Designing Persuasive Technology to Reduce Peak Electricity Demand in Ontario Homes

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

When it comes to environmental sustainability, the time that electricity is consumed matters. For example, using an air conditioner on a hot summer afternoon as the power grid is strained necessitates the use of more polluting sources to meet demand. There are a number of ways to target a reduction in peak demand: better electricity storage technology, for one, has the potential to level out these peaks. In the meantime, electrical utilities aim to incentivize a reduction in demand from households at these times through programs such as Time-of-Use Pricing, and critical peak demand response programs, such as peaksaver in Ontario. However, the effectiveness of these programs has been limited.

In this thesis, we adopted the lens of persuasive technology to improve and support these programs, in order to encourage a reduction in electricity consumption in households at peak load times. To accomplish this, we conducted 18 interviews to examine the practices of households in response to these programs, and learn how they can be improved at the individual level. We found that Time-of-Use pricing encourages shifting some electricity demand, but only when it is convenient. We also found that while potentially effective at a larger scale, the peaksaver program in its current form is unattractive to participants.

We then analyzed our findings using existing behaviour change models, including Fogg's Behaviour Model for Persuasive Design. Using the three aspects of the model – motivation, ability and triggers - we identified where the existing programs are lacking and developed design implications for the design of persuasive technology to support reducing electricity consumption at peak load times. Finally, we designed a smartphone application based on these design implications, and conducted a preliminary evaluation in order to begin to assess their validity.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

The study of technology to support environmental sustainability has been a growing area of research in the HCI community [6,16,34]. One area of interest to HCI researchers has been the study of tools, interfaces, and devices that can encourage a reduction in electricity consumption. In this area, we find studies of in-home displays [15,23], prototypes of the smart grid [14] and use of smart thermostat control [36,60], among others. Whether or not it is stated explicitly, much of this work can be put under the umbrella of persuasive technology - technology that aims to change people's attitudes or behaviours [19].

The main approach that persuasive technology has followed with regards to reducing electricity consumption has been making people "more aware" of their consumption, with the intrinsic belief that this increased awareness will lead to behaviour change. More recently, others have begun to note how limited a view of the problem this poses, and express a call to action to for research that goes beyond simple awareness mechanisms. Additionally, previous work in the HCI community related to sustainability has caused Mankoff to argue that *"feel good motivation is not enough"* and that it is necessary to show concrete effects on problems that have a higher potential impact than simply reducing consumption in a few households in the developed world [39].

In this thesis, we target the problem of peak electricity demand, which is a different though somewhat related problem. Instead of persuading consumers to reduce their electricity consumption at all times, we aim to design technology to encourage shifting consumption away from peak times.

1.1 Problem of Peak Electricity Demand in Ontario

On a daily basis, the demand for electricity varies from low during overnight hours to higher during the day. Summer heat waves can cause extremely high demand to be placed on the electrical grid. Failure to meet this peak demand can cause disruptions in electricity availability – brown outs, rolling black outs, or even wide-spread power outages. In order to avoid this, utilities manage supply to ensure that they meet peak demand. One option is to simply have larger power plants with surplus generating capacity. The downside is that power plants are most efficient when they are being run

consistently at their full capacity, i.e. with a high load factor. Thus, this option implies the attendant pollution caused by that surplus capacity, exists on the electrical grid at off-peak times. Alternatively, special generating plants can be constructed solely to be used during times of particular need – which could be as infrequently as a few hours per year [61]. While the approaches can be mixed, Ontario uses the latter option. Currently, the baseline electricity needs of Ontario are met by nuclear and large hydroelectric power stations. The peak demand is generally met with natural gas powered plants, as well as some smaller hydroelectric plants [62]. Thus, reducing peak demand in Ontario can directly lead to reduced greenhouse gas emissions.

There are also issues of social sustainability surrounding power generation in Ontario. In 2013, political decisions to relocate new natural gas power plants to pacify concerned voters during an election campaign resulted in almost $1 billion in costs to Ontario taxpayers. Essentially, power consumption in Ontario is an issue of active public discourse, increasing public awareness of both the environmental, economic, and social problems surrounding electricity production and consumption and programs designed to address these problems.

Given these consequences, electrical utility companies have devised programs to encourage more optimally timed consumption of electricity, including:

- **Variable pricing schemes**, where electricity rates vary consistently depending on time-of-day. The goal of variable pricing is to encourage behavior change on the part of the consumer, to use less electricity at daily peak times.
- **Critical peak load programs**, where participants opt-in and allow the utility to selectively control their home air conditioning units. This allows the utilities to lower the demand for electricity at critical peak times.

1.2 Research Goals

The end-goal of the programs described above is to persuade consumers to change their habits. However, their effectiveness has been limited [1,52]. In order to explore how these programs can be improved, we adopt the lens of persuasive technology. We understand that this approach has been criticized recently for taking a narrow view of the problem. Past work has focused on providing awareness mechanisms with the assumption that users, by being made more aware, will inherently want to change their behaviour and reduce their electricity consumption [9,35]. Our approach takes a

broader view of persuasive technology. Instead of simply focusing on awareness mechanisms, we draw from Fogg's Behaviour Model for Persuasive Design [21] in order to bring a more holistic perspective to our design of persuasive technology. We also consider other behaviour change models, such as the Transtheoretical Model of Behaviour Change [48] and particularly research within HCI that has learned from these models [12,28,29].

In order to design effective and useful technology, our first goal was to learn about the everyday practices of Ontario households related to shifting in response to the Ontario programs, and with respect to important contributors to peak load including home cooling. We set out to answer questions about how households engaged with these programs, whether they were effective at a micro level, and how they could be augmented and how shifting could be made easier through the use of technology. Then, building from this knowledge of households, our next goal was to analyze these findings in the context of behaviour change knowledge, and distill a set of design recommendations for technology in this area. Lastly, we set out to validate these design implications through the development of a prototype application that aims to both motivate and simplify reducing consumption at peak times.

1.3 Scope

In this research, we chose to focus on the residential electricity sector, and specifically on influencing occupant behaviour. In Ontario, the residential community comprises approximately one third of electricity consumption, alongside commercial and industrial use. However, residential cooling is the single biggest contributor to critical peak demand in Ontario, accounting for nearly 22% of consumption at these times, ahead of commercial HVAC (17%) and consumption from residential refrigeration and appliances (13%) [32]. Different types of programs already exist for other sectors, and many industrial clients already use real time pricing of electricity, or are billed based on consumption at peak times, so an incentive structure already exists for them.

Targeting occupant behaviour is thought to be a productive and relatively inexpensive approach to the problem [2], because behaviour has been shown to have a greater impact on energy consumption than variances in construction of the home itself, such as insulation [17]. Even within 9 identical homes in the UK, variations in energy consumption of up to 600% were found in July 2004 [3].

1.4 Findings

This thesis introduces a set of design implications for persuasive technology to encourage or enable a reduction in electricity demand from households at these peak times. To develop these, we conducted interviews with 18 people who were automatically enrolled or opted in to versions of the industry-led programs in Ontario, Canada, in order to understand the impact of these programs on their day to day practices. We identified themes in behaviour surrounding Daily Peaks and TOU pricing, Critical Peaks and Peaksaver, Home Comfort/Cooling and Desire to Engage.

These findings were then analyzed using Fogg's Behaviour Model for Persuasive Design [21], along with consideration of other models of behaviour change to see where these programs are missing opportunities and how they can be improved. The design implications identified are centred on Fogg's aspects of motivation, ability, and triggers. Along with the widespread availability of smartphones and internet-enabled thermostats, we developed and began to evaluate a concrete design based on the identified recommendations, which further reinforced the findings.

1.5 Contributions and Impact

This thesis offers the following four contributions to the domains of persuasive technology, reduction of peak electricity load in Ontario, and HCI:

- An analysis of the Ontario demand response programs from the perspective of end users, including how they respond to and feel about them, in their own words;
- Design implications for the design of persuasive technology to support and encourage the reduction of electricity consumption in homes at peak load times;
- Design and preliminary evaluation of a smartphone app based on the identified design implications; and
- A case study of using Fogg's Behaviour Model for Persuasive Design to explore and analyze an application area for persuasive technology.

The field of Human-Computer Interaction has taken an increasing interest in the design and support of fields such as sustainability, and the increasingly complex practices of energy consumption with regards to smart grid technologies, though demand response programs have not been fully explored. In particular, Costanza et al. *"believe that HCI is well positioned to strike the right balance through studying deployments of prototypes before the infrastructures are fully in place"* [14].

The perspective offered by the HCI field is that of interventionist – we study this area with the intention of building new interactive systems and technologies that better support users in their intended task. To accomplish this, we first need to understand users and their existing practices before designing new technologies. Our findings can, and hopefully will, improve future programs and technologies fit better into the lifestyle of ordinary people, and empower them to make better and easier decisions. While in this thesis we focus specifically on the Ontario context, similar problems of peak demand exists elsewhere, and the results are hypothesized to be generalizable to other situations, such as temporary reduced supply from more inconsistent renewable sources.

As Pierce et al. put it *"HCI and interaction design should, and will, play a role in shaping new paradigms of energy consumption"* [47].

1.6 Organization

This thesis is organized as follows:

Chapter 2 explores related work from the HCI community, including some more recent criticisms and calls to action on the future of sustainability research in HCI. It also presents further background information on the existing programs, devices and technologies that attempt to address this problem, and further details of Fogg's Behaviour Model for Persuasive Design.

Chapter 3 presents details of the methodology of the 18 interviews we conducted with Ontarians, while Chapter 4 presents the analyzed results of these interviews, structured according to our affinity diagram analysis.

Chapter 5 contains the Design Implications identified from analyzing the interview data in the context of Fogg's Behaviour Model for persuasive design. These implications are synthesized from our interview data and structured according to Fogg's axes of motivation, ability and triggers.

Chapter 6 presents the details of the smartphone application we designed based on our design implications, and the results of the preliminary evaluation we conducted. We include screen captures of our design.

Chapter 7 provides discussion of the results and the persuasive technology approach, and our conclusions. We also include an evaluation of our impressions of Fogg's Behaviour Model as a tool for persuasive design, and discuss avenues for future work.

Chapter 2 Background and Related Work

There is related work from a number of areas that are relevant to this thesis. The overall domain is in persuasive technology and behaviour change. As a result, this chapter first explores persuasive technology and behaviour change theory, focusing specifically on Fogg's Behaviour Model for Persuasive Design. We then provide further background information on the problems of peak electricity demand in Ontario, and the programs and technologies that have been developed thus far that target or have the potential to target reduction in peak electricity demand, and consider existing research and findings related to these. Finally, we end with an exploration of the work on sustainability, resource management from within the HCI community, including some meta work on the future of sustainability research in HCI.

2.1 Behaviour Change

In embarking on an analysis of electricity shifting programs in Ontario, a first step is to identify an analytical tool that enables us to assess how effective these programs might be from the perspective of behaviour change, and where gaps and further opportunities lie. While much of the data about what people do and how people change can be gleaned from people who participate in any studies we conduct, at a higher level, the understanding of why people act or do not act can usefully be structured around analytical tools that have been developed in HCI. In particular, one popular paradigm that explores how to motivate people is the domain of persuasive technology.

2.1.1 Persuasive Technology

BJ Fogg defines persuasive technology as *"any interactive computing system designed to change people's attitudes or behaviours"* [19]. He presents a general framework for thinking about persuasive technology, and emphasizes that interactive technology can take advantage of kairos - the opportune

moment to persuade, which is often lacking from offline types of persuasion (such as media campaigns, for example).

In his exploration of persuasive technology, Fogg describes 7 different types of persuasive technology tools [19]:

- Reduction, reducing the steps needed to accomplish a given desirable action;
- Tunneling, leading a user through the steps necessary to accomplish an action;
- Tailoring, providing relevant information tailored to the individual to foster a behaviour;
- Suggestions, interjecting to encourage a desired behaviour at an opportune moment;
- Self-monitoring, providing people with information about their actions so they can change their behaviour;
- Surveillance, being monitored by others, thus encouraging positive behaviours; and
- Conditioning, providing positive reinforcement when individuals take desired actions.

Persuasive technologies can use combinations of these tools to be effective, though it is suggested that the more subtle the intervention, the more likely it is the target behaviour will be sustained [37].

Designers of persuasive technology need to consider the ethics of persuasion as it is obviously important to avoid coercion. Fogg considers the ethics of designing persuasive technology from three perspectives: intentions, methods and outcomes. In this work, we consider our intentions to be fully ethical - the intention is reduced greenhouse gas emissions to combat global warming, and this objective is clearly communicated. The methods we use and suggest include reduction, tailoring, suggestions, and just a hint of minor anonymous surveillance. While designers could in theory take these general design implications and implement them using malicious methods, this seems unlikely given the altruistic intentions. Fogg suggests that the first strategy for evaluating methods should be asking oneself if it would be appropriate for a human to persuade in this way. Lastly, the outcomes can be used to evaluate the ethics of the system. Since we only evaluated our system in a preliminary way, we do not have full information about unintended outcomes.

2.1.2 Fogg's Behaviour Model for Persuasive Design

To further help designers and researchers create persuasive technologies that promote behaviour change, Fogg introduced a Behaviour Model for Persuasive Design, essentially a design space for persuasive technologies. This model proposes that in order for a target behaviour to take place, three

criteria are necessary [21]. First, the person must be sufficiently *motivated*. Second, the person must have the *ability* to execute the behaviour. Third, if the first two criteria are met, there must be some sort of *trigger* to actually suggest the behaviour at an opportune moment. Fogg places the first two aspects as axes demonstrating a tradeoff between *motivation* and *ability* (see Figure 1). For example, even if a person's *motivation* is low, if you can make the target behaviour very easy to do (high *ability*), then it is likely a *trigger* will succeed in promoting the desired behaviour. Successful persuasive design will increase the position on at least one of the axes, or will provide opportune *triggers*. The seven tools described above can be used to affect ability or trigger desired actions.

This model provides important insight, and while perhaps intuitive, using the model allows an analysis more structured than intuition. It is intended to be used to study users and see how systems can better encourage them to achieve the desired behaviour.
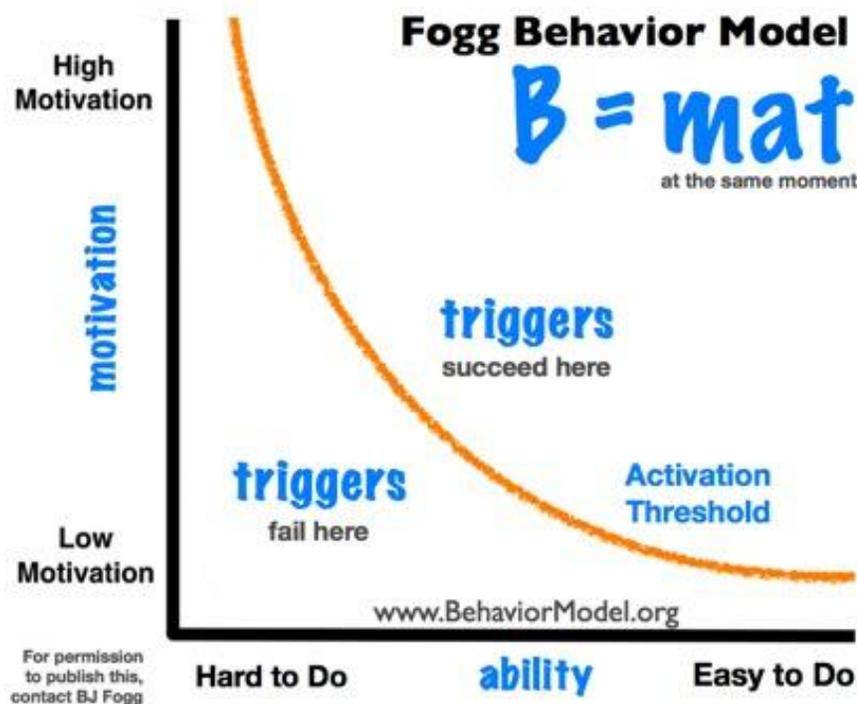
Figure 1 Fogg's Behaviour Model for Persuasive Design [20] (used with permission)

Fogg lists a number of specific factors that fall into the categories of motivation and ability, as well as three types of triggers. The core motivators are:

- Pleasure/pain: which focuses on the immediate response

8

- Hope/fear: which focuses on the anticipated outcome of the behaviour
- Social acceptance/rejection: which focuses on social norms as very strong motivators

It is also possible for these motivational elements to interact, and even counteract one another. One example from daily life is that people may be willing to endure the discomfort, or pain, of being hungry because of their longer term hope of losing weight.

