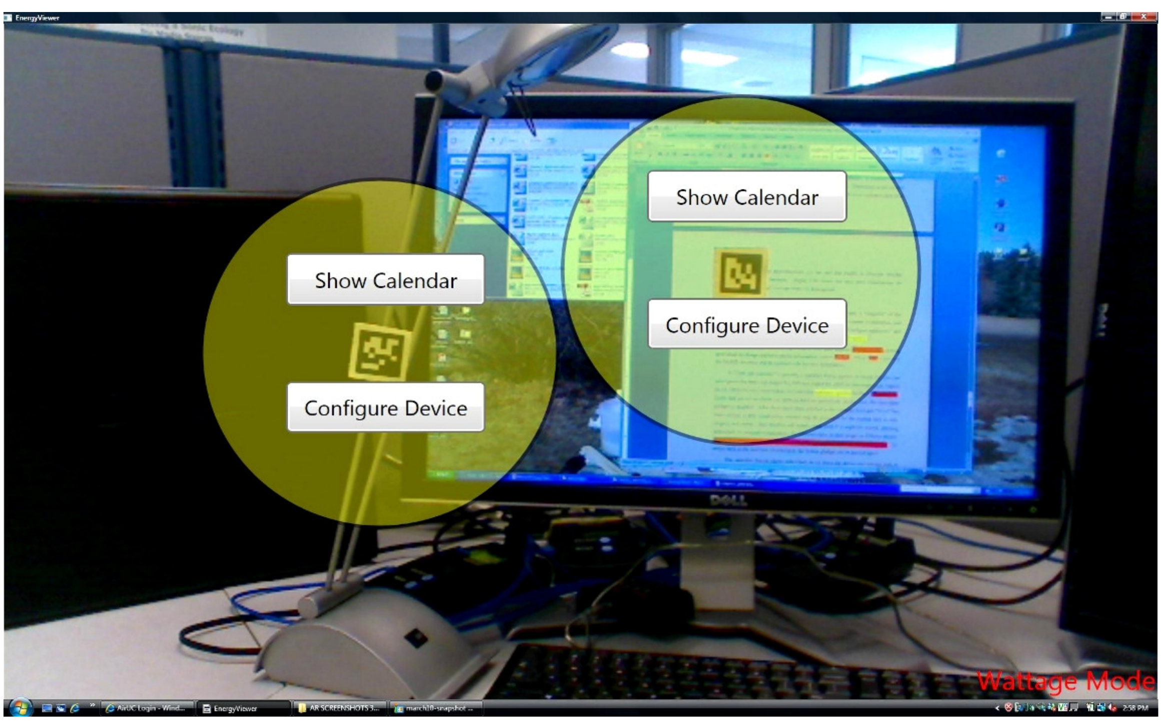


Figure 3.6: The interface when the snapshot button is pressed.

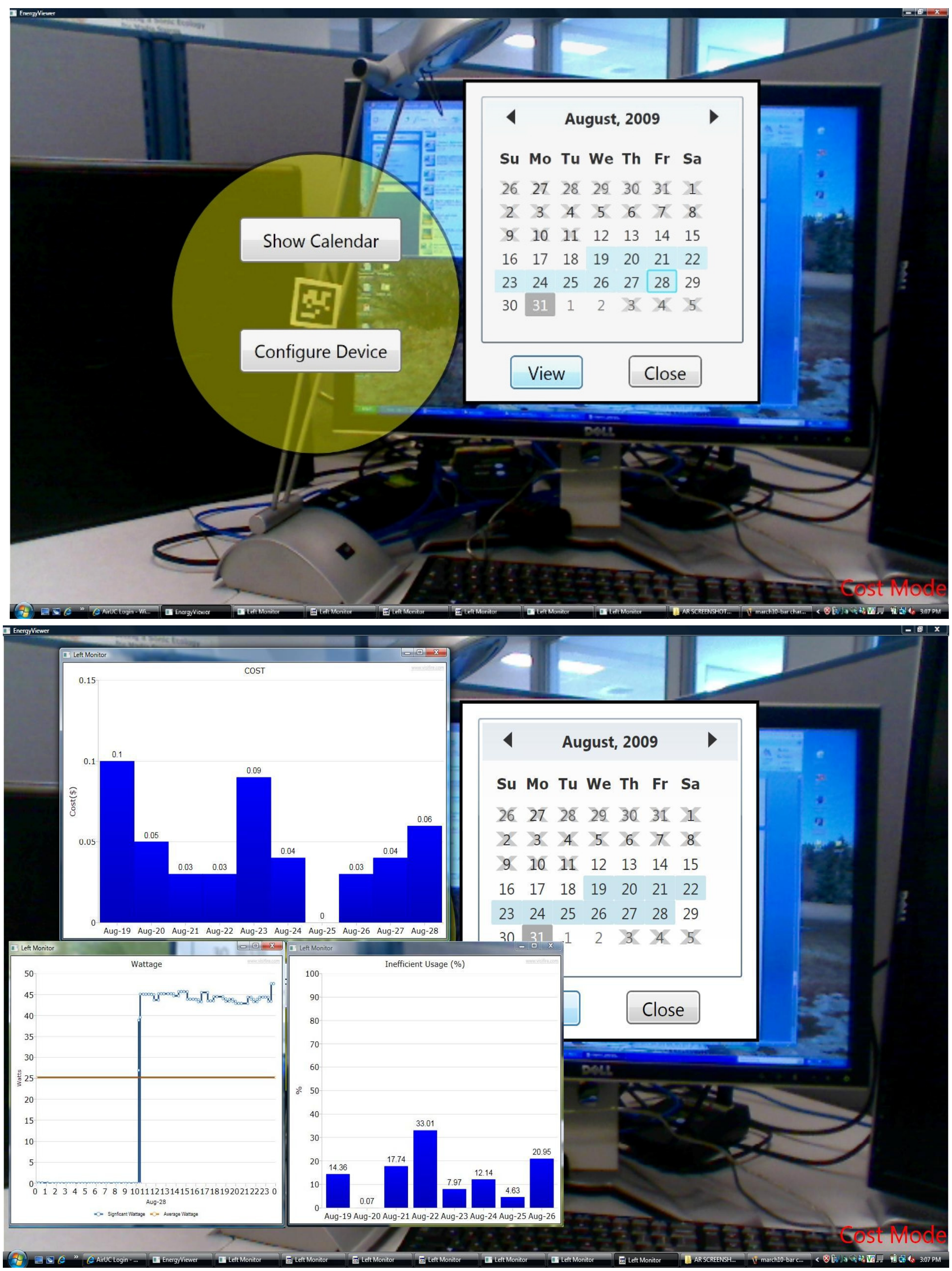


Figure 3.7: (Top): Selecting dates from the calendar for the monitor. (Bottom): Comparing different visualizations of monitor usage.

If "Show calendar" is pressed, a calendar dialog appears in which the user can select particular dates (e.g. August 14, 2009 and August 18, 2009) or date ranges (e.g. August 19-28, 2009) for which they wish to view detailed, appliance-specific feedback (Figure 3.7, top). Dates that are not available (i.e. have no data) are crossed out. In this view, the time slider phidget is disabled. After dates have been selected in the calendar GUI and "View" has been clicked, a new visualization window will be generated for the current date or date range(s) and mode. This window will remain open until it is explicitly closed, allowing individuals to compare visualizations for different dates or date ranges in different modes. Figure 3.7 (bottom) shows three generated views for different modes. In comparison to the near view, the snapshot feature allows comparisons of multiple dates and modes, though the visualization method (i.e. bar and line charts) is the same. To exit the snapshot mode, the button phidget can be pressed again.

If "Configure device" is pressed after taking a snapshot, a GUI form appears, allowing individuals to change appliance profile information (Figure 3.8). When "Save" is pressed in the GUI form, the MySQL database will be updated with this new information.

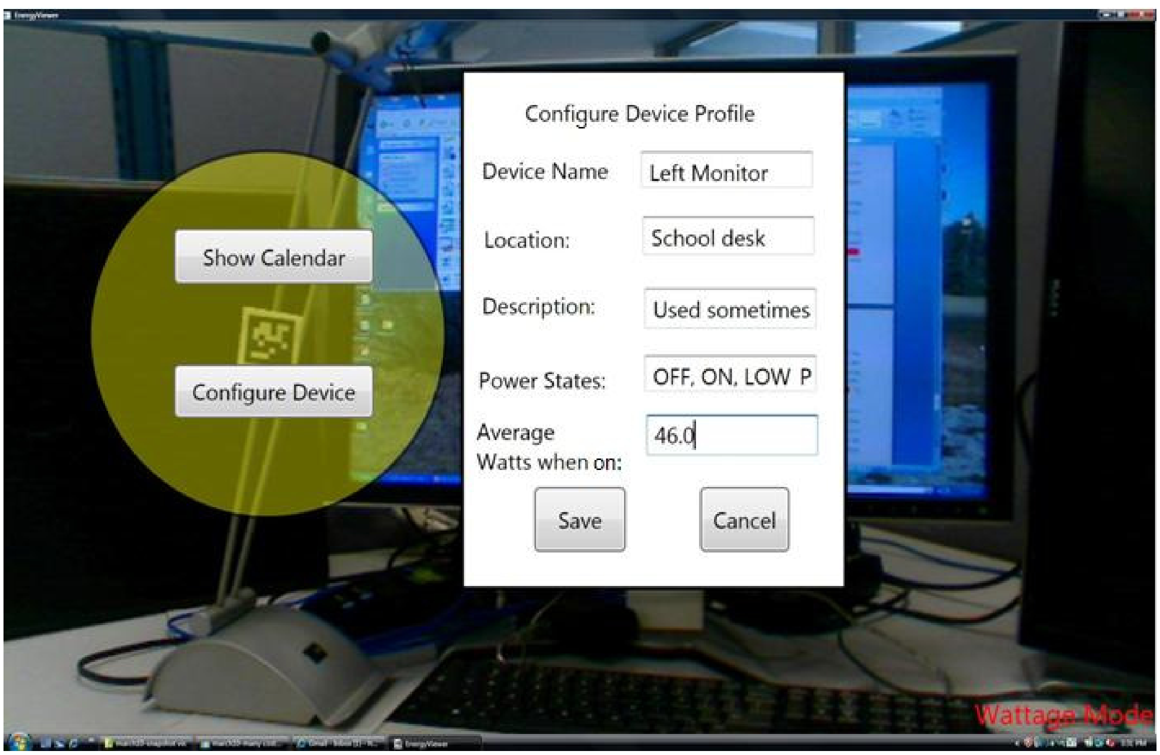


Figure 3.8: "Configure device profile" GUI for the monitor.

3.4.3 Measured appliances: Desktop computer and peripherals

In our instantiation of an augmented reality feedback system concept, we used the following example setup. We measured the electricity consumption of the following appliances: a central processing unit (CPU), two 21" LCD monitors, and a table lamp. These appliances are located at my desk in the Interactions Lab at the University of Calgary. Figure 3.9 (next page, top image) shows the measured appliances (labelled in red) and the client computer (labelled in yellow) that captures feedback from these appliances. The following discusses the limitations and choices that led us to measure these particular appliances.

First, appliance electricity consumption is measured at the plug outlet-level using a commercial device called the "Watts Up" (WU) (presented in Chapter 2, Figure 2.1b). We chose this device, as at the time, it was one of the only commercial feedback devices that allowed easy interfacing of feedback data to a computer. However, the usage of the Watts Up severely limited the scope of appliances we were able to feasibly measure. As shown in Figure 3.9 (next page, bottom image), each WU device measures one appliance, where each WU requires a power cord and USB connection to a separate computer to capture appliance feedback. This heavyweight equipment requirement and the stationary nature of equipment setup led to our decision to do a simple, co-located setup for tractability and keep equipment costs reasonable.

Due to the previous decision, we decided to use the specific appliances of the desktop computer and its peripherals. We chose this for two reasons. First, computer usage is becoming increasingly prevalent in our everyday lives. In the U.S., approximately 111.1 million housing units have 58.6 million desktop computers and 16.9 million laptop computers (Chetty et al, 2009). Second, unlike other commonly-used appliances such as the refrigerator, microwave, or TV, the computer provides customizable, automatic power management features including sleep, hibernation, and automatic monitor standby. However, despite the existence of power management features, many people do not know where such features are located on their machine or how to use them (Chetty et al., 2009). Therefore, many opportunities exist to inform household residents of the best ways to make use of power savings (Chetty et al., 2009), where estimated potential savings from improved

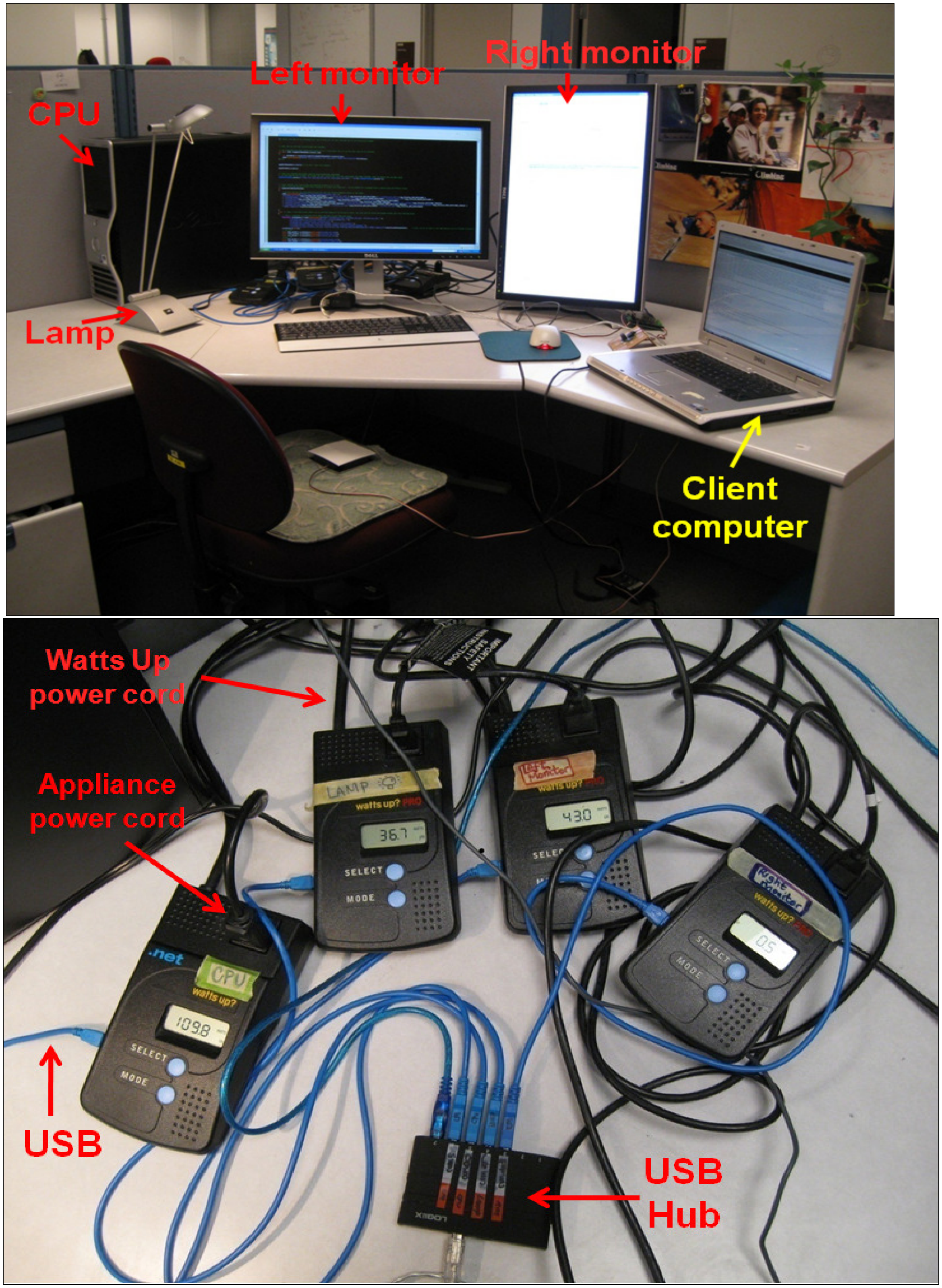


Figure 3.9: (Top): Four measured appliances (labelled in red) and the client computer (labelled in yellow). (Bottom): Each Watts Up device captures individual appliance feedback through USB.

computer power management in the U.S. is in the order of terawatts per year (Kawamoto et al., 2001).

Given the previous decision, we decided to measure my computer unit in the Interactions Lab. This decision was largely influenced by factors of convenience and practicality, as it allowed me to easily implement and test the system, while manually supervising the WU data capturing process of the measured appliances.

3.4.4 Network architecture

I now discuss the network architecture of AREnergyViewer (shown in Figure 3.10). I present each component in separate, in order of data capture (client), data calculation and storing (server), and data retrieval for visualization (AREnergyViewer).

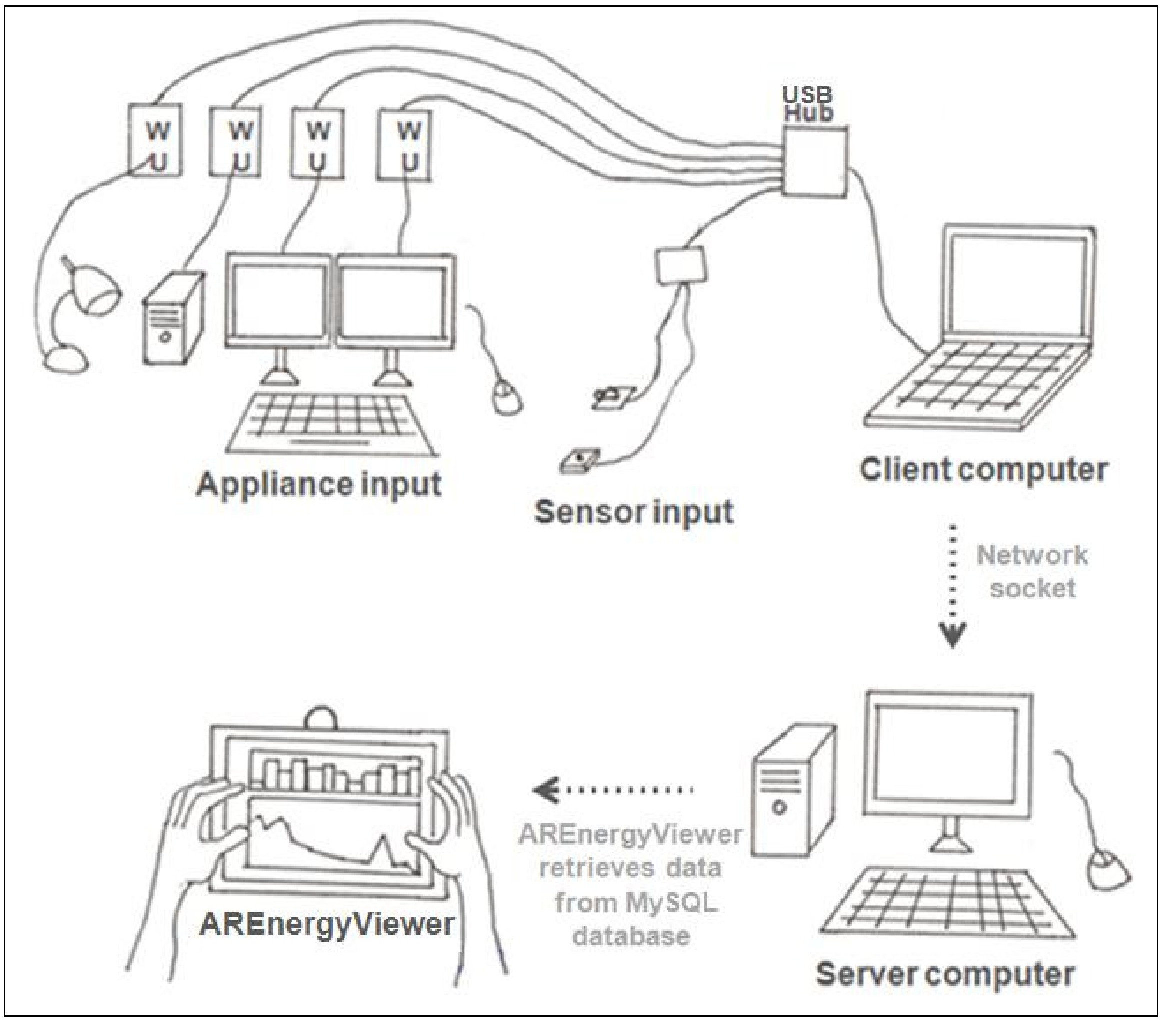


Figure 3.10: Diagram of network architecture and system components.

Client: The client computer (Figure 3.9, top) is located beside the measured appliances and captures appliance-specific, electricity feedback using Watts Up (WU) devices. The client code is written in C# and is a wrapper around the Watts Up API[12]. In addition to appliance consumption feedback, the client computer also captures phidget sensor feedback using the Shared Phidgets Toolkit[13]. As shown in Figure 3.11, phidgets include 1) a motion sensor facing towards the keyboard and mouse to capture activity at the measured computer, and 2) a force sensor placed on the seat of the chair to capture presence information at the measured computer. Finally, both appliance and sensor feedback is sent through a network socket (in a string format) to a centralized MySQL database server. The socket stream includes the date, day of week, time of day, motion sensor state, force sensor state, total watts (of all measured appliances), individual appliance wattage(s) and power state(s) (e.g. on, off, in transition, or low power (standby)).

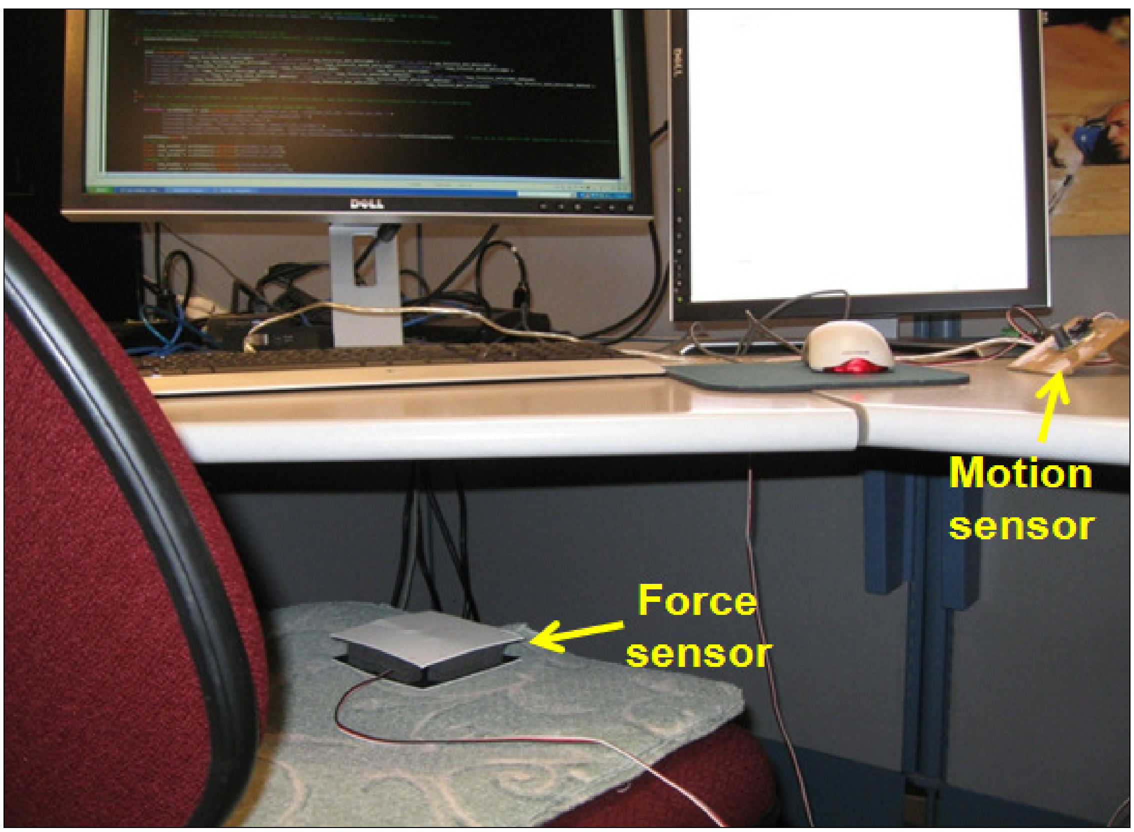


Figure 3.11: Phidget sensors attached to the client computer.

[12] https://www.wattsupmeters.com/secure/downloads/CommunicationsProtocol090824.pdf. Retrieved June 15, 2007.

[13] http://grouplab.cpsc.ucalgary.ca/cookbook/index.php/Toolkits/SharedPhidgets. Retrieved June 20, 2008.

Server: The server computer is located in an office in the Interactions lab, a few meters away from the client computer. It receives raw appliance and sensor feedback through socket streams from the client computer. It parses this data, performs calculations on it, and stores the processed data into a centralized MySQL database. The server is programmed in Java and JDBC. Appendix B includes the database table designs.

AREnergyViewer: AREnergyViewer retrieves data from the MySQL database and performs minor calculations on the retrieved data before visualizing it. It uses ARToolKitPlus[14] to calculate camera position and orientation of physical AR markers in real-time and WPF and VisiFire[15] to generate charts and simple graphics. It operates independently of the MySQL database server. In this way, it acts similar to the "view" in a Model-View-Controller (MVC) architectural pattern, where multiple views can be generated from the same data.

3.5 AREnergyViewer: Future work

The previous section presented our limited instantiation of a "proof-of-concept" feedback system called "AREnergyViewer". I now discuss future work regarding AREnergyViewer.

First, AREnergyViewer uses Watts Up (WU) devices to capture real-time electricity feedback of appliances. This is heavyweight: each measured appliance requires a WU device, a power cord, and a USB connection to a computer that receives the captured feedback. Future development can explore the use of wireless protocols (such as Zigbee) to obtain real-time, electricity feedback of household appliances in a wireless and lightweight manner.

Second, AREnergyViewer uses AR markers to recognize the position and orientation of physical appliances. This approach is limited in terms of marker recognition distance and accuracy when determining appliance position and orientation. Future work can explore the use of more powerful and accurate AR approaches to recognizing physical appliances.

