UNDERSTANDING THE DESIGN OF ENERGY INTERVENTIONS TO REDUCE END-USER DEMAND IN ORGANISATIONAL AND DOMESTIC ENVIRONMENTS

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To my family, who matter most.

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To my family, I will always be thankful for their unwavering support and for putting up with the endless nights of keyboard tapping into the wee hours of the morning.

LIST OF RELATED PUBLICATIONS

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Foster, Derek and Lawson, Shaun and Linehan, Conor and Wardman, Jamie and Blythe, Mark (2012) ***'Watts in it for me?' Design implications for implementing effective energy interventions in organisations***. In: CHI 2012, 5-10 May 2012, Austin, Texas.

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ABSTRACT

Energy demand is on the rise globally due to unchecked factors such as population growth, lifestyle choices, and the industrialization of developing countries. Governments are investing in technologies for efficient and renewable energy in an attempt to secure energy for the future over current dependencies on fossil fuels, but the development costs are high, and the rate of developed technologies is projected to fall far short of meeting global requirements. Overshadowing this growing appetite for energy is the global issue of climate change, igniting the scientific and humanitarian debate over the use of fossil fuels and a need for renewable energy, presenting a societal problem of generating clean, sustainable and secure energy for future generations. As part of understanding how society can make positive changes to daily practices around energy use, many governments have turned to behaviour change, or ‘nudge’ units, that research work on changing energy consumption behaviours. The importance of this is underlined by a focus on reducing end-user energy demand (EUED) by providing contextual energy feedback, interwoven with behaviour change strategies, in both residential and organizational sectors. EUED in large organisations and small-medium enterprises (SMEs) accounts for a significant proportion of a nation’s energy requirements. In Europe, the services sector saw a 34% growth in EUED in the period 1990-2012, with computers and other appliances in the office substantially contributing to this. In the UK, for example, 13% of total energy consumed in 2011-2012 was within the services sector, which accounts for services and business, while the residential sector consumed 30% of total consumption. Given a lack of academic HCI research in the organisational energy intervention space when comparted to domestic, the principle research undertaken in this thesis was to understand employee energy consumption practices and attitudes in the workplace, through a combination of qualitative enquiry and analysis. Additionally, alternative forms of feedback such as aversive stimuli are often ignored in the HCI literature, with favour focused on positive feedback alone as a means for behaviour change. The work in this thesis presents findings on the design implications and considerations that inform the design of in-the-field organisational energy interventions that integrate feedback and antecedent behaviour contingencies. Additionally, research is undertaken in understanding the design of aversive feedback as part of domestic energy interventions. A significant contribution is made to the HCI sustainability literature on understanding the workplace energy intervention design space, and a contribution made on how aversive feedback can in fact be a useful and engaging method for the domestic environment.

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1 INTRODUCTION

It is generally acknowledged amongst scientists and, increasingly, politicians and corporations that current levels of societal energy consumption are not sustainable [62]. Many people already know very well they consume too much energy at home and in the workplace. At the moment society wants to cut carbon emissions without changing our lifestyles; we do not appear to want sustainable technologies but perhaps we want to want them. Given these complex lifestyle and socio-technical issues, and to set the overarching theme of this thesis, reducing energy consumption raises an important question:

"How can technologies to change behaviour be designed to support compelling, desirable, and achievable energy interventions?"

In one of their recent reports the Intergovernmental Panel on Climate Change (IPCC) states the negative environmental impact of humanity clearly: "*Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system*." [156]. Indeed, with global energy needs rising by 1.6% annually [32], the issue of climate change has created a polarised political debate around the profound social and economic implications, including resource shortages, global conflict, and pollution.

While engineering and technical innovation has paved the way for more efficient technologies in the energy supply side, particularly on peak demand management and enabling the dynamic switching of energy tariffs from vertically integrated energy providers [277][264][129], it has been increasingly acknowledged in academic and government circles that energy use is also a socio-technical issue with underlying complex human behaviours between people, technology, society and government [255][24][209]. Despite advances in energy efficiency, emissions are often quickly offset by consumerism; more cars on the road, larger disposable income, access to cheaper electronic goods [90], and perhaps most worrying - the rise of developing countries as they work towards becoming industrialised nations with their citizens enjoying westernised lifestyles [256].

It can be argued that as well as academic research, there is an urgent need for government-led policies and interventions on efficient use of energy, and the encouragement of pro-environmental behaviours at scale. Recently, the UK government initiated the creation of a behavioural insights team to explore the application of behaviour change strategies across a number of societal areas [25][209]. The team is colloquially referred to as the *nudge* unit, the same term popularised by work by Thaler et al. [179] in persuasion. Part of the insights team remit is being tasked with understanding energy-use behaviour for residential and business sectors, however to date no large scale energy intervention studies have been carried out or evaluated by the team. The insights team also resonates with popular press around contemporary societal issues in general, and change can happen collectively [247], as well as the UK government's 'Big Society' initiative [103][69].

Although mandatory carbon policies, or 'green' taxes, are already in place in the UK for businesses which include Carbon Dioxide (CO2) emission allowances, and capping in an attempt to limit them, for the most part these are policy-driven fiscal measures with no targeted behaviour modification programmes for employee end-user energy demand (EUED) practices. In the domestic space there is an absence of policy-led, mandatory carbon taxes to reduce energy; there is little incentive to save energy beyond financial gain in paying less in utility billing. Strikingly, in some cases it can actually cost more to buy energy on a tariff marketed as being 100% sourced from renewable power. As yet, there is no clear and cohesive link between government, energy providers, and energy end-users to create large scale interventions that effectively address the negative impact of energy use, particularly climate-threatening CO2 emissions.