Fogg also lists six elements of ability, to help define the simplicity of a behaviour. It is important to keep in mind that these elements can apply very differently depending on the individual. They should also be thought of as links in a chain - if any element is not simple, then the behaviour is not simple. The six elements of simplicity and ability are:

- Time: If the behaviour requires too much time, it is not simple
- Money: If the behaviour costs money is not simple
- Physical Effort: If the behaviour takes more physical effort, is less simple
- Brain Cycles: If the behaviour requires too much thinking, it is less simple
- Social Deviance: If the behaviour requires going against social norms, it is not simple
- Non-Routine: If the behaviour is outside of routine, it is not simple

The simplicity of the behaviour is assessed at the time that it is triggered. People can be persuaded to do things even if they are not particularly motivated, as long as it is easy enough for them to do.

Lastly, Fogg describes three types of triggers:

- Spark: Trigger with a motivational element
- Facilitator: Trigger that also makes the behaviour easier to do
- Signal: "pure" trigger - i.e. a reminder

These types of triggers should be used appropriately to help increase whichever of the elements is lacking.

2.1.3 Other Models

Other models of behaviour change have been used in HCI research, including the Transtheoretical Model, or stage-based model of behaviour change [48]. This model divides people based on the stages of pre-contemplation, contemplation, preparation, action, maintenance and termination.

He et al. incorporate the Trantheoretical Model and acknowledge that it is necessary to target eco-feedback design interventions to the individual because of the different stage and unique circumstances they are in [28]. We take this into account and consider people and their individual circumstances in our design implications. However, their work focuses exclusively on the motivation axis of Fogg's Behaviour Model. Consolvo et al. also draw from the Transtheoretical Model and other psychology research, but their focus is more about lifestyle-related health behaviour change, which was also the original intention of the Transtheoretical Model [12]. With this type of change, it is difficult for technology to be able to increase ability. Once again, Fogg's Behaviour Model allows consideration of a fuller picture of how technology can help. While perhaps less used historically, we argue that Fogg's Behaviour Model offers a holistic perspective for the type of behaviour change being targeted in this work.

Hekler et al. attempt to bridge the gap between behaviour change research in HCI and established Behavioural Theory [29]. In this work, we leverage existing theory and concepts, combined with our own empirical research into the practices of households in this specific context to present "design hypotheses" to be validated in future designs and deployments.

Many other theories of behaviour modification exist. Classical concepts such as operant conditioning (positively reinforcing or punishing certain behaviours) are considered throughout this work, particularly with respect to the monetary incentives. Operant conditioning is part of the larger discussion of increased motivation, ability and triggers. However, operant conditioning through positive reinforcement can lead to the "over-justification effect" [38] where the incentives or rewards reduces intrinsic motivation. Countering the over-justification effect is self-perception theory, which argues that attitudes are influenced by behaviour. Other theories abound: balance theory, cognitive dissonance theory, social comparison theory, discursive practices, etc. At heart, these theories examine how attitudes and behaviours are linked, and these theories are implicitly incorporated into Fogg's Behaviour Model. Many of the psychological theories of the link between attitude and behaviour or of behaviour change can be mapped onto these dimensions of Fogg's Behaviour Model.

2.2 Existing Programs and Technologies for Addressing Peak Electricity Demand in Homes

2.2.1 Programs in Ontario

Ontario has two programs in place that take aim at smoothing the peaks in electricity demand: Time of Use pricing and the peaksaver program. Time of Use pricing is widely deployed in the province, and aims to level the daily peaks in demand by offering cheaper prices for electricity overnight and on the weekends. Peaksaver is an opt-in program that aims to tackle the critical peak problem by automatically reducing air conditioning use on hot summer days. The main focus of our exploratory work was with respect to these programs that exist in Ontario, since that is what our participants had been exposed to.

Here we present work that may not fall directly within the field of HCI, but is relevant to the two Ontario programs we use as context. In contrast to the HCI work presented later, much of the research discussed in this section is at the macro level which offers a different perspective to the micro level which is critical when assessing behaviour and behaviour change and how it fits into current practice.

2.2.1.1 Time of Use Pricing (TOU)

While many variants of differential pricing of electricity exist, Ontario's TOU pricing scheme varies the price of electricity throughout the day at three different levels (off-peak, mid-peak and on-peak) on a consistent schedule. This schedule has two different seasons, nominally summer and winter, and thus changes twice per year on May 1st and November 1st. Overnight (7pm to 7am) is always off-peak, as are weekends and holidays. As of May 2014, 95.9% of households and small business pay these variable rates for electricity in Ontario [43]. Figure 2 shows the breakdown and prices as of May 1st, 2014, in the same form as it is commonly communicated to consumers. TOU pricing is made possible through smart meters, which were installed in Ontario homes and small businesses starting in 2005.
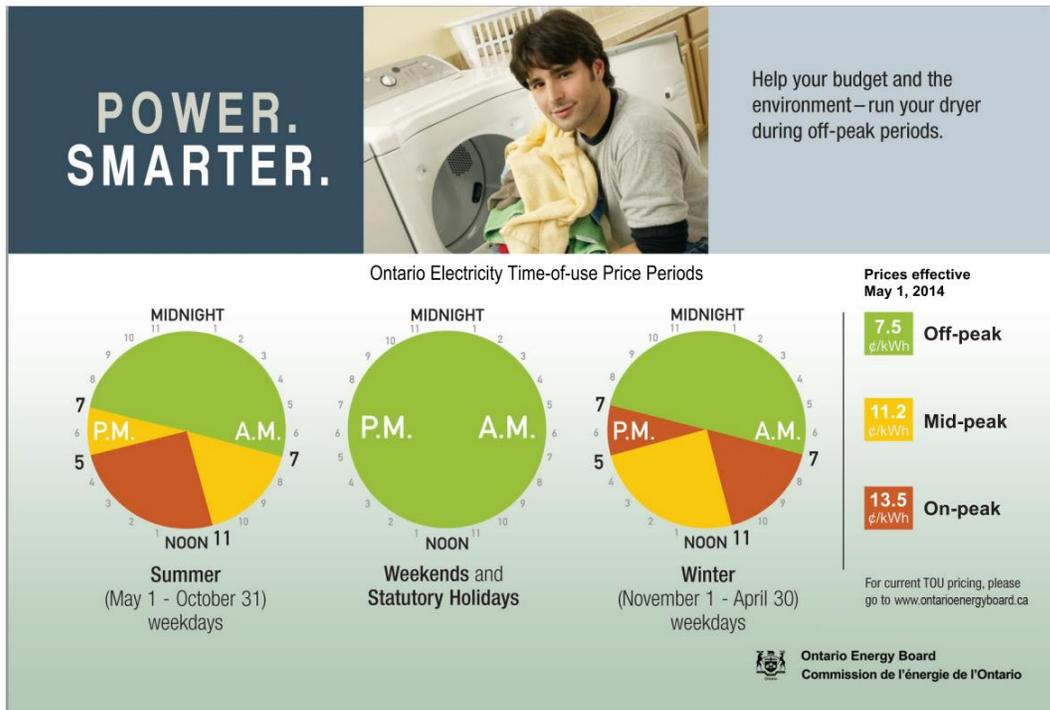
Figure 2 Sample communication from the Ontario Energy Board about Time of Use pricing [44]

Because of the scope of the Ontario model of TOU pricing, several researchers have explored the effect of the program. Strapp et al. found that TOU pricing does encourage some shifting, and there is often a small net conservation effect when the shifted consumption is less than the peak period reduction [55]. Other quantitative research on TOU pricing includes work by Rowlands and Furst, who explored the monetary impact of TOU pricing in Ontario on consumers [51]. For most customers, bills changed by less than 5% in either direction.

When considering the potential financial impact of TOU pricing, it is important to keep in mind that about half of the typical electricity bill in Ontario is allocated to distribution charges and fees. In practice, the overall financial benefits for many consumers from shifting usage due to TOU pricing are small, particularly when considering that paying for electricity makes up only about 1.8% of average total household expenditure in Ontario [50]. This makes the percentage impact on the bill of shifting consumption smaller than one would expect when looking at the given price differential from peak to off-peak times.

There is work that suggests that the details of the chosen implementation of TOU pricing in Ontario is neither optimal nor effective [1]. Adeptu et al. study the data from Ontario and find that the price levels should change four times per year instead of twice, and the actual times associated with on, off- and mid-peak should vary at these times as well. For example, currently it is always off-peak after 7pm, whereas they find the transition to off peak should not happen until 10pm in the winter.

2.2.1.2 Peaksaver

The peaksaver program is an opt-in program, designed to address critical peaks in electricity consumption [63] . Residents of single-family homes with central air conditioning are offered a free internet-connected, programmable thermostat. The peaksaverPLUS program also offers an in-home energy display (see section 2.2.3 Devices and Technologies) for new or existing peaksaver customers. In exchange, the utility installs a controller on their air conditioner. During critical peak load times, the target temperature of the air conditioner is either increased by up to 2ºC or cycled off for 15 to 30 minutes every hour for up to four hours at a time. These events are usually restricted to weekdays between certain hours (e.g. noon to 7pm). The details of the implementation are up to the local utility. They are generally also limited to maximum of 10 times per year, but in practice occur less frequently.

A report from the Ontario Power Authority analyzing the summer of 2012 (the most recent report available at the time of writing) indicates that there were approximately 180,000 peaksaver control devices installed as of December 2012 [54]. From their analysis, they find that peaksaver is capable of relieving 87MW from the electricity grid during 1 in 10 year extreme weather conditions, or 69MW in more normal weather conditions. For context, the yearly top five peak demand events since 2010 are generally 23,000MW and over [64]. As of summer 2014, the number of peaksaver load control devices installed had grown to over 190,000 [45].

Examining specifically the peaksaver program in Ontario, Singla and Kehsav suggest that there are not enough people participating in the program on a voluntary basis to significantly impact consumption [52]. They devise a scheme that would pay participants up to $2 per degree hour that they increased the setpoint of their thermostat in the summer (for central air conditioning) and demonstrate that this scheme would still reduce operating costs in Ontario by $688 million in the next 20 years, by eliminating the need for the construction of new power plants. Their model works by identifying 3 groups of consumers - altruistic, medium and selfish - where altruistic people would

already join peaksaver for free, selfish would never participate, and the medium group would participate proportionally to the financial incentive.

2.2.2 Programs Beyond Ontario

The Ontario peaksaver program is one example of a program dealing with critical peak electricity load, but many other programs exist. These include demand response programs similar to peaksaver but implemented differently, critical peak pricing programs, and rebate programs

2.2.2.1 Real-Time and Critical Peak Pricing

Real-Time electricity pricing passes on the actual in the moment cost of generating the electricity on to the consumer. In Ontario the wholesale electricity market is managed by the Independent Electricity System Operator (IESO), by accepting bids and offers from suppliers and consumers to set the price. Many industrial electricity customers on Ontario are charged these real-time prices.

Critical peak pricing is a scheme that approximates, though simplifies, the real time pricing of electricity described above by significantly increasing prices that consumers pay when the real cost of electricity is at its highest. Critical peak pricing schemes were piloted for households in Ontario, along with a similar, though less effective program that offers critical peak rebates to customers who reduce consumption at these peak times [55]. In the end, they were not implemented in Ontario.

Strengers studied critical peak pricing in Australia, with day ahead notice by email or phone call [56]. In this scheme, prices increased by 10 to 20 times on hot weekday afternoons, and reductions in consumption of households of up to 50% at critical peaks times was found. Most were motivated by trying to "do the right thing" by helping with the "problem" despite little knowledge of what they were helping. They got the impression there was some sort of crisis situation. In some way, they were motivated by fear. She found that those who participated in the critical peak pricing program were more likely to sacrifice their comfort for short periods of time.

2.2.2.2 Other Programs

Those with a Nest thermostat (see section 2.2.3 Devices and Technologies) and who get their electricity from a partnered utility company have access to a program called Rush Hour Rewards [65]. Participants are rewarded with money, up to $250 (the value of a free Nest thermostat) for signing up or US$1.25/kWh saved compared to normal during "Rush Hours", which are simply an

analogy for peak load times. With this feature enabled, the Nest thermostat pre-cools the home, then ensures that the air conditioner runs only intermittently during peak times. The user can override the Rush Hour if desired, though potentially sacrificing their rewards depending on the implementation of the program.

2.2.3 Devices and Technologies

2.2.3.1 In-Home Energy Displays

In-home energy displays (IHDs) are devices that show the current electricity consumption on a display in the home. Often information about the price of the electricity and consumption history is also included. Certain IHDs also include a colour-coded ambient display that could indicate the TOU price level [66], the total consumption in the home surpassing a threshold [56] or whether there is a critical peak occurring [56].

As indicated above, new signups for the peaksaverPLUS program, or existing peaksaver participants who re-enrolled in peaksaverPLUS were provided with an IHD.

2.2.3.2 Programmable and Internet-Connected Thermostats

Programmable thermostats allow users to enter a schedule for the setpoint temperature for heating or cooling their home, instead of leaving it constant. In theory, they could program the schedule to coincide with the TOU price points to reduce consumption at the expensive times. The issues that come up in practice with programmable thermostats are discussed above.

Internet connected thermostats allow users to control temperature and schedule remotely, often through a browser or smartphone application. This is particularly interesting from the perspective of addressing peak load, since it allows changes in the settings from afar, which could include reducing the time the air conditioner is running by turning it on dynamically in time for the house to be cool. The thermostat provided by the peaksaver program is one such thermostat.

A well-known internet connected thermostat is the Nest thermostat [67]. It has gained popularity due to its industrial design and the marketing of its machine learning features. It has been studied in the HCI and ubiquitous computing community from the perspective of home automation [59,60].

2.2.3.3 Other Technologies

There exist other technologies that could support reduction of electricity consumption at peak load times. These include programmable and remote controllable power bars or outlets such as the Belkin WeMo line of products [68]. Many of these products are marketed more as home automation gadgets, with the potential for reducing electricity consumption as a peripheral potential benefit. This is likely because given the current pricing of both the devices and electricity, they only offer negligible cost savings. Other technologies include Kill-A-Watt [69] and similar plug level awareness mechanisms for increasing awareness of the consumption of specific appliances.