Third, AREnergyViewer uses a medium-sized computer tablet to visualize energy feedback. There are two limitations. First, the weight of the tablet requires physical effort

[14] http://studierstube.icg.tu-graz.ac.at/handheld_ar/artoolkitplus.php. Retrieved July 1, 2009.
[15] http://visifire.com/. Retrieved July 10, 2009.

on part of the individual to 1) hold the device and point it towards a specific appliance and 2) manipulate proximity to change the level of detail in the provided feedback. Thus, the weight of the tablet may limit the mobility and ease of use of AREnergyViewer in these situations. Second, the tablet is a separate appliance (which itself uses energy) that the individual must turn on to view appliance feedback. To address these limitations, future work can explore the use of smaller, hand-held devices (e.g. iPhone) that are lighter to hold, more mobile, require less energy to power, and already incorporated within the individual's daily routine.

Finally, AREnergyViewer employs simplistic visualizations of energy feedback, using numbers, text and simple graphics (e.g. animated colored circles, bar and line charts). Currently, the system does not support *interactive* exploration of data within the feedback interface (other than GUI interaction in the "snapshot" view, manipulation of physical phidget sensors and manual proximity manipulation). Future development can explore the use of more aesthetically-pleasing and complex feedback visualizations, which support more powerful interactive data exploration capabilities.

3.6 Summary

This chapter presented the motivation and concept behind an augmented reality feedback system that provides real-time, energy feedback in context, allows exploration at multiple levels of information, provides support for an in-depth analysis of energy usage patterns, allows alternate views of feedback using physical phidgets, and provides personal activity information in relation to energy consumption. Following this, I presented our limited instantiation of this concept – a "proof-of-concept" feedback system called 'AREnergyViewer'. I discussed the physical components of AREnergyViewer, followed by details of interface design and interaction, the measured appliances, and the network architecture. Finally, I discussed future directions of exploration regarding AREnergyViewer.

In summary, despite the novelty and potential of this augmented reality feedback system concept, we did not consider the issue of *motivation* in our design – that is, whether the user is even interested or motivated to use such a feedback device. Thus, in parallel to our development of this system, I also explored motivational psychology literature in regards to its application in the context of motivating sustainable energy behavior. Hence, the next chapters will switch focus to 1) review relevant motivational psychology literature (Chapter 4), 2) assess existing feedback technologies from a motivational perspective (Chapter 5), and 3) offer a motivational framework based on motivational psychology literature to guide energy feedback technology design (Chapter 6). Finally, Chapter 6 will revisit AREnergyViewer by providing initial, high-level, redesign ideas based on the motivational framework's recommendations.

Chapter 4. A review of motivational psychology literature

Research question # 1 asked: "What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?". Chapter 2 partially addressed this question by reviewing the landscape of energy feedback technologies. This chapter further addresses this question by providing a review of selected motivational psychology literature. Chapter 5 will finish addressing this question by assessing energy feedback technologies through a motivational psychology lens.

Throughout this thesis, I refer to "motivational psychology" as the relevant techniques, theories, and therapies from a variety of psychological subfields and schools of thought. In this chapter, I present literature from environmental psychology, foundational motivation theories, social psychology, applied psychology, and behaviour change theories and therapies. I first present *techniques*, which represent the "how" of motivating energy behaviour change. I then present *theories*, which represent the "why" of motivation and behaviour. Finally, I present *therapies*, which represent the "how" of facilitating behaviour change. All of the above interact and overlap on some level. In later chapters, I will show how their union provides a reasonably comprehensive understanding of the aspects that influence motivation in regards to sustainable energy behaviour.

A caveat - I am not a psychologist, nor do I have any specialized training in motivational psychology beyond the readings I have done and my discussions of these readings with others. While many of the motivational psychology theories and concepts presented in this chapter are likely the topic of ongoing investigations, debate and refinement, I leave that to experts in the area. Rather, my intent in this and later chapters is to apply motivational psychology concepts to further our understanding of energy feedback technology effectiveness and the design space of such technologies.

4.1 Understanding "motivation"

Motivation is "an inquiry into the *why* of behaviour" (Deci & Ryan, 1985). It is "an internal state or condition (sometimes described as a need, desire, or want) that serves to activate or energize behaviour and give it direction" (Huitt, 2001). Motivation is closely tied to emotional processes (Hockenbury & Hockenbury, 2003). Emotions may be involved in the *initiation* of behaviour, for example, the emotion of loneliness might motivate the action of seeking company. Alternatively, the desire to *experience* a particular emotion may also motivate action (Hockenbury & Hockenbury, 2003), for example, the decision to run a 10km race may be motivated by the desire to experience a sense of accomplishment.

4.1.1 Extrinsic and intrinsic motivation

There are two primary types of motivation: extrinsic and intrinsic. *Extrinsic motivation* is "the doing of an activity in order to attain some separable outcome" (Deci & Ryan, 2000). Examples of separable outcomes include monetary or material incentives, and social recognition.

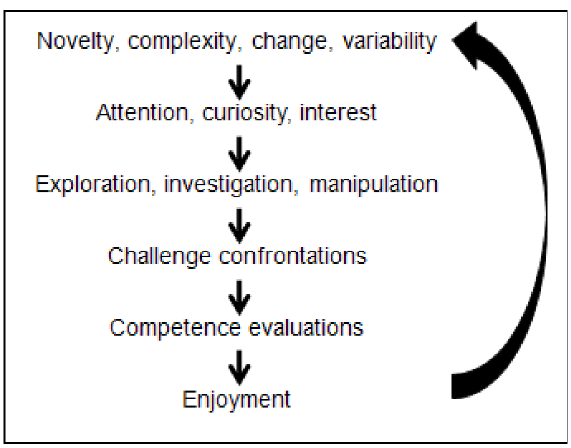


Figure 4.1: My own depiction (based on literature) of the intrinsic motivation cycle.

Intrinsic motivation is "the doing of an activity for its inherent satisfactions rather than for some separable consequence" (Deci & Ryan, 2000). Intrinsic motivation can be characterized by an on-going, cyclical sequence of behaviour that includes exploration, investigation, manipulation, challenge confrontations, and after an experience of competence feedback, persistence and engagement (Condry & Chambers, 1978). Specifically, it is a two step process. First, stimuli such as novelty, complexity, change and variability (Berlyne, 1961) attract attention, curiosity and interest. These emotions make activities intrinsically motivating, inviting exploration, investigation, and manipulation of the stimulus (Reeve, 1989). Second, competence performances on challenging tasks are enjoyed, and increased enjoyment increases one's willingness to continue the activity and to confront additional, similar challenges in the future (Csikszentmihalyi, 1975). Figure 4.1 shows my own depiction of the cyclical sequence described above.

4.1.2 Constructs of motivation

Attitudes, beliefs and values are "learned psychological constructs that motivate and influence behaviour" (Beebe et al., 1999). Within these constructs, attitudes are the *least* enduring (most likely to change), and values are the *most* enduring (least likely to change) (Beebe et al., 1999). I discuss these constructs within the context of sustainable energy behaviour.

Attitudes are "learned predispositions to respond to a person, object, or idea in a favourable or unfavourable way" – in other words, they reflect what one likes or dislikes (Beebe et al., 1999). For example, a person might hold a favourable attitude towards water conservation: in particular, taking short showers.

Beliefs are "the ways in which people structure their understanding of reality" – in other words, "what is true and what is false" (Beebe et al., 1999). Most beliefs are based on previous experience (Beebe et al., 1999), e.g. recycling is good for the environment.

Values are "central to our concept of self" (Beebe et al., 1999), and can be conceptualized as "behavioural ideals" or as "preferences for experiences" (Miller & Rollnick, 2002). As *behavioural ideals*, values function as "enduring concepts of good and bad, right and wrong" (Miller & Rollnick, 2002), e.g. it is wrong to litter. As *preferences for experiences*, "values guide individuals to seek situations in which they may experience certain emotions" (Miller & Rollnick, 2002), e.g. I compost because it makes me feel good.

Throughout this thesis, I discuss the concept of values in relation to motivating sustainable energy behaviour. In particular, I draw upon two primary contributors to value theory. The first is social psychologist Milton Rokeach, who defined a set of 18 "instrumental" and 18 "terminal" human values. He defined *instrumental values* as "preferable modes of behaviour" (e.g. capable, logical), and *terminal values* as "desirable end-states of existence" (e.g. a comfortable life) (Rokeach, 1973). In this thesis, I refer to only a subset of these values, which in later chapters, I show to be relevant in the context of energy behaviours (I list these in Table 4.1, left and middle column). Another contributor to value

Behavioural Ideals (Rokeach)	Preferences for Experiences (Rokeach)	Preferences for Experiences - Low to high level (Maslow)
Ambitious: hardworking and aspiring **Capable**: Competent, effective **Helpful**: Working for the welfare of others **Honest**: Sincere and truthful **Imaginative**: Daring and creative **Independent**: Self-reliant; self-sufficient **Intellectual**: Intelligent and reflective **Logical**: Consistent; rational **Obedient**: Dutiful, respectful **Responsible**: Dependable and reliable	**A comfortable life**: a prosperous life **Family security:** taking care of loved ones **Freedom:** independence and free choice **Health:** physical and mental well-being **Inner harmony:** freedom from inner conflict **A sense of accomplishment:** a lasting contribution **Social recognition:** respect and admiration **Wisdom:** a mature understanding of life **A world of beauty**: beauty of nature and the arts	**Physiological:** Homeostasis and appetites **Safety:** Security of body, employment, resources, family, health, property **Love/belonging:** Affection and belongingness, be accepted **Esteem:** Self-respect, self-esteem, esteem of others **Self-actualization:** To find self-fulfillment and realize one's potential

Table 4.1: Left column: Rokeach's behavioural ideals. Middle column: Rokeach's preferences for experiences. Right column: Maslow's preferences for experiences.

theory is psychologist Abraham Maslow. Maslow's values (traditionally called "needs") (Table 4.1, right column) consists of a hierarchical structure where he believed humans must satisfy the lower level values (i.e. physiological, safety) before the higher ones (i.e. love/belongingness, esteem, self-actualization) (Maslow, 1943) (Maslow, 1971). In Table 4.1, for purposes of convenience in terminology, I use the term *"behavioural ideals"* to refer to Rokeach's "terminal values", and *"preferences for experiences"* to refer to Rokeach's "instrumental values" and Maslow's values.

Both Maslow and Rokeach proposed the idea that people have *value systems* – "a value hierarchy or priority structure based on the relative importance of the individual values" (Fritzsche, 1995). Rokeach believed that differences in behaviour between individuals occur due to differences in the ranking of value importance (Rokeach, 1973) – e.g. Bob, an energy auditor, values being "logical" more than he values being "imaginative" during an audit. Maslow's value system is portrayed in his hierarchical structure of values.

4.2 Motivation techniques and theories

In this section, I present selected motivational psychology techniques and theories. I first present techniques from environmental psychology. I then present foundational motivation theories, social psychology theories, and applied psychology theories.

4.2.1 Environmental Psychology: Techniques to motivate conservation behaviour

Environmental psychology is the subfield of psychology that "examines the interrelationship between environments and human behaviour" (De Young, 1999). One focus in this subfield is *conservation behaviour* - the exploration of individuals' environmental attitudes, perceptions and values, as well as intervention techniques for promoting environmentally sustainable behaviour (De Young, 1999). The following presents selected *techniques* for motivating conservation behaviour.

The *Attitude Model* assumes that "pro-environmental behaviour will automatically follow from favourable attitudes towards the environment" (Shipworth, 2000). Figure 4.1a (next page) shows an advertisement that employs the Attitude Model.

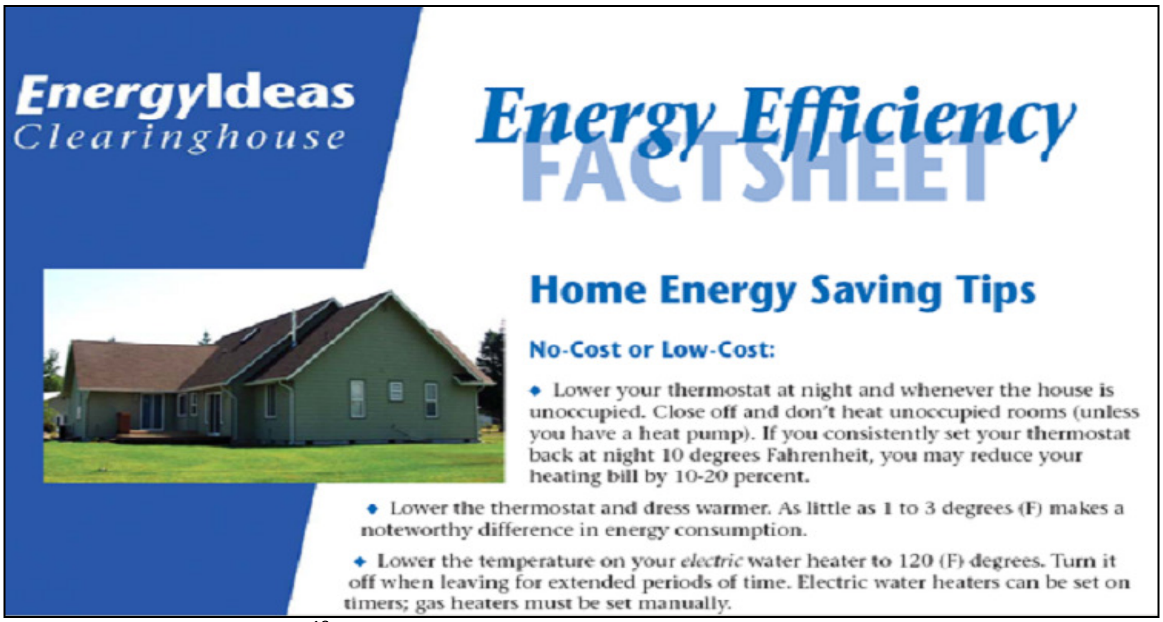
The Rational-Economic Model (REM) assumes "people will make pro-environmental decisions based on economically-rational decisions" (Shipworth, 2000). In other words, monetary cost is the primary motivator. Figure 4.1b (next page) shows an advertisement employing this model.

The *Information Technique* provides information to a problem, why it is a problem, and the steps required to solve the problem (Shipworth, 2000). It assumes that providing information is enough to motivate individuals to take energy action. Figure 4.1c (next page) shows an advertisement employing this technique.

Adaptive muddling is a technique that encourages people to apply their personal knowledge or expertise to a situation (De Young & Kaplan, 1988). When this happens,

a) Attitude Model[16]

b) Rational-Economic Model (REM)[17]



c) Information Technique[18]

Figure 4.2: (Clockwise): Advertisements that try to motivate sustainable energy behaviour using the stated models or techniques.

people are more inclined to act, as they perceive a role for themselves and sense that their contribution is not only optional but a necessity (Kaplan, 1990) (Folz, 1991).

Social competition can motivate pro-environmental action due to feelings of social comparison or social pressure (Abrahamse et al., 2005). The winner of the competition may be rewarded with material incentives (e.g. money) or social reinforcement (e.g. recognition) (Abrahamse et al., 2005).

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16 http://images.cafepress.com/image/18204846_400x400.jpg. Retrieved Feb.10, 2010.
17 http://ecosimply.com/wp-content/uploads/save-money-and-environment.jpg. Retrieved Feb.10, 2010.
18 http://www.energyideas.org/documents/factsheets/hometips.pdf. Retrieved Feb 10, 2010.

Social diffusion refers to how the modeled behaviour of others is far more effective than advertising (Yates & Aronson, 1983). Specifically, people are more likely to accept an innovation when they come into contact with others who have successfully adopted it (Rogers and Shoemaker, 1971).

Finally, people are more motivated to act when presented with *vivid and personalized* information (Shipworth, 2000) (Yates & Aronson, 1983). Vividness can be achieved through emotionally persuasive messages, or having direct experience with a role model who has already adopted the energy action (Shipworth, 2000). For example, *social diffusion* may be effective due to the vivid nature of receiving information from familiar people (Shipworth, 2000). Personalization can be achieved by targeting specific information towards the individual, rather than general information geared towards the public.

4.2.2 Foundational motivation theories

Whereas the previous section presented *techniques* of motivation, this section presents theories that explain the *why* of motivation and behaviour. A *theory* is a "collection of interrelated ideas and facts put forward to describe, explain and predict behaviour and mental processes" (Hockenbury & Hockenbury, 2003). The following lists four foundational motivation theories from various psychological schools of thought. However, I do not delve into their details here.

Incentive motivation is the view that behaviour is motivated by the pull of external goal objects, such as rewards, money, and recognition (Hockenbury & Hockenbury, 2003). For example, the Rational-Economic Model appeals to incentive motivation.

Achievement motivation is the view that behaviour is motivated toward excelling, succeeding, or outperforming others at some task (Hockenbury & Hockenbury, 2003). For example, social competition appeals to achievement motivation.

Arousal Theory proposes that people are motivated to maintain an optimal level of stimulation or arousal that is neither too high nor too low (Hockenbury & Hockenbury, 2003). For example, this theory explains why some people enjoy watching scary movies.

Valence-Expectancy Theory (VET) (Vroom, 1964) is an explanation of how people's expectations and beliefs guide their behaviour. It proposes the equation that "motivation =

valence * expectancy * instrumentality". Valence refers to the depth of want for a particular (intrinsic or extrinsic) outcome. Expectancy refers to the individual's belief in their capability to obtain the outcome based on their self-confidence and perceived difficulty of the performance goal. Instrumentality refers to the individual's belief that their efforts will lead to the desired results. When valence, expectancy and instrumentality are high, motivation is high. When low, motivation will be low.

4.2.3 Social Psychology: The impact of social groups on individual motivation

Social psychology is "the scientific study of how people's thoughts, feelings and behaviours are influenced by the actual, imagined, or implied presence of others" (Allport, 1985). (Note that "social psychology" is not to be confused with "sociology" – "the study and classification of human societies" (WordNetWeb). The following presents several *theories* of how social groups affect individual motivation. I categorize these theories into five sections: 1) helping behaviour, 2) social norms, 3) message framing, 4) individual motivation and performance within a group, and 5) attitude and behaviour.

Helping behaviour

I now present theories of factors that influence individual helping behaviour.

Social value orientations are people's perceptions of the personal costs incurred from engaging in certain behaviours (Cameron & Brown, 1998). There are two types of social value orientations: pro-social and pro-self. *Pro-social* individuals consistently make choices that benefit the common good (Cameron & Brown, 1998). *Pro-self* individuals tend to have higher perceptions of personal costs, and thus choose outcomes that suit their own needs (Cameron & Brown, 1998). The majority of the population are pro-self individuals (Cameron & Brown, 1998). As such, energy campaigns targeting pro-self individuals should focus on minimizing the personal cost of energy actions, rather than maximizing the benefit for the common good (Cameron & Brown, 1998).

One type of pro-social behaviour is *altruism* - defined as "feeling or acting on behalf of the welfare of others in cases where self-interest could not be involved" (Jencks, 1990). This definition indicates that there cannot be a compensating benefit to the self, thereby implying some sort of self-sacrifice (Kaplan, 2000). In practice, however, "altruism must coincide with self-interest sufficiently to prevent the extinction of either the altruistic motivation or the altruist" (Mansbridge, 1990).

Social norms

Social norms are the "'rules' or expectations for appropriate behaviour in a particular social situation" (Hockenbury & Hockenbury, 2003). Social norms exist on the social structural level, and are adopted by each of us on a personal level. From here, they become *personal norms*, which are "strongly internalized moral attitudes" (Hopper & Nielsen, 1991). The following discusses motivation theories based around social norms.

Normative messages are textual or graphical messages that aim to reduce problem behaviours (or increase pro-social behaviour) by appealing to social norms. There are two types of normative messages: descriptive and injunctive.

Descriptive norms appeal to "perceptions of behaviours that are typically performed" (Cialdini, 2003). One example is a park sign that says "Many past visitors have removed large pieces of petrified wood from this park, changing the natural state of the forest", with a red circle and bar superimposed on it (Cialdini, 2003). While descriptive norm messages have good intentions, within the statement "many people are doing this undesirable thing", is the normative message that "many people are doing this" (Cialdini, 2003). As such, when using this theory, one must be extra careful. Although descriptive normative information may *decrease* an undesirable behaviour among individuals who perform at a rate *above* the norm (e.g. people who remove many large pieces of petrified wood), the same message may actually serve to *increase* the undesirable behaviour among individuals who perform that behaviour at a rate *below* the norm (Schultz et al., 2007) (e.g. people who do not remove anything from the forest). This occurs because descriptive norms provide a standard from which people do not want to deviate (Schultz et al., 2007).

Injunctive norms appeal to perceptions of behaviours that are typically approved or disapproved (Cialdini, 2003). Using the same example, an injunctive normative message with a red circle and bar superimposed on it could say "To preserve the natural state of the forest, please do not remove petrified wood from the park" (Cialdini, 2003).

In summary, descriptive and injunctive norms aim to motivate behaviour in different ways. One can optimize the potential of these theories by aligning both descriptive and injunctive norms in order to highlight popular pro-environmental behaviours that are socially approved (Cialdini, 2003).

Message framing

Prospect Theory proposes that people's decisions are sensitive to how information is presented (Rothman et al., 2009). One factor that influences the degree of message processing is whether the message is gain-framed or loss-framed (O'Keefe & Jensen, 2008). A *gain-framed* appeal emphasizes the benefits of performing a behaviour (Rothman et al., 2009) (e.g. "Gain $100 a year by installing insulation on your home"). A *loss-framed* appeal emphasizes the cost of not performing a behaviour (Rothman et al., 2009) (e.g. "Lose $100 a year if you do not install insulation on your home"). Studies have shown that loss-framed messages are an effective means to promote behaviour if and only if individuals perceive engaging in that behaviour to be risky or uncertain (Rothman et al., 2009). Energy actions are often perceived as a risky investment for two reasons: 1) they do not add financial value to a home, and 2) the annual return on an energy investment is very uncertain (due to energy prices, weather, household energy behaviour, etc.) (Shipworth, 2000). As such, for risky energy actions, loss-framed messages are more effective than gain-framed (Yates, 1983). For non-risky actions, there is no significant advantage for loss-framed appeals over gain-framed appeals (O'Keefe & Jensen, 2008).

Individual motivation and performance within a group

I now discuss how social groups can influence individual motivation and performance.

Social loafing is the tendency for individuals to expend less effort on a task when it is a group effort (Hockenbury & Hockenbury, 2003). This phenomenon is especially pronounced when it is difficult or impossible to assess each individual's contribution to the collective effort. Generally, the more people involved in a collective effort, the lower each individual's output (Karau & Williams, 1993). This phenomenon may occur for two reasons. First, the responsibility for attaining the group goal is divided across all group members, resulting in reduced effort by each individual group member (Latane, 1981). Second, individuals may expect other group members to "slack off", and as such, may reduce their own efforts to match the level of effort they expect other group members to display (Jackson & Harkins, 1985). Social loafing can be reduced or eliminated if: 1) the individual knows the group members, 2) the group is highly valued, or 3) the task is meaningful or unique (Karau & Williams, 1993).

Attitude and behaviour

Social psychology theories such as cognitive dissonance and the Elaboration Likelihood Model discuss attitude, behaviour, and the relationship between these constructs.

Cognitive dissonance is an uncomfortable state that occurs when a person holds two cognitions (typically between an attitude and the corresponding behaviour) that are psychologically inconsistent (Festinger, 1957). When this happens, people try to reduce this uncomfortable feeling, either by changing their attitude or their corresponding behaviour (Festinger, 1957). Most often, people change their attitudes (rationalization), rather than their actions (Shipworth, 2000). In the context of motivating sustainable energy behaviour, cognitive dissonance can be used in two ways.

The first method is to motivate the individual's *behaviour* to be consistent with their pro-environmental *attitude*. While many people may hold general pro-environmental attitudes, there is rarely a strong, direct, or consistent relationship between attitudes and subsequent environmental actions (Shipworth, 2000). To address this issue, cognitive dissonance can inform people of the discrepancy between their pro-environmental attitude and their non-proenvironmental behaviour, thereby invoking an uncomfortable feeling that the individual wishes to resolve. Then, by providing specific action steps and encouraging a change towards pro-environmental *behaviour*, individuals can be motivated to resolve cognitive dissonance through a change in behaviour, rather than a change in attitude (Shipworth, 2000).

The second method is to motivate the individual's *attitude* to be consistent with their pro-environmental *behaviour*. The use of cognitive dissonance in *"Foot-in-the-door"* theory uses external behaviour to inspire consistent attitudes. The idea is that if people can be encouraged to perform a small energy action at their own accord, they can be encouraged to perform larger energy actions in the future (Abrahamse et al., 2005) (Shipworth, 2000). This occurs because once an individual performs a small energy action, they may begin to see themselves as an energy-efficient person, and with encouragement, can be motivated to perform larger energy actions on account of their newly inspired attitude (Shipworth, 2000). For example, if an individual willingly helps an energy auditor do small energy actions (such as holding the electric meter, or measuring tape) for an hour, at the end of this hour, the individual may think: "Well, I just spent an hour helping this guy, I *must* care about the environment!". "Foot-in-the-door" theory also means that the higher dissonance a person experiences (usually due to effort, time, or money already expended), the more committed the person will become to the particular course of action (Levy-Garboua & Blondel, 2002). In the previous example, if the household resident spent 5 hours instead of 1 hour on the audit, their commitment to their pro-environmental attitude would be even stronger.

The *Elaboration Likelihood Model (ELM)* (Petty & Cacioppo, 1994) proposes two routes of cognitive processing to influence attitude change. The central route processes arguments according to logic and rationale, where one is sensitive to the quality of the argument. The peripheral route uses emotional persuasion, where one is influenced by factors unrelated to the argument's validity (such as emotional responses). When the audience's attention level is *high*, changes in attitude are most enduring when logical appeals to the *central* route are used (Heath, 2007). At a *low* level of audience attention, emotional appeals to the *peripheral* route are more effective (Bornstein, 1992). This is because emotions and feelings are formed subconsciously and independent of will (Damasio, 2000). Without conscious processing of affective elements in the argument, people cannot counter-argue (Heath, 2007).

4.2.4 Applied psychology: Self-reflection and Goal theory

Applied psychology is "the branch of psychology that uses psychological principles to help solve practical problems of everyday living" (Lefton et al., 2000). Within this subfield, I present the concepts of self-reflection and goal theory.

Self-reflection refers to "those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations" (Boud et al, 1985). In other words, the outcome of reflection is *learning* (Boud, 2001). There are three stages of the reflective process (Atkins & Murphy, 1993): 1) an awareness of uncomfortable feelings and thoughts, 2) a critical analysis of the situation, involving a constructive examination of feelings and knowledge, and 3) a perspective transformation, where affective and cognitive change may or may not lead to behaviour changes. Journal-writing is one way to support self-reflection (Hiemstra, 2001).