Greater focus on energy efficiency by governments to meet global CO2 emission treaties, and national policies that require energy utilities to reduce end-user consumption, is also driving the development of smart-metering infrastructure, providing interactive energy feedback systems for both domestic and organisational sectors. Smart meters are being rolled out by utility companies around the world with countries such as the UK with a mandatory roll-out strategy [208][76]. General rules on how smart meters are rolled out in the UK [251] must address the following issues:

- Data access and privacy;
- Security;
- Technical standards for the smart metering equipment;
- Meeting the needs of vulnerable consumers.

A body of research is now developing around the exploration of the above concerns in the context of smart meter deployments [95][133][78][53]. Some of the greater concerns identified around smart meters are i) utility providers having the capability to remotely disconnect a household's power supply, and ii) data privacy [78]. Such issues are of particular note in relation to low-income households [78][74]. The work presented in this thesis is primarily focused on researching the design and deployment of energy interventions, however issues around data privacy and technical interoperability for technology-enabled interventions are also given some consideration where appropriate.

In Europe, 80% of all households will have a smart meter implemented by 2020 [102]. Early research on smart meters and technology-enabled feedback by Darby at the Oxford Energy Institute suggests savings of up to 15% could be made by giving end-users information they can act on - effectively low-cost savings made through focusing on changing human behaviour [75]. Smart meters can also facilitate dynamic tariff switching, allowing a household or business to automatically use energy at an optimal time for cheaper energy costs, effectively the end-user will shift their EUED to a time period when it's less expensive, with the additional benefit of placing less demand on the grid at peak times. Smart meters coupled with digital interaction platforms are positioned as ideal tools that allow bespoke energy feedback systems and energy interventions to scale with large numbers of end-users, and provide a number of convenient and timely communication channels to disseminate information on consumption practices. Early work by Siero et al. [248] on organisational energy interventions using comparative feedback, was successful simply by using physical poster information updated asynchronously on a weekly basis. Now the same approach can be scaled further and in near real-time using smart metering and emergent, cloud-scale, Internet of Things (IoT) platforms [131]. Essentially every household and business, in the UK at least, now has the opportunity to access inexpensive off-the-shelf energy monitoring equipment that provides detailed information on their consumption. A pilot smart-metering study involving 2000 German and Swiss households revealed a 3.7% average saving [239]. Opower, perhaps the world's largest provider of social-comparative feedback systems for enhanced smart-metering and paper billing for utilities, claim that up to a 3% saving on an end-users EUED is possible with their systems. Essentially, Opower market domestic end-users as an 'untapped demand resource', where savings can be made through their behaviour change software platform, with behaviour strategies designed by social psychologist academics [214]. With millions of utility customers using Opower's comparative and social feedback system to interact with their EUED, savings of 11 terawatts-hours have been claimed by Opower [212]. Even the possibility of more modest savings from a smart meter roll-out of around 2% per household/business is significant when scaling to millions of customers. Smart-metering presents an opportunity not only for reducing EUED, but for designing different types of contextual consumption feedback, such as individual or social [112][220], peak-demand shifting alerts [232], and per appliance feedback [135].

However, care should be taken when designing feedback technologies that use smart meters for behaviour change. End-user engagement and intervention adherence can be problematic, for example static table top energy monitors often offer little in the way of affordances and interaction, and unlikely to make meaningful changes to behaviour. This is somewhat compounded by utility providers bundling free basic energy monitors with selected tariffs [105]. Often the monitors themselves are generally of a table-top design, with a basic display showing energy used in kWh units with associated cost. Work by Pierce et al. [222] suggests this type of energy monitor is quickly discarded after the novelty effect wears off, while work by Strengers [259] suggests disengagement occurs with the monitor when a disconnect between the resource (energy) and the non-negotiability of daily energy-use practices takes place. The 'disconnect' identified by Strengers can occur, for example, when cost alone is not motivation enough when norms and everyday social practices can be the overriding factor against change. People do not always make rational choices around being more energy efficient [56], indeed some energy intensive tasks such as baking a cake would have the intrinsic enjoyment characteristics of such a task taken away from it, simply by making it more efficient [48]. By this token, smart metering technologies may not be the panacea for ‘low hanging fruit’ energy savings, and need careful consideration in their design, implementation, and situational context.

1.1 Approach

The psychological factors of behaviour change methods have been understood over many decades of work by the behavioural and social sciences, it is only relatively recently that attempts have been made by Human Computer Interaction (HCI) and behavioural and environmental science researchers to apply such methods in digitally-mediated interventions for reducing EUED in domestic [112] and workplace settings [196]. Empirical behaviour change methods have also been applied to other technology-enabled interventions, such as supporting insomnia [159] and increasing physical activity [115]. Such examples need to first go through robust data collection and analyses to fully understand the end-users who will use such systems, to support mapping behaviour change strategies to technology. Essentially this approach can be seen as the application of empirical behaviour change methods to design, and in this thesis, mapping behaviour change methods to the design of workplace and domestic energy interventions. It is important to note that residential and organisational spaces have very obvious different cultural and constraining attributes in terms of understanding intervention design, this is discussed further in the literature review in chapter 2, section 2.1. Generally, a household is likely to have a flat hierarchy when it comes to using energy, from heating water to watching T.V – it’s unlikely there are enforced rules on when you can use electricity or gas to meet your needs, whilst in the workplace an employee may not have access to switch devices and appliances specific to their job role on or off, or to control comfort levels, in some cases it may be inappropriate to do so. Again, we come back to the main opening question:

“How can technologies to change behaviour be designed to support compelling, desirable, and achievable energy interventions?”