The increasing inclusion of delayed start timers on major appliances such as the dishwasher and washing machine would also fit in to this category. In theory, these allow users to delay the start of the appliance to off peak times.

2.3 Sustainability and Electricity Consumption Research in HCI

Creating a sustainable future requires contributions from a large set of disciplines – engineering, green design, and renewable generation, among others. HCI has made valuable contributions, from evaluating eco-feedback mechanisms to prototyping future smart grid infrastructure. These and many more are discussed in this section.

2.3.1 Thermostats

Given the importance of the impact of home cooling on peak electricity demand, thermostats have been an interesting area of study. Recent research has shown that programmable thermostats are no longer considered an energy saving tool, and have lost their EnergyStar designation because the difficulty programming the thermostats is such that many people do not use them to maintain an energy efficient program [40]. Those users who do make use of the thermostats appropriately are often those who were already setting back the temperature manually [40]. In the context of Fogg's Behaviour Model, programmable thermostats, because they are difficult to program, require a significant effort to use, representing low ability. Given low ability, only those with high motivation will bother to optimize the use of these devices. This is in contrast with the intended purpose of programmable thermostats - eliminating the need to make manual setbacks which, in theory, should increase ability to perform the behaviour. Improvements in interfaces, the application of user-centric machine learning, and remote interfaces to over-ride defaults are currently being explored as paths to

significantly enhance the effectiveness of programmable thermostats [24,36,67], and all of these are within the scope of HCI research. However, the traditional focus on research in this area has been on either reducing consumption as a whole, or from the perspective of smart home automation. While we can learn from this existing research in terms of how systems integrate with daily life, learning how to fit in control of home comfort with reducing consumption at peak times has yet to be explored.

2.3.2 Eco-Feedback

A large focus of research both within the HCI community and beyond for reducing electricity consumption has been in the area of eco-feedback. This is the use of IHDs or other methods, such as the power-aware cord [25], for communicating resource consumption information to the consumer, with the intention that if they know more about their consumption, they will be inherently motivated to reduce it. A number of survey papers e.g. [15,23] have indicated that the actual reduction in consumption is rarely more than 5-15%, and is often less, especially over time. In particular, Hargreaves et al. studied the impact of IHDs in the home in the UK over the course of a year [27]. They found that over time, the IHDs faded into the background of everyday life. While they did find that the households learned more about their electricity consumption, the IHDs themselves did not specifically motivate changes in behaviour. They also found that households became more aware of the limits of their choices as an individual, leading to frustrations in the impact they could make. In Ontario specifically, it was concluded that there was no measurable, statistically significant conservation effect from the IHDs distributed as part of the peaksaverPLUS program [54]. However, this report also notes that the IHD was attractive to participants enrolling in the program.

Depending on the design of the IHD, it can actually lead to much confusion and inaccurate deductions about consumption, such as seeing certain high consuming small appliances like the kettle or coffee maker as big culprits because they cause instant consumption to spike [8]. In reality, the bigger culprits are more in the background, either from phantom load or steady load appliances such as the refrigerator or air conditioner.

Strengers examined smart metering demand management programs in Australia [56], which included the use of IHDs along with a critical peak/TOU pricing scheme. Based on interviews with 38 households, she notes that the decisions people make about using resources for the comfort and cleanliness of their homes is much more complex than a rational decision about optimizing resource

consumption or cost. Specifically, programs and technologies that seek to foster behaviour change should consider the social context [56], which we aim to do in this work.

Much of the work studying eco-feedback has also been quite limited in deployment, with a few exceptions, e.g. [18], which studies a deployment at a city-wide level.

2.3.3 Going Beyond Increasing Awareness

Some argue that HCI researchers have, to date, only provided limited contributions to reduce electricity consumption in homes. Brynjarsdóttir et al. provide a review of HCI research in persuasive technology for sustainability from 2009 to 2011, and argue that much of the research done so far has focused on making users "more aware" of their consumption, which is taking a limited view of the problem [9]. Pierce and Paulos express similar views in another review of HCI research that emphasizes eco-feedback [46]. The assumption made in the work they analyze is that awareness inherently leads to behaviour change. Using the Fogg's Behaviour Model, many of these awareness tools, such as a display that is visible in the kitchen, can at best act as a trigger to those whose motivation and ability are already high.

Among other further avenues of research, Pierce and Paulos also suggest that investigating demand response technologies could be particularly interesting from an HCI perspective, given the deeper behaviour change that would be required [46]. Our work forays into this area.

Boucher et al. [7] discuss the intricacies of the electricity grid in the UK, including problems of peak load, however the designs they present continue to focus predominantly on increasing awareness of the problem to consumers. On the other hand, they do go beyond simple electricity consumption feedback and leverage community involvement, including making people aware of how their individual actions contribute to a greater overall effect given wide-spread participation.

2.3.4 Focus on the Human and Everyday Practice

Strengers gives a name to this practice of designing for increasing awareness: designing for "Resource Man" [58]. This fictional faceless character is interested in technology, educated, motivated to manage his resource consumption in a fully rational way, and stereotypically male. She argues that we must go beyond designing for resource man, since he is completely abstracted from the

18

lived experience of everyday life. Instead, there needs to be more focus on the individual. Others have begun to respond to this call, and we follow suit.

Pierce et al. investigated [47] how people consume energy in the home. They defined a vocabulary of energy-conserving interactions, including cutting, trimming, switching, upgrading, and shifting. They have some interesting findings, including emphasizing the importance of defaults, and suggestions such as "1-click" cutting, i.e. taking advance of Fogg's principle of increasing ability, or reduction. They also have similar findings with regard to small absolute monetary amounts seeming insignificant to certain people. The last concept, shifting, is not fully explored in the findings in this particular study, which instead focuses on electricity consumption as a whole.

Katzeff and Wangel [33] emphasize the emerging perspective of considering peak demand in the context of social practice theory. They argue that this perspective allows a more holistic view when considering people and their practices in context beyond the technological viewpoint of the smart grid. Strengers has also written about this [57].

Nyborg and Ropke [42] study consumer flexibility in Denmark, with regard to new smart grid approaches given an increase in wind power combined with new consumption areas for electricity including head pumps and electric cars. They specify which groups are more or less flexible, and why.

2.3.5 The Future of Sustainability Research in HCI

There has been an increasing amount of meta work and reflection within the HCI community about how this field can best impact sustainability, and the challenges along the way. For example, Hakansson and Sengers [26] present their thoughts and experiences with trying to design technology to make meaningful change in sustainable HCI. Instead of trying to learn *about* their past study participants of simple living families and organic food farmers, they attempt to learn *from* their participants, and think of them as designers, since they are already designing their own resource unintensive lives. They question what the *best* role is for HCI in sustainable design, and present 5 dilemmas present in sustainable HCI research. These include:

- **Constant rethinking** which can be exhausting both in the design and criticism space, and impede "progress"

- **Scale of change**: which is limited in many HCI studies. However, from their participants they learn there can be significant value in small changes in everyday life because it is what people are actually able to do
- **Finality of change**: since it's such an ongoing process, there is never real success
- **Sustainability of change**: there is little knowledge about sustaining the change over time. They learn about many ways to make changes from the families
- **Being in vs. out of the system**: there are tensions of wanting to live more simply, but potentially giving up influence in society as a result. They present a parallel with the research community, which requires travel to conferences, usually via airplane, which can be in tension with personal sustainability goals

We came across a number of these dilemmas throughout this work.

Knowles et al. [35] explore persuasive technology for sustainability from the perspective of persuading users to change their values, and argue that the type of motivation is extremely important. They draw from work in Value Sensitive Design [22]. They explain the concepts of positive and negative spillover – where the type of value that motivated the behaviour (intrinsic or extrinsic), is a determining factor in whether that person will adopt other related behaviour. For example, someone who is financially motivated to reduce electricity consumption may not be motivated to recycle because there is no financial incentive, in contrast with someone who is motivated to reduce electricity consumption because of environmental concerns. They present a set of patterns and anti-patterns for good design of persuasive technologies for sustainability, which include Broad Self-Transcendence, Consistency in the motivation and information presented, Designing to the value, which emphasizes addressing the cause of behaviour as opposed to simply removing barriers to unsustainable behaviour, goes in contrast with the increase ability axis of the Fogg's Behaviour Model. On the other hand, there is little discussion about *how* to actually persuade a change in values. The remaining patterns include to Facilitate reflection (in contrast with simply providing information), and Measuring impact ripples to go beyond incremental impact and change. The deeper look that they bring to the problem of long-term sustainability is necessary where it has been shown that less intrusive interventions have failed. The case of demand response to critical peak load has of yet been relatively unexplored beyond price adjustments and utility driven programs. We intend to start work at a more practical interventionist's level.

2.3.5.1 Prototyping for the Smart Grid

The way everyday consumers interact with the energy grid is changing, as a result of inconsistent availability of electricity from renewable sources, micro generation (i.e. household solar panels and turbines), and local storage of electricity. The increased complexity of this smart grid means that households will be taking on a new role [33], and exploring this area is becoming increasingly common in recent HCI work, particularly with regards to interaction with "smart" agents [14,49,60].

Rodden et al. [49] used animated sketches to communicate potential smart grid agent implementations, and gather responses to users impressions. They found that while there was some level of feeling obligated to engage with such systems, participants were largely disinterested and were not trusting of the energy companies who designed these agents. Costanza et al. explore a future scenario with inconsistent renewable sources and real time electricity prices based on supply and demand, as well as each home having a battery that could be charged at cheaper times [14]. They prototyped and deployed a system for a month where 10 households could schedule a time to run the washing machine, based on predictions of electricity prices. The found the system worked well for some people, while others were more spontaneous in their laundry habits and had difficulty planning ahead. They discuss the tradeoff of utility versus convenience, but suggest that systems like this are in our future. They emphasize that future systems need to carefully consider the balance of retaining control vs. making things simpler. In this study, the focus was not on persuading users, but studying the effects of the system with the financial incentives provided.

2.4 Summary

The field of human-computer interaction has a lot to contribute to research in sustainability. In recent years that has been an emphasis on getting beyond a limited view of awareness mechanisms labeled as persuasive technology. There have been a number of calls to action that emphasize how new designs must integrate with social practice, and go beyond designing for Resource Man, as well as to consider problems that have a higher potential impact. The wealth of ideas and suggestions for research going forward in this area is inspiring and shows how important making real change in this area is to the community.

We bear in mind the findings and suggestions of others throughout the work presented in this thesis. The target of peak electricity demand in Ontario is an area that has been shown to have

important impact not just on the environmental side, but also on the social and political landscape. We interview households to learn about their current practices as a result of the current programs, learn from what is working about the current programs, and aim to design technology that can help address the shortcomings. Through the use of Fogg's Behaviour Model, we focus on persuading and inciting behaviour change in the individual when presenting the design implications for persuasive technology that arise from our findings. While doing this, we incorporate the macro findings from the more traditional study of demand response programs, as well as learn from their mistakes.

Chapter 3 Interview Study

We set out to learn about the effect of TOU pricing and peaksaver on the electricity consumption practices of Ontarians. To achieve this, we conducted interviews with a variety of participants.

3.1 Objectives

There were a number of objectives for the interview study. The first objective was the to gather information about the current practices of Ontarians at peak load times, and answer questions like are they aware of these times? Do they understand the impact? What changes are they willing to make? The second objective was to learn about their experiences with TOU pricing and the peaksaver program, and how this affects their consumption habits, i.e. to find out what is working well with existing habits, and where there is room for improvement.

3.2 Overview

The study consisted of 18 semi-structured interviews that took place in person, by phone or by Skype. Including the option for remote interviews allowed us to interview participants from a broader geographic area to allow for a more representative sample. Participants received a $20 gift certificate to use at an online retailer as remuneration for their time. This type of remuneration was chosen for its ease of distribution to remote participants - the code could be emailed to them.

An initial set of participants was recruited through an email list of Graduate students at the University of Waterloo in the summer of 2013. In order to reach broader demographics, additional participants were recruited in the summer of 2014 using online classified ads throughout Ontario, word of mouth and posters in local community centres and libraries. In certain cases, snowball sampling was used in order to reach more participants in various categories, including those with a Nest thermostat or those who participate in the peaksaver program. Participants were pre-screened before being interviewed in order to ensure a variety of participants with respect to age, household composition, what type of dwelling they inhabit, whether they have central air conditioning, the type

of thermostat they use, and involvement and knowledge about the peaksaver program. Interviews lasted between 30 minutes and 1 hour.

Given that the research involved human participants, approval from the Office of Research Ethics was obtained before conducting the research.

3.3 Interview Topics

The interviews were semi-structured in nature. They started by explaining the details of the study, and gathering consent. Next, we went over the pre-screening questions to confirm the answers to the demographic and high level household practices, and to gather more context for the basic survey replies.

Moving into the body of the interview, we had a set of topics and some starter questions to discuss. They were also open ended in order to accommodate specific habits, devices and programs of the participants.

The list of topics included:

- Usage of air conditioning
- Control of the thermostat
- Awareness and consideration of TOU pricing when making consumption decisions
- Awareness and consideration of peak load times
- Thoughts about various existing demand response programs and pricing schemes
- Awareness and consideration of the peaksaver program specifically

At the end of the interview, participants were asked if they had anything else they wanted to discuss on this topic. In some cases, this resulted in additional insights.

3.4 Participants

We chose to start with a population of graduate students since it provided a balance of those with a university education who are predisposed to making consumption changes [41]. For some of these participants, it was expected that small monetary incentives would be at least somewhat meaningful. A number of our participants recruited in this way were actually part time students, or lived with a significant other who was working full time, so this was not always the case even in these first

24

interviews. Additionally, among the first 12 participants, there were 2 who were not students in any form, but were reached through snowball sampling of initial respondents who knew others who used the Nest thermostat.

After analyzing the data and assessing our findings, we wanted to explore the practices and considerations of additional demographics to see whether our findings were generalizable. We aimed to target those approximately 40 years of age and older, perhaps with children, both with and without central air conditioning. This population was underrepresented in our initial interviews. These participants were targeted through word of mouth, further snowball sampling, online classified ads, and posters at local community centres, libraries and bulletin boards.

Table 1 provides further information about the diversity of the participants we interviewed.

Table 1 Demographics of Interview Participants

Age	20s: 6
	30s: 7
	40s: 5
Gender	Female: 13
	Male: 5
Air Conditioning	Central Air Conditioning: 14
	Portable or window: 4
Lives with	Partner only: 6
	Partner and children: 5
	Parents (with or without siblings): 3
	Roommates: 3
	Alone: 1
Peaksaver	Enrolled: 3
	Previously enrolled: 1

Based on the results of the interviews, there were no apparent trends in demographic data that reflected in the sustainability practices of participants. For example, we found examples of both

students and non-students who made extensive use of air conditioning, and also examples of both who were reluctant to turn it on.

3.5 Analysis Process

In order to conduct a thorough analysis, all interviews were audio recorded, which complemented the interviewer's notes. The interviews were transcribed for analysis. A Grounded Theory approach was used for analysis of the interview data [13]. The Grounded Theory method is a bottom-up analysis approach where data is collected and analyzed by categorizing concrete examples into codes, and eventually combining these to extract theory. In our case, the data comes from the interview transcripts.