A *goal* is "an internal representation of a desired outcome" (Austin & Vancouver, 1996). Working towards a goal can provide a major source of motivation to actually reach the goal, which in turn, improves performance (Locke, 1968). Several factors determine the effectiveness of goal achievement: goal setting, goal commitment and implementation intentions. I discuss these in the following.

- Specific, difficult and self-set goals lead to higher performance and commitment than do-best, easy or assigned goals (Wright & Kacmar, 1994). *Specific* goals make clear when the goal has been achieved. *Difficult* goals are more attractive because although there is a lower possibility of success, there is a greater sense of achievement.
- *Goal commitment* is defined as "one's attachment to or determination to reach a goal" (Locke et al., 1988). If there is no commitment to goals, goal-setting does not work.
- *Implementation intentions* are the "plans that specify the when, where and how to lead to goal attainment" (Gollwitzer & Brandstatter, 1997); in other words, how people plan to achieve the goal or how they will behave in the face of certain stimuli (Gollwitzer, 1999). Goal intentions that are furnished with implementation intentions are more easily attained than mere goal intentions (Gollwitzer and Brandstatter, 1997). For example, if Alex commits to reducing her energy use by 15% for the upcoming month, she will need an action plan of what to do differently in the face of existing habits and stimuli to reach her goal. Finally, as goals can be obtained in many ways, flexibility on goal attainment is good, as it allows people to switch to alternative routes if necessary (Wicklund & Gollwitzer, 1982).

4.3 Behaviour change processes: Theories and models

The previous section presented techniques and theories of *motivation* and *behaviour*. I now turn to theories and models of *behaviour change processes*. This is by no means an exhaustive list, but rather are selected theories and models that in later chapters I show to be relevant to motivating sustainable energy behaviour change.

4.3.1 Behaviourism: Learning theories

Behaviourism is the "school of psychology and theoretical viewpoint that emphasizes the study of observable behaviours, especially as they pertain to the process of learning" (Hockenbury & Hockenbury, 2003). *Learning* is defined as "a relatively enduring change in behaviour or knowledge that is due to past experience" (Hockenbury & Hockenbury, 2003). One fundamental theory is operant conditioning: in particular, reinforcement.

Conditioning is defined as "the process of learning associations between environmental systems and behavioural responses" (Hockenbury & Hockenbury, 2003). Through conditioning, behaviour modification can be achieved. One type of conditioning is *operant conditioning* - "the basic learning process that involves changing the probability of a response being repeated by manipulating the consequences of that response" (Hockenbury & Hockenbury, 2003). One particular type of operant conditioning is reinforcement.

Reinforcement is defined as "the occurrence of a stimulus or event following a response that *increases* the likelihood of that response being repeated" (Hockenbury & Hockenbury, 2003). A general rule of thumb is to *positively reinforce* the behaviours that you want to increase (Hockenbury & Hockenbury, 2003) (rather than using negative reinforcement or punishment). This is because although punishment may temporarily decrease the occurrence of a problem behaviour, it does not promote more desirable or appropriate behaviours in its place (Hockenbury & Hockenbury, 2003). For this reason, I discuss only positive reinforcement in this thesis.

Positive reinforcement (PR) is "a situation in which a response is followed by the addition of a reinforcing stimulus, increasing the likelihood that the response will be repeated in similar situations" (Hockenbury & Hockenbury, 2003). For example, receiving money for recycling bottles will result in an increase in likelihood of future recycling behaviours. There are several ways to enhance the effectiveness of PR (Hockenbury & Hockenbury, 2003). First, the positive reinforcer should be delivered immediately after the preferred behaviour occurs. Second, the positive reinforcer should initially be given every time the preferred behaviour occurs. When the desired behaviour is well-established, gradually reduce the frequency of reinforcement. Third, use a variety of positive reinforcers, such as tangible items, praise, special privileges, recognition, and so on. Fourth, encourage the individual to engage in self-reinforcement in the form of pride, a sense of accomplishment, and feelings of self-control.

4.3.2 Health Psychology: The Transtheoretical Model (TTM)

Health psychology is defined as "the study of how biological, psychological, environmental, and cultural factors are involved in physical health and the prevention of illness" (Naire, 2000). One established theory of behavioural change processes is the Transtheoretical Model (TTM), also known as the Stages of Change Model (Prochaska & DiClemente, 1982). Chapter 5 will assess energy feedback technologies from a motivational psychology perspective, using this model as the primary lens. Chapter 6 will construct a motivational framework to guide energy feedback technology design, using this model as the primary basis.

The TTM was originally developed based on studies of smoking cessation behaviours (Prochaska & DiClemente, 1982). It states that intentional behaviour change is a *process* occurring in a series of *stages*, rather than a single event (Miller & Rollnick, 2002). Motivation is required for the focus, effort and energy needed to move through the stages (Miller & Rollnick, 2002). The idea is that, rather than assume that all individuals are ready for action, individuals should instead be grouped according to the stage of change that they are in (Prochaska & DiClemente, 1982). The stages progress as follows:

Precontemplation*:* The individual may be unaware, uninformed, unwilling or discouraged to change the problem behaviour (Miller & Rollnick, 2002). They are not intending to take action in the foreseeable future, usually measured as the next 6 months (Prochaska & Velicer, 1997).

Contemplation*:* Individuals are *intending* to change in the next 6 months (Prochaska & Velicer, 1997), though may be far from making an actual commitment (Miller & Rollnick, 2002). Individuals acknowledge that their behaviour is a problem and begins to think seriously about solving it (Miller & Rollnick, 2002). While contemplators can be quite open to information about the problem behaviour, they may still feel ambivalent with regards to the pros and cons of changing (Miller & Rollnick, 2002).

Preparation: The individual is ready to take action in the immediate future, usually measured as the next month, and aims to develop a plan they can commit to in the near future (Miller & Rollnick, 2002). They have made at least one 24 hour change attempt in the past year (DiClemente et al., 1991).

Action: The individual takes action by overtly modifying their behaviour (Prochaska & Velicer, 1997).

Maintenance, Relapse, Recycling: The individual works to sustain the behaviour change, and struggles to prevent relapse (Prochaska & Velicer, 1997). If relapse occurs, individuals regress to an earlier stage and begin to progress through the stages again (Miller & Rollnick, 2002).

4.4 Behaviour change therapies

I now switch focus from behaviour change *theories* to behaviour change *therapies*. *Psychotherapy* is "the treatment of emotional or behavioural problems through psychological techniques" (Hockenbury & Hockenbury, 2003). In this section, I focus on *client-centered therapy* - "a type of psychotherapy in which the therapist is nondirective and reflective, and the *client* directs the focus of each therapy session" (Hockenbury & Hockenbury, 2003). One technique of interest within client-centered therapy is "Motivational Interviewing".

4.4.1 Motivational Interviewing (MI)

Motivational interviewing (MI) is "a directive, client-centered counselling style for eliciting behaviour change by helping clients to explore and resolve ambivalence" (Rollnick & Miller, 1995). Motivational Interviewing has no theoretical backbone (Treasure, 2004) and as such, is often used in conjunction with the TTM, where specific intervention strategies are proposed to target people at different stages of change (Miller & Rollnick, 2002). The goal is to motivate a move towards the next stage of change (Miller & Rollnick, 2002). Two key points characterize the spirit of the method (Rollnick & Miller, 1995):

1. Motivation to change is elicited from the client, and not imposed from without (e.g. coercion, persuasion, constructive confrontation. As such, direct persuasion is *not* an effective method for resolving ambivalence. While it is tempting to be "helpful" by

persuading the client of the urgency of the problem and the benefits of change, these tactics generally increase client resistance and diminish the probability of change.

2. It is the client's task, not the counsellor's, to articulate and resolve his or her ambivalence. *Ambivalence* is "a conflict between two courses of action, each of which has perceived benefits and costs associated with it". Instead, the counsellor is *directive* in helping the client to examine and resolve ambivalence.

Four central principles summarize MI:

1. Support self-efficacy by building the patient's confidence that change is possible (Treasure, 2004), where *self-efficacy* is defined as "the belief in one's capability to organize and execute the courses of action required to manage prospective situations" (Bandura, 1997) – in other words, confidence in one's ability to change the problem behaviour (Littell & Girvin, 2002).

2. Support clients in developing *intrinsic attributions* to successful behaviour change (Miller & Rollnick, 2002).

3. Develop discrepancy between the patient's *values* and their current behaviour (Treasure, 2004). A focus on values may stimulate motivation for change (Miller & Rollnick, 2002). When one focuses on the discrepancy between ideal life conditions and actual conditions, the individual may feel a desire to "recalibrate" daily behaviours to be more congruent with deeply held beliefs (Miller & Rollnick, 2002).

4. Express *empathy* using reflective listening to convey understanding of the patient's point of view and underlying drives (rather than confrontation) (Treasure, 2004).

4.5 Summary

This chapter further addressed ***research question #1 – "What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?"*** by reviewing selected motivational psychology literature. First, I defined motivation, intrinsic and extrinsic motivation, and the constructs of motivation. Then, I presented techniques within environmental psychology of how to motivate conservation behaviour. Next, I presented foundational motivation theories, social psychology motivation theories, and applied psychology theories. Following this, I presented theories and models regarding behaviour change processes. I concluded with behaviour change therapies.

What should be clear from this chapter is that there are many complementary, overlapping, perhaps even contradictory approaches to motivating behaviour change. Indeed, this is perhaps why there are so many different feedback technologies, where each draws (perhaps tacitly) on different motivational perspectives. The next chapter will finish addressing research question #1 by recasting feedback technologies (presented in Chapter 2) from this motivational perspective. Specifically, I will use the Transtheoretical Model's stages of change as the main organizing principle, as it brings a broader perspective to motivation under which a variety of motivational methods may be understood.

Chapter 5. An assessment of energy feedback technologies from a motivational perspective

Research question # 1 asked: "What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?". Chapter 2 provided the background to this question by reviewing energy feedback technologies. Chapter 4 then set the scene by reviewing motivational psychology literature. This chapter finishes addressing this question by assessing selected energy feedback technologies (presented in Chapter 2) from a motivational perspective. That is, I evaluate these systems (or relevant portions of them) in terms of their potential effectiveness in motivating sustainable energy behaviour. I do this by drawing upon relevant motivational psychology literature (presented in Chapter 4).

I make two contributions in this chapter. First, I frame motivational psychology literature as key notions for designers of technology that aim to motivate sustainable energy behaviour. Second, I show how these notions can be used to assess existing feedback technologies from a motivational perspective. I begin this chapter by identifying three shortcomings of current energy feedback technology design, which will be illustrated via the following assessment. I then assess selected energy feedback technologies using the primary lens of the Transtheoretical Model's (TTM) stages of behavioural change, and the secondary lens of other relevant motivational psychology literature.

5.1 Shortcomings of energy feedback technology design

I now identify three shortcomings of current energy feedback technology design, which will be illustrated via the following assessment.

1) Most feedback systems that aim to motivate sustainable energy behaviour do so tacitly (with the exception of Waterbot (Figure 2.6c)). That is, they do not explicitly refer to or draw upon motivational psychology literature. Of the few that do, their employment of

motivational psychology is limited to one or two strategies, and often without a deeper understanding of *why* these strategies are effective (or not).

2) Motivational psychology literature offers rich knowledge in motivation *concepts*, *techniques*, *theories* and *therapies* from a variety of subfields and psychological schools of thought. However, while rich, this literature is fragmented, making it difficult to apply to energy feedback technology design in a cohesive and meaningful way. For example, it is not clear how behaviour change models such as the TTM's stages of change relate to foundational motivation theories such as Valence Expectancy Theory or social psychology theories such as cognitive dissonance.

3) Most energy feedback systems use a "one-size-fits-all" solution, providing the *same* feedback to *differently* motivated individuals at different *stages* of willingness, ableness and readiness to change. This is problematic. First, different people hold different attitudes, beliefs and values (Beebe et al., 1999), and are motivated by different things. Second, the TTM states that intentional behaviour change does not occur as an event, but rather, as a *process* in a series of stages (Miller & Rollnick, 2002). Individuals move from being unaware or unwilling to acknowledge the problem, to considering the possibility of change, to preparing to make the change, to taking action, and finally, to maintaining the desired behaviour over time (Miller & Rollnick, 2002). In general, most systems design for *already* "green" individuals – that is, individuals in the later stages of change (i.e. preparation, action or maintenance). Most systems do not consider motivation of individuals in the earlier stages of change (i.e. precontemplation or contemplation), who do not yet believe non-sustainable energy behaviours are problematic.

5.2 A motivational perspective assessment

I now assess selected energy feedback technologies from a motivational perspective. Specifically, I draw upon feedback systems (or portions of them) and classify them according to their best fit to particular motivational techniques, theories or models. I evaluate these systems in terms of their potential effectiveness in motivating sustainable energy behaviour. To do this, I use the primary lens of the Transtheoretical Model's stages of behaviour change, and the secondary lens of other relevant motivational psychology literature. This is *my* classification and interpretation - the actual systems were not necessarily designed with these explicit techniques, theories or models in mind. Furthermore, the following presents only *one* perspective of feedback system categorization. Other categorizations exist, as the motivational literature by which I categorize these systems is not mutually exclusive.

Caveat: The creators of the various energy feedback technologies presented in Chapter 2 designed them to serve a broad variety of intentions, which may or may not have included motivation. As with all designs, the final product is often a result of an interplay between preferences, constraints, and trade-offs. Thus, critiquing these prior systems from the author's descriptions of them solely from a motivational psychology perspective and using criteria that may not be aligned with the goals of the systems or their designers is not really 'fair'. Thus, the goal of this assessment is *not* to provide an overall comparison of feedback systems or argue for which feedback system is the "best". My intent, rather, is to reflect on these designs, where I reconstruct, as best as I can, how well a particular design as constructed is justified (or not) as a motivational device. Regardless of how well the design fits this somewhat narrow motivational view, I recognize that the device's overall effectiveness as an energy feedback technology could be heavily influenced by other design considerations not discussed in this chapter.

5.2.1 Attitude Model

The Attitude Model appeals to Rokeach's value of "a world of beauty", assuming that if one values nature, then they will act to protect it. While almost all feedback systems embody the Attitude Model, I illustrate using two examples that *primarily* employ this model: The 'Power-Aware Cord' (Gustafsson & Gyllensward, 2005) (Figure 2.3a) and '7000 Oaks and Counting' (Holmes, 2007) (Figure 2.5). The 'Power-Aware Cord' uses changes in illumination to reflect feedback of one's electricity consumption. It assumes this feedback is enough to motivate individuals to take electricity-saving action. '7000 Oaks and Counting' visualizes a building's carbon footprint by equating energy used with number of trees required to offset the carbon emissions. This work assumes that providing feedback of the building's energy usage, carbon emissions, and trees required to offset the emissions suffices in motivating building residents to reduce their energy usage. I assess these works below.

Feedback systems primarily employing the Attitude Model have two fundamental limitations. First, they do not consider the TTM's stages of behavioural change. Specifically, the assumption of a pro-environmental attitude does not hold for *precontemplators* who have not yet acknowledged their behaviour is problematic. For *contemplators*, feelings of ambivalence may mean that a pro-environmental attitude does not necessarily lead to commitment or action. While the Attitude Model may be effective in the *preparation* stage to motivate individuals who are ready to act in the near future, it does not provide them with information on specific action steps they can take. In the *action* and *maintenance* stages, individuals have already acted, and thus motivations based on attitude alone may have no further effect. Second, these systems do not consider external factors, such as situational circumstances (e.g. time, convenience, comfort, aesthetics), social influences (e.g. friends, family, neighbours), government regulations, and so on that often override the decisional influence of a pro-environmental attitude (Shipworth, 2000).

5.2.2 The Rational-Economic Model (REM), Attitude Model

The Attitude Model is often used in conjunction with the REM. The REM appeals to Maslow's value of "safety" – specifically, "security of resources" and Rokeach's values of being "responsible" and "logical". Examples of systems primarily employing these models include 'Cent-A-Meter' (Figure 2.1d), 'Power-Cost Monitor' (Figure 2.1e) and 'Energy Orb' (Figure 2.3c). 'Power-Cost Monitor' and 'Cent-A-Meter' provide numerical and textual feedback of electricity used, monetary cost, and CO_2 emissions on small, LCD displays. 'Energy Orb' changes color to provide feedback of current energy prices.

Systems employing these models have three limitations. First, the motivating effect of material incentives (such as money) is non-durable; just as the behaviour is quickly started using material incentives, their removal likewise terminates behaviour change (De Young, 1993). These may be especially true for *precontemplators* and *contemplators*, who are not inherently motivated to take energy action, but may do so in the short-term to receive monetary incentives. Second, when the cost of energy is low in proportion to one's income, feedback is not as effective (Geller et al., 1982). This may be especially true for high-income precontemplators and contemplators, who (respectively) do not believe non-sustainable energy behaviours are problematic, or do not want to sacrifice the benefits and luxuries that come with non-sustainable energy usage. In contrast, individuals in later stages (i.e. *preparation*, *action*, *maintenance*) are more inherently motivated, and may take sustainable energy actions despite low energy costs in proportion to their income. Third, similar to the Attitude Model, the REM does not consider situational circumstances that may override the logistics of cost, or the positive influences of pro-environmental attitude (Yates & Aronson, 1983).

5.2.3 Information Technique, REM, and Attitude Model

Some feedback systems supplement these earlier models with an Information Technique. This technique appeals to Rokeach's values of being "responsible" and "obedient", assuming that once you know what to do, you will do it. 'Ecomagination' (Figure 2.2a) and 'Energy Tree' (Arent, 2007) (Figure 2.7) are two examples. They provide complex feedback visualizations for energy use, cost and CO_2 emissions, summarize trends over days to months, and provide action steps for more efficient usage. These help to explain why current energy use is problematic and how more efficient usage can be achieved.

The combination of these models improves upon the previous categories. Still, from a motivational perspective, limitations remain. First, information *alone* rarely motivates action (Shipworth, 2000) as information is only effective if the individual *already* holds a strong goal to act based on that information (McCalley & Midden, 2002). Second, humans have a psychological tendency to *avoid* non-supportive and *seek out* supportive information (Bem, 1967). Specifically, *precontemplators* who do not believe their behaviours are problematic may psychologically discount information that contradicts with their current energy behaviours. In contrast, the Information Technique can be effective for *contemplators,* as they are the most open to receiving information and feedback (Miller & Rollnick, 2002). However, while this information is useful, it may not be enough to motivate contemplators to resolve their ambivalence and commit to action (Miller & Rollnick, 2002). The Information Technique can be very effective in the *preparation* and *action* stages, improving upon the Attitude Model by providing specific energy actions one can take. In the *maintenance* stage, the Information Technique can be effective if the information provided deepens over time to match with the individual's increasing knowledge and commitment.

5.2.4 Positive reinforcement (PR)

I now present three examples of feedback systems that primarily employ positive reinforcement. These include 'Flower Lamp', 'Energy Curtain', and 'Ubigreen'.

'Flower Lamp' (Lagerkvist et al., 2006) (Figure 2.3b) changes shape to reward low household energy usage, where the 'blooming' of the lamp acts as positive reinforcement. However, reinforcement (i.e. blooming) does not occur until "household usage has been low for some time". However, one of the principles for effective PR is that "the positive reinforcer should be delivered *immediately* after the preferred behaviour occurs" (Hockenbury & Hockenbury, 2003). Thus, the viewer may find the connection between the desired behaviour (low energy usage) and the reward (blooming of the lamp) unclear.

'Energy Curtain' (Ernevi et al, 2006) (Figure 2.8) is a window shade that asks individuals to decide whether to collect sunlight during the daytime and visualize the captured energy in a glowing curtain pattern in the evening (positive reinforcement), or to open the curtains during daytime to allow natural sunlight in (no reinforcement in the evening). In this work, the active decision-making process may encourage individuals to undertake critical reflection of their lighting usage behaviours. However, the underlying message is somewhat contradictory, in that the most energy-efficient action (i.e. opening the curtains during daytime to let sunlight in, reducing the need for artificial lighting) is *not* positively reinforced. As such, for *precontemplators* who do not believe non-sustainable energy behaviours are problematic, and for *contemplators* who feel ambivalent in regards to taking energy action, the message of encouraging sustainable lighting behaviours may be too ambiguous. Individuals in the *preparation* stage are ready to take energy action, though the curtain does not provide information of specific action steps they can take to improve their lighting efficiency. Individuals in the *action or maintenance* stage may find the curtain novel and interesting, though as the less energy-efficient action is positively reinforced, the curtain may not be effective to promoting long-term sustainable lighting behaviours.

In 'Ubigreen' (Froehlich et al., 2009) (Figure 2.4 top left, bottom), positive reinforcement is provided using a sequence of icons that progress as one's transportation behaviours become "greener" over time (i.e. the polar bear's ecosystem improves until the Northern Lights appear). One limitation of this work is the possible *extrinsic* nature of the positive iconic reinforcement (polar bears). Specifically, several participants viewed the visualization to be a "game", where participating in green transit behaviours earned "points" and making it to the last screen was the "final level" (Froehlich et al., 2009). One participant complained that when a ("green" transportation) trip hadn't been automatically recorded, "I felt like I was being cheated out of my points" (Froehlich et al., 2009). This is problematic. If people are only in it to win, it can have negative impacts on their *intrinsic* motivation (Deci et al., 1981), and may lead to less durable behaviour change (De Young, 1993). As this work aimed to target "already very green individuals" (Froehlich et al., 2009), participants are most likely in the *action* or *maintenance* stages, where *intrinsic* motivation is a necessary factor for long-term success (Miller & Rollnick, 2002).

5.2.5 Prompts, Positive reinforcement

One feedback system that combines the use of prompts and positive reinforcement is 'Waterbot' (Arroyo et al., 2005) (Figure 2.6c) – an augmented physical interface installed at the sink to provide water consumption feedback. This system uses visual and auditory "just-in-time" prompts delivered right at the point of water usage, to act as reminders and "positive reinforcement" for sustainable water usage behavior (Arroyo et al., 2005). 'Waterbot' also uses "adaptive interface fading", where prompts gradually fade as the desired behaviour becomes instantiated (Arroyo et al., 2005).

I assess this system from a motivational perspective. First, the specificity of the prompt may motivate the targeted behaviour (e.g. turning off the tap when brushing your teeth), but may not encourage un-targeted but related conservation behaviours (e.g. taking shorter showers) (Shipworth, 2000). Second, while prompts are relatively successful in the beginning, they decline in reliability as they lose their novelty (De Young, 1993). For *precontemplators* and *contemplators* who are not ready to take energy action, prompts may motivate the desired behaviour, but only for a short time while they are still novel. For individuals in the *preparation* and *action* stages, prompts may serve as useful reminders to engage in sustainable water behaviours at the point of usage. In the *maintenance* stage, the use of "adaptive interface fading" (the gradual withdrawing of prompts over time) satisfies one of the principles for an effective positive reinforcer (Hockenbury & Hockenbury, 2003).

This may help individuals to maintain the desired behaviour in the long term, without becoming annoying or intrusive after the behaviour has become well-instantiated.

5.2.6 Emotional persuasion (through the ELM) and Arousal Theory

Two examples of systems using emotional persuasion (though the Elaboration Likelihood Model (ELM)) and Arousal Theory are 'GreenLite Dartmouth' and 'Infotropism'.

'GreenLite Dartmouth' (Figure 2.11) uses an animation of a mother and child polar bear to create an "emotional connection" between the dorm's energy usage and the well-being of animated polar bears. As it is placed in a student dormitory hallway, it can be thought of as an ambient information system. However, due to the high level of visual detail in the animation and the emotional arousal it aims to provoke (through emotions such as happiness, sadness, guilt, or empathy), this work can also act as a foreground display, one which requires a high level of attention in order to maintain awareness of the visualization. An important critique arises from this. The ELM states that at a high level of attention, emotional persuasion is not as effective, as people can cognitively evaluate the validity of the presented emotional messages or arguments (Heath, 2007).

In this work, the emotionally-persuasive message - the dorm's collective high energy use is negatively affecting the well-being of virtual polar bears - may not be effective for *precontemplators*. First, precontemplators do not hold a high concern for sustainable energy usage and thus, may not be interested in viewing this visualization. Second, precontemplators are often unaware or uninformed of the problem behaviour (Miller & Rollnick, 2002). Thus, the presentation of the dorm's *collective* energy usage makes it difficult for precontemplators to discern the impact of their individual usage on the well-being of the virtual polar bears. This may not be effective to "plant the seed" to precontemplators that their non-sustainable energy behaviours are problematic. For *contemplators* who hold an equal weighing of the pros and cons of taking sustainable energy actions, the lack of individual feedback within the dorm's energy usage may not be enough to motivate ambivalent contemplators to take action. Ambivalent contemplators may also counter-argue against the strength of the visualization's emotional message. Specifically, in the animation sequence when the iceberg breaks, mother and child polar bear are separated, roaring in anguish and helplessness. If contemplators are knowledgeable that polar bears are very good swimmers

(Stirling, 1988), it detracts from the strength of argument that the iceberg breaking has immediate negative impacts on the well-being of polar bears. As contemplators are open to information about the problem behaviour (Miller & Rollnick, 2002), an improvement would be to provide specific and accurate information regarding the complex relationships between human energy consumption and the gradual devastation of polar bear habitats. Finally, while individuals in the *preparation*, *action* and *maintenance* stage may find the visualization emotionally appealing, the lack of personalized energy feedback in relation to dorm feedback makes it difficult for individuals to know what specific energy actions to take, or how their individual, positive changes in energy behaviour have impacted dorm usage over time.

'Infotropism' (Holstius et al., 2004) (Figure 2.6b) is an interactive work that provides feedback of peoples' recycling and trash behaviours by leaning a living plant towards the direction where motion is most frequently sensed (either the trash or recycling bin). It aims to establish an emotional connection between one's recycling and trash behaviours with the well-being of a living plant. The leaning of the plant portrays a somewhat ambiguous message, where the ambiguity may encourage a closer, more personal engagement with the system (Gaver, 2003), and may invoke a high level of cognitive arousal.