Clearly, a one size fits all approach will not fit well when designing energy interventions, researchers need to thoroughly explore the space from the socio-technical perspective with HCI research providing the tools to do so, rigorously. With the aforementioned issues of climate change and rising global energy needs clashing on the political stage with public opinion divided, there is a real need for robust policies and interventions that address energy production and use as seen through a lens of sustainable practices and pro-environmental behaviours.

The design of energy interventions requires an understanding of the complex interplay between people and technology, as well as place, society and government. In other words, it first requires a human-centred approach, before engineering and efficiency methods are adopted or enforced. As such, the methodology adopted for this thesis follows an HCI user-centred approach, with the selection of appropriate and validated HCI qualitative research methods in conjunction with supporting quantitative tools. Essentially a mixed-methods approach is adopted to gain a deeper and wider understanding of the co-joined sustainability and behaviour change research space. When the socio-technical attributes are thoroughly understood, a more effective intervention can be designed that engages end-users and remains sensitive to their needs and desires. A human-centred approach embodied by the HCI research community is an ecologically valid approach to generate findings that inform the design of technology-enabled energy interventions. However, the literature also recognises the need to be mindful of the political backdrop that may be inadvertently driving the creation of design solutions [89]. Moreover, it is increasingly recognised that interaction design must address issues of sustainability, e.g. [36][151][189] with much work in HCI in the past decade on designing persuasive or 'nudging' technologies to change a target behaviour, e.g. [159][115][109][135].

1.2 Contribution Overview

This thesis presents design and technical implementation guidelines on how to design engaging domestic and workplace energy interventions that are informed by applied behaviour change methods. HCI and qualitative research methods were deployed to understand the needs of the end-users and design space across three case studies, one in the domestic space and the others in an organisational setting. Both domestic and workplace studies applied behaviour change methods to a technology-led energy intervention, with a significant Grounded Theory (GT) [55][258] method undertaken for the organisational studies. For the workplace studies, the resultant guidelines and derived implications from the analysis provide benefits to system designers and developers, utility providers, and institutions who wish to implement engaging energy interventions in their organisation.

A substantial set of literature has been produced on developing and evaluating software applications aimed at reducing EUED in the domestic environment by HCI researchers e.g. [106][231][57][121]. As has been noted by other HCI researchers [88][140], this work makes for interesting comparison with contributions from other disciplines, such as environmental psychology, which has also extensively researched domestic energy for several decades [21][42]. Other relevant domestic work in HCI by Odom et al. [204] investigated the use of persuasive applications to reduce student accommodation EUED, with findings of the study demonstrating that social feedback around energy use was effective at engaging students with their consumption practices. Leaving aside the differences in approaches between these research communities, the author is unaware of any substantial work from the HCI sustainability research community on understanding energy related behaviour change with employees in organisational or corporate settings, and further designing and evaluating interventions in the space.

To set this lack of research in context, a study carried out in 2009 [1] indicated that if the 17 million UK workers who regularly use a desktop computer powered it off at night this would reduce CO2 emissions by 1.3 million tons - the equivalent of removing 245,000 cars from the road. With 13% of total UK energy consumption from the services sector [81], and evidenced growth increase of 36% in energy-intensive office equipment in the period 1990–2012 saw a 36% growth in energy demand, with computers and other energy-intensive electrical appliances such as photocopiers and air-conditioning in the office significantly contributing to this [94]. Deploying automated interventions that turn off desktop computers, lighting and air conditioning may be seen as viable interim solutions to save some energy with no requirement of behaviour change - a classic engineering ‘efficiency first’ approach that effectively removes the individual from having input or further interaction.

Prior research knowledge is sparse in robustly understanding the socio-technical attributes of end-user energy in the workplace and in the context of technology-enabled energy interventions. Furthermore, this presents a research gap in understanding the *design* of appropriate and achievable workplace energy interventions, particularly those that encompass novel ways of encouraging people to adopt positive energy use practices and behaviour whilst at work. To address this gap, this thesis starts from the premise of the following question: *“How can technologies to change behaviour be designed to support compelling, desirable, and achievable energy interventions?”*. Following this, three research questions are defined and explored through separate research inquiry, with the experimental methods and findings presented as three separate case studies in this thesis throughout chapters 4-6. These are:

Table 1.2-1: Case studies presenting the thesis research contribution.

Case Study 1	Understanding the design of organisational energy interventions.
Case Study 2	Group goal-setting and feedback in an organisational energy intervention.
Case Study 3	Designing aversive feedback in a domestic energy intervention.

As identified in the literature, much work by the HCI sustainability community when exploring the domestic space for the design of energy interventions commonly adopts positive, or *appetitive*, feedback [155]. This thesis explores the use of aversive feedback, or negative stimuli, as an alternative to positive feedback in a domestic energy intervention. This approach is little explored as part of sustainability interventions, and could be used as a form of ‘consequence’ feedback for potentially increasing intervention engagement. Given that people react stronger to negative feedback, by engaging positively with their energy consumption they can then avoid the aversive stimuli. The use of energy feedback by other researchers in HCI, specifically persuasive technologies [140][66], has previously suggested the use of aversive feedback should be avoided as it leads to a lack of engagement by users. Interestingly, this is in sharp contrast with the findings from applied psychology, where it is suggested that corrective feedback – i.e. presenting consequences regardless of the behaviour observed – is often the optimum approach [166]. To further investigate these conflicting findings this thesis presents a conceptual discussion and analysis of how playful aversive feedback can be harnessed to reduce energy consumption in the kitchen environment [173], with an associated in-thewild field study that evaluates whether punishment of non-desirable behaviour, through aversive feedback, discourages users from engaging with a persuasive application [116].

This thesis contributes to HCI sustainability research in understanding end-users, and their role and requirements in the design of energy interventions for domestic and organisation environments, with the latter the principle area of academic inquiry. Several experimental studies were undertaken in the domestic and organisation space to produce design implications and guidelines for engaging and effective interventions. The studies were designed to successfully engage end-users with their energy consumption through digital feedback systems, and to bring about reductions in EUED through the implementation of empirically validated behaviour change methods.