The specific tool used for analysis was an affinity diagram, which allowed for incremental, open-coding of the data, and is a common and well established analysis tool in Contextual Design [5], which itself is heavily based in Grounded Theory. The interview transcripts were reviewed thoroughly and all relevant comments were summarized and transcribed onto post-it notes, along with the participant identifier. The affinity diagram itself is built by picking up a note, considering its content, and placing it on the wall in close physical proximity to related notes on the wall in an exploratory process. Notes are free to be re-arranged until those building the diagram reach a consensus. The notes that are in close proximity at the end of the diagramming process are given a label that represents the salient point. These themes are then grouped further as appropriate, and the end result is a hierarchical view of the data with emergent themes.

The 4 themes and 16 top level clusters that resulted from the analysis are presented in Chapter 4. Once the themes were identified, they were analyzed again using Fogg's Behaviour Model, by discerning which category of the model (motivation, ability or triggers) that theme fits with, i.e. is lacking in or does well.

Figure 3 Affinity Diagram

3.6 Limitations

While we did our best to speak to a wide variety of participants by expanding our participant pool, we certainly do not claim that is a fully representative sample of Ontario. The response rate for our online classified ads was higher in the urban centres, likely due to increased population density and thus viewership. Despite this, it is important to note that the political situation from the canceled power plants is also particularly relevant in the Greater Toronto Area.

The interviews were generally conducted with only one member of the household. One limitation of this is that we may not have gathered the full picture of the household, but on the other hand, this allowed us to gather the unbiased perspective of that particular member of the household whose voice may have otherwise been drowned out. Examples of this included adult children living at home, or those in a roommate situation where control was not shared equally. By including some participants who were not necessarily the primary controller of the thermostat or instigator of other consumption activities ended up providing additional insight, and helps to remind us to avoid designing for Resource Man by considering the other members of the household [58].

The decision to allow the option to interview participants over the phone or via Skype was made for convenience of the participants. In certain previous work, the researchers have visited the homes of the participants for interviews and a walk through, aiding the interviewees in recalling and allowing the researchers to learn more about the context of their actions (e.g. [56]). In an ideal world, we would have done the same. However, lack of resources made this infeasible. While in person interviews were preferred (on campus), once they were taking place outside of the home, we decided that allowing for remote interviews would allow us to reach a broader range of participants and so it was worth the potential trade-offs.

Chapter 4 Findings and Analysis

This chapter reports on the findings from the interview study, after the affinity diagram analysis. The findings are divided into the themes identified. The various high level clusters that were identified from the affinity diagram serve as subheadings, with details and quotes from participants.

When creating the affinity diagram, there was much deliberation about grouping codes in a cross-cutting way, or separately with regards to the daily or critical peaks. We eventually decided to keep the analysis of the two separate, and that is how they are presented here. The learning from both are cross-cut in the presentation of design implications. There were also two additional themes that did not fit in the context of peak load or shifting per se, but arose in our interviews and are very relevant to the design of programs and technologies to reduce peak electricity demand.

The themes identified are: Daily Peaks and TOU Pricing, Critical Peaks and peaksaver, Home Comfort and Cooling, and Desire to Engage. Some aspects of the last two themes are included in the first two themes, but they were significant enough to warrant a high level discussion.

4.1 Daily Peaks and TOU Pricing

The purpose of time of use pricing is to encourage shifting of consumption to the off-peak times of nights and weekends by creating a price differential that favours the off-peak times. These prices have been implemented for several years in Ontario.

TOU pricing provides a financial incentive to persuade electricity consumers to change their behaviours. As well, an awareness of the different cost levels of electricity also provides some guidance to consumers on how, specifically, they should modify their behaviours, i.e. avoid peak-period use because it is more expensive, but also because it is worse for the environment. In practice however, the overall financial impact for many consumers from TOU pricing is small [51]. This raises an interesting question within the scope of time-shifting of electricity consumption. Do consumers shift? And if they do, how much do they shift and what limits exist with respect to

shifting? We analyze these questions in this section, and, in Chapter 5, we use this analysis to derive a set of design implications for technology to promote reducing consumption at these peak times.

4.1.1 Money Incentivizes Easy Shifting

There was a common sentiment of why not shift usage if it saves a bit of money and is convenient. This was particularly evident with respect to doing laundry and running the dishwasher, where shifting was very common behaviour among those participants who were aware of TOU pricing. The consensus was that the off-peak times are a convenient time to do laundry and dishes for those with a regular weekday working schedule. As P4 notes, *"most of the stuff I do is probably during that time anyway"*.

On the other hand, many participants noted that, without the potential to save money, they might not consider load shifting, and that the money causes them to act. P7 indicates that *"our schedule lends itself to that, but you know, it is convenient in a way, but yeah, no it's just to save a little bit of money"*. For P4, *"if it works in your schedule, any money is worth it",* since *"money is a tangible thing, where you're like 'I'll wait that extra hour'"*. Although we probed, we found little evidence that participants were motivated by sustainability concerns when shifting usage.

Correspondingly, it came up with our participants that when they were not paying TOU pricing, many did not pay attention to the time that they ran certain appliances. P5 paid little attention to when she did the laundry while staying with her parents in a different province, since they did not have TOU pricing. P16 made the explicit choice to sign up with an alternative energy provider that offered mid-peak pricing at all times. She explained that *"I find it a big pain and I don't like getting those prices jacked up, you know, I understand the concept of it, but I don't like it. So I am glad that we have just the set pricing, and I don't have to worry. I can use the washing machine or dishwasher whenever I want"*.

In summary, when it is convenient for participants, i.e. when ability is very high, the pricing differential was valuable in fostering behaviour change.

4.1.2 Not all Shifting is Easy

Another interesting question to explore is the limits of shifting usage. As we explore the limits on time-shifting consumption, we note that the perceived cost of shifting heavily influences what shifting

occurs. Typically, this is represented on the ability axis in Fogg's Behaviour Model. There was a clear spectrum of how much participants were able and willing to shift their electricity consumption to off-peak times, particularly with regards to specific activities. As discussed above, certain shifting was very common (laundry, dishwasher), but not fully ubiquitous. P17 worked from home, and found it convenient to do laundry at lunch time. She was fully aware that it cost a little more, but felt that *"I'm also like, I don't want to do this tonight, when I'm tired, so, I'll pay the extra"* combined with justifying the small expense by saving money in other ways.

Cooking was an interesting example for participants too, and behaviour fell on a continuum which varied from never shifting despite TOU pricing (P2), to saving long roasting for the weekends but using the stovetop on weeknights (P10, P11, P5), to P7 who stated *that "I've actually sat there like ok we're going to make dinner. Ok like I could start cooking at 6, but I'll just wait until 7".* P11 suggested that *"I think it would play a bigger role in our lives if say for example we were cooking a turkey dinner every day and using the stove for a long time"* i.e. that the magnitude of potential savings did play a role in some participants' decision making process. P16 found TOU particularly frustrating when it came to cooking: *"say I want my air conditioner fine, that's optional, I kind of, I get that, but say something like dinner and you know I'm getting dinged for you know, putting on the oven when that's supper time, so what am I going to do? I hated that".* A number of our participants had gas ranges, so this discussion did not apply.

One challenge with our research was that the act of probing created introspection in our participants that had negative consequences for sustainability. During the interview, P7 had a realization that she did not actually have a good sense of how much money she was saving from load shifting, but that *"it's got to be something but I have no idea how much it is".* After reflecting on the limited savings, she commented that she might think twice about waiting for 7pm to start cooking in the future.

4.1.3 Considering TOU in Home Cooling is Uncommon

One of the most critical aspects of electricity demand is the use of air conditioners during hot, humid summers in Ontario. Only two participants directly mentioned making explicit changes in home comfort using the thermostat because of TOU pricing or consideration of daily peaks. These included purchasing a programmable thermostat for use with both air conditioning and electric heat (P10) and pre-cooling the house to avoid using the air conditioner during peak hours (P2). Other participants

had programmable thermostats, but either did not program them or did not consider TOU in the process. Most focused only on the overall cost of using their air conditioner. Many also noted that they were more concerned about the temperature in their home for the comfort of family members - children and older parents at home during the day - guests and pets, as opposed to themselves. This resonates with Fogg's inclusion of social acceptance as an important contributor to the motivation axis [21], as well as Strengers' findings [56].

4.1.4 The Impact of Shifting is Unclear

It is important to note that our participants were, however, concerned about the environmental consequences of their actions, and the overall environmental benefit that collective action could provide, even if environmental concerns did not factor into their decisions to shift usage. A few participants raised concern about not knowing enough about the impact of their individual actions. Specifically, P5 explains she has *"a hard time visualizing what my little impact of not doing my load of laundry in the, during the day has on the broader system, although I recognize that if everyone was doing their laundry during the middle of the day it might be a bit of an issue".* While only a few talked about it directly, it was implied by others that, if they understood more about the impact, it might matter to them more intrinsically, as opposed to being motivated by small amounts of money. Without some awareness of the broader impacts of collective action, our participants, instead, weigh the cost versus inconvenience to them. This, in turn, can lead to fatigue in performing the desired behaviour, and, as Strengers notes, more limited high-level behaviour change [56].

4.2 Critical Peaks and peaksaver

Arguably of more importance in Ontario are the critical peaks that tend to occur on hot summer afternoons, particularly as a result of increased air conditioning use. This section first explores knowledge of, and behaviour at, critical peak load times and then examines the peaksaver program from the perspective of both those who have joined, and those who are unaware or uninterested in joining.

4.2.1 Few Understand Critical Peak Load

Having some awareness of critical peak load times and their significance is the first step towards having some non-zero motivation to reduce usage at times of critically high demand for electricity. For our participants, even this awareness is missing. Some participants were able to identify that peak

load times correspond to heat waves, but did not make the connection to the impact on electricity demand in the moment, at these critical peak times.

A number of participants did mention thinking about overall consumption when setting the temperature for their air conditioners, but with more concern about general electricity bill. P17 indicated that , *"I do try and avoid using it if I can, for you know, umm, billing purposes because it's expensive, and also too, I like fresh air better, so you know I only use it on very hot days".* P16 was an exception - while the behaviour was similar she had more nuanced motivation. She made a conscious decision to set her air conditioner *"fairly high, around like 24 degrees",* and explains *"we can have it a little warmer in the house, we don't need it freezing cold, it saves us some money, it's good for the environment, I know it's good for the "grid" or whatever you want to call it to help take off the strain, so you know, I was definitely aware of it and made that decision because of that".*

4.2.2 Taking Action is Hard

When asked directly about taking action or changing behaviour at peak load times, there was a common sentiment among many of the participants that they were already doing the best they could to reduce electricity consumption at all times, and there was not much that they could change and still live their life comfortably at critical peak times. Some were aware of the environmental impact and the small monetary cost from TOU, but comfort in their home took priority. P11 explains that *"I realize that I probably shouldn't be and I realize that you know, there's probably, every other person in this apartment building is probably doing the same thing, but I do want to be comfortable ".* For P8, *"being so hot, like it kind of trumps, like the amount, or the cost that you know you'll have to pay later".* It seems clear that, for many of our participants, the small financial impact from TOU pricing is especially ineffective at influencing motivation at critical peak times, where motivation is further reduced given the level of discomfort from the heat that causes the critical peak.

One issue that arose during our discussions with participants is that many people do not have any control over the temperature at work, and the choices made by their workplace did not correspond with what they might choose in their own home, either for comfort or financial reasons. P7 suggests that even at critical peak times, *"I don't change any of my habits at work"* because it's *"totally financially motivated, which makes me kind of sad".* P4 laments the lack of control at work, and was frustrated that it makes her own efforts at conservation seem negligible. P15 recalls *"I hated it going in to work and I had to dress like it was winter inside, it doesn't need to be that cold".* Overall, the

complaint that many of our participants voiced was that, in many situations such as work, even if they wanted to reduce consumption there was limited ability for collective action.

Not all participants were unwilling to act. Two participants who had only portable air conditioning units, P5 and P7, discussed going to work in order to be in the air conditioning there. P7 recalls discussing with her partner *"let's hurry up and go* to *work so we can get in the air conditioning"* while P5 was more concerned about the cost, and finds herself wondering *"how much is me laying [in front of the air conditioner] here going to actually cost me?"*

Beyond air conditioning, participants mentioned they would be extra careful to avoid large appliance use at these times, if they were aware of them, such as P17 who often did laundry during the day.

4.2.3 Others May Not Do Their Part

This idea of collective action was also significant when we discussed the threat of rolling blackouts or brownouts because of insufficient supply. P9 noted that *"we would try to reduce [consumption] but then we'd also probably get kind of annoyed when other people don't [...] we'd want that conservation to go on not just from us, we'd want it to be everybody"*. Similarly, P11 suggested that *"I would change my behaviour, yes, but then again if only one person changes their behaviour and no one else does, then it really doesn't help"*. The perceived threat and inconvenience of blackouts was a much bigger motivator for some more than others. For example, P17 explained that a previous blackout *"certainly put a monkey wrench in my day to day existence"* since *"we couldn't get gas for 3 or 4 days"*. On the other hand, P18 figured *"we're not going to be the only ones in the blackout, so it wouldn't really affect our usage"*, and says *"to me a blackout wouldn't be such a big deal"*.

A number of participants also commented on the practices of neighbors or relatives being noticeably inefficient in general. One participant knew others who had *"a really bad habit of running their air conditioning and leaving their windows open. And I think it's ridiculous, and I cannot understand why someone would do that"*. The question then becomes how to design solutions that reach those people too.

4.2.4 Peaksaver

One significant benefit of programs like peaksaver is that it increases ability to participate in conservation by eliminating any need for action on the part of the participant. The focus, therefore, shifts to persuading people to enroll in peaksaver.

Three of our participants were currently a part of the peaksaver program: P1, P3 and P17. P16 had been a part but when she switched energy providers to avoid TOU, that provider did not continue to offer the peaksaver program. P1 learned about peaksaver through an ad in the newspaper promising a free programmable thermostat, but it became clear in the interview that he was not aware of the fact that the utility had the option to cycle down his central air conditioner during peak times. P1 was actually quite averse to the idea of utilities being able to control his home air conditioning unit. The others learned about the program through the mail - either an insert with the electricity bill or a separate flyer. They had a much stronger grasp of what the program entailed, and joined for the purpose of putting less strain on the grid. As P3 put it *"it didn't seem like a big sacrifice"* and she suggested that *"I don't even think it really should be optional"*. We also found that, with the exception of P16, participants were unaware of changes to their air conditioning, and noticed no difference to their comfort level, which supports claims made in advertising materials. P16 noticed it was a little warmer in the house, but *"I totally understood that, made a lot of sense"*. This difference was likely because she set the air conditioning to 24 degrees, which was a higher baseline temperature than others. P12 knew people participating in the peaksaver program, and explains *"they've never complained about it"*.

Our other participants were unaware of the peaksaver program. Some may have heard something about the program, but, because of limited motivation, had not bothered to learn more. For these participants, we described the program and gauged their reactions, finding a continuum of opinion from being actively averse to the idea of someone else controlling some aspect of their home, to accepting utility control but not seeing enough benefit to themselves to bother joining. In other words, most participants acknowledged the goal of the program, and conceded that a change of only a few degrees would not have a big impact on their comfort, but the idea of losing control made them hesitate, or the incentives were not sufficient. Many participants noted that there was some aspect of "big brother" that they found distasteful.

With two days' notice, participants can opt out of peaksaver for a 48 hour period. We probed the issue of control and opt out with our participants. Some participants indicated that if they were to join, they would fully commit to the program, such as P4 who states that if she joined, *"I wouldn't want to go through the hassle of like opting out"*. On the other hand, being able to opt out in the moment, or in some way override the system in the moment, would be absolutely required for others to even consider joining. P9 would want ultimate control out of concern for her family *"they might not know what's going on in the house [...] maybe somebody has a kid who as a fever [...] as long as it's like, in the end, I've got the ultimate control over it, then that would be ok"*.