I assess this work using the stages of change. While *precontemplators* do not hold a high concern for environmentally sustainable behaviours, the ambiguous design may invoke critical thought regarding what the leaning of the plant actually means. This may motivate short-term changes in recycling behaviour, due to the precontemplator's initial interest and curiosity. *Contemplators* hold a pro-environmental attitude, and may be inherently interested in the "green" message communicated by this work. As contemplators are quite open to information about the problem behaviour (Miller & Rollnick, 2002), an improvement to 'Infotropism' would be to provide specific information regarding the positive and negative impacts of waste behaviour, in order to tip the decisional balance towards recycling action. Individuals in the *preparation* stage are ready to act (Miller & Rollnick, 2002). An improvement would be to support individuals in developing specific plans or courses of action that they can take, both for this waste location and others (e.g. their home). For example, information could be provided of how to obtain recycling bins for one's home, as well as changes in purchasing behaviour to result in fewer materials that need to be thrown out or recycled. For individuals in the *action* stage, recycling behaviours are positively reinforced by the gradual leaning of the plant towards the recycling bin. An improvement would be to provide additional reinforcement *immediately* after the recycling action occurs (e.g. the use of pleasant sounding chimes). This is one of the principles for an effective positive reinforcer (Hockenbury & Hockenbury, 2003). Another improvement in the action stage is to enable individuals to engage in alternative waste and recycling behaviours, for example, by providing a variety of recycling bins (i.e. for plastic, glass, metal, compost, etc.). Finally, for individuals in the *maintenance* stage who are already very environmentally-conscious, this work may initially arouse the intrinsic emotions of curiosity and interest, where upon comprehension of the portrayed message, individuals may form a stronger emotional connection to the living plant. This, in turn, may maintain their recycling behaviours over the long term for this location.

5.2.7 Goal commitment, Cognitive dissonance

'7000 Oaks and Counting' (Holmes, 2007) (Figure 2.5) visualizes a building's energy consumption in relation to the number of trees required to offset the carbon emissions. In addition to the visualization, individuals are also encouraged to commit to energy actions by filling out a web form. As soon as the form is submitted, the individual's name is incorporated into the animation sequence, and the carbon offsets (from the proposed energy action) are immediately added to the visualization. This work employs goal commitment (by encouraging users to commit to energy actions) and cognitive dissonance (where individuals who have committed to energy actions, but did not follow up on them) may experience cognitive dissonance due to the discrepancy between their attitude (e.g. saving energy is important) and their action (e.g. I have not followed through on my commitment). An assessment of this work follows.

Precontemplators who do not hold a high concern for sustainable energy usage are likely not motivated to commit to energy goals or actions. *Contemplators* hold a pro-environmental attitude and may be receptive to any provided feedback. However, due to feelings of ambivalence, contemplators may not be ready to commit to action (Miller & Rollnick, 2002). Individuals in the *preparation* stage are ready to act in the near future (Miller & Rollnick, 2002) and thus may be motivated to commit to energy actions. An improvement would be to help individuals self-set specific energy goals, and support them to develop an appropriate plan (course of action) in order to achieve these goals. Individuals in the *action* stage may be motivated to commit to energy actions, though whether the individual follows up on the commitment is based on trust. This may invoke cognitive dissonance. Until the individual completes the committed action, the visualization may serve as a motivator for individuals to resolve the discrepancy between their proposed commitment and their actual behaviour. A further improvement could be to occasionally provide personalized, encouraging reminders (e.g. within the interface or through email) to remind the individual of the discrepancy between their pro-environmental attitude and their corresponding behaviour, and encourage them to perform the committed energy action. This encouragement may address peoples' tendency to rationalize the situation by changing their attitude (e.g. "I don't think it could have made much of a difference anyway"), rather than changing their actions (Shipworth, 2000). Finally, individuals in the *maintenance* stage may not be motivated to continue long-term usage of this visualization due to the lack of *personalized* feedback of how individual energy changes impact the building's collective energy usage over time.

5.2.8 Cognitive dissonance (through "foot-in-the-door" theory)

"A future proofed power meter" (Jeremijenko, 2001) (no image available) is a power meter that requires the household resident to guess the amount of energy they are using before the meter will display it. This work employs cognitive dissonance through "foot-in-the-door" theory, where the time and effort household residents expend in guessing the correct range of their energy usage puts their "foot in the door" to take further energy actions in the future. Specifically, the more effort expended, the higher the cognitive dissonance, and in turn, the more individuals will commit to and internally justify their external behaviours (Levy-Garboua & Blondel, 2002). I assess this work in the following.

Precontemplators who do not hold a high concern for sustainable energy consumption, and who are not informed about their general household energy usage, are not likely motivated to expend the large amount of effort required to use this meter. C*ontemplators* hold a pro-environmental attitude and are open to information about the problem behaviour (Miller & Rollnick, 2002). Due to feelings of curiosity and interest in the novel design, contemplators may be motivated to try the power meter. By expending time and effort in using such a meter, contemplators may experience cognitive dissonance through "foot-in-the-door" theory, which may invoke internal justification of their external behaviours. An improvement could be to remind contemplators of the positive energy efforts they have already taken (in using this meter), and use this to encourage further energy action. Such encouragement may address contemplators' feelings of ambivalence, and "tip the balance" towards action. For individuals in the *preparation* and *action* stages, an improvement would be to provide clues that help individuals guess the correct range, and positively reinforce the individual's guessing efforts. Individuals in the *maintenance* stage may eventually become familiar with their energy consumption patterns. In this case, the creators of this system envisioned individuals to pass the meter to their friends or neighbours, satisfying the "renewal and reuse" principle of Sustainable Interaction Design (Blevis, 2007). An improvement in this stage would be to employ *adaptive muddling* – encourage expert users (i.e. individuals in the maintenance stage) to take an active role in helping energy users in the earlier stages use this device, by contributing their personal knowledge, expertise or experiences in using the meter. This appeals to the Rokeach values of "wisdom" and "social recognition", and may invoke the intrinsic satisfaction of "competence'. Activities that promote appraisals of competence increase reported enjoyment (Harackiewicz et al., 1985) and subsequent "free-choice" behaviour with the activity (Rosenfield et al., 1980).

5.2.9 Value Theory

One work that employs value theory is 'Ubigreen' (Figure 2.4, top left, bottom). In addition to the polar bear visualization, 'Ubigreen' also uses icons to represent "auxiliary benefits" (Figure 2.4, top left), such as a piggy bank to represent money savings, a person meditating to represent relaxation, a book representing the opportunity to read, and a weightlifter to represent exercise (Froehlich et al., 2009). By drawing upon the values proposed by Rokeach and Maslow, I classify these respective icons as appealing to the following values: Maslow's "safety", Rokeach's "inner harmony", "intellectual", and "health".

In 'Ubigreen', the relation of green transportation behaviours to other benefits of value is promising as it provides a *range* of personal benefits (Shipworth, 2000) while minimizing the individual's perception of personal cost (Cameron & Brown, 1998). This works well as most people are pro-self (Cameron & Brown, 1998), who resist making changes that they perceive as reducing their quality of life (Kaplan, 2000). An improvement to this system would be to consider the *specific values* and *value systems* of each individual. For example, Neil holds a high value on exercise and fitness, and a lower value on money savings. As such, the visualization could provide *personalized* feedback of the positive impacts of green transportation behaviours on Neil's fitness level (e.g. heart rate, calories burned, distance biked or walked, and so on). In contrast, the visualization could highlight different benefits for Michelle, who (say) highly values money savings.

5.2.10 Pro-social orientation, Arousal Theory

'Nuage Vert' (Figure 2.6a) projects a green cloud onto the smoke emitted from Helsinki's coal-burning power plant. City residents are rewarded with a bigger projected cloud when energy consumption is low. This work targets individuals with pro-social orientation by representing the city's collective energy consumption. The dynamically-changing green cloud employs arousal theory, as it aims to arouse the intrinsic emotions of curiosity and interest. I assess this work in the following.

Precontemplators and *contemplators* are likely to hold pro-*self* orientations in regards to sustainable energy usage. They may not be motivated to use less energy to create a bigger projected cloud if it does not provide clear *personal* benefits to them. On the other hand, the dynamically-changing shape and size of the cloud may arouse the intrinsic emotions of curiosity and interest. This may motivate short-term sustainable energy behavior, though it is likely they will resort back to their original behavior after the installation ends. Individuals in the *preparation*, *action* or *maintenance* stages are more likely to hold pro-social orientations, and in turn, may respond positively to the visualization. However, because 'Nuage Vert' visualizes energy consumption of the entire city, residents may be discouraged if they cannot see the impacts of their individual energy actions in the cloud. To address this issue, adaptive muddling could be used to encourage individuals to take an active role in reducing their energy consumption (e.g. by applying their local knowledge or expertise to find creative ways to save energy), and encourage teamwork (e.g. by recruiting friends or neighbors to take action). Such actions could be posted on a social community website, where the leaders of such actions receive social recognition. In this way, adaptive muddling allows people to perceive a role for themselves and sense that their contribution (and perhaps the contribution of others) is not only optional but a necessity (Kaplan, 1990) (Folz, 1991).

5.2.11 Social reinforcement (through teamwork)

'CarbonRally' (2.10) is a web-based, social network tool where individuals or teams can commit to small, positive energy actions over time. Social reinforcement for energy actions is provided by the 'CarbonRally' community and the rally teams.

Precontemplators who do not hold a high concern for sustainable energy usage are not likely motivated to access, read, and sign up to be part of this community. Thus, although the strong presence of a social community can be effective in "planting the seed" that non-sustainable energy behaviours are problematic, it must first overcome the precontemplator's lack of interest and concern for environmental issues. *Contemplators* are open to information about the problem behaviour (Miller & Rollnick, 2002), and may find CarbonRally's abundant information of sustainable energy actions to be useful and interesting. However, feelings of ambivalence may mean that contemplators are not yet ready to commit to energy challenges or to join a team. For individuals in the *preparation* and *action* stages, the social community can be a vivid and personalized motivator for individuals to take energy action. Specifically, 'CarbonRally' offers three choices that reduce the phenomenon of social loafing within a group (Hockenbury & Hockenbury, 2003): 1) individuals can take an energy challenge, which the website portrays to be a *valued* and *meaningful goal*, 2) individuals can form their own teams or join an existing team, making it highly likely that teams are formed of *familiar people* (e.g. friends, colleagues, family, etc.), and 3) 'CarbonRally' portrays the *efforts* of each individual and team as highly *valued*. Finally, the presence of a dynamic and ever-changing social network and reinforcement may motivate individuals in the *maintenance* stage to continue usage of this tool in the long-term.

5.2.12 Message framing

'CarbonRally' (Figure 2.10) and 'StepGreen' (Figure 2.9) are social network tools that use message framing to motivate individuals to take energy action. 'CarbonRally' asks individuals to "take a challenge" for sustainable energy action. Upon taking the challenge, 'CarbonRally' states that they have "accepted a challenge". In comparison, 'Stepgreen' encourages individuals to "create or commit to green actions".

Precontemplators who do not hold a high concern for environmental issues are unlikely to access these websites, and much less likely to "take a challenge" or "commit to green actions". For *contemplators*, the word "commit" (used in 'StepGreen') implies a sense of commitment or obligation, one which contemplators may not yet be ready for. In comparison, CarbonRally's use of the words "take" and "accept" implies a sense of choice on part of the individual. Providing choice is effective, as it appeals to the Rokeach value of "freedom", and increases one's sense of personal control (Rotter, 1966) and intrinsic motivation (Iyengar & Lepper, 1999). This, along with a sense of strong social reinforcement, may reduce contemplators' feelings of ambivalence to take energy action. For individuals in the *preparation, action,* or *maintenance* stages, CarbonRally's use of the word "challenge" implies that the energy goal is potentially difficult. Difficult goals are more attractive, because "although there is a lower possibility of success, there is a greater sense of achievement" (Wright & Kacmar, 1994). In comparison, Stepgreen's encouragement to "commit to green actions" may be less effective as it does not necessarily imply a sense of goal difficulty. Finally, an improvement to 'CarbonRally' and 'Stepgreen' for individuals in the *maintenance* stage, is to increase the level of goal difficulty over time in order to keep up with the individual's deepening interest, experience and commitment.

In 'StepGreen', another use of message framing is the presentation of energy actions in relation to monetary cost and CO_2 emissions in terms of potential "savings". An improvement is to frame energy actions that are considered risky or uncertain in terms of *loss* rather than gain. As mentioned in Chapter 4, energy actions are often perceived as a risky investment for two reasons: 1) they do not add financial value to a home, and 2) the annual return on an energy investment is very uncertain (due to energy prices, weather, household energy behaviour, etc.) (Shipworth, 2000). Thus, when motivating "risky" energy actions (e.g. installing insulation for a house), loss-framed appeals are more effective than gain-framed (O'Keefe & Jensen, 2008). For *precontemplators*, loss-framed appeals may be effective in "planting the seed" that non-sustainable energy behaviours are problematic. For *contemplators* who hold an equal weighing of the pros and cons of taking sustainable energy actions, a focus on loss-framed appeals may be especially effective to "tip the balance" towards action. For non-risky energy actions (e.g. "recycle glass"), the use of loss-framed appeals has no clear benefits over the use of gain-framed appeals (O'Keefe & Jensen, 2008). Such message framing could be used for individuals in the *preparation*, *action*, or *maintenance* stages who are preparing to take action, or have already acted.

5.2.13 Social norms

'CarbonRally' (Figure 2.10) employs descriptive and injunctive social norms to motivate energy action. Descriptive norms are used in the following ways. First, 'CarbonRally' uses the slogan "Join the rally", with iconic images of people alongside the text. The words "join" and "rally", as well as the people icons, indicates that this is the joint effort of many people to "save energy" and "reduce global warming". Second, the text: "*x* people have reduced CO_2 emissions by *y* lbs by completing this challenge so far" (where *x*,*y* are increasingly large numbers, depending on the current time and day) portrays the descriptive norm that an increasingly large number of people are taking energy challenges to reduce their energy consumption. Third, the "rally map" shows a 3D view of Rallyers across the nation who have made significant differences to sustainable energy usage. This portrays a national, descriptive norm. Injunctive norms are demonstrated in CarbonRally's "30-Day Leaderboard" and "Rally Highlights". The use of language such as "leader" and "highlights" indicate that the "super conservers" of the Rally receive strong social recognition.

The use of social norms may be effective in "planting the seed" to *precontemplators* that sustainable energy actions are widely performed and socially approved. However, in order for this to be effective, the feedback technology must first overcome precontemplators' lack of interest and concern in accessing or reading websites such as these. As people do not want to deviate from norms (Schultz et al., 2007), the combination of descriptive and injunctive norms may be effective to reducing *contemplators'* feelings of ambivalence and motivate a move towards the preparation stage. For individuals in the *preparation*, *action* and *maintenance* stages, the continued use of social norms may be effective to reinforce and maintain sustainable energy behaviours over the long term.

5.2.14 Social recognition, Adaptive muddling

'CarbonRally' (Figure 2.10) employs social recognition and adaptive muddling in the following ways. 'Leaderboard' provides social recognition of the top leading teams in energy savings, and the best recruiters to 'CarbonRally'. Social recognition appeals to Maslow's value of "esteem", and of course, the Rokeach value of "social recognition". Adaptive muddling is used in conjunction with social recognition, as individuals are encouraged to take a role, and apply their personal knowledge and expertise to helping the rally or the website. For example, Rallyers are encouraged to submit their own energy "challenges" to the website, where every week, the highest voted challenge (by the community) is recognized as the "Featured challenge" of the week. Adaptive muddling appeals to Rokeach's values of being "helpful", "responsible", or having "wisdom", and provides a level of task difficulty, which may make the task more appealing. I assess this work in the following.

Social recognition is hard to provide to *precontemplators* and *contemplators* who have not yet taken external energy actions. Adaptive muddling is unlikely to motivate *precontemplators* to take energy action, as they have not yet acknowledged the problematic behaviour. Adaptive muddling may be effective to tip contemplators towards action, as they may perceive a role for themselves, and may feel an obligation or responsibility to help the change succeed (Folz, 1991). The combination of adaptive muddling and social recognition may be effective to motivate individuals in the *preparation*, *action* or *maintenance* stages to take and maintain energy actions over the long-term. An improvement would be to use adaptive muddling to continually provide new challenges that increase in difficulty and responsibility over time, and reward the participation and achievement of such challenges with increasingly distinguished levels of social recognition.

5.2.15 Social competition

The last work I present is 'GreenLite Dartmouth' (Tice et al., 2009) (Figure 2.11). The polar bear animation is part of a dorm-wide social competition, where the dorm with the lowest energy usage is rewarded with monetary incentives. Competition can motivate behaviour change, due to feelings of social comparison or social pressure (Abrahamse et al., 2005). However, competition has two aspects: *informational* or *controlling* (Deci, 1975). In this way, competition can be a "double-edged sword", with the potential to both undermine intrinsic motivation for those that only wish to win (Deci et al., 1981) (controlling), and enhance intrinsic motivation for those that view competition as providing challenge and positive feedback (informative) (Tauer & Harackiewicz, 1999). I assess this work in the following.

Precontemplators who do not hold a high concern for sustainable energy usage but only wish to win (controlling aspect), may be motivated to take short-term energy actions during the competition. However, after the competition ends, they will likely resort back to their original behaviour. This was the case at Bowdoin College's energy dorm competition, where students significantly reduced their consumption during the competition, but resorted back to their original habits and behaviour after the competition was over (Weller, 2007). For *contemplators*, taking sustainable energy actions during the competition may invoke cognitive dissonance through "foot-in-the-door" theory. Contemplators who expended time and effort during the competition are likely to internally rationalize their external pro-environmental behaviour, which may reduce feelings of ambivalence and lead to a higher commitment to the cause. Individuals in the *preparation*, *action* and *maintenance* stages are already inherently motivated to take energy action. For them, the informative aspect of competition may be more motivating than the controlling aspect, making the use of social competition an effective technique. One exception is for individuals with high achievement motivation, where the controlling aspect of competition may actually *increase* their intrinsic motivation, rather than decreasing it (Tauer & Harackiewicz, 1999).

5.3 Summary

I made two contributions in this chapter. First, I framed motivational psychology literature as key notions for designers of technology that aim to motivate sustainable energy behaviour. Second, I showed how these notions can be used to assess existing feedback technologies from a motivational perspective. The assessment identified three shortcomings of current energy feedback technology design: 1) most feedback technologies that aim to motivate sustainable energy behaviour do not explicitly refer to or draw upon motivational psychology literature, 2) motivational psychology literature is rich but fragmented, making it difficult to apply to feedback technology design in a cohesive and meaningful way, 3) most feedback technologies use a "one-size-fits-all" solution, providing the same feedback to differently motivated individuals at different stages of behavioural change. The next chapter builds upon this assessment to construct a motivational framework that addresses these shortcomings of energy feedback technology design.

Chapter 6. A motivational framework to guide energy feedback technology design

Chapters 2, 4 and 5 collectively addressed ***research question #1*** - ***"What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?"***. Chapter 2 reviewed the landscape of energy feedback technologies, Chapter 4 reviewed motivational psychology literature, and Chapter 5 integrated the two by assessing selected energy feedback systems from a motivational perspective. From this assessment, I identified three shortcomings of current energy feedback technology design.

This led me to ask ***research question #2 - "Can we develop a framework that encompasses relevant motivational psychology literature to apply to energy feedback technology design in a way that addresses individual motivations at different stages of behavioural change?"***. This chapter addresses this question by synthesizing a wide range of motivational psychology literature to develop a motivational framework based on the Transtheoretical Model's stages of behavioural change. I begin by introducing the structure of the motivational framework. Then, I discuss how the framework aims to address the shortcomings of energy feedback technology design, identified in Chapter 5's assessment. Following this, I discuss the role of the designer in applying the framework to energy feedback technology design. Next, I discuss the framework's application of the Transtheoretical Model (TTM) and Motivational Interviewing (MI). Then, I present a scenario of a particular energy user named "Mary". I draw upon the details presented in this scenario to provide textual examples that illustrate one way to apply each of the framework's recommendations. Finally, I revisit our implemented feedback system, 'AREnergyViewer' (presented in Chapter 3) to offer initial, high-level, redesign ideas for the framework's recommendations for each stage of change. Both design scenarios (i.e. the textual examples based on the Mary scenario, and the high-level, redesign ideas for 'AREnergyViewer') address ***research question #3: "Can we use this framework to inform the design of energy feedback technologies?"***. Both approaches are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design. Thus, within this thesis, I do not fully address research question #3.

6.1 Structure of the framework

The motivational framework, based on the TTM's stages of behavioural change and MI's counselling guidelines, propose strategies that aim to target individual motivations at each stage of change. The goal is to motivate a move towards the *next* stage of change, where in the final stage of maintenance, the goal is to motivate durable sustainable energy behaviour.

The structure of the framework is as follows. For each stage, I present the motivational *goal(s),* and *recommendation(s)* for how feedback technologies may reach these goals. Each goal and recommendation is supported by a *rationale* (based on motivational literature). To make the recommendations more vivid, Section 6.6 presents a scenario of a particular energy user named Mary, who holds specific attitudes, beliefs and values. I simplify this scenario to focus on motivating the sustainable energy usage of one appliance –

APPLIANCE	POWER STATE, WATTAGE	
Computer	On	78.0 - 250.0 watts
	In transition	4.1 - 77.9 watts
	Low power ("standby" mode)	0.1 - 4.0 watts
	Off (with phantom power)	0.1 – 3.0 watts
	Off (without phantom power)	0.0 watts
21" LCD monitor	On (at maximum brightness, any contrast)	110.0 – 120.0 watts
	On (at zero brightness, any contrast)	44.0 – 48.5 watts
	In transition	2.7 – 43.9 watts
	Low power ("standby")	0.1 – 2.6 watts
	Off (without phantom power)	0.0 watts

Table 6.1: Electricity consumption of Helen's desktop computer and LCD monitor, measured using Watts Up devices.

the desktop computer. To provide the reader with a general idea of the electricity consumption of computers and monitors, Table 6.1 (previous page) presents the electricity consumption values of my desktop computer and 21" LCD monitors at various power states. (As a side note, while computers are not the major "power hogs" in residential homes, I choose the computer as one example for illustration, though other appliances in the household would be applicable in this scenario as well).

Finally, I draw upon the details presented in the scenario to provide a simple textual *example* for each recommendation.) I do not claim the examples I provide are ideally presented; rather, they illustrate *one* way (and perhaps, not the best way) to realize a recommendation.

6.2 Addressing the shortcomings of current energy feedback technology design

I now restate the shortcomings identified in Chapter 5's assessment, and discuss how the framework aims to address these issues.

Shortcoming #1: While feedback technologies aim to motivate sustainable energy behaviour, their designs could benefit significantly by explicitly incorporating aspects of motivational psychology literature.

Most feedback systems that aim to motivate sustainable energy behaviour do so tacitly, without explicitly drawing upon motivational psychology literature. However, as motivation is fundamental to change (Miller & Rollnick, 2002), feedback technologies could significantly benefit from "looking over the fence" to incorporate aspects of motivational psychology literature to energy feedback technology design. The framework addresses this shortcoming by proposing goals and recommendations to guide energy feedback technology design, where each goal and recommendation is supported by a rationale based on motivational literature.

Shortcoming #2: Motivational psychology literature is fragmented among different psychological subfields and schools of thought, making it difficult to apply to energy feedback technology design in a cohesive and meaningful way.

To address this issue, the framework synthesizes the TTM's stage model of behaviour change and MI's counselling guidelines of facilitating behaviour change with a variety of motivation psychology literature, including *motivation techniques* and *theories* within environmental psychology, social psychology, and applied psychology, *behaviour change theories* and models within behaviourism and health psychology, and *behaviour change therapies* within health psychology. This synthesis ties together a large amount of motivational psychology literature to propose motivational goals and recommendations for each of the TTM's stages of behavioural change. These goals and recommendations are grounded in motivational literature, and offer a systematic method to inform the design of energy feedback technologies.

Shortcoming #3: Feedback technologies tend to design for "one-size-fits-all", providing the same feedback to differently motivated individuals at different stages of behavioural change.

Chapter 1 argued that designers of feedback technologies that aim to motivate sustainable energy behaviour need to consider two important points: 1) different people hold different attitudes, beliefs and values (Beebe et al., 1999), and are motivated by different things, 2) intentional behaviour change does not occur as an event, but rather, as a process in a series of stages, as defined by the Transtheoretical Model (Miller & Rollnick, 2002). Given these design considerations, the motivational framework aims to move beyond a "one-size-fits-all" solution to propose motivational interventions that target individual *attitudes*, *beliefs* and *values* held at each *stage* of behaviour change. For each stage, the framework targets general trends in attitudes, beliefs and values by drawing upon motivational psychology literature. To target individual motivations, the framework draws upon the details presented in the Mary scenario and the specific attitudes, beliefs and values that she holds.

6.3 The role of the designer

The motivational framework informs energy feedback technology design by providing goals and recommendations for each stage of behavioural change. Thus, the role of the designer may be to apply the framework to target a particular behavioural stage, with the goal of motivating a move to the next behavioural stage. However, in the practical application of the framework, the designer must consider three important points.

First, the designer must still make significant efforts in terms of translating the framework to consider the preferences, constraints and trade-offs in developing and deploying a feedback system in a real household. Such factors may include considerations of target behaviours, target audience, social situation, business models, profit margins, among others. In other words, the designer must not blindly apply this framework, but rather, take deep considerations as to what energy behaviours on which appliances they wish to target, as well as the end goal or impact that the feedback device aims to make. In this sense, it is the designer's responsibility to translate the framework to target energy behaviours that can potentially make the most significant, positive environmental impact.

Second, in the practical development of an energy feedback system, there may be several factors (e.g. cost, deadlines, materials, etc.) that compete with the consideration of motivation. However, in this thesis, I argue that the consideration of *motivation* is essential to the design of energy feedback systems that aim to motivate behaviour change, where motivation should be considered the top priority among competing factors. As the following textual examples based on the Mary scenario will show, if a feedback device can present text and numbers, it is capable of considering motivation by applying the motivational goals and recommendations proposed in the framework.

Third, the form factor of the feedback device may afford constraints as to the device itself, and this must be considered when applying the framework. For example, due to decisions outside the designer's control (e.g., cost of components, use of existing devices as a feedback device, etc.), the form factor of available input/output aspects of that device may be pre-determined. The device may range from a conventional desktop computer where a person monitors the system via a web interface, to a specialized control panel in a person's home, to a tablet PC that a person uses to roam the home (as in AREnergyViewer), to an existing device like an iPad or iPhone with its own interface semantics, to a cell phone, to a custom device with a two-line text display, and so on. The affordances and interface style will certainly affect the design choices possible. That is, it is the designer's job to apply the framework to best meet the limitations and the possibilities of the device.

6.4 Application of the Transtheoretical Model (TTM)

I now discuss the framework's application of the TTM: in particular, motivational trends between the earlier and later stages of behavioural change.

In the earlier stages of behaviour change (i.e. precontemplation and contemplation), *cognitive* processes of change appear to be more important (Perz et al., 1996). The framework makes use of this knowledge by targeting general attitudes, beliefs and values that may act as psychological barriers in movement to the later stages of sustainable energy behaviour.