The first case study, titled “Understanding the design of organisational energy interventions”, is presented in chapter 5, and is focused on the use of Grounded Theory (GT) [55], a qualitative research methodology, to perform an analysis of a series of organisational energy workshops with 65 participants, investigating perceptions and behaviours of workplace employee energy practices. The resultant GT analysis provided findings that support a greater understanding of employees and how they use and perceive energy in the workplace. Additionally, the analysis provides a discussion on the challenging design implications of organisational energy interventions, and produced a set of design guidelines to provide guidance on designing and deploying effective interventions. The study methodology adopts an HCI approach, discussed in chapter 3, using a number of qualitative methods such as interviews and participatory design to understand employee-centric energy practices in the workplace. The participants of the study belonged to the UK education sector and various other public and private sector organisations, including the energy industry.

The second case study is titled “Group goal-setting and feedback in an organisational energy intervention.”, and builds directly on the findings of case study 1 to deploy an intervention with antecedent contingencies mapped onto the software. A bespoke energy monitoring system was deployed, capable of near real-time feedback with 16 employees in a professional services department at a UK university. An ABA study design was implemented to demonstrate the effects of the intervention elements, with pre-study baseline and post-intervention energy data collected. A desktop widget was designed and developed to evaluate the intervention conditions, with design attributes derived from the findings of case study 1.

The third and final case study is presented in chapter 6, and is an experimental work investigating the use of innovative social and *aversive feedback* on an online social network (OSN) to display real-time energy feedback of a household [116]. This study provided novel, and to the author's knowledge at the time, the first, useful findings of the effectiveness of 'aversive stimuli' as energy feedback, in engaging end-users with their consumption practices. Although the domestic energy-saving space is not the primary foci of the work presented in this case study, it was felt important to take the opportunity to study this under-explored type of feedback for potential use as feedback in the organisational space. The study builds on the author's previous work in the domestic space of socially-enabled energy interventions [112].

1.3 Thesis Outline Summary

The research presented in this thesis is presented in such a way as to capture and discuss the main topical research areas in organisational and domestic energy intervention work through three case studies. HCI methods, behaviour change theory and research-informed applied studies, and the mechanisms to deliver technology-mediated interventions over digital platforms are discussed throughout the thesis.

Chapter 2 provides a review of previous, relevant efforts by the HCI Sustainability and Environmental and Behavioural Psychology research communities. The review covers domestic and organisational settings, and focuses on highlighting the pivotal differences between HCI and the behavioural sciences in their incumbent methods, and how an inter-disciplinary approach for intervention design between both would be mutually beneficial. Additionally, the current state of energy monitoring technologies will be examined and reviewed, as available equipment and infrastructure can shape and constrain an intervention type and scale, and whether energy data is openly accessible or in a closed silo in the context of end-user security and privacy implications.

Chapter 3 presents the research framework adopted for the main research components of the thesis, including HCI and behaviour change methods in the form of antecedent contingencies, evaluation strategies adapted for the experimental study interventions presented in the case studies, as well as further information on the target research gaps.

Chapter 4 is comprised primarily of a qualitative study carried out across a series of interactive workshops to robustly explore end-user employee’s perceptions, values, and attitudes towards theirs, and that of their colleagues, EUED practices in the workplace. Findings presented in this chapter inform the design of the organisational energy intervention work presented in chapter 5.

Chapter 5 builds upon the work presented in chapter 4 by adopting the produced design guidelines in an organisational energy intervention. A four-month energy intervention was designed and deployed using a bespoke, near-real-time energy monitoring system in an organisational department with 16 employees. Group feedback and group goal-setting were integrated in the intervention as antecedent contingencies.

Chapter 6 disseminates the findings of an experimental domestic energy study exploring the use of an under-explored type of feedback known as aversive feedback. The study aimed to investigate if end-users would disengage if presented with negative feedback.

Finally, the thesis will close with a general discussion of the main findings for energy intervention design as evidenced from each of the case studies, and implications for future work in the HCI sustainability research space.

2 BACKGROUND

This chapter provides a background discussion on academic HCI, Ubicomp and Environmental and Behavioural Psychology literature on behaviour change interventions to reduce EUED, reaching back to the 1970s where appropriate, and to present day. Two main sections are presented, the first provides a background account on the domestic energy environment, while the second is focused on organisational energy use research. The behaviour change strategies used in the literature are highlighted throughout for the roles they play in constructing energy feedback, desirable behaviours, and consequences on the decision making processes of end-users. Additionally, grey literature, governmental policy, and UK/EU energy legislation is also discussed to present a fuller picture of energy use, from end-users through to governmental policy and regulation. By thoroughly reviewing the field, research gaps are discussed, and appropriate methods and tools to support investigation are presented, which are further discussed in chapter 3. Much of research discussed in this chapter is internationally focused with research and case studies presented from a number of different countries. However, the author's work in this thesis was carried out in the UK, and as such, the relevant background literature around national energy consumption by sector, emissions, and climate and carbon policies are UK-centric, and to some extent the wider European Economic Area (EEA) where applicable.

2.1 Organisational Energy Consumption

2.1.1 Energy use in the UK and Europe

The responsible consumption of energy in workplace and domestic environments is a contemporary issue of considerable importance with profound social and economic implications, including resource shortages, global conflict, and pollution. To support and work towards a solution for these issues, the UKs parliamentary Climate Change Act of 2008 and significant Carbon Plan of 2011 set legally binding emission reduction targets of at least 34% for 2020, and 80% for 2050 based on 1990 baseline levels [153][83]. In 2014 the main sector divisions of total EUED in the UK using primary and secondary energy fuels were: industry 17%, transport 38%, domestic 27%, non-energy 5%, with the remaining 13% consumed by the services sector [81][82] see table 2-1-1.