One positive aspect that interviewees brought up about the peaksaver program was that it supports collective action, and removes the burden of taking explicit action off them. P5 says she likes that it works on *"a collective rather than an individual basis"*. Additionally, P8 thinks it makes sense since *"it's not guaranteed that I or another person would make the changes"* and it *"at least guarantees some action taken"*. P17 likes that *"I don't have to think about it. Just one more thing off my list. It's not something I, you know, would worry about then. If they're dealing with it. I mean I'm not sitting there monitoring my email to find out, you know, what's going on with energy consumption in the province for example, they are, so to me that's a good thing. Also they know best what the demand is, right?"*

4.2.5 Incentives are Lacking

We also found that the incentives offered by peaksaver provided little motivation for our participants. P2, P9 and P12 already owned a Nest thermostat, and, for them, the programmable thermostat included with peaksaver was an active disincentive. Even if these participants were permitted to keep their existing thermostat, the lack of any incentive seemed, de facto, a disincentive. For example, P5 suggests that if *"there's some good benefit to it, then I would, I would definitely give it a try"*. P9 was even more convinced: *"if it was going to save money, then definitely"*. This was the case even for those who were extremely opposed to the idea of someone else having control over their home, such as P12 who suggested if a rebate occurred *"that would be a different story"* and would *"relax my concern of someone else being able to control it"*.

Because the desire for a financial incentive to foster participation in peaksaver was raised by our participants, we probed their thoughts of how a hypothetical financial incentive might work. In particular, most participants were more in favour of receiving a rebate for reducing consumption as

35

opposed to having prices increase at these peak times. P6 felt that increased prices would *"irk me. I'd probably do it (reduce consumption), but begrudgingly"*. P4 figures *"either way I would reduce it. It has more like a positive spin when you say you're going to give people money"*. While this discussion regarding monetary incentives was hypothetical, the preference for rebates over increased prices was clear. However, in a pilot study, the Ontario Energy Board found that increased prices resulted in more shifting than rebates of the same amount [55].

4.3 Home Comfort/Cooling

We discussed the use of air conditioning in the context of TOU pricing and peaksaver above, but we found some additional insights that did not fit in these categories. Learning about existing practices, even outside the context of existing shifting programs, is useful for designing new systems.

4.3.1 Comfort as a First Priority

The actual usage of central air conditioners during normal times (i.e. non critical peak) varied among the participants with central air conditioning. One kept it as high as 26°C and turned it off during the day, while another would keep it set as low as 18 or 20°C on a regular basis. Most were closer to 22 or 23°C.

A few participants discussed that as much as they are aware that there is an environmental impact, and they will be paying money for the electricity, their comfort in their home takes priority. P2 feels that *"I want to do the right thing [...] but it always ends up being the third priority"*. For P8, *"being hot trumps the cost you'll have to pay later"*. P18 expresses *"I think yeah, definitely, for a financial reward, we would definitely try and reduce our usage, but then again there'd be times when it's like unbearably hot and it just wouldn't matter regardless of the financial incentive"*.

Humidity was a big comfort concern for a number of our participants. For P12, *"if I can get the house comfortable by just running it briefly then that makes sense ... until the humidity kicks in, then all cards are off the table"*. Other participants mentioned being able to handle a higher temperature in the house as long as the air conditioner was running enough to act as a dehumidifier (P2).

4.3.2 Navigating Social Relationships is Hard

In addition to what was discussed above, where the comfort of guests and others is a priority when it comes to home comfort, there is also the social tension of the control of the air conditioning itself. P8

would most often control the air conditioning for her housemates, and prioritized their comfort despite not actually discussing what temperature they would prefer, because she *"wouldn't expect housemates to take initiative and adjust the thermostat"*. She recalled a situation on a hot summer day where *"it was pretty chilly down here (in the basement), but I knew that everyone upstairs was pretty hot so I just put on like a sweater"*. P4 described a tension with a roommate who took charge and turned on the air conditioning while she would have preferred to keep the windows open, but acknowledges *"if you live with people, you can't get your way all the time"*. P10 discussed family tensions where if he was uncomfortable she would *"just change it. But then he (father) changes it back, so it doesn't help very much"*. These findings reinforce the message that any designs in this area need to take into account the actual practices of households, which tend to be rather complex.

A number of others had no conflict or issues - either one person took primary control of the thermostat, or households had systems, such as the last person out turned off the air conditioning and closed the blinds.

A number of our participants commented on the practices of neighbours or relatives, but only in the context of others setting the air conditioning colder than they did. P16 explained *"I know my in-laws set it to you know 21 or 22, so ours is definitely warmer"*, and noticed that *"I hear our neighbours' either going constantly or kicking in quite a bit"*, but that *"I wouldn't do anything about, I'm not going to tell my neighbours what to do"*. P12 and P17 also expressed concerns over the habits of their neighbours, with P12 suggesting that he suspects his elderly neighbours never touches his thermostat, and P17 noted *"I'll sit there and hear my neighbour's air conditioning on, and it's like, really is that necessary tonight?"*

4.3.3 There are Additional Ways to Keep Cool

Many participants mentioned making taking additional actions to keep their home cool, beyond the use of air conditioning. Generally, the motivation of this was to save money from reduced usage of air conditioning, but for those with only portable air conditioning units, it was a necessity.

P15 mentioned a large tree in her backyard that *"provides so much shade, our house will stay comfortable"* even without central air conditioning, but if it dies they would need to install more powerful wall air conditioners. P5 and P11 mentioned closing vents to redistribute air flow. P4, P5, P8, P16 and P17 made explicit comments about the variation in temperature between different levels

or rooms of their homes. P16 explains *"certain parts of our house will get full sun so it's baking hot in the front of our house, but in the back, so I'll leave maybe the windows in the back just to let natural light in"*. Others mention relocating themselves to cooler areas of the house to stay comfortable.

The use of various types of fans was discussed by many as well. P15 had a fan in her attic that *"has made a significant difference at keeping the house cool in the summer"*. P14 explains "*I'll use the fan as much as I can until I can't take it anymore, then I'll switch to the a/c*", while P17 uses ceiling fans *"constantly"* and explains that *"it definitely helps"* to keep cool.

Getting suggestions from others also came up. P17 expressed concern that a number of others are unaware of these alternative ways of keeping the house cool: "*things like shutting the blinds. Like I think a lot of young people don't know that, to shut the blinds and - I didn't know it until I started living with my husband, and his mom and dad do that"*. P2 discussed comparing energy usage with a friend, and learned "*his explanation of just leaving it at 24 or 25 is why I went home and raised the temperature"*. After trying it for a few days, he *"was fine with it"*.

4.3.4 More Effort Means Less Action

Three of our four participants with portable air conditioners found them to be a "hassle" in a number of ways. Installing the unit itself took physical effort, and for P5 meant she could no longer open that window when the air conditioning was not needed. She also found the need to wear earplugs because of the noise frustrating. P7 found it easier to just sleep in the basement bedroom where it was cooler than to bother hooking up the portable unit. P15 uses portable air conditioners in her house's bedrooms for sleeping, but had a number of painted shut windows on the main floor meaning only a single unit could be installed, and *"we couldn't put them in a good location to benefit the whole floor"*.

4.4 Desire to Engage

4.4.1 Amount of Engagement Varies

There was also a range among our participants in terms of the amount they engaged with TOU pricing. Some all but ignored it, many had the 7pm threshold in their mind. There were also others were active managers that actually fit in to the "Resource Man" stereotype, particularly those who had adopted the Nest thermostat. On the other hand, P16, who signed up to avoid TOU pricing,

explains that she found engaging to be stressful: *"To be honest I found it stressful. I did not like it at all. Because I always felt hinged by this umm, time of use and I hated spending more than I had to, umm, you know, when it just wasn't convenient if I had to step out and then I missed that or whatever. So I actually thought about it way too much and I didn't like it at all"*.

P15 was also exceptionally engaged. She explains that *"we purposefully bought a dryer that uses natural gas instead of electricity so that should we choose to run the washer in the middle of the day, more of the expense for the drying was with the natural gas than with the electricity"*. She also found an *"obvious decrease"* in her family's electricity bill, because *"when they first uhh, initiated the time of use thing, we actually saw our bill go down. Because we paid attention to it and we ran things in off-peak hours".* Yet another example was scheduling a dehumidifier: *"I'm sure like most people we have a dehumidifier in our basement because it can be quite damp, and although in the summer it runs full time because it's, it just tends to be the dampest at that time of year, we do have it on a timer to that it runs 7pm to 7am on uhh weekdays and then it's run full time on the weekends to help control humidity".*

On the other hand, P8 and P14 had very little awareness of TOU pricing. P14 in particular, was confused about the impact and wondered *"if more people did this, would it help the environment? Or reduce costs?"* and *"The peak time, it doesn't refer to like, using appliances in the kitchen, does it?"*

4.4.2 Some Want Full Control and to Optimize

Given their potential to increase ability to make changes to air conditioning usage, we spoke to participants who were already using internet connected remote controllable thermostats, specifically the Nest thermostat, to learn more about how they fit in with their lives.

The Nest users we spoke to were clearly self-selected early adopters who had gone out to purchase the Nest thermostat, and were willing to invest the time in programming an optimal schedule for their needs. They were extremely engaged in optimizing but also very deliberately managing the comfort aspects of their home. P2 and P12 wanted to get more data, since what the Nest provided was limited to only 10 days' worth. They discussed conducting experiments in setting the temperature to reduce furnace usage, and fine tuning the schedule in the summer. P2 wanted the ability to make temporary changes to the schedule that would be in effect for *"only today"*. P9 was more concerned about optimizing energy savings and found that her family was able to beat an estimated seasonal bill by

close to $300. These particular participants were quite reminiscent of Strengers' concept of the fictional Resource Man [58]. While our interviews obviously did not focus exclusively on Nest users, it is worthwhile to note that while not getting stuck in designing for Resource Man is important, there are in fact people out there who fit his description.

Of the three participants with Nest thermostats that we spoke to, all three exclusively controlled the device from their phone, as opposed to interacting with the device itself or the full web interface on the computer. P9 indicates that she *"maybe used the computer once. It works so well on the phone that I just never bothered"*. P2 sets the Nest to Away mode *"in the car before heading to work"* since he found it hard to do on the device itself.

4.4.3 Others Do Not Want to Devote the Mindshare

We also gathered the thoughts of those who did not have a remote controllable thermostat, to understand if this is something they would like to have and use. P4, P7 and P10 thought it might be a feature that is nice to have, but did not imagine using it every day or did not think it was important enough to spend the money on. P7 indicates *"It would be a failsafe. Otherwise, I'd rely on the program for everyday kind of things"*. On the other hand, P5 was reluctant since it presents *"another thing to deal with. I don't see a situation where I would use it other than going away"*. Our peaksaver participants had not set up the ability to control their free thermostat from the web browser, due to lack of interest. P1 explained that he had no interest in setting up internet control since it was *"easier to just do it at the thermostat"*. P3 felt *"no desire to control it remotely. It's programmed and I don't feel the need to change it. Maybe if I travelled more or had other people to worry about it. It's a good idea, but not useful to me"*. P17 thought *"I sometimes feel like it's just a little too much technology involved in a lot of things"*. On the other hand, P13 was particularly excited about being able to control her thermostat from her phone, because it would be easier to turn the air conditioning up if she forgot as she was leaving.

When considering the value of setting up the remote control ability on his thermostat, P1 explained he would only be interested in bothering to set up a remote control if he could monitor and control other aspects of his home, such as the alarm system. The idea of having multiple thermostats to control the temperature in different areas or floors of the house was discussed by four of the participants (P1, P8, P10 and P11). The argument is that they could save energy and be more comfortable this way. So while a number of participants were not enamoured with the idea of

remotely controlling their thermostat because it requires additional brain cycles, others are indeed interested in taking further control of their home.

4.5 Summary

In this chapter, we presented the findings from our interviews, and what we learned about the habits of electricity consumers as a result of TOU pricing, their response (or lack thereof) to critical peak times and the peaksaver program, some habits of home comfort and cooling, as well as the varying desire to engage with these programs and systems. It is important to note that there are many possible hierarchies for the findings, and these were deliberated in the analysis process. We finally settled on the ones presented here.

There are many possible implications from these findings. In this thesis, we focus on the implications for design of persuasive technology, but offer that there may be additional insight to be gathered from our interviews, beyond these design implications.

Chapter 5 Design Implications

There are a number of design implications that we identified from our findings, and supported by relevant related work. The intertwined concepts of motivation, ability and triggers from Fogg's Behaviour Model were used in order to develop these. Specifically, we looked thoroughly at each theme identified from the affinity diagram and considered what our participants were telling us about their habits, and whether it effectively increased or decreased ability or motivation, and whether it was indicative of existing or missing triggers. We gathered what we could learn from existing practices (e.g. shifting usage as a result of TOU pricing) and what barriers were in place to making more dramatic shifts in behaviour at peak load times. In this chapter, we organize these design implications according to the three aspects of Fogg's Behaviour Model: motivation, ability, and triggers.

   As discussed in further detail in Chapter 2, Fogg's Behaviour Model for Persuasive Design was used for this analysis because of its applicability to the domain of behaviour change, and since it largely encompasses various other behaviour change models.

5.1 Motivation

The core motivators identified by Fogg are:

- Pleasure/pain: which focuses on the immediate response
- Hope/fear: which focuses on the anticipated future outcome of the behaviour
- Social acceptance/rejection: which focuses on social norms

5.1.1 DI: Communicate the Impact of Peak Load

It is clear from our interviews that most people are rarely aware of the times that the electricity grid is strained. They are even less aware of the impact that peak load demand has on the construction of new power plants and the environmental consequences. One potential area for persuasive technology to help is in increasing this type of knowledge. These should build from existing knowledge of motivational techniques [35].

This design implication targets the core motivator of hope/fear. Ideally one could instill a hope for a better world, and that should be the focus. On the other hand, in reality, many of our participants were especially motivated by the fear of imminent blackouts. This design implication targets those in the early stages of the Transtheoretical Model, who are not yet aware of the benefits of taking action.

5.1.2 DI: Harness Collective Action

Our participants noted both not being able to comprehend the impact of their individual behaviour (such as shifting laundry) and the worry that they would be the only ones making sacrifices during peak load times. Both of these impacted their motivation to make those changes, and could be addressed by demonstrating collective action. For daily peaks, this could be communicated at the time of making a decision to use an appliance. As the internet-of-things expands to include common household objects, these objects could communicate information about current consumption.

Collective action can particularly be harnessed to address critical peak times. Social media tools can be used to communicate who is making cutbacks within a social circle. They can be used to anonymously communicate the net effect of cutbacks. They can also be used to allow occupants of a large building to collaborate to increase the temperature during times of acute demand. In our work, we found the lack of awareness of collective participation and collective effect sapped motivation. We understand that households cannot always make extreme efforts to conserve, but for those infrequent critical peaks, collective action holds the promise to both motivate and serve as a trigger. The work of Boucher et al. capitalizes on this need [7].