In the later stages of behaviour change (i.e. preparation, action, maintenance), *behavioural* processes are more important (Perz et al., 1996). The framework makes use of this knowledge by targeting existing pro-environmental attitudes, beliefs and values that individuals hold, and using this to support individuals in developing effective plans of action, reinforce their action, and maintain the desired behaviour change.

6.5 Application of Motivational Interviewing (MI)

Motivational Interviewing (MI) is a client-centered counselling style often used in conjunction with the TTM (Treasure, 2004). Whereas the TTM defined stages of behavioural change, MI provides guidelines that aim to *facilitate* behaviour change throughout these stages (Miller & Rollnick, 2002). The following restates the principles of MI (presented in Chapter 4), with a discussion of how the framework applies these principles.

1. Support *self-efficacy* by building the patient's confidence that change is possible

As cognitive processes are more important in the *earlier* stages of change (Perz et al., 1996), the framework aims to build client self-efficacy by addressing barriers to motivation in the precontemplation and contemplation stages. In the later stages of preparation, action and maintenance, the framework aims to build self-efficacy by supporting clients in developing effective energy goals, and providing positive performance feedback to reinforce energy actions and maintain durable sustainable energy behaviour.

2. Develop *intrinsic* attributions to successful behaviour change

At each stage of change, the framework aims to invoke intrinsic satisfactions and emotions with regards to sustainable energy behaviour. In precontemplation, the framework aims to invoke the intrinsic emotions of *interest* and *curiosity*, with the goal of motivating individuals to explore and investigate energy information. In contemplation, the framework provides many choices of potential energy actions, where the presence of *choice* increases one's sense of intrinsic motivation (Iyengar & Lepper, 1999). In preparation, the framework aims to provide the individual with *optimal challenges* with regards to goal-setting and goal implementation of sustainable energy actions. The action stage provides *competence performance feedback* on these challenges, which in turn leads to an intrinsic *enjoyment* of the activity (Csikszentmihalyi, 1975). The maintenance stage aims to maintain the *cyclical loop* of intrinsic motivation: curiosity, interest, exploration, optimal challenge, competence feedback, and enjoyment, with the end goal of motivating durable sustainable energy behaviour.

3. Develop discrepancy between the patient's *values* and their current behaviour

"Values function as motivational guideposts, stimulating an increase in value-behaviour consistency, thus improving self-esteem" (Rokeach, 1979). Throughout the stages, the framework aims to target the values and value systems that people may hold, drawing upon the preferences for experiences and behavioural ideals proposed by Rokeach and Maslow. In addition, the framework targets what I call *"intermediate values"* - values that reflect or may lead to the attainment of preferences for experiences or behavioural ideals. For example, *money* is an extrinsically motivating incentive, but is also an intermediate value that may reflect the desire to attain Rokeach's preference for experience of "a comfortable life" or "social recognition".

Within the framework, values are targeted in two ways. The first is by providing energy feedback in relation to what the individual values. For example, Contemplation's Goal #1, Recommendation #1, provides feedback on the benefits of sustainable behaviour and the consequences of non-sustainable behaviour, where the benefits and consequences are presented in relation to what the individual values. Second, the use of specific techniques and theories may appeal to certain values. For example, the use of cognitive dissonance in the contemplation stage appeals to Rokeach's preference for experience of "inner harmony" and Rokeach's behavioural ideal of being "honest".

Finally, the framework follows MI's guideline that once values are identified, "individuals do not need to change their values per se but must simply find different ways to fulfill their preferences for experiences" (Miller & Rollnick, 2002). In the context of motivating sustainable energy behaviour, the framework does not aim to change the value of (for example), having "a comfortable life", but rather aims to satisfy this value in a more environmentally sustainable way.

4. Express *empathy* using reflective listening

Empathy is "the ability to put one's self into the psychological frame of reference or point of view of another, to feel what another feels"(MindControlForums). The framework does *not* support this principle, as empathy is a human emotion that technology cannot imitate. That being said, precontemplation's goal #1, recommendation #1 (presented shortly in Section 6.7) is grounded by MI's principle to provide empathy. The recommendation states to "Provide personalized feedback that acknowledges *both* the benefits and consequences of the individual's *non-sustainable* energy behaviour". The rationale is that feedback technologies must acknowledge *both* the benefits and consequences of non-sustainable energy behaviour before it can expect precontemplators to "decrease resistance" and become open to considering the "not so good things". While this recommendation does not provide empathy, it is grounded by the goal to consider empathy.

6.6 An example scenario: Mary

I now present an example scenario of a person named "Mary", who holds specific attitudes, beliefs and values towards her computer energy usage. Throughout the framework, I draw upon the details presented in this scenario to provide simple textual examples[19] which illustrate one way to apply the framework's recommendations. For these examples, I make three assumptions: 1) the individual will always be in one stage at a time, 2) the individual will always progress towards the *next* stage of change (i.e. no stage skipping), and 3) the feedback device is knowledgeable of the specific attitudes, beliefs and values Mary holds, the

[19] Calculations in the textual examples of Mary's computer and monitor usage are based on real, electricity consumption values of my school desktop computer and monitors. These values were measured using Watts Up devices. Calculations were made based on the following assumptions: 1) Mary uses the computer actively for 8 hours each day, Monday to Friday, 2) computer usage is 89 watts, 3) Mary has two 21" monitors, where each monitor uses 91 watts, and 4) the number of full-grown pine trees required to offset carbon offsets are based on values from http://www.erasecarbonfootprint.com/treeoffset.html (Retrieved March10, 2010).

activities she takes part in during the week, as well the times and duration in which Mary uses her computer. On the outset, the scenario suggests that the feedback system has considerable intelligence (i.e. system "smarts"), in that the software knows and/or can infer about the domain, what people are doing, their goals, and can state output in well-formed natural language terms. We stress that such "smarts" are not essential; its inclusion in this scenario is made for brevity, i.e., they illustrate how the framework's recommendations can be applied within a visually simple interface.

About Mary: Mary is 37 years old, married, the mother of two school-age children (Logan and Sarah), and lives in Edsen Community. She is a novelist and works on a home desktop computer with two 19" monitors. Due to familial responsibilities (e.g. grocery shopping, driving her kids to school and extra-curricular activities, etc.), Mary works flexible but long hours on the computer. Mary values work and productivity, family, and physical health. Though money is not a problem, Mary is a frugal spender.

Computer usage: Mary uses MS Word, Internet and email. She browses the web for inspiration and ideas and often keeps her computer and monitors on so she can readily access her open Internet tabs and work when desired. Mary knows about but does not make use of her computer's automatic power management features. Last month, Mary's computer got a virus, though she is not sure how it was contracted.

Motivational stage: I begin this scenario with Mary as a precontemplator. While Mary is somewhat aware of general environmental problems, she does not believe her personal energy use (and in particular, her computer usage) has much negative effect. In general, Mary does not believe she has the time or energy to make big energy changes.

6.7 A motivational framework

I now present the motivational framework for each stage of change.

STAGE 1 - PRECONTEMPLATION

GOAL #1: Present information in moderation to "plant the seed" (Miller & Rollnick, 2002) for individuals to acknowledge their current non-sustainable energy behaviours are problematic.

Rationale: Precontemplators can be reluctant, resistant, resigned, or rationalizing (Miller & Rollnick, 2002). Through inertia or lack of knowledge of the effect of the problem behaviour, precontemplators do not want to consider change (Miller & Rollnick, 2002). The goal in this stage is to "plant the seed" that non-sustainable energy behaviours are problematic (rather than to necessarily motivate energy action). Once planted, precontemplators often need time to let them germinate (Miller & Rollnick, 2002). Finally, information should be provided in moderation as more intensity will often produce fewer results with this group (Miller & Rollnick, 2002).

Recommendation #1: Provide personalized feedback that acknowledges *both* the benefits and consequences of the individual's *non-sustainable* energy behaviour. Present these benefits and consequences in relation to what the individual values, in a neutral, non-biased way.

Rationale: Technologies must acknowledge both the pros and cons of the individual's current non-sustainable energy behaviours before they can expect precontemplators to "decrease resistance" (Miller, & Rollnick 2002) and become open to considering the "not so good" things (Miller & Rollnick, 2002). This is especially important when motivating energy action, as *non-sustainable* energy behaviours offer many existing benefits, such as comfort, luxury, convenience, social status, and sometimes cost. These benefits appeal to Rokeach's values of "a comfortable life" and "social recognition".

Example, centered on Mary's computer and monitors usage

SUMMARY FOR THIS WEEK

Total energy used: 45.5 kWh (ON for 168 hours, 37% while not present)

Pros: With your busy family and work schedule this week, keeping your computer and monitors ON 24/7 fit well with your sporadic usage patterns, and allowed you to immediately and conveniently access your work.

Cons: 1) This week's cost = $4.66 (At this rate, monthly cost will be $18.64, equivalent to 53% of Logan's monthly soccer league fee), 2) Your computer when ON and connected to the Internet is more susceptible to contracting viruses, 3) This week's $C0_2$ emissions = 113.75 kg (At this rate, monthly emissions will be 455 kg, requiring 66.7 full-grown pine trees in Edsen Community in order to offset the emissions within one year).

Recommendation #2: Refer to social norms regarding sustainable energy behaviours by aligning the use of descriptive and injunctive normative messages – that is, highlighting *popular* pro-environmental behaviours that are socially *approved*. However, be careful not to highlight descriptive norms that may *increase* the undesired behaviour.

Rationale: *Social norms* are "the 'rules' or expectations for appropriate behaviour in a particular social situation" (Hockenbury & Hockenbury, 2003). The idea is to motivate the individual to think: "if many people value it, maybe I should as well". *Descriptive norms* are "perceptions of behaviours that are typically performed" (e.g. "85% of your neighbourhood recycles"). These appeal to Maslow's value of "love/belongingness". *Injunctive norms* are "perceptions of behaviours that are typically approved or disapproved" (e.g. a thumbs-down sign with the text: "Protect the environment – don't litter!). These appeal to Rokeach's value of being "obedient". Normative messages that *align* descriptive and injunctive messages tend to have higher rates of success (Cialdini, 2003). Finally, as descriptive norms provide a standard from which people do not want to deviate (Schultz et al., 2007), one must be careful to present descriptive norms that will motivate a *decrease* in the undesired behaviour, rather than an *increase* in the undesired behaviour to be the same as the norm.

Example: Feedback technologies could send a community message update to Mary with a thumbs-up sign and the following text. The words "join" and "rally" employ descriptive norms. The phrase "Way to go!" employs injunctive norms.

> Join the rally for efficient computer usage! This month, your community reduced energy consumption by 29%, saving 271 kWh, $27.75 and 677.5 kg in CO2 emissions (equivalent to 99.3 full-grown pine trees), just from simple changes in computer power management! Way to go! ☺

Recommendation #3: Incorporate components of novelty, complexity and variability in the interface with the goal of motivating the individual to explore, investigate, and manipulate energy information within the interface.

Rationale: Novelty, complexity and variability give rise to the intrinsically arousing emotion of interest (Reeve, 1989). Interest underlies curiosity, attention, stimulus selection, investigatory activity, and exploration (Izard, 1977). A satisfaction-based joy follows an exploration-based interest (Reeve, 1989). Invoking intrinsic satisfactions to motivate individuals to explore energy information within the interface addresses the barrier that precontemplators are not initially interested in sustainable energy information. Such exploration of the interface may "plant the seed" that non-sustainable energy behaviours are problematic and may motivate precontemplators to explore energy information for "fun" or "curiosity", despite a lack of inherent interest in the topic.

Example: As Mary values productivity in her work and spends money frugally, feedback technologies could visualize Mary's sporadic computer usage rhythms, with particular emphasis on how small changes in her computer usage behaviour can lead to more productive work outcomes, more sustainable energy usage and more cost-effective computer usage. As this visualization provides novel and complex information that appeals to Mary's values, it may arouse her intrinsic emotions of curiosity and interest.

STAGE 2 - CONTEMPLATION

GOAL #1: Address barriers to motivation, such as 1) not valuing an activity (Ryan, 1995), 2) not feeling competent (Deci, 1975) and 3) not believing it will yield a desired outcome (Seligman, 1975).

Rationale: *Amotivation* is defined as "a state of lacking intention to act", and typically occurs due to the above barriers (Ryan and Deci, 2000). These barriers relate to people's beliefs and expectations regarding sustainable energy behaviours and must be addressed in order for change to occur. These barriers can be explained by the Valence-Expectancy Theory (VET), where valence is equivalent to barrier #1, expectancy is equivalent to barrier #2, and instrumentality is equivalent to barrier #3. As in the VET, all factors must be high, in order for motivation to be high. When they are low, motivation is low. The goal here is to increase these factors in order to motivate behaviour change.

Recommendation #1: Provide personalized feedback on the *pros* of *sustainable* energy behaviour, and the *cons* of *non-sustainable* energy behaviour. The pros should emphasize an improvement to the individual's quality of life (in relation to what they value). The cons of the behaviour (if considered risky or uncertain) should be presented in terms of loss (in relation to what they value) rather than gain. If the cons are neither risky nor uncertain, loss and gain-framed message presentation are equally effective (O'Keefe & Jensen, 2008).

Rationale: This recommendation addresses the barrier of "not valuing an activity" (Ryan, 1995) by aiming to increase the value placed on sustainable energy action. In comparison to the neutral presentation of Precontemplation's Goal #1, Recommendation #1, this recommendation provides a more one-sided perspective of sustainable energy action. Specifically, the individual should perceive the 'pros' of sustainable behaviour as *enhancing* their quality of life. This is important as people resist making changes that they perceive as reducing their quality of life, in particular, those that stress self-sacrifice for the welfare of the common good (Kaplan, 1990). The 'cons' (if risky or uncertain) should focus on the costs of *non*-sustainable behaviours, from a perspective of *loss* rather than gain (O'Keefe & Jensen, 2008). As energy actions are often perceived as a risky investment (Shipworth, 2000), this maximizes the impact of information as people are more willing to take actions to avoid or minimize a loss, than do the same action for gain (Yates & Aronson, 1983). The focus on values emphasizes *personally relevant* information or feedback, which can be extremely persuasive at this stage (Miller & Rollnick, 2002).

Example: In the following text, a one-sided message framing of information is employed by the use of words such as "wasted", "loss", "inefficient", "efficient" and "benefits".

SUMMARY FOR THIS WEEK
Total energy used: 45.5 kWh (ON for 168 hours, 78% of energy wasted)
***Loss* from inefficient computer management:** 1) $3.63 – the price of today's morning coffee, 2) an increased susceptibility to contracting computer viruses while the computer is ON and connected to the internet, 3) 88.73 kg CO_2 emissions – requires 13 full-grown pine trees in Edsen Community to offset the pollution within one year.
***Benefits* of efficient computer management:** 1) Decreasing monitor brightness and increasing the contrast can save up to 50% of monitor power consumption, while maintaining viewing quality, reducing eye strain and, in turn, supporting increased work productivity, 2) Sleeping your computer reduces consumption by 97%, while still allowing you to access open work applications and Internet tabs almost immediately after "waking" your computer, 3) Setting your computer's automatic power settings is only a one-time effort, but is a convenient way to save you electricity, time, money and the environment in the long term!

Recommendation #2: Provide personalized feedback of a variety of small energy actions that, if performed, would have positive impacts on the environment.

Rationale: This recommendation addresses the barriers to motivation: "not feeling competent" (Deci, 1975) and "not believing it will yield a desired outcome" (Seligman, 1975). Addressing these barriers is important as one study (Donn, 1999) found that a substantial decline in concern about environmental issues was attributed to a sense of *futility* and *helplessness*, rather than apathy (Kaplan, 2000). As such, providing information of energy actions that can make a positive environmental impact addresses the barrier of "not feeling competent" and appeals to Rokeach's value of being "capable". Providing projections of the positive impacts of potential energy actions addresses the barrier of "not believing it will yield a desired outcome". Presenting a variety of energy action *choices* appeals to Rokeach's value of "freedom", increases one's sense of *personal control* (Rotter, 1966), and increases one's intrinsic motivation (Iyengar & Lepper, 1999).

Example: One energy tip could be provided each day, with a projection of the positive environmental impact it would make.

> **TODAY'S ENERGY TIP** – ***Efficient monitor usage***
> Tired eyes? Turn down your monitor brightness and increase the contrast instead! You can reduce monitor power consumption by almost 50%, doing a big favour for your eyes *and* the environment! Click here to find out how.

GOAL #2: "Tip the balance" in favour of change (Miller & Rollnick, 2002).

Rationale: Contemplators have acknowledged the problem, are open to information, but are not yet ready to take action (Miller & Rollnick, 2002). At this stage, ambivalence is the key issue that must be resolved in order for change to occur, as evaluations of the pros and cons of the current behaviour are more or less equal (Miller & Rollnick, 2002). Although many contemplators move to the action stage, it is possible to spend many months or years in contemplation (Carbonari et al., 1999). As contemplators do not believe the negative aspects of the current (problem) behaviour outweigh the positive (Miller & Rollnick, 2002), the goal is to "tip the balance" towards change or action.

Recommendation #1: Remind individuals of their pro-environmental attitude, inform them of the *discrepancy* between their attitude and the corresponding behaviour, and encourage a change towards more sustainable behaviour.

Rationale: Contemplators hold pro-environmental attitudes but do not behave consistently to those attitudes. This recommendation uses this discrepancy through *cognitive dissonance* - "an uncomfortable state" that occurs when a person holds an attitude and a behaviour that are "psychologically inconsistent" (Festinger, 1957). When this happens, people try to reduce this uncomfortable feeling, either by changing their attitude or their behaviour (Festinger, 1957). As people often change their attitudes, rather than their behaviour (Shipworth, 2000), an emphasis on encouraging sustainable *behaviour* change is important. Cognitive dissonance appeals to Rokeach's values of "inner harmony" and being "honest", and can lead to enduring changes in attitude or behaviour (Thibodeau & Aronson, 1992).

Example:

Your energy inefficiencies: Did you know that yesterday, ***67%*** of your computer power consumption was used while you were away from your desk? We know how much you care about efficient computer power management! You can do better tomorrow! ☺

Recommendation #2: Provide encouragement for small energy actions (whether or not the individual's original intention was sustainable energy usage) to motivate larger energy-saving actions in the future.

Rationale: This recommendation uses cognitive dissonance through *"foot-in-the-door"* processes (Yates & Aronson, 1983). The idea is that if people can be encouraged to perform a small energy action on their own accord, they can be encouraged to perform larger energy actions in the future (Shipworth, 2000). This occurs because of *cognitive dissonance* - individuals will change their internal attitudes to justify or rationalize their already performed external actions (Festinger, 1957). In fact, the more effort, time or money they expend, the more committed the individual will become to further courses of action (Levy-Garboua & Blondel, 2002).

Example: Yesterday, Mary was working on Logan's birthday invitations when he came home. Mary turned off her monitors to keep the invitation a secret in case he glanced over. While Mary's original intention was not energy savings, a message the next day could say:

Mary, thanks for turning off your monitors! You saved 2.73 kWh, $0.28, and 6.83 kg in CO_2 last night! Way to go! ☺ To be even more *'green'* in your computer usage, consider sleeping your computer when finished for the workday – it only takes a few seconds, reduces consumption by 97%, and gives you (almost) immediate access to your work whenever you want!

Recommendation #3: Provide contemplators with information of the experiences and stories of sustainable energy users in the community.

Rationale: Providing an opportunity for contemplators to read about the experiences of sustainable individuals in their community is a *vivid* and *personalized* way to appeal to *social norms* of sustainable energy usage, without pushing any type of commitment.

Example: The feedback technology could provide a link to a website introducing 'green' individuals in the community:

Visit the Edsen Community 'Green' Lifestyles Website - Read about the experiences of real people in your community who've made **small** energy changes with **BIG** environment impacts!

STAGE 3 - PREPARATION

GOAL #1: Support the individual's decision in preparing to take energy action.

Rationale: Individuals in preparation are ready to act in the near future (Miller & Rollnick, 2002). However, being prepared for action does not mean that all ambivalence is resolved (Miller & Rollnick, 2002). As such, the goal in this stage is to support individuals in their decision to take sustainable energy action, with the hopes to reduce conflicting feelings about the change (Miller & Rollnick, 2002).

Recommendation #1: Affirm the individual's choice in preparing to take energy action by appealing to social and personal norms of sustainable energy usage. Combine this with projections of the positive impacts they will make by taking these energy actions.

Rationale: *Social norms*, such as descriptive and injunctive norms, appeal to Maslow's value of "love/belongingness" and Rokeach's value of being "obedient". Social norms are adopted by each of us on a personal level, and hence become *personal norms* (Hopper & Nielsen, 1991). Violating personal norms engenders guilt, and to uphold these norms engenders pride (Hopper & Nielsen, 1991). Encouraging behaviour that is consistent with one's personal norms may create a focus on values, which in turn, may stimulate motivation for change (Miller & Rollnick, 2002). Clarifying the relative importance of these values may help reduce ambivalence (Miller & Rollnick, 2002). Thus, social and personal norms, in conjunction with projections of the positive impacts that one's energy actions will make, can be effective to support an individual's decision to take energy action.

Example:

Congratulations in your decision to take energy action! ☺ Not only will your future actions save you money and reduce CO_2 emissions, you can feel great about joining the rally for a greener and more sustainable world!

GOAL #2: Support individuals in developing a *plan* that is acceptable, accessible and effective (Miller & Rollnick, 2002). These plans can relate to "one-off actions" (e.g. purchasing an energy-efficient fridge) or "day-to-day" actions (e.g. taking shorter showers) (Shipworth, 2000).

Rationale: A *goal* is defined as "an internal representation of a desired outcome" (Austin & Vancouver, 1996). Individuals in preparation may have abstract goals to take energy action, but do not necessarily know the best ways to achieve them.

Recommendation #1: Support individuals to self-set specific and quantifiable goals (preferably at medium to high levels of difficulty) and make firm commitments to them.

Rationale: Goals and feedback are inextricably intertwined (Klein, 1991). If a goal to save energy does not exist, then feedback should have no effect (McCalley & Midden, 2002). In other words, the motivational effect previously attributed either to feedback or to goal setting is actually due to their *joint* effect (Becker, 1978).

Goal-setting and *goal commitment* are two factors that influence the success of goal achievement. *Specific*, *difficult* and *self-set* goals lead to higher performance and commitment than do-best, easy or assigned goals (Wright & Kacmar, 1994). Specific goals make clear when the goal has been achieved (Wright & Kacmar, 1994). Difficult goals provide a greater sense of achievement, though there is a lower probability of success (Wright & Kacmar, 1994). In addition, difficult goals present an *optimal challenge*, where competence performances on challenging tasks lead to the intrinsic emotion of enjoyment. Achieving difficult goals appeals to Rokeach's value of being "capable", and Maslow's value of "esteem". Goal difficulty can start at the easy level, as success builds on success, and with each small change the individual builds self-efficacy about making bigger changes (Miller & Rollnick, 2002). Finally, individuals in this stage need to make "firm commitments to follow through on the action option they choose" (Miller & Rollnick, 2002).

Example:

> I, Mary Williams, commit to a medium difficulty level goal to reduce my CPU and monitor usage by 25%. My current monthly usage is 175.8 kWh. My goal for next month is 131.9 kWh. My goal begins: January 1, 2010 and ends: February 1, 2010.

Recommendation #2: Support individuals in developing multiple methods to achieve their goals, while encouraging them to apply their personal expertise and knowledge in developing these plans.

Rationale: *Implementation intentions* are the "plans that specify the when, where and how to lead to goal attainment" (Gollwitzer, 1999). Goal intentions that are furnished with implementation intentions are more easily attained than mere goal intentions (Gollwitzer & Brandstatter, 1997). Flexibility in goal attainment is good, providing the option to switch to alternative routes (Gollwitzer, 1999). Implementation intentions appeal to Rokeach's values of being "logical" or "imaginative". Encouraging the individual to apply their personal expertise to a situation is called *adaptive muddling* (Kaplan, 1990). When this happens, people perceive a role for themselves, and may feel an obligation or responsibility to help the change succeed (Folz, 1991). This has two benefits. First, it increases the individual's level of goal commitment, while targeting Rokeach's values of being "responsible", "helpful" or having "wisdom". Second, adaptive muddling may encourage self-reflection of one's energy behaviours, arousing the intrinsic emotions of *curiosity* and *interest* when developing implementation intentions.

Example: Feedback technologies can automatically generate a variety of implementation intentions, while also encouraging individuals to create their own:

To reach this goal, I will:
√ Set automatic power settings to turn my monitors off after 30 minutes of inactivity
__ Sleep my computer when finished for the workday
√ Decrease my monitor brightness by 40 units (and increase the contrast instead)
Be creative! What other ways can you reach this goal?
Turn computer off before family vacation next week!

Recommendation #3: Provide individuals in the preparation stage with the option to be connected to energy "mentors" - people in the action or maintenance stages of sustainable energy behaviour change.

Rationale: Being connected to an energy mentor employs *social diffusion* - the observation that people are more likely to follow the modeled behaviour or example of others who have successfully adopted energy actions (Yates & Aronson, 1983). In addition, being connected to an energy mentor implies a level of commitment, which may be acceptable for individuals who are preparing to act in the near future.

Example: Feedback technologies could provide Mary with a variety of energy mentor profiles and descriptions, highlighting those with similar energy needs or interests (e.g. stay-at-home working mothers who have modified their lifestyles to be more 'green'). Once Mary has selected a mentor, the feedback technology could provide a variety of options in which Mary and her mentor could communicate and share their experiences (e.g. emails, Facebook, instant messaging, phone calls, etc.).

STAGE 4 – ACTION

GOAL #1: Positively reinforce sustainable energy actions

Rationale: Positive reinforcement (PR) is the most effective technique for motivating the *increased* occurrence of a desired behaviour (Hockenbury & Hockenbury, 2003). In comparison, techniques such as punishment or negative reinforcement stop the undesired behaviour, but do not replace anything in its place (Hockenbury & Hockenbury, 2003).

Recommendation #1: Positively reinforce energy actions in multiple ways, and immediately after the preferred behaviour occurs. As the desired behaviour becomes well-established, gradually reduce the frequency of PR.

Rationale: Delivering PR immediately, in multiple ways, and gradually fading PR are three principles that enhance the effectiveness of PR (Hockenbury & Hockenbury, 2003).

Example: Technologies could use multiple methods (e.g. sound, rewarding changes in graphics, energy "points", social recognition of Mary's actions on the community website, etc.) to positively reinforce Mary's energy actions immediately after she performs them. PR can gradually fade when energy use of the measured appliances indicate when the desired behaviour has become well-established.

Recommendation #2: Provide positive performance feedback in relation to progress made towards energy goals set in the preparation stage.