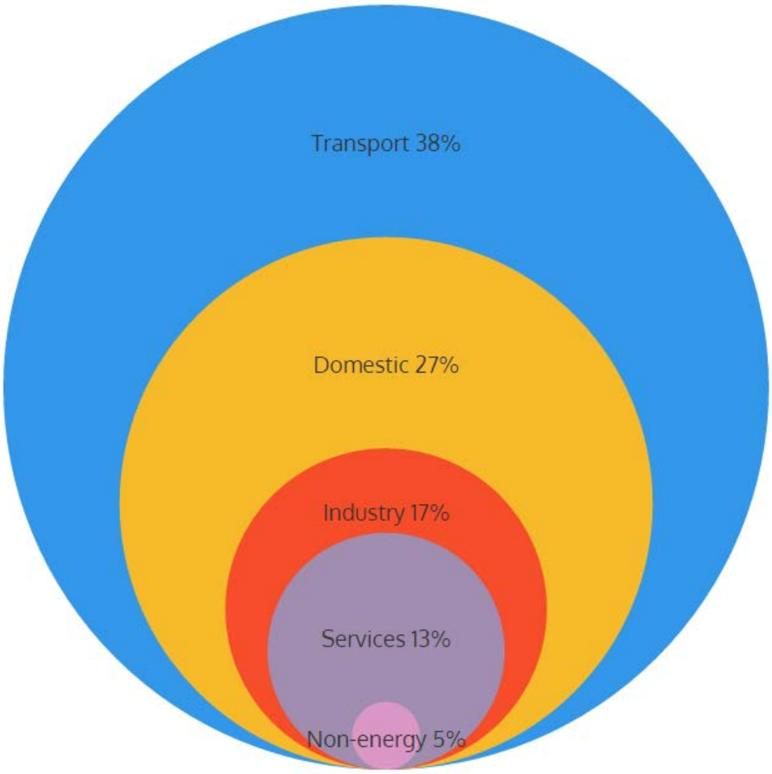

Figure 2.1-1: Total % UK energy consumption by sector

Within the services sector are a large numbers of employees who consume energy in public, private, and other types of commercial organisations. Small-Medium Enterprises (SMEs) - businesses of fewer than 250 employees - also come under the services ‘private’ sub-sector, accounting for 59% of UK private sector employment and 48% of its turnover with 15.2 million employees [33]. A number of studies have suggested that a substantial amount – possibly totalling up to £2.64 billion or more annually - of SME expenditure on energy is thought to be wasted through inefficient practices, with more than £300million of savings potentially coming from behaviour change interventions alone [94][102]. Behaviour change at work in this instance is through raising end-user awareness of greener products, services, and optimal practices. The same studies [ibid] report that SMEs have a greater energy saving potential of 20% compared to 8% for large organisations. Given the significant numbers of employees in service sector large organisations and SMEs there is recognised scope for substantial savings in both economic and environmental factors by reducing EUED through targeted, low-cost, behaviour change interventions.

The EEA states the European services sector, in the period 1990–2012, saw a 36% growth in energy demand, with computers and other energy-intensive electrical appliances such as photocopiers and air-conditioning in the office significantly contributing to this [94]. Despite modern appliances in the workplace becoming more energy efficient through evolving engineering approaches, their widespread proliferation and growing demand quickly offsets such savings. There is also the issue of the ‘rebound effect’ [127], where savings made with the introduction of new technologies can quickly be offset by a systemic response by purchasing/consuming more of the same technology or other technologies, or by an adverse behavioural response by end-users, an example of which is circumventing automated air conditioning/heating controls [224]. The rebound effect predicts that even if we manage to tame our desires for a specific resource we will often spend savings on other resource-intensive activities e.g. use money saved on utility bills to buy extra flights or a new car. Whilst there is considerable debate surrounding the rebound effect it seems reasonable to say that improved energy efficiency does not necessarily reduce overall consumption.

Similar to the UKs total energy by sector values, Europe’s services sector consumes 13% of total energy demand. In particular, electricity consumption by the services sector is of increased importance as it has grown by 91% since 1990 [94]. Figure 2.1-2 shows the total energy use in Europe by sector in 2012, highlighting the similarity to the UK [ibid].

With the importance of the climate, economic, and legislative issues surrounding energy consumption by organisations in the UK and Europe, the design and rigorous evaluation of innovative approaches to reduce EUED in the workplace through behaviour change is therefore a large scale national and Europe-wide problem, requiring urgent, multi-disciplinary attention from the research community. Such behaviour interventions can be deployed alongside engineering solutions, such as building management systems and self-regulating appliances. Sector wide regulation such as the mandatory EU Energy