5.1.3 DI: Give Consumers Ultimate Control

We found a number of participants who were not opposed to the small or imperceptible reduction in comfort from peasksaver, but the specific implementation details turned them off – specifically the idea of an outsider having control, combined with not having the ability to opt out in the moment. Giving consumers ultimate control over adjustments and thus the ability to opt out in the moment using the thermostat would reduce this fear. One concern of the designers of peaksaver was that people could in theory opt out en masse at the times when changes were most needed. However, in practice, peaksaver participants were unaware of the changes, so this is unlikely to be the case.

Nest is already working with a limited number of utility companies to offer rebates, or even a free Nest thermostat for signing up for their Rush Hour Rewards program, which does not preclude opting out in the moment.

5.1.4 DI: Allow Flexibility and Customization

As others have noted, it is essential to target behaviour change interventions to what stage the participant is in the Transtheoretical Model [12,28]. Even beyond this, there is a need for further flexibility and ability for customization tailored to the individual, since they have different thresholds for comfort and willingness to contribute to the greater good, as well as perceptions of social norms.

While in general our participants understood that a small change in temperature would not have a large impact on their home comfort, the primary motivation for cooling the home was for the pleasure of being cool on a hot day. But our participants had different thresholds for how they set their air conditioner. Further flexibility would allow users to cycle down their air conditioning only to the extent that they are comfortable with it, perhaps even as little as 5% or 10% cycling, or a 1 degree Celsius increase for a proportionally smaller reward. Perhaps this amount could be slowly increased until it was noticed. If this increased flexibility means that more people would sign up, even if the individual impact was small, collective impact would still have an important impact on peak load.

5.2 Ability

Fogg also lists six elements of ability, to help define the simplicity of behaviour. It is important to keep in mind that these elements can apply very differently depending on the individual. If any element is not simple, then the behaviour is not simple. The six elements of simplicity and ability are:

- Time: taking too much time is not simple
- Money: costing too much money is not simple
- Physical Effort: taking physical effort is not simple
- Brain Cycles: too much thinking is not simple
- Social Deviance: going against social norms is not simple
- Non-Routine: breaking routine is not simple

The simplicity of the behaviour is assessed at the time that it is triggered. People can be persuaded to do things even if they are not particularly motivated, as long as it is easy enough for them to do.

5.2.1 DI: Allow Users to Set it and Forget It, or Customize and Optimize

Even the simple implementation of TOU pricing was not fully understood by most of our participants. Many people were unable or unwilling to invest the time or "brain cycles" in learning the details of this program, including the actual price differential, or the mid-peak and on-peak hours, beyond the 7pm threshold to off-peak. On the other hand, some made very deliberate choices about running home comfort systems and appliances with respect to these prices. New appliances are increasingly coming with timers in order to make it easy to consume at off-peak times. In a fully connected future, these appliances could even connect to the grid directly and run at the best time given the constraints of the user.

In the same vein, the fact that peaksaver made the changes automatically was appealing to a number of our participants, since they did not have to think about making the changes themselves. There are also those who have demonstrated a desire to be more actively engaged in managing their resource consumption and home comfort, and to be able to customize systems to their individual needs. While Strengers cautions us of designing only for Resource Man, it is important to design for both types of users.

5.2.2 DI: Use Appropriate Incentives

Many participants were reluctant to forego the comfort of air conditioning on hot days. In these cases, the small monetary savings of TOU pricing were particularly ineffective. For some, no feasible amount of money would be enough to convince them, but others were willing to make changes for appropriate monetary incentives. Still others indicated that the hypothetical financial reward was not necessary, and they were happy to do their part. An additional concern is how to handle the problem of putting a monetary value on a behaviour can actually have negative spillover on other environmentally conscious activities [35].

The existing one-time gift of a thermostat for the long-term commitment of participation in peaksaver seemed disproportionate to many of our participants. While different participants are going to have different levels of price-sensitivity, in order to expand the reach of utility driven air conditioning demand response programs, more appropriate incentives are required.

45

It is also important to consider how these incentives are communicated to users. Whether it is presented as per hour, per event or per season has the potential to impact the perceived value of the reward.

5.2.3 DI: Offer Suggestions of How to Reduce Consumption at Peak Times (And Make These Easy To Do)

Our participants simply did not know of reasonable ways to reduce their consumption at critical peak times, which correlated with [56]. In order for behaviour change to occur, it is necessary for them to not have to think too hard about what to do, or work too hard to do it, or as Fogg explains it, decrease the brain cycles and physical effort required. Thus, easy to do suggestions are required, such as:

- Using the barbecue to avoid heating up the house (and causing the air conditioner to work harder);
- Cooking in advance of a heatwave and using the microwave or toaster oven to reheat;
- Closing window blinds; and
- Spending time in larger groups at places that are already air conditioned instead of at home.

Many of these behaviours were gathered from those who do not have central air conditioning at home, as necessities for staying comfortable. Admittedly, they do have higher motivation to find ways to keep cool since they do not have the simple option of turning on the air conditioning. But there are alternative ways to keep cool that could help reduce peak demand, including closing windows blinds [4], the use of ceiling, circulating or portable fans which were mentioned by a number of our participants to reduce their need for air conditioning in order to save money. Making these suggestions of other ways to keep cool without much discomfort, and with lower cost, may be beneficial to those who did not take these actions already. Exploring the automation of some of these lower tech solutions in order make them easy for those that do have the option is one path going forward.

Taking these suggestions to the next level, families could plan a group barbeque and consolidate their need for air conditioning, with the added benefit of increasing a sense of community and social action at these critical peak times. Issues of sustainability around food preparation has also been studied within the HCI community [11]. Making this behaviour part of accepted social practice and pitching in to help with this problem is where the design challenge lies. One interesting example of

success in this area is in Japan, where the Cool Biz campaign has been successful encouraging people not to wear suits in the summer, in order to reduce the need for over air-conditioning [70]. Taking more intensive action at the more infrequent critical peak load times is where efforts should be directed, given the increased impact [52]. This could also help overcome the fatigue noted by our participants

5.3 Triggers

Fogg describes three types of triggers:

- Spark: Trigger with a motivational element
- Facilitator: Trigger that also makes the behaviour easier to do
- Signal: Notification or reminder

These types of triggers should be used appropriately to help increase whichever of the elements is lacking. They are an essential piece of the puzzle when it comes to encouraging desired behaviour.

5.3.1 DI: Integrate Triggers

To provide a small trigger, some participants did post the TOU schedule in the kitchen or laundry room to remind themselves of peak times. Additionally, certain IHDs do provide feedback about the price level in the form of a traffic-light like display (green for off-peak, red for peak TOU). However, these IHDs require the user to engage with the display to be informed, i.e. they are separated in space from the location of the instantaneous decision. An alternative trigger could be a set of small displays attached on or near the controls of electricity-intensive appliances such as the washing machine, dryer, dishwasher or electric stove that signals whether it is an appropriate time to use the appliance, combined with an increasingly common delayed-start feature. Such ubiquitous devices would be more appropriate triggers as they are in-the-moment, localized awareness mechanisms that are visible as a decision is being made.

Participants were often unaware of critical peak times, and so lack any form of trigger to alter their behaviour in-the-moment. The most obvious trigger, particularly for critical peaks, is some form of simple notification such as an email or text message. While we had difficulty finding scientific studies on the effectiveness of basic email or text message notifications, it is also worthwhile to note that the use of a generic notification is sufficiently undirected that it may be ineffective as a trigger if motivation and ability are not high enough [21]. Utilities are proficient at predicting demand days in

advance of critical peak periods, and could easily notify customers in advance to increase consumers' ability to plan, which has been shown to be feasible for some [14]. Because critical peak periods are less common than everyday peaks, notifications are less frequent, and, potentially, more actionable in the short-term.

5.3.2 DI: Consider Sparks and Facilitators

Critical peaks are particularly amenable to sparks and facilitators, because they are sufficiently infrequent that the spark or facilitator will not become so commonplace that they become irksome.

Networked thermostats could be used to spark behaviour change in a variety of ways. Given the ability of utilities to pay up to $2 per degree hour for savings during these periods [52], one could imagine using the network interface to provide significant incentives to consumers. Imagine a smartphone interface where, by leaving your house and idling your air conditioner, you obtained a free cold drink at a local cafe, as indicated by a coupon on your smartphone. If the interface included a simple button to raise the temperature, the interface combines the positive attributes of a spark and facilitator to promote high-impact, low-frequency behaviour change, particularly important during critical peak periods. However, those who choose to forgo central air conditioning should not be unduly punished. Additionally, designers need to be careful that this system does not encourage excess car use, which could undermine potential benefits.

5.4 Discussion

In this section, we leveraged Fogg's Behaviour Model for Persuasive Design to develop design implications for persuasive technology to encourage households to reduce consumption at peak load times. We find that focusing attention the three areas of motivation, ability, and triggers in turn allows our analysis to gain deeper insights and provide stronger recommendations, beyond the traditional paradigm of raising awareness.

We also learned from and incorporated what others have learned about using behaviour change models in HCI research - specifically the need to customize the intervention to the current stage of the user in the Transtheoretical Model. While we present a few design implications that span these stages, our focus is on those who are either prepared and willing to act already, or more particularly, those who are considering acting in the near future, but need some additional persuasion.

The financial incentive that exists from TOU pricing and the hypothetical critical peak demand scheme provide some extrinsic motivation, and increase ability to shift consumption. A number of our participants indicated that they were unlikely to be persuaded to change their behaviour by other means, some declared that comfort and convenience will always come first, while others declared the financial reward was unnecessary for them to participate. What our design implications suggest is to design programs and systems with enough flexibility in order to capitalize on the participation of as many of these types of participants as possible. As we know from research into reducing electricity consumption as a whole, there is inherent financial benefit to consuming less, but different people have different ability to pay and are thus affected differently. We focus on designing systems that make shifting consumption easier to do, so the financial reward then feels like a low effort bonus to users.

With regard to financial incentives, researchers have noted that one problem with TOU pricing is that it disproportionately benefits those who are employed and thus out of their home during the day, i.e. during times of higher cost [51]. Less affluent groups – retirees/the elderly and the unemployed, for example – are at home during the day and are unduly penalized when they try to preserve their comfort. If one takes the critical peak pricing example in Australia where electricity climbed to 10 to 20 times the base level price during times of critically high load, those who are more affluent can make choices such as leaving their home to eat in restaurants, choices which may be impractical for those whose physical mobility (possibly including the elderly) or financial situation (possibly including the unemployed) limits their options.

Overall, research shows that there are financial benefits for the province to use money to incentivize behaviour change instead of building new power plants [52]. It is our intention to build systems that support behaviour change in response to these existing incentives.

Chapter 6 Validating Design Implications: A Technology Probe

In order to close the loop of the preceding work, we used the design implications identified in order to realize a concrete implementation. Until validated, the design implications identified can be thought of as design hypothesis instead [29]. Thus, we designed a smartphone application to cycle participants' air conditioning and the accompanying study to evaluate the app. We conducted a prompted interview with 6 of the interview participants, and present their impressions.

6.1 Overview

We designed a smartphone application that receives configurable push notifications at critical peak load times in Ontario. If the user has a Nest thermostat, and authorizes our app with their Nest account, they can respond to these notifications by opting in to cycling down their air conditioner with two finger taps, and can control the amount of cycling through a slider. They receive a financial reward proportional to the amount of air conditioning they cycle, of $1 per 15 minutes per hour of cycling. We also designed a "dummy" version for those without a Nest thermostat, where the air conditioning changes are not actually made. The intention of this dummy version was to gather more data about how such an application would integrate with the daily life of other users, since we had already identified that Nest users tended to embrace technology and devoting brain cycles more than non-Nest users. In other words, we intended to prototype a system for those where the infrastructure was not yet in place [14]. The app also provides anonymous information about what percentage of others are opted in for cycling at that time, as well as a simplified presentation of the current Ontario demand. In the "real" version, users have the option to opt-in by default and avoid the need to respond to the notifications.

This app was designed as a technology probe [31] to learn about how such a technology would fit in with the lives and everyday practices of users.

6.2 Design Process

The objective in designing this app was to take what we learned from the design implications we identified through interviews and behavioural theory, and design a concrete implementation.

We decided to focus on critical peaks in Ontario, since that has the potential to have a more important impact than the daily peaks. We do this while still taking into account what we have learned from the practices surrounding TOU pricing.

The app targets those who are already willing to take action - where the benefits of taking part have already been communicated to them. The aspect of marketing and communicating this need is beyond the scope of this implementation, though no less important given the marketing troubles of peaksaver.

We specifically chose a smartphone application because it allows an in the moment response to a peak load notification, whether the user is at home, at work or elsewhere. With growing smartphone use, there are fewer and fewer users who would be left out from such a system.

The app builds off of a number of the design implications we identified. Specifically we:

- **Harness Collective Action**: by showing how many others are participating
- **Give Consumers Ultimate Control**: they are free to opt in or out at any time
- **Allow Flexibility and Customization**: users have the flexibility to choose the amount of cycling they opt in to
- **Allow Users to Set it and Forget it, or Customize and Optimize**: Users can opt in to cycling by default, and not need to make any further changes. On the other hand, those who prefer more control can receive the notifications and make changes that are appropriate for them in the moment
- **Use Appropriate Incentives**: Users are remunerated for making changes. While the dollar amounts may not be enough for some, they are based on research findings that the Ontario government could pay consumers to reduce usage at peak times, and still come out ahead in the next 20 years [52]
- **Consider Sparks and Facilitators**: the notification of peak load times is accompanied by the ability to make the changes right away. Combining a trigger with technology that makes the behaviour easier to do is the definition of a facilitator. Combining the trigger of the

51

notification with information about others who are participating is designed as a spark, though perhaps less strong.

As noted in related work, when encouraging motivation through changing of social norms, it is necessary to tread carefully [35]. In response to this, the app only communicates the fact that others that have opted in to some level of cycling, though obscures to what degree. The design is cautious about encouraging reductions from some groups but justifying increases in consumption from others. One potential issue with sharing even anonymous data about participation is that bootstrapping may be a problem. One solution is to start with motivated people who can then influence others.