Rationale: Positive performance feedback tends to increase intrinsic motivation, whereas negative performance feedback tends to decrease intrinsic motivation (Deci, 1971). Providing positive feedback on goal progress may lead to the intrinsic satisfaction of *competence*, which appeals to Rokeach's value of being "capable". Activities that promote appraisals of competence report increased *enjoyment* (Harackiewicz et al., 1985), as well as subsequent "free-choice" behaviour with the activity (Rosenfield et al., 1980). Enjoyment encourages future encounters with the activity and increases one's willingness to seek out and conquer task challenges (Reeve, 1989). Thus, by focusing on the individual's successful activity, reaffirming their decisions, and helping them make intrinsic attributions of success, feedback technologies can bolster the individual's evaluations of self-efficacy (Miller & Rollnick, 2002). If individuals do not have adequate self-efficacy, they are not likely to experience long-term success (Miller & Rollnick, 2002).

Example: A progress bar visualizing goal progress can be presented with the following text:

> Despite your busy schedule, you made excellent progress towards your goal today! ☺ Keep up the great work, and you'll reach your goal in only 1 day!

STAGE 5 - MAINTENANCE, RELAPSE AND RECYCLING

GOAL #1: Maintain *durable* sustainable energy consumption behaviour

Rationale: In maintenance, the individual works to consolidate the gains attained during the action stage and struggles to prevent relapse (Miller & Rollnick, 2002). Often change is not established even after six months or so of action (Prochaska & Velicer, 1997). People who do relapse slip to an earlier stage, though they have a better chance of success during the next cycle as they have learned valuable lessons (Miller & Rollnick, 2002). At some point, behaviours will become sustained over time and integrated into their lifestyle so that the individual can exit the cycle of change (DiClemente & Prochaska, 1998). Finally, while it is not possible for every decision to be "maximally green", the goal in this stage may be to be "just a little more conscious and aware" (Woodruff et al., 2008).

Recommendation #1: Provide individuals with the choice to engage in social competition with other individuals in the maintenance stage to compete to be the most energy-efficient. Throughout the competition, individuals can compare their own progress with that of others. Reward the "super-conserver" winners of the competition with social reinforcement (such as social recognition).

Rationale: Social competition can motivate behaviour change due to social comparison or social pressure (Abrahamse et al., 2005). However, when one is only in it to win, competition can have negative effects on intrinsic motivation (Deci et al., 1981). On the other hand, individuals in the maintenance stage already hold a high concern for sustainable energy behaviours. As such, the use of competition may invoke a stronger motivation to take sustainable energy action, without undermining intrinsic motivation. Rewarding winners of the competition with social reinforcement (rather than material incentives) is more likely to lead to durable and intrinsically motivated sustainable energy behaviour change (De young, 1993), while appealing to Maslow's value of "esteem" and Rokeach's value of "social recognition".

Example: The feedback device could send the following message to Mary:

> *Who* is the **energy star** in *your* community? Next week, join us in a friendly neighbourhood month-long competition between green individuals in your community to see who is the most energy-efficient! The top three winners of the competition will receive our most distinguished "Energy Star" Recognition, and a formal award ceremony celebrating those who continually make positive, environmental impacts!

Recommendation #2: Support the transition from energy actions to energy *habits* by providing individuals with the choice to use opportune prompts reminding them to take specific energy actions. Choice should be provided as to which actions, situations and times individuals wish the prompts to appear. As the habit becomes well-instantiated, these prompts can gradually disappear.

Rationale: *Habits* are "associations between goals and actions that allow the instigation of *automatic* behaviour on activation of these goals by the environment" (Aarts & Dijksterhuis, 2000). In other words, when a behaviour has been performed many times in the past, future behaviour becomes increasingly under control of an automaticized process (Fishbein & Ajzen, 1975). The instantiation of habits may be especially important to maintaining a desired behaviour, as it may help to reduce the occurrences of stage relapse and stage recycling. Providing choice regarding what, how and when prompts are used increases one's sense of personal control (Rotter, 1966) and intrinsic motivation (Iyengar & Lepper, 1999).

Example: With Mary's permission, technologies can make use of automatic sensing technologies (e.g. a motion sensor by the computer) and detection of Mary's computer usage rhythms to provide reminder prompts (e.g. using text, sound, and/or graphics) based on Mary's proposed goals and goal implementations. An example reminder using text could be:

> Going grocery shopping? Don't forget to turn off your monitors!

Recommendation #3: Provide the choice for individuals in the maintenance stage to become "energy mentors" to individuals in the preparation stage.

Rationale: This recommendation employs *cognitive dissonance* - "individuals who have attempted to persuade someone else will internally rationalize their behaviour, and therefore are particularly prone to increase their commitment" (Wright & Kacmar, 1994). In addition, the social component of being a mentor adds a dynamic factor to the technology, which may inspire new and unpredictable ways in which the mentor's motivation could be sustained. Being a mentor appeals to Rokeach's values of "social recognition" and "wisdom", and in turn, may invoke the intrinsic satisfactions of competence and enjoyment.

Example: The feedback device could send the following message to Mary:

> **Dear Mary, our sustainability guru** ☺: Would you be willing to share your knowledge and expertise with less experienced energy users in the community? Click here to find out how you can become a valued e*nergy mentor*!

If Mary showed interest, she could be asked to submit a profile of herself, her interests and experiences, and would be contacted when someone has chosen her for a mentor.

Recommendation #4: Encourage individuals to *self-reflect* and *self-reinforce* their energy experiences over time. The aim is to invoke deeper thought and a sense of intrinsic pride regarding their energy behaviours, in hopes to encourage individuals to take more advanced energy actions as time passes.

Rationale: *Self-reflection* of one's energy behaviours and viewing one's progress over time may invoke the intrinsic satisfactions of interest, competence and enjoyment. *Self-reinforcement* (in the form of pride or a sense of accomplishment) may invoke feelings of competence, and lead to higher perceptions of self-efficacy. This is important as "in order for individuals to experience long-term success, they require adequate *self-efficacy* and *intrinsic* attributions of the behaviour" (Miller & Rollnick, 2002). In addition, individuals can also engage in reflection and reinforcement of collective energy actions taken with their mentor, or by the community. Finally, if desired, individuals can share their journal entries with other members of the community or with the public (e.g. through an internet blog).

Example: One method for self-reflection and self-reinforcement is through the use of journal-keeping. Journal-keeping is a form of expressive practice and promotes reflection on one's experience (Boud, 2001). Feedback technologies could provide flexible ways in which Mary could journal-keep within the interface. For example, Mary could take visualization snapshots of notable milestones in her goal progress, or annotate visualizations of her energy usage by circling or highlighting areas of interest and writing her thoughts. If desired, the technology could automatically record energy summaries for each day or week in the journal, or make specific journal entries public (e.g. through a blog), allowing Mary to share her experiences with the community.

Recommendation #5: Maintain the cyclical loop of intrinsic motivation: interest, curiosity, optimal challenge, competence feedback and enjoyment.

Rationale: Intrinsic motivation is a cyclical, two-step process (Reeve, 1989). First, stimuli such as novelty, complexity and change (Berlyne, 1961) attract attention, *curiosity* and *interest* (Reeve, 1989). This invites exploration, investigation, and manipulation of the stimulus (Reeve, 1989). Second, *competence* performances on *challenging* tasks are enjoyed, where increased *enjoyment* increases one's willingness to continue the activity and to confront similar challenges in the future (Csikszentmihalyi, 1975). From the perspective of arousal theory, the goal is to maintain behaviour by sustaining this loop of arousing stimuli.

The importance of intrinsic motivation is supported by the work of Woodruff et al. (2008), who studied the motivations and values of "extremely green individuals" who made "significant accommodations to their homes and lifestyles" to be more environmentally responsible". Participants pursued their "environmental goals", "creatively solved problems" and "modest mental challenges", where they derived satisfaction from the "cleverness and resourcefulness" of their solutions and gained a strong sense of "empowerment and confidence" (Woodruff et al., 2008). From these findings, I argue that participants maintained their behaviour due to *intrinsic* satisfactions of performing energy actions. Specifically, pursuing "goals", "problems" and "challenges" indicate the intrinsic satisfactions of *curiosity* and *interest* leading to *exploration,* taking on *challenges* and receiving *competence* performances. These reflect Rokeach's values of being "intellectual", "imaginative" and "capable". Participants also gained "empowerment and confidence", reflecting Rokeach's value of "a sense of accomplishment", and perhaps appealing to the intrinsic emotion of *enjoyment.*

Example: Technologies could continually provide Mary with novel, complex and changing information to maintain her curiosity and interest. Technologies could also encourage Mary to take on new challenges and responsibilities in regards to sustainable behaviour, and providing her with such opportunities (e.g. setting new goals, being an "energy leader" in the community, sustainable energy usage extending beyond computer usage, etc). Feedback technologies could also make use of social components (e.g. social networks) to incorporate a dynamic factor in the system which may sustain Mary's motivation and behaviour in ways technology alone cannot.

6.8 Revisiting AREnergyViewer: A high-level redesign

Chapter 3 presented our limited instantiation of the concept of an augmented reality feedback system, called 'AREnergyViewer'. However, despite the novelty behind this concept, AREnergyViewer did not consider the issue of *motivation* within its design – that is, whether the user is even interested or motivated to use such a feedback device. To address this issue, I now revisit AREnergyViewer by offering initial, high-level, redesign ideas based on the framework's recommendations for each stage of change. These high-level redesign ideas are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design.

Throughout the redesign, I draw upon the motivation and concepts presented in Chapter 3, including mobile, in-context viewing, real-time (immediate) feedback, overview to detail by semantic zooming, snapshot feature, and alternate views using phidgets. To generate a richer redesign scenario, I assume that 1) all appliances in the household are measured (rather than only the computer and peripherals as was the case in Chapter 3), and 2) in addition to providing feedback using screen visualizations, AREnergyViewer can also provide sound and vibrational feedback. Finally, for the reader's convenience, Table 6.2 (next page) *summarizes* the goals and recommendations for each stage of change, and can be used as a reference for the following text.

6.8.1 Precontemplation

Before discussing how the redesign aims to satisfy the framework's recommendations, I first provide a general description of the redesign. For the precontemplation stage, AREnergyViewer can be redesigned as an energy game, where in order to obtain game points, players must physically move around to different appliance locations in the household by answering questions relating to energy usage. The game is played in a team of pairs. The team winner of the game is rewarded with a large material incentive (e.g. $25), as well as the appearance of the players' names in an "Energy Star" scoreboard. The following discusses this description in terms of the framework's recommendations.

Goal #1, recommendation #1: Rather then *presenting* benefits and consequences of non-sustainable energy behaviours (as in the framework's textual example), players could be asked to *answer questions* regarding benefits and consequences of non-sustainable energy usage for household appliances. To do this, players must manually manipulate proximity for semantic zooming to receive differing levels of information and feedback. For example, at a far proximity, AREnergyViewer could provide brief, appliance-specific, energy-related background information of why non-sustainable energy behaviours are problematic (e.g. "Your TV, among many other appliances, draw phantom power even when it is switched off. While the phantom power usage for this individual appliance is low, the collective phantom usage for all appliances in your home becomes very high."). As precontemplators may be unaware or uninformed about the problem behaviour (Miller & Rollnick, 2002), such background information may help to provide information in moderation to "plant the seed" that non-sustainable energy behaviours are problematic, and help precontemplators answer energy-related questions in the middle view (discussed next). The middle proximity can build upon the background information provided in the far view to present questions regarding the benefits and consequences of non-sustainable energy behaviours (e.g. "What are five benefits of leaving appliances plugged in?"). The near view could take advantage of the players being in context, by encouraging them to try out manual energy actions on the physical appliances and learning from the immediate feedback received from that action. This type of manual exploration can be used to help players answer the question and "plant the seed" of the problem behaviour. Finally, players can answer the question in the snapshot view, where for every question answered correctly, game points are gained.

Pre-contemplation	**GOAL #1:** Provide information in moderation to "plant the seed" that non-sustainable energy behaviours are problematic. • **Rec1):** Acknowledge *both* the benefits and consequences of *non-sustainable* energy behaviour in relation to one's values. • **Rec2):** Refer to social norms of sustainable energy behaviour by aligning descriptive and injunctive normative messages. • **Rec3):** Incorporate components of novelty, complexity and variability in the interface with the goal of motivating the individual to explore,

	investigate, and manipulate energy information.
Contemplation	**GOAL #1:** Address barriers to motivation, such as 1) not valuing an activity, 2) not feeling competent and 3) not believing it will yield a desired outcome. • **Rec1):** Provide personalized feedback on the *pros* of *sustainable* energy behaviour, and the *cons* of *non-sustainable* energy behaviour in relation to one's values. Present (risky) cons in terms of loss rather than gain. • **Rec2):** Provide personalized feedback of small energy actions that, if performed, would have positive impacts on the environment. **GOAL #2:** "Tip the balance" in favour of change. • **Rec1):** Remind individuals of their pro-environmental attitude, inform them of the *discrepancy* between their attitude and the corresponding behaviour, and encourage a change towards more sustainable behaviour. • **Rec2):** Use "foot-in-the-door" processes by encouraging small energy actions to motivate larger energy actions in the future. • **Rec3):** Provide information of the experiences of sustainable energy users in the community.
Preparation	**GOAL #1:** Support their decision in preparing to take energy action. • **Rec1):** Affirm their decision by appealing to social and personal norms of sustainable energy usage, and combining this with projections of the positive impacts of their potential energy actions. **GOAL #2:** Develop a *plan* that is acceptable, accessible and effective. • **Rec1):** Self-set specific and quantifiable goals, and firmly commit to them. • **Rec2):** Automatically generate multiple methods to achieve these goals, while encouraging individuals to apply their personal expertise to develop these plans. • **Rec3):** Provide the option to be connected with an energy "mentor".
Action	**GOAL #1:** Positively reinforce (PR) sustainable energy actions • **Rec1):** PR energy actions immediately and in multiple ways, gradually reducing the frequency of PR as the behaviour becomes well-instantiated. • **Rec2):** Provide positive performance feedback in relation to goal progress.
Maintenance	**GOAL #1:** Maintain *durable* sustainable energy behaviour • **Rec1):** Engage in social competition with other individuals in the maintenance stage. Reward winners with social reinforcement. • **Rec2):** Use opportune prompts to turn energy *actions* into energy *habits.* • **Rec3):** Become "energy mentors" to individuals in the preparation stage. • **Rec4):** Encourage self-reflection and self-reinforcement of one's energy experiences over time. • **Rec5):** Maintain the cyclical loop of intrinsic motivation: interest, curiosity, optimal challenge, competence feedback and enjoyment.

Table 6.2: Summary of motivational goals and recommendations for each stage of change.

Goal #1, recommendation #2: AREnergyViewer can employ descriptive norms in the following ways. First, the energy game is played with a teammate. The presence of another person playing the game employs a descriptive norm. Additionally, for precontemplators who do not hold a high concern for sustainable energy usage, the presence of a teammate may reduce their shyness or inhibitions in playing an energy-related game, and increase the likelihood of interaction and discussion between the players. Second, before starting the game, AREnergyViewer could provide a message indicating the descriptive norm of many others who have already played the game (e.g. "Sally and Jennifer, you are the 48th team to play the "Energy Star!" game. Thanks for playing and have fun!").

AREnergyViewer can employ injunctive norms in two ways: 1) rewarding the team winner of the game with a valuable material incentive, and 2) providing social recognition of the top scoring teams in the "Energy Star Top Scorers" board. While precontemplators may not hold a high value on receiving social recognition, a large material incentive may be enough to motivate precontemplators who do not hold a high concern for sustainable energy usage to play an energy-related game. From a motivational perspective, a large material incentive provides *external* justification for precontemplators to play the game, where players may only play with the goal to win. While this can have negative impacts on their intrinsic motivation (Deci et al., 1981) and lead to less durable behaviour change (De Young, 1993), this is acceptable as the goal in this stage is not to motivate energy *action*, but to increase *awareness* and "plant the seed" that non-sustainable energy behaviours are problematic.

Goal #1, recommendation #3: The unique interaction method in which teams play this game (e.g. running around to different physical locations in the household, viewing real-time, energy feedback in context, manually manipulating proximity for semantic zooming, etc.) incorporates components of novelty, complexity and variability within the interface.

This has two benefits. First, this unique interaction medium may arouse the intrinsic emotions of interest and curiosity, which may motivate players to explore and investigate the provided feedback. This satisfies recommendation #3. Second, the unique interaction medium requires *foreground attention* (Table 2.1, design dimension #2) and *active interaction* (Table 2.1, design dimension #3) on the part of the players. However, as precontemplators are not inherently interested in energy information, using this interaction medium to arouse the players' curiosity and interest is necessary in order to maintain the high level of cognitive attention required to play this game. As a side note, having the precontemplator's full attention means that logical arguments appealing to one's central attention are more effective than emotional arguments appealing to one's peripheral attention (Heath, 2007). This is because conscious processing of affective (emotional) elements weakens their potency, as it allows the individual to rationally evaluate and counter-argue against the influence (Bornstein, 1992).

6.8.2 Contemplation

Before discussing how the redesign aims to satisfy the framework's recommendations, I first provide a general description of the redesign, with particular focus on the *differences* in redesign between the precontemplation and contemplation stage:

1) Game-play can still be used in the contemplation stage, where in order to gain game points and win the game's prize, one must answer energy-related questions. However, in contrast to precontemplators, contemplators have acknowledged the problem and are open to energy information (Miller & Rollnick, 2002). Thus, players in this stage are likely to have a higher inherent interest in energy information. This has three redesign implications: 1) contemplators can play as individuals rather than as a team, 2) rather than providing information in moderation as in the precontemplation stage, AREnergyViewer can provide lots of detailed energy feedback information, and 3) whereas the goal in precontemplation was to provide information to "plant the seed" that non-sustainable energy behaviours are problematic, the goal of providing information in contemplation is to enable action and "tip the balance" towards action.

2) In comparison to precontemplation, winners in the contemplation stage are rewarded with a *small*, material incentive (e.g. $5 or a free travel mug) and social recognition of their name in a public newspaper.

3) In addition to answering *questions* (as in the precontemplation stage), contemplators must also take small, manual energy *actions* in order to gain game points.

The following discusses these differences in terms of the framework's recommendations.

Goal #1, recommendation #1, #2: To satisfy these recommendations, AREnergyViewer can require the player to manually change proximity for semantic zooming. For example, the far view can present background energy information of personalized feedback of the pros of sustainable energy behaviour and the cons of non-sustainable energy behaviour (*recommendation #1).* As in the framework's textual example, a one-sided message framing can be used to present this feedback (e.g. the use of the words "loss", "benefits", "efficient", "inefficient"). Similar to the precontemplation stage, this information provides the background for energy questions presented in the middle view (discussed next). The middle view can present energy questions in a multiple choice format, where appliance-specific information for a variety of small energy actions is provided, and contemplators are required to guess (from a list of multiple choice answers) the positive environmental impacts that taking these actions would make (*recommendation #2*). To assist the contemplator in guessing the correct answer, the near view can provide detailed, step-by-step instructions of energy actions, with encouragement for "in-context" contemplators to use these instructions to try out manual actions on the physical appliances, where the immediate feedback received can help contemplators figure out the correct answer to the questions.

Goal #2, recommendation #1: Recommendation #1 is satisfied by rewarding winners of the energy game with a small material incentive and social recognition of their name in a public newspaper. Such rewards, in conjunction with the contemplator's inherent interest in energy information, may be enough to motivate contemplators to play an energy-related game, though may not be enough for contemplators to *externally* justify their behaviours. This is beneficial. A cognitive dissonance discrepancy is invoked when players who have expended time and energy to play the game seek to *internally* justify (e.g. I must care about sustainable energy consumption) their external behaviours (e.g. I demonstrated pro-environmental behaviour by playing an energy game). In fact, the more effort and time contemplators expend in playing the game, the higher the cognitive dissonance, and in turn, the more individuals will commit to and internally justify their external behaviours (Levy-Garboua & Blondel, 2002).

Goal #2, recommendation #2: AREnergyViewer provides real-time, energy feedback in context of the physical appliances being measured. Being in context makes it easy for individuals to take manual energy actions on the physical appliances, as recommended in the near view redesign for goal #1, recommendations #1 and #2. This can be further extended to encourage the individual to take manual energy actions that require larger amounts of effort and time (e.g. bending down to unplug something, going behind an obstacle, etc.). Such manual actions may appeal to more senses (e.g. going behind a computer to turn off the switch may allow the contemplator to feel the heat and hear the fan used by the computer), making the experience more vivid. This employs "foot-in-the-door" processes, as the more time and effort individuals expend in performing energy actions, the more committed they become to further courses of energy action (Levy-Garboua & Blondel, 2002).

Goal #2, recommendation #3: AREnergyViewer could provide contemplators with stories and experiences of individuals in the maintenance stage, who have used AREnergyViewer or other feedback devices, to make positive, environmental impacts.

6.8.3 Preparation

Game-play is not used in the preparation stage. Rather, as individuals are ready to act in the near future, the goal of AREnergyViewer shifts from providing information to "plant the seed" or to enable action, to helping individuals *prepare* for action.

Goal #1, recommendation #1: Upon the individual's entrance to the preparation stage, AREnergyViewer could use rewarding changes in the visualization, pleasant sounds, and a textual message to congratulate the individual in their decision to take energy action.

Goal #2, recommendation #1, #2: AREnergyViewer can use different levels of proximity to support individuals in setting energy goals (*recommendation #1*) and developing implementation intentions (*recommendation #2*) to reach those goals. For example, the far view visualization could use color to indicate the amount of positive impact of potential energy actions that could be taken for that appliance. To see the impact for different modes of information (e.g. cost, kWh, CO_2 emissions, efficiency, etc.), individuals can turn the phidget mode dial. The middle view could enhance the far view's visualization with available goal difficulty levels of potential energy actions that could be taken for that appliance. In addition, the visualization could highlight a recommended goal difficulty level, given the individual's current energy usage patterns. Upon selecting a goal difficulty in the middle view, the near view could support individuals to self-set a specific and quantitative goal by providing a variety of goal options, as well as automatically generating implementation intentions for that goal. Finally, individuals can employ the snapshot view to commit to their goal (e.g. by signing their name), and deciding the goal start and end time (e.g. on the visualization's calendar). Individuals can also modify the goal, or generate their own implementation intentions in the snapshot view. To further employ adaptive muddling, AREnergyViewer can take advantage of being in context and seeing immediate energy feedback by encouraging individuals to explore with "what if" questions of energy usage, for example, by trying out manual energy actions, and seeing the immediate impact of those actions. This type of exploration may help individuals to gain experience and apply their own expertise to generate implementation intentions.

Goal #2, recommendation #3: Viewing energy feedback in context allows the individual to easily share the feedback visualization with others in the same physical space. Thus, individuals in preparation could meet with their energy mentors in person, where the mentors could relay their expertise and experience to them using AREnergyViewer.

6.8.4 Action

Goal #1, recommendation #1: As the individual takes energy actions, AREnergyViewer could provide immediate positive reinforcement, using rewarding changes in graphics, sound, and textual messages. In this way, the individual can use AREnergyViewer to remind them of what energy actions to take and how to take them (based on the goals and implementation intentions generated in the preparation stage), as well as to provide immediate feedback and reinforcement upon taking those actions.

Goal #1, recommendation #2: AREnergyViewer could use proximity to provide differing granularities of goal progress information. For example, the far view could use color or a progress bar to visualize the goal progress for each appliance since the goal start date. The middle view could enhance the far view visualization with numerical details of goal progress, as well as a projection of when the goal may be achieved, given current energy usage patterns. The near view could provide bar and line chart visualizations of the individual's long-term energy usage patterns in relation to goal progress. At any proximity, the snapshot view could be used to view or modify existing goals and implementation intentions set in the preparation stage. Additionally, whenever goals or significant milestones have been achieved, AREnergyViewer could reward the user with pleasant changes in graphics or sound.

6.8.5 Maintenance

Goal #1, recommendation #1: Social competition can be used to inform and engage individuals in the maintenance stage with energy-related questions and challenges that increase in difficulty as the competition goes on. Providing a challenge is important, as *competence* performances on *challenging* tasks are enjoyed, where increased *enjoyment* increases one's willingness to continue the activity and to confront similar challenges in the future (Csikszentmihalyi, 1975). In addition, during the competition, individuals can use AREnergyViewer to assess their progress and status over time, in comparison to other individuals in the competition.

Goal #1, recommendation #2: Individuals can use AREnergyViewer to quickly assess the status of household appliance consumption and take actions based on the provided feedback. In this way, AREnergyViewer can be used to support the individual's transition from energy actions into energy *habits*. To do this, each proximity could provide differing levels of detail in terms of information and instruction. For example, the far view could use color, along with small beeps or vibrations in the feedback device to highlight appliances (within camera view) that require energy action. Whether an appliance is highlighted or not is based on its level of efficient usage in the last x hours, where x represents the time interval on the time slider phidget. The middle view could enhance the far view visualization with appliance-specific, numerical values of current wattage consumption and efficiency information. The near view could provide brief instructions of energy actions that should be taken for that appliance. In this way, AREnergyViewer can provide just-in-time prompts while the individual is walking in the same physical space as the appliances.

Goal #1, recommendation #3: Individuals who have agreed to be energy mentors could take the initiative to connect with individuals in the preparation stage to meet them in person. Meeting in person may be desirable, as viewing energy feedback in context allows the individual to easily share the feedback visualization others in the same physical space (discussed in Chapter 3, Section 3.3). If meeting in person is not desirable or possible, AREnergyViewer could provide other opportunities for mentor and mentee to communicate through live chatting or recorded video messages. *Recommendation #4* describes this option in further detail.

Goal #1, recommendation #4: Individuals can use AREnergyViewer to engage in self-reflection and self-reinforcement by taking visualization screenshots of significant milestones in their goal progress, or making live video blogs. Both the screenshot and video blog can be done while physically walking around their house to different appliances, where individuals can self-reflect by narrating the video blog, or by annotating text on top of the screenshot visualization. Both approaches take advantage of the fact that AREnergyViewer provides real-time, energy feedback in context, and offer an active way for individuals to self-reflect and self-reinforce their energy behaviours. Finally, in addition to self-reinforcement and self-reflection, energy mentors, if desired, could share these screenshots and video blogs to their mentee, as another way to relay their expertise and experience (this satisfies *goal#1, recommendation #3*).