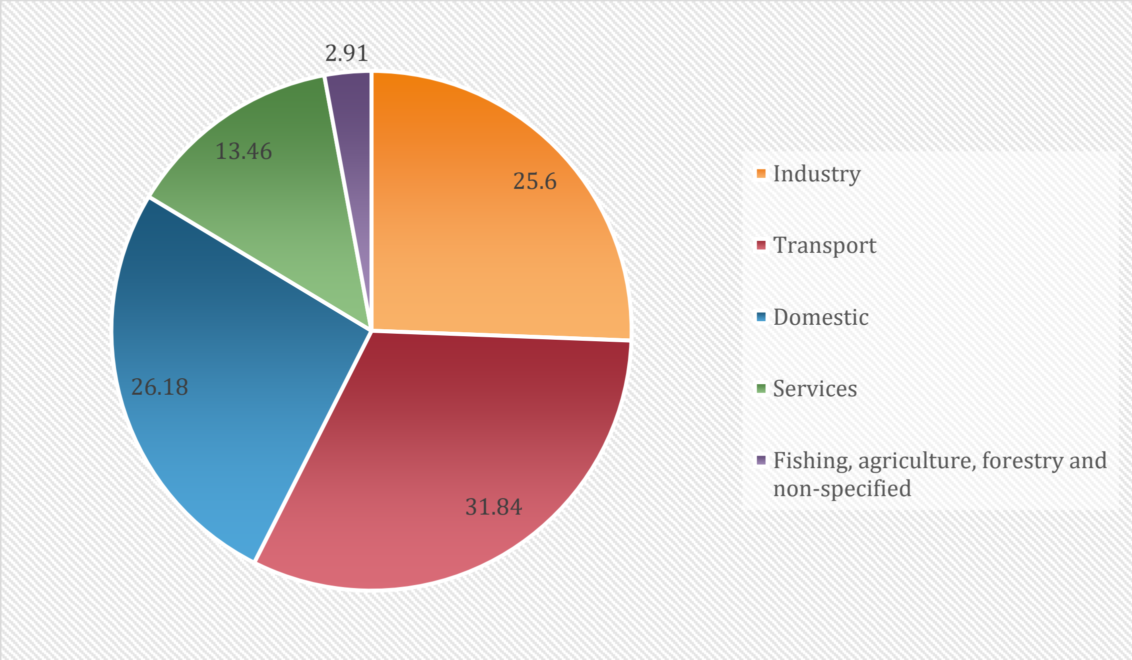

Figure 2.1-2: Total % European Economic Area energy consumption by sector.

Efficiency Directive [102] is in place to help improve and incentivise large organisational and SME energy efficiencies, and support the wider objectives of the both the UK and EU carbon management plans. These and other pertinent regulations are discussed in the next section.

2.1.2 UK government and European energy regulation

Perhaps the most significant collaborative milestone in recent times to reduce global emissions and the effects of climate change is the Kyoto Protocol, a global treaty of 192 countries that came into force in 2005 [128][227]. The majority of member countries signed up to the treaty committed to binding targets of Greenhouse Gas Emissions (GHG) at a reduction of 5% on 1990 baseline levels. To date, Canada is the only country to leave the treaty. It left in 2011 when its emissions were 17% higher than in 1990, coincidentally this was during the time period the country was exploring extraction of shale oil. As of 2013, the EU countries committed to the Kyoto Protocol have cut emissions by 18% since 1990 [120], and in the case of the UK and other member states, implementing further reduction initiatives over and above the original Kyoto targets. With the Kyoto Protocol giving global credence to reducing GHG across many countries, a further significant directive for European countries is the EU Energy Efficiency Directive [102], which requires EU member states to implement Article 8 of the directive. Article 8 states large organisations and SMEs must undergo regular energy audits and implement energy efficiencies as necessary. In response to meeting the directive, the UK government established the Energy Savings Opportunity Scheme (ESOS) [246], which requires qualifying (based on employee numbers and turnover) large private-sector organisations to undergo an energy audit every 4 years and identify and disclose cost-effective energy saving measures. Collectively, and individually, such directives and schemes with mandatory adherence should have the positive effect of organisations exploring effective ways to reduce energy. Much grey literature has been produced by businesses in an effort to understand how to reduce energy consumption in the workplace, through both behaviour change and automated energy-efficiency approaches [132][108][85]. In the case of the UK, increasing focus had been given to the application of behavioural sciences to governmental energy policy and research [25][209], popularised as *nudging* to bring about desirable behaviours. To support this approach, the UK government set up a 'Behavioural Insights Team' as part of the Cabinet Office with the task of applying the insights from behavioural sciences to energy policy [ibid]. Nudging is a term that academic work by Thaler and Sunstein [179] has recently re-popularised the interest in the idea of 'Nudge', where a combination of the right environment and contextual information delivered at the right time can encourage people to adapt and improve their behaviour. Similarly, work by Shirky has explored how societal change can come about by people self-organising through emergent online social platforms [247]. From a governmental perspective, the focus is on understanding how nudging can be applied to improve energy-saving behaviours in organisational and domestic settings, with a UK government white paper produced on this topic for behaviour change and energy savings [24].

The UK, against a backdrop of national, European, and global energy obligations and directives, is progressive in exploring innovative ways to support its current energy production and emission obligations, as well as promoting further reductions through independent UK-driven schemes. One such UK-centric scheme is the Carbon Reduction Commitment Energy Efficiency Scheme (CRC) [96][160], which requires large UK private and public sector organisations who consume 6000 megawatt hours (MWh) over the course of a year to be registered on the scheme. Organisations that are required to participate must monitor their energy use and purchase allowances for each tonne of CO2 they emit that falls within the scheme. The scheme is designed to incentivise energy efficiency and cut emissions in large energy users in the public and private sectors across the UK, which together are responsible for around 12% of the UK's greenhouse gas emissions. Participants include supermarkets, water companies, banks, local authorities and all central government departments. The more CO2 emissions an organisation outputs, the more CRC allowances it must purchase. This provides an immediate fiscal incentive for organisations to reduce their energy use through exploring the use of interventions such as behaviour change or automated efficiencies. A private UK organisation may find itself obligated to participate in both CRC and ESOS, which cumulatively could invoke considerable expense. As such the CRC and ESOS schemes can be viewed as fiscal incentives to reduce energy consumption. It can be argued that such 'greening' policies may in some instances actually increase the cost of business in terms of leasing of buildings, with research by Hinnels et al. [145] stating the standard commercial lease is a systemic barrier to environmental improvement, given the often significant upgrade costs of retrofitting for energy efficiencies.