6.3 Detailed Description

The first step after installing the app is to either authenticate with the Nest API, or register without a Nest. If the participant is registering with the Nest API, they press the appropriate button in the app (**Error! Not a valid bookmark self-reference.**) which opens a webpage directly from Nest that explains what permissions the app is asking for (Figure 5). If they agree to grant these permissions, it takes them to the next webpage (again, hosted by Nest) which asks for the username and password of their Nest account (Figure 6). Once entered, the authorization token for that account is sent to the
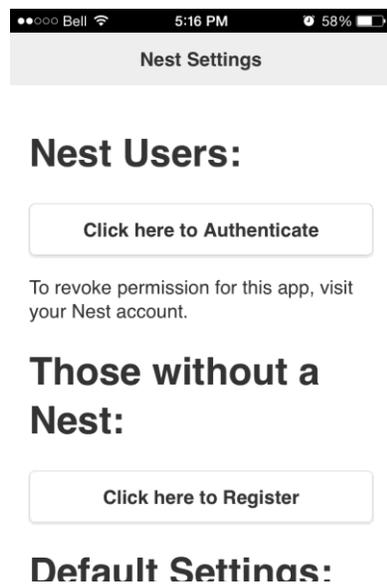
Figure 4 Screen capture of settings page for initial authentication

52

Google App Engine backend. If the participant does not have a Nest thermostat, or chooses not to authorize the app, they simply register with our custom backend using a different button (**Error! Not a valid bookmark self-reference.**).
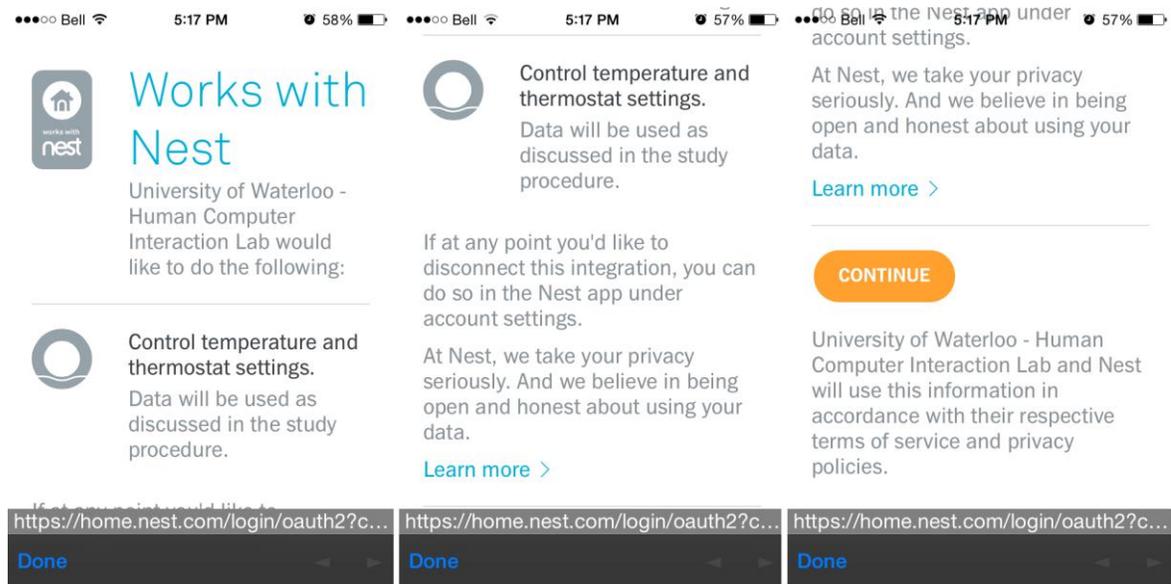

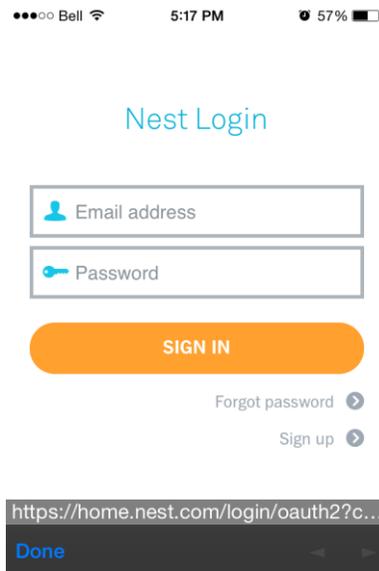**Figure 5 Screen captures of Nest authentication permissions page**

Figure 6 Screen capture of Nest authentication page

After registering, the next step is to enter default settings for indicating whether they want to opt in or out of cycling their air conditioner. Non Nest users are asked to imagine that the app could in fact work with their thermostat when making the decision. If they opt in, they are asked for what the default amount of air conditioner cycling should be - in increments of 15 minutes per hour (i.e. 0, 15, 30, 45 or 60 minutes per hour the air conditioning would be turned off) (Figure 7).
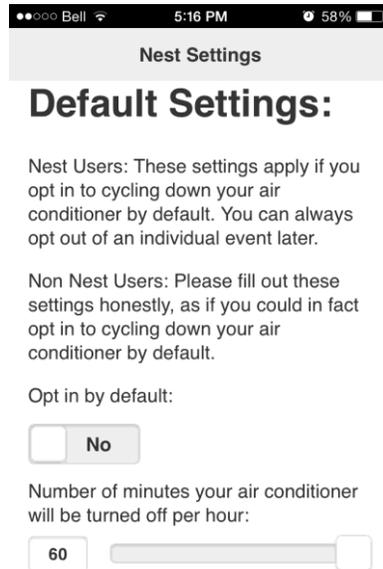

Figure 7 Screen capture of default settings configuration

After this registration and setting of defaults, when participants open the app they are directed to the home screen, which provides information about current consumption in the province, as well as when the peak load hour of the day is predicted to be (Figure 8). Along with this information, a scaled version of the actual data is presented. Since general understanding of data in kWh or MW is often meaningless to many users, a rough approximation of a scale with 100 as a peak was devised by dividing the current consumption by 1000 and multiplying by 4. A colour coded scheme shows values of 85 and above as red, 80 to 84 as yellow, and less than 80 as green. This scheme was created as a liberal threshold for a peak, given the cool summer of 2014. A link to the IESO webpage providing more information about current consumption was provided for those who are interested and want to learn more. It was not necessarily expected that participants would use the app on a regular basis outside of peak times. Including the consumption information was simply to have something there were they to visit the app outside of a peak time, and allow those who were somewhat interested to

54

see a simplified version of the consumption data, and provide an easy source for those who wanted to learn more about the details.
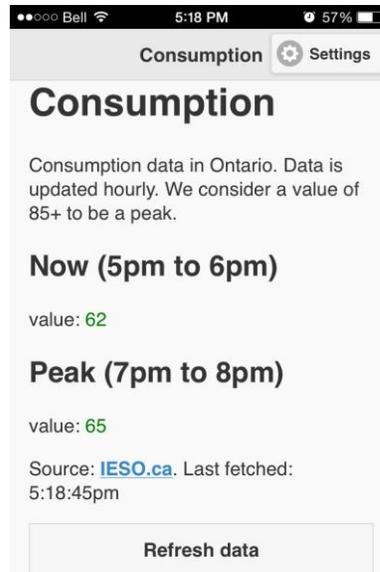

Figure 8 Screen capture of app home screen, showing current Ontario consumption and the time of the predicted peak of the current day

From the home screen, users are able to change their default settings of opting in or out by clicking on the settings button (top right of Figure 8). They can also refresh the consumption data, though it is noted that this data is only updated once per hour. It is also automatically refreshed whenever the app is opened.

The main purpose of the app was to address critical peak load times. The app was configured to allow push notifications from the Pushwoosh service. These notifications could be configured by the user just like the notifications from any other app, such as an email, e.g. whether they wanted a sound, or a vibration, or what volume the notification should play at, etc. Notifications would be sent in the morning of a day with the time of the predicted peak, as well as again 1 hour before the peak, and at the start of the peak. Allowing the user to customize the timing of these notifications is left for future development.

A peak time is declared manually by us based on predicted consumption, through a restricted interface of the Google App Engine backend. Whenever the app is opened, it queries the backend. If a peak time has been declared for that day, a highlighted notice appears on the home page displaying

the time. Included in this notice is the percentage of participants who are currently opted in for cycling during that event, which is initially gathered from the default status, but is updated if a participant opts in to the specific event that day even if they have opted out by default. For Nest users, a summary of their current status is presented (e.g. you are currently opted in to cycling for 30 minutes per hour) along with a button that takes them to a page with the ability to change the settings for that particular day (Figure 9). For non-Nest users, a series of very short questions appear that ask for information about whether they would be willing to cycle their air conditioning that day, during the noted peak time (Figure 10). The same survey appears on the change screen for Nest users also, for the purposes of the technology probe. The users can submit data as often as they like using this form. The data is logged by the backend, along with a timestamp. The survey itself asks questions including whether they have discussed the control decision with other members of their household (see Figure 10).
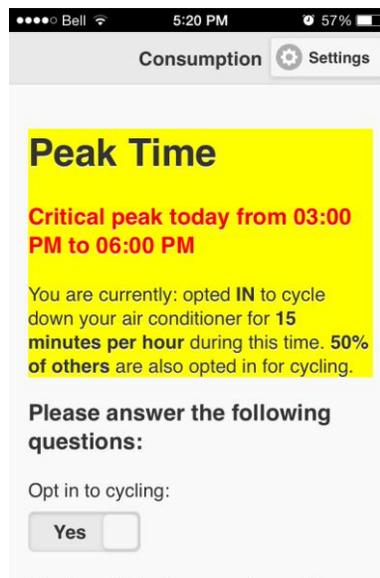

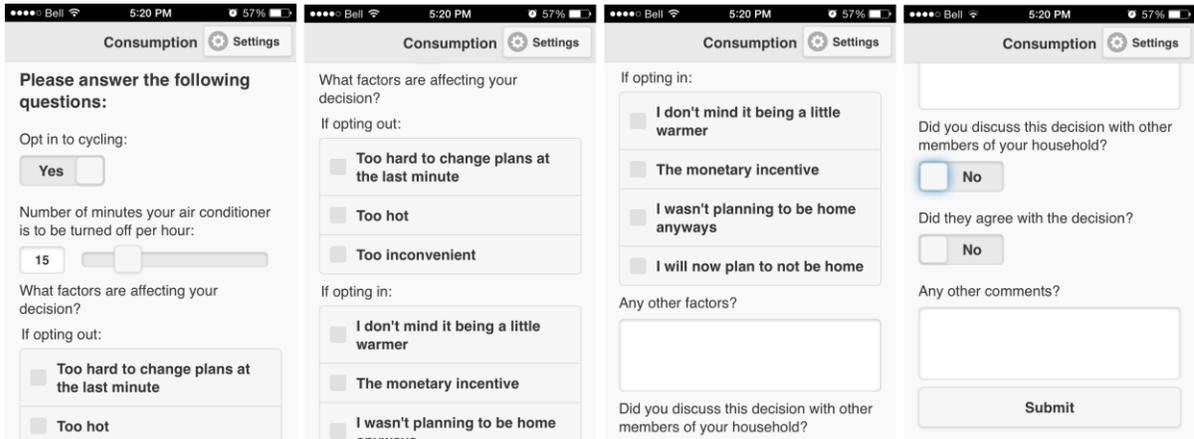**Figure 9 Screen capture of sample details of peak time**

Figure 10 Screen capture of technology probe survey

6.3.1 Additional Implementation Details

The app was developed using the Adobe Phonegap framework, which uses HTML5, CSS and Javascript. Phonegap was chosen since the app can be written once, then compiled and installed on both Android and iOS devices with little extraneous effort. The Phonegap Build service was used, which imports the application code from a GitHub Repository, and compiles it in the cloud, providing a link to download the compiled app directly to the phone.

In order to allow the installation of the app on a iOS device for development purposes, it was necessary to join the Apple Developer Program.

The app allows participants with a Nest thermostat to authorize the app to control their thermostat using OAuth 2 authentication. In other words, participants were able to authenticate themselves to Nest by entering their username and password of their Nest account, which provided an authorization token to be used to control the Nest thermostat remotely.

The backend of the app uses Google App Engine. Pushwoosh was used for push notifications for both the Android and iOS versions, using the provided Phonegap plugin.

If the app does not detect an internet connection, an error page is shown explaining the problem. This is because there is nothing the app can do properly without an internet connection. This is required for both getting the current consumption information, as well as submitting changes in settings to the app backend, which would then be communicated with the Nest thermostat.

57

6.4 Study

As it turned out, the summer of 2014 was unusually cool, and the typical peaks were simply not experienced - the top day as of September 23rd, 2014 did not even approach the top 10 of peak days from 2012 or 2013 [71]. We considered doing a test deployment of the app with fake peak days being declared (with the user understanding that it was a fake peak to avoid deception which requires additional approval from the Office of Research Ethics), and built this functionality into the app, but considered the lack of ecological validity to be problematic. It is easy to forgo air conditioning when it simply is not hot outside. In the next subsection, we discuss the design of the planned study that is left for future work.

6.4.1 Future Study Design

We designed and received approval for running the following study. The study would include a field deployment with approximately 10 participants (5 with Nest and 5 without). The participants would first be interviewed as described in Chapter 3, in order to gather even more data for refining the design implications. Then they would install the prototype app, and use it as described above for a period of 1 to 6 weeks, depending on the number of peak days forecast. Then participants would be interviewed again about their experiences using the app, their responses to the notifications, the financial incentives, and how the app fit into their daily life. The survey data they submitted would be retrieved and used for discussion during the interviews.

   In addition to the remuneration for cycling down the air conditioning (available to Nest users only, where we could actually do the cycling), participants would receive the same $20 for the first interview, $10 per week of using the app, and $25 for the exit interview also in the form of a gift card to Amazon. Full approval for this study was received from the Office of Research Ethics at the University of Waterloo.

6.5 Prompted Interviews

We conducted prompted interviews to gather thoughts on the app at the end of the interviews with the last 6 participants (P13 to P18). For this process, we described an overview of the application and gathered responses, which are discussed in the next subsection.

6.5.1 Findings

A number of participants liked the ability to opt in by default, for many of the same reasons they found peaksaver appealing – they did not have to think about making changes. P14 indicated *"both will work, so I guess ...I dunno, that's a tough one. I don't mind receiving notifications, but, if I set the default I don't... you know the old default, like you set it and forget it? I think I'd rather just do that way. For me I'd probably choose the, set the default. That way I wouldn't have to worry about it, you know?"*

P15 really liked the control of being able to opt-in in the moment - *"I like the opt-in features, getting the little warning, and then getting to choose whether or not to do it, umm, because it makes a difference, whether or not you're at home, if you have guests, umm, you know, you might not want to do it, but if you went out to get your groceries, it's not going to bother you, umm, yeah, that sounds really good"*. P13 in particular really liked the idea of receiving notification at peak times, and responding to them as appropriate, and but would consider opting in by default later: *"I think I just kind of want to have a little bit of control, but the fact that I'm getting these notifications, I don't have to be paying attention to the news or whatever, be waiting to hear people telling me that oh it's a peak time you should really cycle down. By then it's probably over anyways. But if I get that notification and if I could adjust it at work or when I'm away, then yeah that's a really great thing. But yeah I think I would want to do that for a bit, then I would do the opt-in."*

Learning that others were taking part through the app was also well received. P13 thought it would be a good thing to see *"all these people are doing it so clearly it's making a difference"*. P18, who was not motivated at all by the threat of a blackout, was particularly motivated by the social aspect, *"because if you know that a lot of people are doing it, then you want to kind of be part of something that it making a difference I guess. As opposed to kind of being the one left out"*, but admits *"if it's sort of like really hot, and I just can't be bothered, and the incentive is not worth it, then I wouldn't"*.

P15, P16 and P18 did not use a smartphone. P16 indicated *"it's kind of a bummer that I would miss out on something like that, but umm, the majority, I would probably say I'm one of the minority that don't have a phone like that, I think it's a great idea"*. P16 and P18 discussed some other ideas of ways to be notified, such as the television or via an IHD.

Similarly to responses to TOU pricing in general, our participants had mixed feelings about the actual dollar value of the financial reward for participating. P15 thought it would be a nice bonus, but

not necessary for her participation. *"I'd look at that as like a little bonus of yay I got you know a dollar off my hydro bill or something. But I personally would not need that in order to use an application like that"*. P13 thinks that *"it's definitely an extra incentive that I know I'm missing out on a couple of bucks here or there"*. On the other hand, P18 was more concerned about *"what's in it for me kind of thing"*, and *"I think the incentive wouldn't be enough for people"*.

P17 and P18 expressed concern over the amount of technology creeping in to their lives. Specifically, P18 expressed that *"I guess for someone that's sort of into technology, this would be great"*, while P17 was concerned that *"I just think people are, younger people especially, always looking for like a high tech solution to it, when there's like everyday little things that you can do that really improve energy use and consumption"*.