Goal #1, recommendation #5: To maintain the cyclical loop of intrinsic motivation, AREnergyViewer can continually provide new challenges to individuals in the maintenance stage (e.g. using adaptive muddling to encourage individuals to take on new responsibilities, such as being a community leader in sustainable energy usage). However, due to the active nature of interaction and manual effort required to use AREnergyViewer (i.e. pointing the feedback device at an appliance in order to receive feedback for it, and manually manipulating proximity to change the level of detail in the provided feedback), individuals in the maintenance stage may no longer be motivated to expend the effort required to use this device after they have become familiar with their energy usage patterns and feedback. Thus, in terms of the lifecycle of AREnergyViewer, it may be well-suited to be passed to a friend or neighbour after individuals become thoroughly familiar with their energy usage patterns.

6.9 Summary

To address the shortcomings of current energy feedback technology design, I offered a motivational framework based on the Transtheoretical Model's stage model of behavioural change and Motivational Interviewing's counselling guidelines to propose specific goals and recommendations that aim to target individual motivations at each stage of change. Each goal and recommendation was supported by a rationale based on motivational psychology literature, and illustrated by a simple textual example based on a scenario of a person named Mary and her computer usage. Following this, I revisited our implemented feedback system, 'AREnergyViewer' (presented in Chapter 3) to provide initial, high-level, redesign ideas based on the framework's recommendations for each stage of change.

Chapter 7. Discussion, future work and conclusion

This chapter provides a discussion of my work, discusses future directions of exploration, and summarizes my research contributions. I begin by discussing the motivational framework - in particular, the framework's application of the Transtheoretical Model (TTM) and Motivational Interviewing (MI). Next, I discuss future work regarding the framework. I then restate my research questions, and the approach and processes by which I addressed them. Finally, I summarize my research contributions and conclude this work.

7.1 Discussion of the motivational framework

This thesis explored how motivational psychology literature can be leveraged within energy feedback technology design with the goal of motivating sustainable energy behaviour. I now discuss the main contribution of this thesis - the motivational framework. In particular, I discuss the framework's application of two primary concepts - the Transtheoretical Model (TTM) and Motivational Interviewing (MI).

7.1.1 Application of the Transtheoretical Model (TTM)

The motivational framework is based on the TTM's stage model of behaviour change. The following discusses several challenges that arise in the practical application of the framework to inform energy feedback technology design. Specifically, I discuss two topics: 1) the TTM as a stage-based model, and 2) applying the TTM to motivate sustainable energy behaviours.

The TTM as a stage-based model

The TTM assumes that behaviour change occurs in discrete states, in which individuals can only be in one stage at a time (Littell & Girvin, 2002). However, studies have shown that "rather than simply being in one stage or another, clients show patterns of differential involvement in each of the stages" (McConnaughy et al., 1983). If this is the case, "the concept of stages loses its meaning" (Littell & Girvin, 2002). For example, in our scenario, Mary could be in the maintenance stage of sustainable computer usage, and in the contemplation stage of composting. To date, there is little empirical evidence of sequential transitions between stages and no published studies of progression through the entire stage sequence (Littell & Girvin, 2002). Critics suggest that, like all stage models, this model "oversimplifies the complexities of behavioural change by imposing artificial categories on continuous processes" (Bandura, 1997). In addition, rather than a progression through stages, change can come about swiftly, often as a result of life events or external pressures (Little & Girvin, 2002). As such, the change process is likely to vary between individuals, depending on whether motivation for change is internal or external (Stotts, et al, 1996).

While the debate continues as to whether change is best represented as a "continuous process" or by "discrete stages" (Prochaska & DiClemente, 1998), the framework makes use of the TTM's stages of change for its *heuristic* value, recognizing it is a simplified model of "*ideal* change" (Littell & Girvin, 2002), rather than how energy behavioural processes necessarily occur in real life. I hope the value of this framework lies in its contribution of a new and potentially useful way of thinking about motivating sustainable energy behaviours, while also inspiring new ideas and approaches to this problem.

Applying the TTM to motivate sustainable energy behaviours

The TTM was originally developed based on studies of smoking cessation behaviours (Prochaska & DiClemente, 1982). Since then, it has become regarded as a general model of behaviour change (Littell & Girvin, 2002), with applications in a wide variety of addictive and health-risk behaviours (Miller & Rollnick, 2002), including physical exercise, child welfare, intimate partner violence, organizational change, safe sexual practices, and so forth (Littell & Girvin, 2002). To my knowledge, no other work has applied the TTM to motivating sustainable energy behaviours.

In this thesis, I believe I have shown that the use of the TTM in the framework provides a useful starting point to inform energy feedback technology design. However, some obvious differences exist between addictive/health-risk behaviours versus energy behaviours. For example, the cessation of smoking primarily has pro-*self* benefits, whereas performing sustainable energy actions primarily has pro-*social* benefits. Such differences indicate that further exploration is needed to understand these differences and the value of the TTM as a suitable model to apply to this problem.

7.1.2 Application of Motivational Interviewing (MI)

The TTM's stages of change are often used in conjunction with MI's client-centered counselling style (Treasure, 2004). Within the framework, the feedback technology acts in the place of the counsellor to facilitate behaviour change. I now discuss the framework's application of MI's key principle of "eliciting client motivation to change".

Eliciting client motivation to change

A key principle of MI is that "motivation to change is elicited from the *client*, and not imposed from without (e.g. coercion, persuasion, constructive confrontation" (Rollnick & Miller, 1995). "If it becomes a trick or manipulative technique, its essence has been lost" (Miller, 1994). While in general, the framework aims to follow this guideline, certain recommendations in the framework do not. I present three examples. The first is contemplation's goal #1, recommendation #1 – "Provide feedback of the pros of sustainable behaviour and the cons of non-sustainable behaviour". This recommendation uses one-sided message framing of information with the goal of persuading behaviour change without the client's awareness of this manipulation. The second and third example is contemplation's goal #2, recommendations #1 and #2. These recommendations employ cognitive dissonance by bringing up a disharmony between one's attitude and behaviour, and use this to motivate either attitude or behaviour change, again, without the client's realization of the manipulation. While such recommendations can be an effective means to motivate attitude or behaviour change, I acknowledge that the framework does not follow this key principle of MI in every recommendation that it makes.

7.2 Future work: Motivational framework

I now discuss future areas of exploration regarding the motivation framework. The first is the continued development and refinement of the framework based on motivational psychology literature. Other directions of exploration include extensions to the framework with regards to 1) demographics, 2) social, cultural, contextual and situational factors, 3) personality, 4) stage relapse, 5) moving beyond motivational psychology, 6) motivating higher-level changes, 7) adapting the framework to other problem behaviours, and 8) evaluation. The following discusses these in detail.

7.2.1 Demographics

Demographic factors such as income level, family size, cost of energy, age, home ownership or home rental, gender, and so on can influence the effectiveness of feedback on motivation in several ways. I illustrate with three examples. First, there are differential effects for *high* and *low consumers* of energy, with the latter group increasing their energy use as a result of feedback (Abrahamse et al., 2005). Second, feedback is not as effective for households where the *cost of energy* is proportionally low with respect to *income* (Geller et al., 1982). Third, the most *influential group* for middle and upper-income households are social reference groups, whereas the most influential group for low-income households are community groups (Coltrane et al., 1986). Such examples show the importance in considering demographic factors within the framework.

7.2.2 Social, cultural, contextual and situational factors

Motivating sustainable energy behaviour change is a psychologically, socially, and culturally complex problem (Shipworth, 2000). The framework approached this problem from the *psychological* perspective. However, energy consumption is seldom an end in itself, but rather a by-product of a variety of diverse actions (Froehlich, 2009) (e.g. cooking, socializing, doing laundry). Hence, it is also important to consider the influence of social, cultural, contextual, and situational factors in motivating sustainable energy behaviour. The following discusses these factors in detail.

Social factors: A person's motivational balance and ambivalence cannot be understood outside the social context of family, friends, and community (Miller & Rollnick, 2002). Social factors affect people's perception of their behaviour, as well as their evaluation of its costs and benefits (Miller & Rollnick, 2002). While the current framework takes initial steps to consider how social groups affect individual motivation (for example, through social networks and social diffusion), future extensions to the framework should explore in depth the influence of social factors on individual motivation.

Cultural factors: *Culture* is defined as "the attitudes, values, beliefs and behaviours shared by a group of people and communicated from one generation to another" (Hockenbury & Hockenbury, 2003). Extensions to the framework should consider culture in two ways.

First, the most important energy consumption differences seem to have been rooted in ethnic and other cultural differences in behaviour and household organization (Lutzenhiser, 1992). As such, the framework must consider the influence of cultural rituals and traditions on energy usage behaviour. I illustrate with two examples. First, the Japanese daily bathing routine has deep cultural roots, but is very energy-intensive. Even with higher energy prices, it is likely that this cultural routine will still persist (Deci et al, 1981). Second, the concept of "koslighet" (cosiness) is a state of space heat comfort which is virtually mandatory for Norwegian living rooms (Shipworth, 2000). When guests visit, the absence of a strong affirmation of cosiness constitutes a social disaster, causing household residents to overheat and overlight as insurance against social failure.

Second, extensions to the framework should consider the influence of cross-cultural differences on motivation. For example, Western cultures (such as Canada and the United States) are *individualistic*, where the needs and goals of the individual are emphasized over the needs and goals of the group (Hockenbury & Hockenbury, 2003). In contrast, Asian cultures (such as China and Japan) are *collectivistic*, where the needs and goals of the group are emphasized over the needs and goals of the individual (Hockenbury & Hockenbury, 2003). Such differences mean that the motivational interventions used should be appropriate to the culture. For example, when using teamwork as a motivational intervention, it is important to understand that social loafing is not only absent in collectivist cultures, but reversed (Bond & Smith, 1996). Instead, individuals exhibit social striving, where they work harder in a group than when they are alone (Bond & Smith, 1996). Such examples show that an understanding of cross-cultural differences is important to motivating sustainable energy behaviour.

Contextual factors: This thesis looked at motivation of individuals in the home setting. However, as people have different value structures for different life roles (e.g. work vs. social) (Brown & Crace, 1996), extensions to the framework could explore motivation of sustainable energy behaviours in other contextual locations (e.g. workplace, restaurant, coffee house, movie theatre, library, etc.). Particular focus could be given to how social and cultural routines within that context affect motivation.

Situational factors: Behaviour is the result of an interaction between the situational pull and personal tendencies (Miller & Rollnick, 2002). Chapter 5's assessment argued that feedback technologies employing the Attitude Model and Rational-Economic Model (REM) were limited due to its lack of consideration of situational factors (such as time, convenience, comfort, and so on). The current framework takes initial steps to consider situational factors in terms of Mary's computer usage (e.g. to support Mary's situational value of immediate availability of computer usage). Future exploration could consider how different *appliances* and the *activities* people perform with those appliances afford different situational factors. For example, motivating sustainable energy usage of always-on, communal appliances such as the refrigerator will have different situational circumstances than sometimes-on, individual appliances such as a lamp.

7.2.3 Personality

The framework aims to move *beyond* a "one-size-fits-all" solution to designing energy feedback technologies by considering *individual* motivations at different stages of behavioural change. To consider "individual motivations", the framework aims to address the attitudes, beliefs and values that individuals hold. An extension to this consideration is to take into account *personality* - "an individual's unique and relatively consistent patterns of thinking, feeling and behaving" (Hockenbury & Hockenbury, 2003), and its influence on the motivation of sustainable energy behaviour. For example, individuals with *high achievement motivation* often find social competition more intrinsically motivating than individuals with *low achievement motivation* (Tauer & Harackiewicz, 1999). This example shows that motivational interventions should also target the unique personality traits of the individual.

7.2.4 Stage relapse

The current framework does not consider the possibility of *stage relapse* – a slip to an earlier stage in the change process (Miller & Rollnick, 2002). The TTM recognizes that relapse is possible (even likely) when moving through the stages of change, where people may "recycle" through the stages many different times before reaching success (Miller &

Rollnick, 2002). This is particularly true if the environment is filled with cues that can trigger the problem behaviour (Miller & Rollnick, 2002). Relapse should not be considered an utter failure, but rather, a step back, as during the next cycle, individuals will have a better chance of success as they have learned valuable lessons (Miller & Rollnick, 2002). Given the likelihood of stage relapse, extensions to the framework should account for when relapse occurs, and appropriately modify interventions to draw upon already learned lessons for the next cycle.

7.2.5 Moving beyond motivational psychology

The framework leveraged *motivational psychology* literature to develop goals and recommendations to inform energy feedback technology design. The following discusses extensions to the framework that move beyond motivational psychology, including information visualization of feedback, attractiveness of form factor and design, and principles of sustainable interaction design (SID).

Information visualization: *Information visualization* is "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" (Card et al., 1999). Without effective visualization of complex energy feedback data, it is unlikely that the household resident will read (or remember) this data, even if valuable information is present (Froehlich, 2009).

Attractiveness of form factor and design: An attractive design invokes a relaxed or happy state in those who use it, allowing them to be more creative, and thereby more tolerant of any minor design difficulties (Norman, 2004). In addition, an aesthetically-pleasing design may offer pleasure and invoke engagement, which in turn, may encourage sustainable interaction as desired by the goal of the product (Pierce & Roedl, 2008).

Principles of SID: Blevis (2007) defined *Sustainable Interaction Design (SID)* as the perspective that "sustainability can and should be a central focus of interaction design". Two primary principles of SID include 1) linking invention and disposal, and 2) promoting renewal and reuse. To achieve the goal of sustainable energy consumption, feedback technologies must consider SID principles. From this perspective, Pierce et al. (2008) proposed two approaches regarding the life cycle and end goal of feedback technologies: 1) should technologies "evolve over time" to keep pace with user's "deepening commitment and understanding", or 2) should they "act as a type of training device that is no longer needed after certain behavioural or intellectual changes have been made"?. If technologies are adaptive, I argue that a dynamic component should be present (e.g. the use of social networks), as technologies cannot be expected to keep up with complex human motivations. No matter if technologies are adaptive or act as training devices, SID principles must be considered within their design.

7.2.6 Motivating higher-level changes

To achieve the goal of sustainable development and sustainable consumption, holistic and integrative solutions are required (Houghton, 1997). Specifically, a move towards improved energy efficiency will entail a concerted effort on the part of consumers, manufacturers, energy-supply companies and governments, where mechanisms are needed which would provide incentives for these groups to work together towards the common goal of more efficient energy production and use (Dincer & Rosen, 1999).

This thesis (and in turn, the framework) aimed to motivate sustainable consumption behaviour changes on part of the *individual*. This is only a partial solution. Future work should also explore the adaptation of the framework to target motivation of government and business policy-makers to affect higher-level changes that can potentially make a bigger impact. No matter the domain, I believe the issue of motivation is still crucial. For example, although household residents and policy-makers are driven by different incentives, the motivation of each is necessary in order for policy-makers to *propose* effective environmental policies, and for the public to *support* them.

7.2.7 Adapting the framework to other problem behaviours

The framework was developed to inform energy feedback technology design with the goal of motivating sustainable energy behaviour. Future work could explore the adaptation of the framework to other problem behaviours that would benefit from computerized feedback and motivational interventions. As the TTM is a health psychology model, a reasonable starting point is the framework's adaptation to consider health-risk behaviours (e.g. exercise, dietary change, smoking cessation, etc.). Although the behaviour change targets differ, the structure of the change process appears to be the same (Miller & Rollnick, 2002).

7.2.8 Evaluation

Longitudinal data is needed to test any stage theory (Littell & Girvin, 2002). Future work should conduct a longitudinal evaluation of energy feedback technologies which apply the framework, where the success of such technologies lies in its effectiveness in motivating a move towards the *next* stage of change. To do this, technologies must be able to 1) correctly assess the stage of change the individual is in, and 2) evaluate whether a move to the next stage has occurred. Given the limitations of stage models (discussed in Section 7.1.1), this puts forth some difficult challenges in terms of validity and reliability of stage assessment and staging algorithms. This clearly needs further exploration and study.

7.3 Research questions and approaches

I now restate the research questions presented in Chapter 1, and summarize the approaches and processes by which I addressed these questions.

Research question #1: What can we learn about the landscape of energy feedback technologies when we recast them within the lens of motivational psychology?

I took three approaches:

d) To understand the "landscape of energy feedback technologies", Chapter 2 reviewed related work in energy feedback technologies that aim to motivate sustainable energy behaviour.

e) To understand the literature of "motivational psychology", Chapter 4 reviewed selected techniques, theories and therapies from a variety of subfields and schools of thought within motivational psychology literature. Chapters 5 and 6 showed this literature to be relevant in the context of motivating sustainable energy behaviour.

f) To "recast energy feedback technologies within the lens of motivational psychology", Chapter 5 assessed selected feedback technologies from a motivational perspective: that is, I evaluated their potential effectiveness in motivating sustainable energy behaviour, using the primary lens of the TTM's stages of behaviour change and the secondary lens of other relevant motivational psychology literature. From this assessment, I identified three shortcomings of current energy feedback technology design:

1) While feedback technologies aim to motivate sustainable energy behaviour, their designs could benefit significantly by explicitly incorporating aspects of motivational psychology literature.
2) Motivational psychology literature is fragmented among different psychological subfields and schools of thought, making it difficult to apply to energy feedback technology design in a cohesive and meaningful way.
3) Feedback technologies tend to design for "one-size-fits-all", providing the same feedback to differently motivated individuals at different stages of behavioural change.

The identification of these shortcomings led me to ask research question #2.

Research question #2: Can we develop a framework that encompasses relevant motivational psychology literature to apply to energy feedback technology design in a way that addresses individual motivations at different stages of behavioural change?

Chapter 6 addressed this question by offering a motivational framework that aims to move *beyond* a "one-size-fits-all" solution to inform energy feedback technology design. Using the TTM's stages of change and MI's counselling guidelines as the primary basis, the framework synthesized a wide range of motivational psychology literature to provide insights as to which motivational interventions may be most effective at each stage of behavioural change. The structure of the framework is as follows. For each stage, I proposed motivational *goal(s)* and *recommendation(s)* of how feedback technologies can achieve these goals. Each goal and recommendation is supported by a rationale based on motivational psychology literature.

Research question #3: Can we apply this framework to the design of a particular energy feedback technology?

I took two initial approaches to illustrate the application of the framework to inform energy feedback technology design. Both approaches are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design. As such, I do *not* fully answer this question within this thesis.

First, Chapter 6 provided simple, textual examples, which illustrated one way (and perhaps, not the best way) to apply each of the framework's recommendation. The examples were based on a scenario of a particular energy user named Mary who holds specific attitudes, beliefs, and values, and simplified to focus on motivating the sustainable energy usage of one appliance – the desktop computer.

Second, Chapter 6 revisited our implementation of 'AREnergyViewer' (presented in Chapter 3) by offering initial, high-level, redesign ideas based on the framework's recommendations for each stage of change.

7.4 Research Contributions

Primary:

1) A framing of motivational psychology literature as key notions important to designers of technology that aims to motivate sustainable energy behaviour.

2) An assessment of selected energy feedback technologies in terms of their potential effectiveness in motivating sustainable energy behaviour change.

3) A motivational psychology framework based on the Transtheoretical Model's stages of behaviour change and MI's counselling style, to guide energy feedback technology design in a way that addresses individual motivations at different stages of behavioural change.

Secondary:

4) Two design scenarios as initial approaches to illustrate the application of the motivational framework to inform energy feedback technology design. The first are textual examples based on a scenario of a particular energy user named "Mary". These examples illustrate *one* way to apply each of the framework's recommendations. The second revisits our implemented feedback system, 'AREnergyViewer' by offering initial, high-level, redesign ideas based on the framework's recommendations for each stage of change. Both approaches are meant to be *initial* probes into what future directions of research could be, rather than concrete recommendations for design.

7.5 Conclusion

This thesis explored how motivational psychology literature can be leveraged within energy feedback technology design to motivate sustainable energy behaviours by household residents. In this chapter, I discussed the application of the TTM and MI within the motivational framework, as well as future directions of exploration regarding the framework. Next, I restated my research questions, approaches and contributions.

To conclude, I wish to discuss this research from a broader perspective: in particular, I would like to offer my opinion on two topics of global debate. First, in a world where disease, war, poverty, starvation, homelessness, racism, economic crises, and so on are everyday affairs, the world is in debate as to whether sustainable development and sustainable consumption is really the most pressing global issue[20]. My opinion on this topic is that rather than considering these problems from an "either-or" perspective, holistic and integrative approaches should be taken to understand how problems relate together, and in turn, can be addressed together. To demonstrate, I provide three examples of how energy consumption relates to and may impact other global issues. First, global warming, and the climate change it induces, has led to the increased emergence, resurgence, and spread of infectious diseases (Epstein, 2000), indicating serious public health concerns as direct or indirect results of climate change (Gerberding, 2007). Second, the United Nations predicts that within a decade, climate change disasters will cost the world's financial centers as much as $150 billion annually (Environmental Defence, 2007), a situation that may intensify the current economic crisis and government debt. Third, the Pentagon predicts that climate change will be a bigger global threat than terrorism (Townsend and Harris, 2004). Millions are expected to die of famine, especially in the subtropical regions, where wars will be fought for sheer survival over the major waterways (Townsend and Harris, 2004). This potential for war is made even grimmer by the predicted proliferation of nuclear weapons by Japan, South and North Korea, Germany, Iran and Egypt (Townsend and Harris, 2004). Additionally, Israel, China, India and Pakistan are expected to use the bomb (Townsend and Harris, 2004).

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20 "Copenhagen Conference: success or failure?" Debatewise: where great minds differ. http://debatewise.org/debates/1541-success-or-failure. Retrieved Feb 19, 2010.

Such examples show relations between global warming and several major world issues, indicating the importance of holistic approaches to consider and address these problems.

Second, the complexities and uncertainties of global warming and the climate change it induces, have led to a global debate as to whether our individual consumptive behaviours can make a difference in the fate of our planet. From this debate, the question of "Should we even try?" often arises. From a motivational psychology perspective, I believe that we should, and we must. That is, we must continue to hope that our actions *can* make a difference. As hope is an "essential and distinctive feature of human agency", we cannot live a life without hope (McGeer, 2004). In addition, hope is a "deeply social phenomenon" (McGeer, 2004). In this way, "hope involves empowering ourselves in part through empowering others with the energy of our hope" (McGeer, 2004). Thus, it is our individual hope and the actions inspired from it, which will lead to collective energy actions that may ultimately "save the planet". Therefore, campaigns to motivate sustainable energy behaviour should look to empowering people through hope, rather than the presentation of hope*less*, climate change situations (as is often the case).

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Appendix A. AREnergyViewer calculations

The following discusses how different modes of information within AREnergyViewer were calculated, including wattage, kilowatt-hours (kWh), monetary cost ($), CO_2 emissions (g), and percentage of energy-efficient usage (%).

Wattage uses the raw data captured by the Watts Up (WU) devices, where each appliance is measured by a single WU device.

Kilowatt-hours (kWh) is calculated using the current wattage value for an appliance:

kWh = wattage/1000 * number_of_hours_at_that_wattage

Monetary cost ($) is calculated by multiplying kWh with a constant[21] representing dollars per kWh:

cost = kWh * 0.1024

CO_2 emissions (g) are calculated by multiplying kWh with a constant[22] representing grams of CO_2 per kWh (in Canada):

CO_2 = kWh * 2.50

Percent of energy-efficient usage (%) is calculated using the following equation:

Energy-efficient usage (%) = (not_energy_efficient_usage_in_kWh / total_energy_usage_in kWh) * 100

where, whether an appliance is or is not using "energy efficiently", is determined by the appliance's current powerstate (e.g. on, off, or using standby power), as well as the state of the motion (activity) sensor and the state of the force (presence) sensor. For example, during the period of time which the CPU is in an "on" power state, and the motion and force sensor are both false, appliance use is *not* "energy-efficient" (as the appliance is "on" while no one is there). If the CPU is "on" and both the motion and force sensor are true, then appliance use is "energy-efficient" for that period of time (as the appliance is "on" while someone is there and actively using the appliance).

---

[21] This constant was taken from a monthly utility bill, and is used as one example of what cost per kWh is.

[22] This constant was calculated by taking the average reading between the years 2000-2005, from the "Greenhouse Gas Intensity" table, with units "g CO_2 eq/kWh" from: http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/ta9_10_eng.cfm

Appendix B. MySQL Database Table Design

The following shows the MySQL database table and view structure. As the reader may notice, some fields in the existing tables are calculated but not used within the AREnergyViewer visualization.