With fiscal-aligned and mandatory emission reduction policies at the forefront of reducing emissions in UK private and public sector organisations, there has been growing interest in recent years around behaviour change for reducing energy consumption. This is often seen as the converse of, and softer approach, compared to deploying automated interventions that turn off desktop computers, lighting, and air conditioning with no visible requirement of behaviour change - a classic engineering approach that effectively removes the 'human' from the equation. The behaviour change approach loosely aligns itself with the UK government's 'Big Society' and 'Nudging' approaches to rally communities and societal issues, in an attempt to bring about positive behaviour change [69]. The concept is best exemplified by the work of the behavioural insights team at the UK Cabinet Office where a number of initiatives have been carried to explore and address a number of societal issues including health-related [27][26], and energy [24].

However, social science research undertaken by Corbett and Walker [ibid] argues that the concept of the Big Society is in direct contrast to the UK government's social policy agenda, namely the hollowing out of the state, which has direct implications on the values and social capital fuelling community initiatives, which also encompasses pro-environmental behaviours. Nevertheless, the UK behavioural insights team published the stand-alone 'Behaviour Change and Energy Use' white paper drawing upon behavioural economics and psychology literature [24], and additionally published a recent paper on engagement with smart meters and in-home energy use displays [28]. For the energy work undertaken by the insights team it is important to emphasise how little content is focused on the organisational context over domestic energy consumption, with main emphasis on automating lighting and heating settings for organisations, effectively there was not enough detailed information on how behaviour change methods could be used. Cursory mention is given to organisational behaviour change using social norm theory, competition and feedback - crucially without intervention design or deployment guidelines, making it difficult for large organisations (and SMEs) to easily follow a set of guidelines for implementation. From this, and academic work discussed later in this chapter, it may be assumed that little work has been carried out in the organisational environment combining behaviour change and energy saving practices, highlighting the significant challenges ahead. Similarly, numerous ‘grey literature’ reports produced by consultancies and other non-academic, non-scientific organisations on the topic of sustainability in the work-place (e.g. [132][108][85]), primarily attempt to engage employees with ‘automated’ energy-saving interventions, with little to no understanding of the underpinning behavioural change methods required for successful intervention engagement and adherence to best energy-saving practices. Several of the large energy providers in the UK including British Gas and EDF currently offer basic energy dashboards to small and large businesses with varying levels of feedback granularity [43][93]; to the author’s knowledge these dashboards have not been informed by behaviour change theory or subjected to empirical research methods.

The UK is not alone in its efforts to explore nudging through setting up experimental units similar to their Behavioural Insights Team to encourage positive behaviour in its citizens across a range of societal issues. Denmark has set up its own Mindlab initiative [194], while the US has setup the Social and Behavioural Sciences Team (SBST) [130].

In summary, the creation of UK government Energy and Behaviour Change reports, as well as EU, and UK ESOS and CRC energy directives/schemes for large private and public organisations, demonstrates a pro-active movement from government and business alike towards energy policy making and behaviour-driven savings on EUED. However, more academic work is needed in the context of understanding the design and application of energy behaviour change interventions in the organisational environment for reducing

EUED, particularly applied, longitudinal intervention studies. Academic research in the space of designing and implementing energy interventions is discussed later in this chapter.

2.1.3 Organisational energy monitoring technologies

Contemporary energy monitoring technologies, commonly known as smart-metering, are a critical requirement in the capture of energy consumption for reporting purposes, for example for CRC and ESOS reporting. They are also necessary for behavioural interventions where accurate energy feedback is displayed to end users as part of a behavioural strategy to reduce consumption. As such they are a convenient platform to support the basic requirements of designing technology-enabled energy interventions that use feedback systems. For example, a large UK organisation that consumes over 6000MWh per annum is required to record overall building consumption at 30 minute intervals, a rather coarse metric but perfectly acceptable for the purposes of CRC and ESOS reporting. A basic, networked smart-meter infrastructure will be in place to record the mandatory collection of the energy data.

A typical organisation smart-meter deployment network will be comprised of a smart-meter for each building containing a logger, which records timestamped energy values, normally every 30 minutes. Additionally, for networking purposes and remote sending of data the meter will house either a GSM modem or WIFI module, see figure 2.1-3; energy data is stored in the data logger and can be pulled by dialling into the GSM modem or in the case of WIFI the data is automatically sent to a base station. Using a GSM modem is not uncommon, at least in the UK. From the point of view of designing an energy intervention to display feedback on energy used, typical organisational metering at the building level is problematic on three counts: i) interval frequency, ii) granularity of data, and iii) publishing the data from the meters for consumption by third party applications. These three issues need to be considered when designing an intervention in the context of applying behaviour change attributes - for example if an intervention is planned for reducing a specific department’s energy use in the same building as other departments then the data may not be available at the required granularity. Work by Darby [75] in the domestic space identified that direct and frequent feedback delivered via display from a smart meter can bring about savings of between 5-15%, however organisational metering is typically not configured for real-time viewing of the stored data as it is usually stored in 30 minute intervals. With significant potential gains achievable through a combination of smart meters and feedback through external displays, it is worth pursuing in the organisational space, albeit with careful consideration of the design implications.

Figure 2.1-3: Left to right; Multilog data logger with gsm modem allowing remote access to energy data.

Enabling the publishing of open and timely energy data, for use in technology-led interventions is an important first step in effectively engaging end-users with their consumption practices. The availability of open online energy data means monitoring usage is not reliant on the smart meter display (if present) or a fixed display within the building providing feedback to capture the attention of the user. Indeed, some companies in the UK and the US are already producing smart meter systems that are internet enabled, providing access to proprietary online services such as energy and reporting dashboards [43][93][2], however the software side of such systems is often costly to maintain with yearly and expensive site-licencing. However, for the most part such consumer off-the-shelf systems do not provide the wider developer and open data community with access to fully open energy data and services required for the organisational space; they are often an additional cost to end-users through yearly corporate based subscriptions using a ‘walled garden’ approach for data access.