Overall, participants echoed many of the same themes that arose from the initial interviews. Even among the 6 interviewed, there was a range in the desire to engage, and the amount that incentives would help. These findings further reinforce a number of the identified design implications.

6.6 Discussion and Future Deployment

Using prompted interviews, we gathered impressions from 6 participants about the app. Their responses further reinforced the design implications identified form the initial set of interviews.

Immediate future work involves executing the small field deployment of this application, ideally in the summer of 2015. Future development, including integrating more customization of when notifications arrive (or opting out of notifications entirely if they opt in to air conditioning cycling by default) would be a good idea to further follow the design implications.

When brainstorming about the application, one idea we had was to tie the financial remuneration with a gift card to a coffee shop, ice cream shop, mall or movie theatre. Upon further discussion, we returned to the idea that different people would be motivated by different rewards, and it was infeasible to develop such a number for the prototype research deployment. We intended to discuss this concept with participants in the exit interview, to see if a targeted reward, combined with a suggestion might have incentivized them further.

This prototype app does not do any active pre-cooling or take into account the effect of snapback load - the additional energy draw that follows air conditioner cycling required to cool homes back to the level they were before the beak period [52]. Perhaps tapering the cycling in the last hour, or

extending the hours of cycling could help with this. Additionally, allowing participants to indicate whether they are home or intend to be home during the afternoon could indicate whether pre-cooling is necessary or irrelevant.

It is also important to consider the tension of greenhouse gas emissions when suggesting using the barbeque versus reducing electricity consumption from heating up the house. As well, if the rewards do tie in with suggestions of getting out of the house to reduce the discomfort from reduced air conditioning, having people use their cars to get there, and the increased gas consumption from that usage also needs to be measured and taken into consideration.

Ultimately, this system is essentially an improved version of the peaksaver program which targets the more impactful critical peak times, and targets the largest offender - residential air conditioning. It allows those with a smartphone and (in this implementation) a Nest thermostat to retain control, customize their experience, receive a financial reward for participating, and be reassured that others are taking part. This removes the distasteful big brother connotation.

When it comes time to actually deploy the technology probe, it will be important to screen out people in pre-contemplation stage of the Transtheoretical Model [29].

Chapter 7 Discussion and Conclusion

Peak electricity demand is an important problem in Ontario, with political, social and environmental consequences. In order to reduce the demand at peak load times, we examine the problem from the perspective of persuasive technology in residential homes. We adopt a more holistic perspective beyond the awareness mechanisms that have been criticized in persuasive technology research on reducing electricity consumption as a whole. Through the use of Fogg's Behaviour Model for Persuasive Design, we design for improving ability and creating triggers, as well as increasing motivation.

Previous work in the HCI community related to sustainability has caused Mankoff to argue that *"feel good motivation is not enough"* and that it is necessary to show concrete effects on problems that have a higher potential impact than simply reducing consumption in a few households in the developed world [39]. We have argued that the issue of peak electricity load is one such higher potential impact problem – especially in Ontario where it has impacts beyond environmental pollution and is a multi-billion dollar problem – and have presented design implications to address this problem.

7.1 Research Goals

We set out with an interventionist, though human-centred attitude to understand the user more deeply in terms of how load shifting can or would fit in to daily life. From this knowledge, we intended to apply knowledge of behaviour change theory to see where existing programs and technologies were lacking and how they could be improved, and identify a set of design implications for technologies in this area.

Our final objective was to learn from these design implications to create and deploy a specific instance of persuasive technology.

7.2 Findings

We learned about existing shifting practices inspired by TOU pricing, and the peaksaver program in order to understand more about how shifting fits in with everyday practices of households. Our interview findings were clustered around 4 themes:

- Daily Peaks and TOU Pricing;
- Critical Peaks and peaksaver;
- Home Comfort and Cooling; and
- Desire to Engage.

This research, along with an analysis using Fogg's Behaviour Model for Persuasive Design, allowed us to identify the following set of design implications, clustered around the three aspects of motivation, ability, and triggers. We found that persuasive technology in this area should:

- Communicate the Impact of Peak Load;
- Harness Collective Action;
- Give Consumers Ultimate Control;
- Allow Flexibility and Customization;
- Allow Users to Set it and Forget It, or Customize and Optimize;
- Use Appropriate Incentives;
- Offer Suggestions of How to Reduce Consumption at Peak Times (And Make These Easy To Do);
- Integrate Triggers; and
- Consider Sparks and Facilitators.

Then, we developed a smartphone app that took a large number of these design implications into account. While we were not able to do a field test of the application in the summer of 2014, we gathered thoughts from new participants on the app which further reinforced the design implications identified.

7.3 Use of Fogg's Behaviour Model for Persuasive Design as a Tool

Using Fogg's Behaviour Model for Persuasive Design allowed for structured approach of identifying where current programs and technologies were lacking in terms of increasing motivation, ability and

the use of triggers. More traditional use of persuasive technology has focused almost exclusively on the motivation axis, so the use of this model allowed for a broader perspective in developing our design recommendations. It allowed for a structured analysis.

Modeling the monetary incentives, either from TOU pricing or hypothetical critical peak rebates or price increases, was difficult using this model. We eventually decided to keep these on the ability axis, where Fogg identifies money as a link in the ability chain, and since this captures the idea that for those with enough money, it is easy to justify not shifting consumption. However, for others, the financial incentive provided motivation to do certain behaviours as long as they were already able (i.e. it was convenient).

Overall, using Fogg's Behaviour Model allowed us to develop design implications, and we built a tool based on them. Our preliminary evaluation of this tool supported the design implications we identified using this approach. While we cannot make any bold claims from this preliminary evaluation, we expect to find them further validated in a future deployment.

7.4 Future Work

As a whole, the problem of peak load needs to be, and is being addressed from a variety of angles, of which persuasive technology to support occupant behaviour is one. This is an important problem that needs to be addressed, and continued work and learning, alongside engineering research in generation efficiency, and electricity storage.

Hekler et al. propose that design implications should be thought of as more of design hypotheses until validated [29]. In this spirit, it is clear that future work involves developing and deploying concrete designs based on the identified design recommendations, and refining them as new knowledge is acquired. We proposed one design and conducted a preliminary evaluation, but more implementations and evaluations are necessary.

7.4.1 Other Domains

While we focus on the problems and programs in Ontario, other regions have both similar and different problems. Many of the design implications that come out of this work could be generalized or adapted. As discussed by Boucher et al. [5] there are other reasons for occasional, more unpredictable short-term changes in demand. Inclement weather can cause damage to distribution

64

systems, or incidents at generating facilities can constrict supply. In such cases, centralized control, or opted in by default is the preferred solution, since there is not enough time for people to become informed and to react. Renewable energy sources, such as solar and wind power are often constrained on the supply side, so having systems and technologies for temporarily reducing demand can again reduce the need to rely on more polluting sources. We would argue that our work provides a path toward broader participation in demand management programs like peaksaver, and that the broader participation in these programs extends beyond simply addressing critical demand peaks.

The design implications we propose all fit within the domain of persuasive technology, and they could generalize to other similar applications, where individual decisions made today can have collective long-term consequences in the future. One example is that of water conservation and use. As with electricity, the timing of use of water is important, and the desire to use water increases when supply is most constrained (i.e. watering your lawn during a drought). Additionally, in other regions beyond Ontario, such as Prince Edward Island for example, winter peaks in electricity consumption from electric heating can have similar consequences. While ability to use less heating is obviously much more constrained than going without air conditioning, lowering the temperature overnight in particular, and using an extra blanket or an alternative heat source, can help reduce the need to build new power plants in these situations as well.

7.5 Only Part of the Solution

It is important to realize that even air conditioning demand management programs would only be part of the solution. Researchers in areas like engineering are working on other types of solutions—reducing waste in the grid, better efficiencies in generation, better electricity storage [10], improved home design etc.—which will help in the long term. One questions that might be asked is why even target residential behaviour change at all? It has been shown that occupants of identical buildings can have huge variation in electricity consumption resulting solely from occupant behaviour [17,53]. Allcott and Mullainathan also argue that interventions that target in-home behaviour are often cheaper to implement, specifically in the shorter term [2].

Also, while air conditioning is an important and logical starting point, it is not the only possibility for curtailing demand at peak times. Some utilities have adapted the peaksaver to include cycling down pool pumps, but it could also be expanded to pool heaters, and even electric hot water heaters in

homes. For very short term peaks, such as those caused by accidents, even refrigerators or chest freezers could be cycled down by a few percent without negative consequences, if the ability to do so was available. On the other hand, people really want to retain ultimate control. Other research has looked at agents and their role going forward [49].

7.6 Going Beyond the "Limitations" of Persuasive Technology

Huber and Hilty [30] discuss some limitations of a persuasive technology-based approach to sustainability. In this work, we feel we have gone beyond and addressed many of these concerns, which we address in turn. Others have also criticized the perspective of persuasive technology for sustainable behaviour change, but their concerns are well encompassed below [9].

- **Focus on Measurable Effects:** Specifically, they criticize deviation from benchmarks approach. Our work is not stuck on the details of electricity consumption in the home but instead encourages behaviour that can have an important impact, specifically targeting the use of air conditioning. This concern is also somewhat in conflict with Mankoff [39] who argues making that a focus on the concrete and measurable big picture effect is essential.

- **Assumption of Rational Choice:** Through our interviews, we attempt to learn more about how people actually shift their usage in response to pricing and incentives, and how this fits in to their practices, in order to design technology that is aware of these practices. This echoes Strengers' Resource Man. While we do not assume users are fully rational, we have found with TOU pricing and even a small, practically insignificant incentive is enough for people to make some change, as long as it does not inconvenience them significantly. Combining this fact with our findings that many people do not think cycling down their air conditioner is a major inconvenience, there is definitely potential for technology to enable this practice.

- **Insufficient Account of Individual Differences in Social Context:** We came to similar conclusions in our design implications and absolutely account for this in our test design.

- **The Paradigm of Raising Awareness and Changing Attitudes:** We identified a similar problem, and our use of Fogg's Behaviour Model allows our work to go beyond simply raising awareness, though this is a part of it when it comes to critical peak load. The focus on increasing ability helps round out the discussion and design implications.

66

- **Inherent Technology Paternalism:** This limitation is perhaps the least addressed in our work. Yes, we are trying to persuade people to specifically consume less electricity at peak load times. In our defense, the persuasion is extremely transparent, and the technology absolutely required the consent of the participant.

7.7 Final Words

While there has been a growing body of research regarding reducing electricity consumption in general within the HCI community, the shifting of consumption to off peak times was largely unexplored. Some findings and knowledge about electricity consumption in general were applicable, and our findings echo the message that it is important to not consider the user in a vacuum. The realities of everyday life get in the way, and persuasive technologies in this area must account for this in their design.

The HCI approach is often that of interventionist – exploring how the relationship between humans and computers can be improved, and when introducing new technologies, first studying how they fit in with existing practices of humans. Our design implications, with preliminary evaluation of our prototype that follows them, are the contributions of our investigation.

Letter of Copyright Permission

Tanna F. Drapkin <tannad@stanford.edu>   Fri, Oct 17, 2014 at 1:23 PM
To: Valerie Sugarman <vsugarman@uwaterloo.ca>
Cc: "Tanna @ Stanford" <tannad@stanford.edu>, BJ Fogg <bjfogg@stanford.edu>

Dear Ms. Sugarman,

Thank you for your interest in using the Fogg Behavior Model in your thesis exploring persuasive technology to encourage and assist households to consume less electricity at peak load times, when the grid is strained.

We appreciate your asking permission.

You are granted permission to use the Fogg Behavior Model graphic in your thesis in both written and digital forms, including its online publication.

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BJ Fogg. (2007). [Graphic illustration of the Fogg Behavior Model]. *BJ Fogg's Behavior Model*. Retrieved from http://behaviormodel.org/.

Feel free to be in touch if you have any questions.

We wish you good luck with the successful completion of your thesis.

Many thanks,

Tanna Drapkin

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Appendix A Participant Information and Consent Letter

The letter that follows was printed on University of Waterloo letterhead.

Title of Project: **Investigating Technology for Reducing Peak Electricity Load Demand**

Student Investigator: **Valerie Sugarman, 519-888-4567 x38318, vsugarman@uwaterloo.ca**

Faculty Supervisor: **Dr. Edward Lank**

Purpose and Summary of the Project:

This research study will investigate perceptions of and experiences with technology surrounding electricity consumption, specifically at peak load times. In Ontario, these peak load times occur on hot weekday afternoons, where air conditioners play an important role. The peak load has important consequences for air pollution and the construction of new power plants.

Procedure:

Participation in this study involves being interviewed either in person or by phone or Skype. The interview will focus on perceptions of and experiences with technology surrounding electricity consumption in the home, and may take from 30 to 60 minutes. With your permission, the interview will be audio recorded.

Certain participants will then be asked if they would like to continue to the second phase of the study. If you are selected and you are interested, you will be contacted within one month of the initial interview. The second phase of this study has two separate procedures and is limited to participants with an Android or iOS smartphone, and involves installing a custom application on your smartphone, and responding to notifications about peak load times, as well as a final interview about your experiences using the application.

Participation in this study is voluntary. You may withdraw from the study at any time without penalty by informing the Student Investigator. You may also decline to answer any questions during the interview(s).

Confidentiality and Data Security:

All information you provide is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations may be used.   In these cases participants will be referred to as Participant 1, Participant 2, ... (or P1, P2, ...) along with gender and age (e.g. Female, 32) or collectively as a group (Group A, B,...). Data collected during this study will be retained indefinitely on encrypted media, and in locked cabinets. A separate identity dataset will be kept which links participant IDs to contact information. The identity dataset will be retained for 30 days after the final interview, and then deleted. After this time has elapsed, it will not be possible for you to retroactively withdraw consent for the use of your data, since it will be fully anonymized.

Remuneration for your Participation:

You will receive a giftcard of $20 to Amazon as remuneration for participating in this interview. **The amount received is taxable. It is your responsibility to report the amount received for income tax purposes.**

Risks and Benefits:

There are no known or anticipated direct risks or benefits to you from participating in this study.

The results of this research may contribute to the knowledge base of persuasive technologies in the field of Human-Computer Interaction.

Research Ethics Clearance:

I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

Thank you for your assistance in this project.

Valerie Sugarman

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CONSENT FORM - PHASE 1

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

_____

Project: Investigating Technology for Reducing Peak Electricity Load Demand

I have read the information presented in the information letter about a study being conducted by Valerie Sugarman of the School of Computer Science, under the supervision of Dr. Edward Lank. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

 I am aware that I may allow excerpts from the conversational data collected for this study to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware that I may withdraw my consent for any of the above statements or withdraw my study participation at any time without penalty by advising the researcher.

This project has been reviewed by, and received clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director in the Office of Research Ethics at 519-888-4567, ext. 36005.

Please circle and initial choice

With full knowledge of all foregoing, I agree, of my own free will
to participate in the first interview.

<div align="right">

YES NO _____

</div>

I agree to let my conversation during the interview(s) be audio recorded.

<div align="right">

YES NO _____

</div>

I agree to let my conversation during the interview(s) be directly quoted,
anonymously, in presentations of research results.

<div align="right">

YES NO _____

</div>

I agree, to be contacted regarding taking part in the second phase of the study.

<div align="right">

YES NO _____

</div>

Participant Name: _____
(Please print)

Participant Signature: _____

Witness Name: _____
(Please print)

Witness Signature: _____

Date: _____