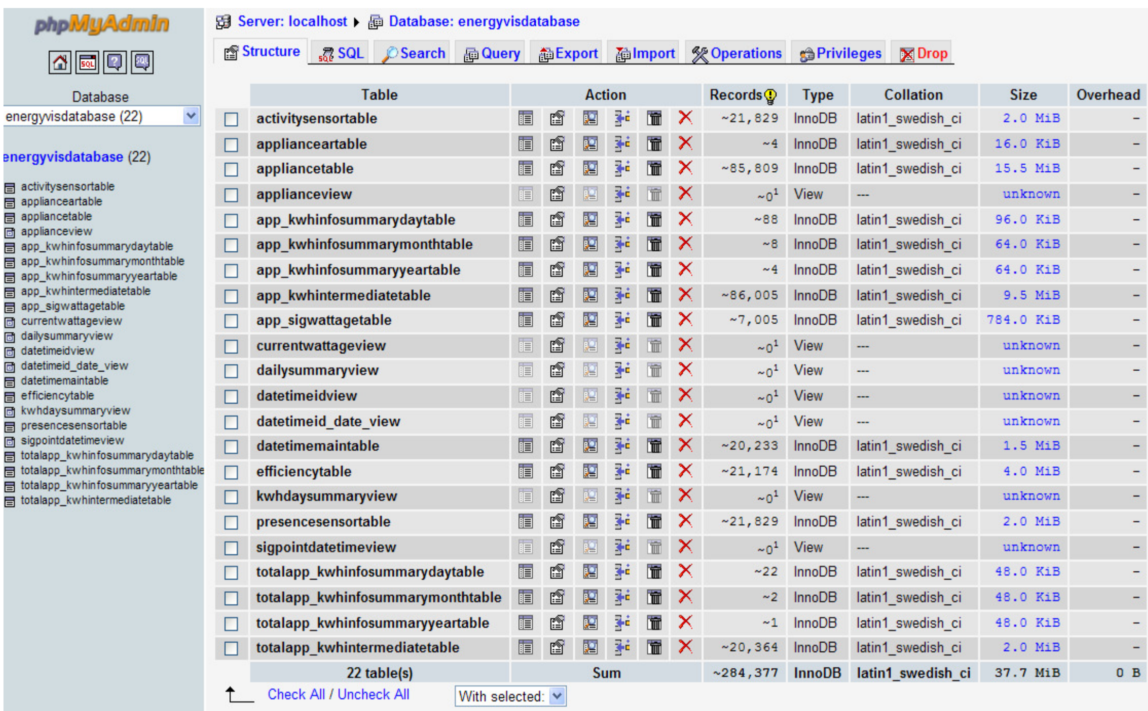
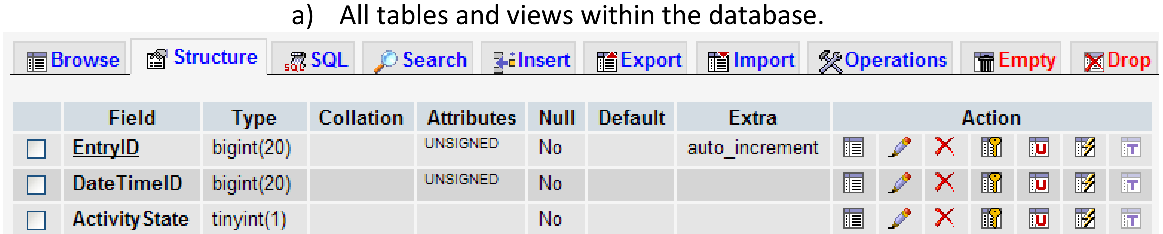


Table	Action	Records	Type	Collation	Size	Overhead
activitysensortable		~21,829	InnoDB	latin1_swedish_ci	2.0 MiB	–
appliaceartable		~4	InnoDB	latin1_swedish_ci	16.0 KiB	–
appliancetable		~85,809	InnoDB	latin1_swedish_ci	15.5 MiB	–
applianceview		~0[1]	View	---	unknown	–
app_kwhinfosummarydaytable		~88	InnoDB	latin1_swedish_ci	96.0 KiB	–
app_kwhinfosummarymonthtable		~8	InnoDB	latin1_swedish_ci	64.0 KiB	–
app_kwhinfosummaryyeartable		~4	InnoDB	latin1_swedish_ci	64.0 KiB	–
app_kwhintermediatetable		~86,005	InnoDB	latin1_swedish_ci	9.5 MiB	–
app_sigwattagetable		~7,005	InnoDB	latin1_swedish_ci	784.0 KiB	–
currentwattageview		~0[1]	View	---	unknown	–
dailysummaryview		~0[1]	View	---	unknown	–
datetimeidview		~0[1]	View	---	unknown	–
datetimeid_date_view		~0[1]	View	---	unknown	–
datetimemaintable		~20,233	InnoDB	latin1_swedish_ci	1.5 MiB	–
efficiencytable		~21,174	InnoDB	latin1_swedish_ci	4.0 MiB	–
kwhdaysummaryview		~0[1]	View	---	unknown	–
presencesensortable		~21,829	InnoDB	latin1_swedish_ci	2.0 MiB	–
sigpointdatetimeview		~0[1]	View	---	unknown	–
totalapp_kwhinfosummarydaytable		~22	InnoDB	latin1_swedish_ci	48.0 KiB	–
totalapp_kwhinfosummarymonthtable		~2	InnoDB	latin1_swedish_ci	48.0 KiB	–
totalapp_kwhinfosummaryyeartable		~1	InnoDB	latin1_swedish_ci	48.0 KiB	–
totalapp_kwhintermediatetable		~20,364	InnoDB	latin1_swedish_ci	2.0 MiB	–
22 table(s)	Sum	~284,377	InnoDB	latin1_swedish_ci	37.7 MiB	0 B

Check All / Uncheck All With selected:

a) All tables and views within the database.



Field	Type	Collation	Attributes	Null	Default	Extra	Action
EntryID	bigint(20)		UNSIGNED	No		auto_increment	
DateTimeID	bigint(20)		UNSIGNED	No			
ActivityState	tinyint(1)			No			

b) Activitysensortable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	ApplianceID	bigint(20)		UNSIGNED	No		auto_increment	
☐	ApplianceName	char(100)	latin1_swedish_ci		No			
☐	comPort	char(100)	latin1_swedish_ci		Yes	NULL		
☐	ARTagID	mediumint(10)		UNSIGNED	No			
☐	averageWattageWhenOn	float			Yes	NULL		
☐	location	char(100)	latin1_swedish_ci		Yes	NULL		
☐	sigwatts	float			Yes	NULL		
☐	description	char(100)	latin1_swedish_ci		Yes	NULL		
☐	powerstate1	char(100)	latin1_swedish_ci		Yes	NULL		
☐	powerstateMin1	float			Yes	NULL		
☐	powerstateMax1	float			Yes	NULL		
☐	powerstate2	char(100)	latin1_swedish_ci		Yes	NULL		
☐	powerstateMin2	float			Yes	NULL		
☐	powerstateMax2	float			Yes	NULL		
☐	powerstate3	char(100)	latin1_swedish_ci		Yes	NULL		
☐	powerstateMin3	float			Yes	NULL		
☐	powerstateMax3	float			Yes	NULL		
☐	powerstate4	char(100)	latin1_swedish_ci		Yes	NULL		
☐	powerstateMin4	float			Yes	NULL		
☐	powerstateMax4	float			Yes	NULL		

c) applianceartable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

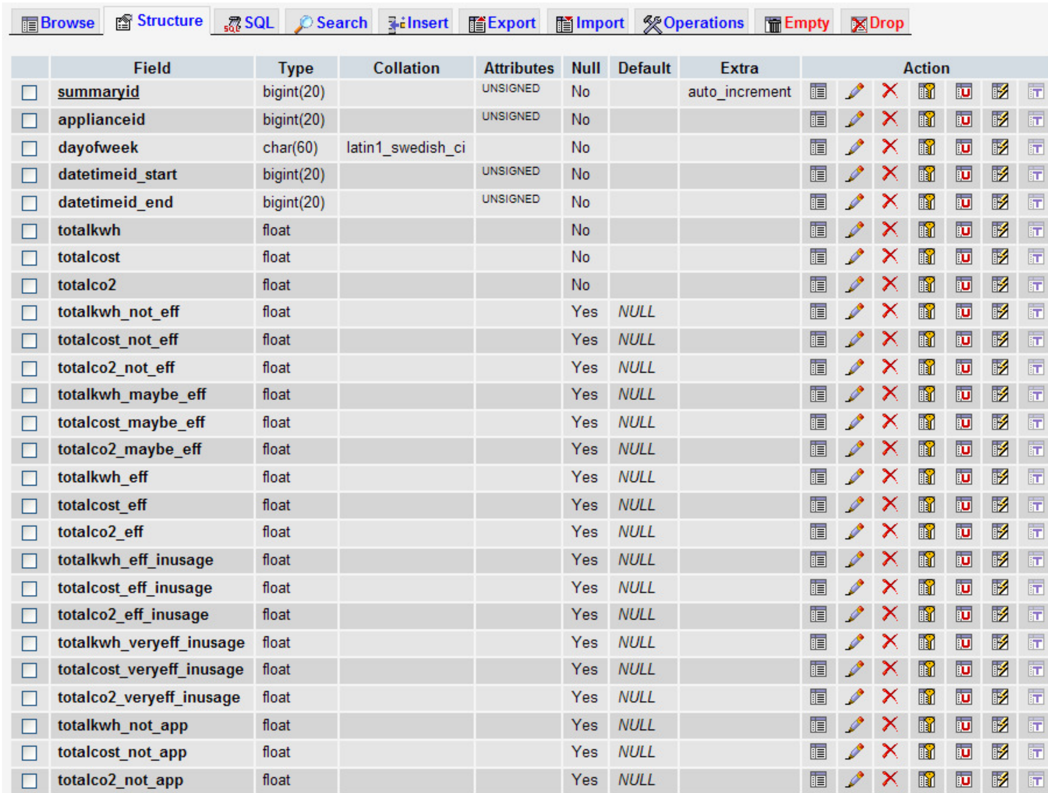
	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	entryid	bigint(20)		UNSIGNED	No		auto_increment	
☐	datetimeid	bigint(20)		UNSIGNED	No			
☐	applianceid	bigint(20)		UNSIGNED	No			
☐	wattage	float			No			
☐	powerstate	char(60)	latin1_swedish_ci		No			
☐	wattagedurationinseconds	bigint(20)			No			

d) appliancetable

Browse | Structure | SQL | Search | Insert | Export | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	View
☐	entryid	bigint(20)		UNSIGNED	No	0		
☐	datetimeid	bigint(20)		UNSIGNED	No			
☐	applianceid	bigint(20)		UNSIGNED	No			
☐	wattage	float			No			
☐	powerstate	char(60)	latin1_swedish_ci		No			
☐	wattagedurationinseconds	bigint(20)			No			
☐	timestamp	timestamp			No	0000-00-00 00:00:00		

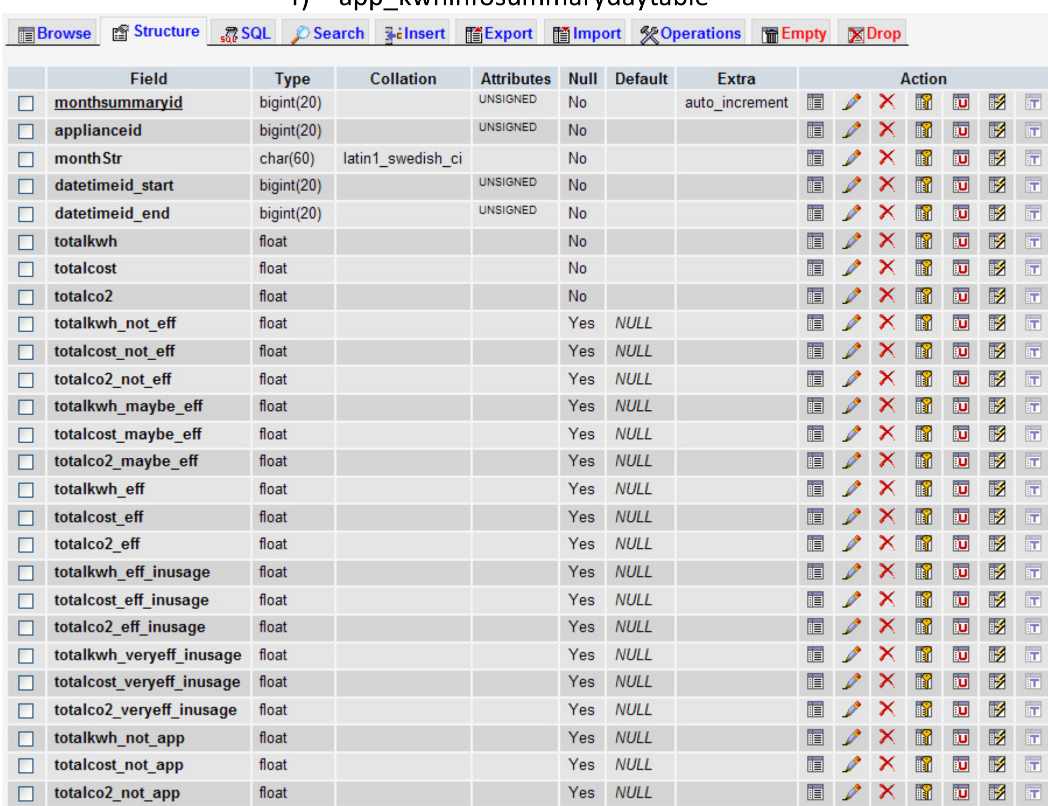
e) applianceview



Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
summaryid	bigint(20)		UNSIGNED	No		auto_increment	
applianceid	bigint(20)		UNSIGNED	No			
dayofweek	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	NULL		
totalcost_not_eff	float			Yes	NULL		
totalco2_not_eff	float			Yes	NULL		
totalkwh_maybe_eff	float			Yes	NULL		
totalcost_maybe_eff	float			Yes	NULL		
totalco2_maybe_eff	float			Yes	NULL		
totalkwh_eff	float			Yes	NULL		
totalcost_eff	float			Yes	NULL		
totalco2_eff	float			Yes	NULL		
totalkwh_eff_inusage	float			Yes	NULL		
totalcost_eff_inusage	float			Yes	NULL		
totalco2_eff_inusage	float			Yes	NULL		
totalkwh_veryeff_inusage	float			Yes	NULL		
totalcost_veryeff_inusage	float			Yes	NULL		
totalco2_veryeff_inusage	float			Yes	NULL		
totalkwh_not_app	float			Yes	NULL		
totalcost_not_app	float			Yes	NULL		
totalco2_not_app	float			Yes	NULL		

f) app_kwhinfosummarydaytable



Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
monthsummaryid	bigint(20)		UNSIGNED	No		auto_increment	
applianceid	bigint(20)		UNSIGNED	No			
monthStr	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	NULL		
totalcost_not_eff	float			Yes	NULL		
totalco2_not_eff	float			Yes	NULL		
totalkwh_maybe_eff	float			Yes	NULL		
totalcost_maybe_eff	float			Yes	NULL		
totalco2_maybe_eff	float			Yes	NULL		
totalkwh_eff	float			Yes	NULL		
totalcost_eff	float			Yes	NULL		
totalco2_eff	float			Yes	NULL		
totalkwh_eff_inusage	float			Yes	NULL		
totalcost_eff_inusage	float			Yes	NULL		
totalco2_eff_inusage	float			Yes	NULL		
totalkwh_veryeff_inusage	float			Yes	NULL		
totalcost_veryeff_inusage	float			Yes	NULL		
totalco2_veryeff_inusage	float			Yes	NULL		
totalkwh_not_app	float			Yes	NULL		
totalcost_not_app	float			Yes	NULL		
totalco2_not_app	float			Yes	NULL		

g) app_kwhinfosummarymonthtable

Browse Structure SQL Search Insert Export Import Operations Empty Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	yearsummaryid	bigint(20)		UNSIGNED	No		auto_increment	
☐	applianceid	bigint(20)		UNSIGNED	No			
☐	yearInt	bigint(20)			No			
☐	datetimeid_start	bigint(20)		UNSIGNED	No			
☐	datetimeid_end	bigint(20)		UNSIGNED	No			
☐	totalkwh	float			No			
☐	totalcost	float			No			
☐	totalco2	float			No			
☐	totalkwh_not_eff	float			Yes	NULL		
☐	totalcost_not_eff	float			Yes	NULL		
☐	totalco2_not_eff	float			Yes	NULL		
☐	totalkwh_maybe_eff	float			Yes	NULL		
☐	totalcost_maybe_eff	float			Yes	NULL		
☐	totalco2_maybe_eff	float			Yes	NULL		
☐	totalkwh_eff	float			Yes	NULL		
☐	totalcost_eff	float			Yes	NULL		
☐	totalco2_eff	float			Yes	NULL		
☐	totalkwh_eff_inusage	float			Yes	NULL		
☐	totalcost_eff_inusage	float			Yes	NULL		
☐	totalco2_eff_inusage	float			Yes	NULL		
☐	totalkwh_veryeff_inusage	float			Yes	NULL		
☐	totalcost_veryeff_inusage	float			Yes	NULL		
☐	totalco2_veryeff_inusage	float			Yes	NULL		
☐	totalkwh_not_app	float			Yes	NULL		
☐	totalcost_not_app	float			Yes	NULL		
☐	totalco2_not_app	float			Yes	NULL		

h) app_kwhinfosummaryyeartable

Browse Structure SQL Search Insert Export Import Operations Empty Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	interkwhid	bigint(20)		UNSIGNED	No		auto_increment	
☐	applianceid	bigint(20)		UNSIGNED	No			
☐	datetimeid	bigint(20)		UNSIGNED	No			
☐	intermediatekwh	float			No			

i) app_kwhintermediatetable

Browse Structure SQL Search Insert Export Import Operations Empty Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	SigID	bigint(20)		UNSIGNED	No		auto_increment	
☐	Applianceid	bigint(20)		UNSIGNED	No			
☐	Datetimeid	bigint(20)		UNSIGNED	No			
☐	Wattage	float			No			

j) app_sigwattagetable

Browse | Structure | SQL | Search | Insert | Export | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	View
wattage	float			No			
powerstate	char(60)	latin1_swedish_ci		No			
applianceid	bigint(20)		UNSIGNED	No	0		
ARTagID	mediumint(10)		UNSIGNED	No			

k) currentwattageview

Browse | Structure | SQL | Search | Insert | Export | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	View
summaryid	bigint(20)		UNSIGNED	No	0		
applianceid	bigint(20)		UNSIGNED	No			
dayofweek	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	*NULL*		
totalcost_not_eff	float			Yes	*NULL*		
totalco2_not_eff	float			Yes	*NULL*		
totalkwh_maybe_eff	float			Yes	*NULL*		
totalcost_maybe_eff	float			Yes	*NULL*		
totalco2_maybe_eff	float			Yes	*NULL*		
totalkwh_eff	float			Yes	*NULL*		
totalcost_eff	float			Yes	*NULL*		
totalco2_eff	float			Yes	*NULL*		
totalkwh_eff_inusage	float			Yes	*NULL*		
totalcost_eff_inusage	float			Yes	*NULL*		
totalco2_eff_inusage	float			Yes	*NULL*		
totalkwh_veryeff_inusage	float			Yes	*NULL*		
totalcost_veryeff_inusage	float			Yes	*NULL*		
totalco2_veryeff_inusage	float			Yes	*NULL*		
totalkwh_not_app	float			Yes	*NULL*		
totalcost_not_app	float			Yes	*NULL*		
totalco2_not_app	float			Yes	*NULL*		
date	date			No			

l) dailysummaryview

Browse | Structure | SQL | Search | Insert | Export | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	View
summaryid	bigint(20)		UNSIGNED	No	0		
applianceid	bigint(20)		UNSIGNED	No			
dayofweek	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	*NULL*		
totalcost_not_eff	float			Yes	*NULL*		
totalco2_not_eff	float			Yes	*NULL*		
totalkwh_maybe_eff	float			Yes	*NULL*		
totalcost_maybe_eff	float			Yes	*NULL*		
totalco2_maybe_eff	float			Yes	*NULL*		
totalkwh_eff	float			Yes	*NULL*		
totalcost_eff	float			Yes	*NULL*		
totalco2_eff	float			Yes	*NULL*		
totalkwh_eff_inusage	float			Yes	*NULL*		
totalcost_eff_inusage	float			Yes	*NULL*		
totalco2_eff_inusage	float			Yes	*NULL*		
totalkwh_veryeff_inusage	float			Yes	*NULL*		
totalcost_veryeff_inusage	float			Yes	*NULL*		
totalco2_veryeff_inusage	float			Yes	*NULL*		
totalkwh_not_app	float			Yes	*NULL*		
totalcost_not_app	float			Yes	*NULL*		
totalco2_not_app	float			Yes	*NULL*		
date	date			No			

m) datetimeidview

Browse | Structure | SQL | Search | Insert | Export | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	View
DateTimeID	bigint(20)		UNSIGNED	No	0		

n) datetimeid_date_view

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
DateTimeID	bigint(20)		UNSIGNED	No		auto_increment	
timestamp	timestamp		ON UPDATE CURRENT_TIMESTAMP	No	CURRENT_TIMESTAMP		
Date	date			No			
DayOfWeek	char(18)	latin1_swedish_ci		No			
Time	time			No			
TotalWatts	float			No			

o) datetimemaintable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
efficiencyID	bigint(20)		UNSIGNED	No		auto_increment	
ApplianceID	bigint(20)		UNSIGNED	No			
Datetimeid_start	bigint(20)		UNSIGNED	No			
Datetimeid_end	bigint(20)		UNSIGNED	No			
EfficiencyState	char(60)	latin1_swedish_ci		No			
temp_done	smallint(6)		UNSIGNED	Yes	*NULL*		

p) efficiencytable

Browse | Structure | SQL | Search | Insert | Export | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	View
summaryid	bigint(20)		UNSIGNED	No	0		
Date	date			No			
applianceid	bigint(20)		UNSIGNED	No			
dayofweek	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	*NULL*		
totalcost_not_eff	float			Yes	*NULL*		
totalco2_not_eff	float			Yes	*NULL*		
totalkwh_maybe_eff	float			Yes	*NULL*		
totalcost_maybe_eff	float			Yes	*NULL*		
totalco2_maybe_eff	float			Yes	*NULL*		
totalkwh_eff	float			Yes	*NULL*		
totalcost_eff	float			Yes	*NULL*		
totalco2_eff	float			Yes	*NULL*		
totalkwh_eff_inusage	float			Yes	*NULL*		
totalcost_eff_inusage	float			Yes	*NULL*		
totalco2_eff_inusage	float			Yes	*NULL*		
totalkwh_veryeff_inusage	float			Yes	*NULL*		
totalcost_veryeff_inusage	float			Yes	*NULL*		
totalco2_veryeff_inusage	float			Yes	*NULL*		
totalkwh_not_app	float			Yes	*NULL*		
totalcost_not_app	float			Yes	*NULL*		
totalco2_not_app	float			Yes	*NULL*		

q) kwhdaysummaryview

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
	EntryID	bigint(20)		UNSIGNED	No		auto_increment	
	DateTimeID	bigint(20)		UNSIGNED	No			
	PresenceState	tinyint(1)			No			

r) presencesensortable

Browse | Structure | SQL | Search | Insert | Export | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	View
	SigID	bigint(20)		UNSIGNED	No	0		
	Applianceid	bigint(20)		UNSIGNED	No			
	Datetimeid	bigint(20)		UNSIGNED	No			
	Wattage	float			No			
	timestamp	timestamp			No	0000-00-00 00:00:00		

s) sigpointdatetimeview

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
	summaryid	bigint(20)		UNSIGNED	No		auto_increment	
	dayofweek	char(60)	latin1_swedish_ci		No			
	datetimeid_start	bigint(20)		UNSIGNED	No			
	datetimeid_end	bigint(20)		UNSIGNED	No			
	totalkwh	float			No			
	totalcost	float			No			
	totalco2	float			No			
	totalkwh_not_eff	float			Yes	NULL		
	totalcost_not_eff	float			Yes	NULL		
	totalco2_not_eff	float			Yes	NULL		
	totalkwh_maybe_eff	float			Yes	NULL		
	totalcost_maybe_eff	float			Yes	NULL		
	totalco2_maybe_eff	float			Yes	NULL		
	totalkwh_eff	float			Yes	NULL		
	totalcost_eff	float			Yes	NULL		
	totalco2_eff	float			Yes	NULL		
	totalkwh_eff_inusage	float			Yes	NULL		
	totalcost_eff_inusage	float			Yes	NULL		
	totalco2_eff_inusage	float			Yes	NULL		
	totalkwh_veryeff_inusage	float			Yes	NULL		
	totalcost_veryeff_inusage	float			Yes	NULL		
	totalco2_veryeff_inusage	float			Yes	NULL		
	totalkwh_not_app	float			Yes	NULL		
	totalcost_not_app	float			Yes	NULL		
	totalco2_not_app	float			Yes	NULL		

t) totalapp_kwhinfosummarydaytable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
monthsummaryid	bigint(20)		UNSIGNED	No		auto_increment	
monthStr	char(60)	latin1_swedish_ci		No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	NULL		
totalcost_not_eff	float			Yes	NULL		
totalco2_not_eff	float			Yes	NULL		
totalkwh_maybe_eff	float			Yes	NULL		
totalcost_maybe_eff	float			Yes	NULL		
totalco2_maybe_eff	float			Yes	NULL		
totalkwh_eff	float			Yes	NULL		
totalcost_eff	float			Yes	NULL		
totalco2_eff	float			Yes	NULL		
totalkwh_eff_inusage	float			Yes	NULL		
totalcost_eff_inusage	float			Yes	NULL		
totalco2_eff_inusage	float			Yes	NULL		
totalkwh_veryeff_inusage	float			Yes	NULL		
totalcost_veryeff_inusage	float			Yes	NULL		
totalco2_veryeff_inusage	float			Yes	NULL		
totalkwh_not_app	float			Yes	NULL		
totalcost_not_app	float			Yes	NULL		
totalco2_not_app	float			Yes	NULL		

u) totalapp_kwhinfosummarymonthtable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

Field	Type	Collation	Attributes	Null	Default	Extra	Action
yearsummaryid	bigint(20)		UNSIGNED	No		auto_increment	
yearInt	bigint(20)			No			
datetimeid_start	bigint(20)		UNSIGNED	No			
datetimeid_end	bigint(20)		UNSIGNED	No			
totalkwh	float			No			
totalcost	float			No			
totalco2	float			No			
totalkwh_not_eff	float			Yes	NULL		
totalcost_not_eff	float			Yes	NULL		
totalco2_not_eff	float			Yes	NULL		
totalkwh_maybe_eff	float			Yes	NULL		
totalcost_maybe_eff	float			Yes	NULL		
totalco2_maybe_eff	float			Yes	NULL		
totalkwh_eff	float			Yes	NULL		
totalcost_eff	float			Yes	NULL		
totalco2_eff	float			Yes	NULL		
totalkwh_eff_inusage	float			Yes	NULL		
totalcost_eff_inusage	float			Yes	NULL		
totalco2_eff_inusage	float			Yes	NULL		
totalkwh_veryeff_inusage	float			Yes	NULL		
totalcost_veryeff_inusage	float			Yes	NULL		
totalco2_veryeff_inusage	float			Yes	NULL		
totalkwh_not_app	float			Yes	NULL		
totalcost_not_app	float			Yes	NULL		
totalco2_not_app	float			Yes	NULL		

v) totalapp_kwhinfosummaryyeartable

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Empty | Drop

	Field	Type	Collation	Attributes	Null	Default	Extra	Action
☐	InterKwhID	bigint(20)		UNSIGNED	No		auto_increment	
☐	datetimeid	bigint(20)		UNSIGNED	No			
☐	IntermediateKwh	float			No			

w) totalapp_kwhintermediatetable

Appendix C. Co-author Permission

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I, Saul Greenberg, give Helen Ai He permission to use co-authorized work from our papers:

He, H.A., Greenberg, S. and Huang, E.M. (2010)
One Size Does Not Fit All: Applying the Transtheoretical Model to Energy Feedback Technology Design. In Proceedings of the ACM Conference on Human Factors in Computing Systems - ACM CHI'2010. ACM Press, 10 pages, April. In Press. Earlier version as: Report 2009-943-22.

He, H.A. and Greenberg, S. (2009)
Motivating Sustainable Energy Consumption in the Home. In ACM CHI Workshop on Defining the Role of HCI in the Challenges of Sustainability. (Workshop held at the ACM CHI Conference), 5 Pages, April. Also in: ACM CSCW Workshop on Designing for Families (Workshop held at the ACM CSCW Conference), November, 2008. Also as Research Report 2008-914-27, September.

Sincerely,

Saul Greenberg

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I, Elaine May Huang, give Helen Ai He permission to use co-authored work from our paper:

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Sincerely,

Elaine May Huang