The typical software that communicates with the data logger in figure 2.1-3 is not simple in operation, neither does it provide options for opening access to the data. Figure 2.1-4 shows a screenshot of the interface at the University of Lincoln.

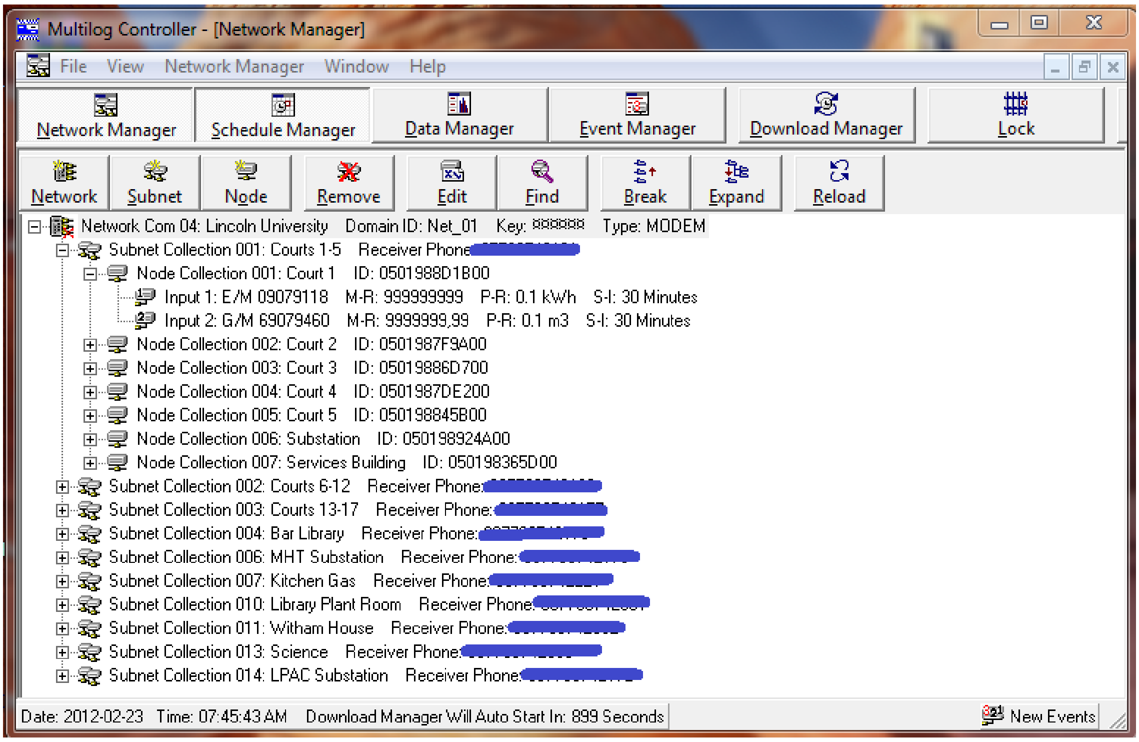

Figure 2.1-4: Multilog energy data logging communication software circa. 1995.

The communication software shown in figure 2.1-4 is generally the middle component of a typical organisational smart meter infrastructure configuration. Large organisations usually resort to purchasing enterprise class software systems that collect the energy data from the data logs for complex analyses and reporting, such as through e-Sight and RtEmis carbon monitoring systems [101][237]. Enterprise class systems are normally proprietary in nature, and the carbon management systems are no exception to this in that they generally offer little in the way of open access to the underlying energy data. Work by Vikhorev et al. explored energy management systems such as e-Sight and RtEmis and found that they were useful in understanding baseline energy consumption, as well as large appliance monitoring to help optimise manufacturing processes [274]. Anecdotally, at the University of Lincoln, the e-Sight system helped to identify anomalous outliers in consumption during overnight periods, where a significant quantity of energy was being consumed by heating units when buildings where closed.

Although the aforementioned carbon management systems may be useful for baseline measurements and identifying outliers, they are dependent on the configuration of the smart meter infrastructure – essentially they are only as good as the data that is collected from the smart-meters, which may only be offered at the granularity of building level. As such, interfacing with enterprise class energy monitoring systems in the design and deployment of bespoke energy interventions is a challenging task, as evidenced in the work carried out in this thesis. As a result, a bespoke energy monitoring system was built to run the experimental study presented in chapter 5, as the best available data for the participating organisational department was 4 hourly data, at building level.

2.1.4 Academic research

The workplace can safely be classed a special environment for energy intervention design research, with unique constraints, implications (internal corporate policies and legal obligations), and hierarchal structures (management) that are not present in the household space. The problem therefore is neither solely a human nor engineering issue, but rather socio-technical in nature. Given this, the argument may be made that the organisational intervention space is more challenging than the domestic arena, where ultimate responsibility for energy management lies with the householder, as an employee's responsibility is far from clear.

A report by the EEA presenting energy statistics for the European services sector saw a 36% growth in energy demand in the period 1990-2012, with end-user office equipment such as computers, photocopiers, and air-conditioning significantly contributing to this [94]. A business energy report [1] indicated if the 17 million UK workers who regularly use a desktop PC powered it off at night this would reduce CO2 emissions by 1.3 million tons - the equivalent of removing 245,000 cars from the road. The UK's commercial and services sector, which covers education, is responsible for 12% of the UK's total energy consumption [81]. Therefore, despite public sector governmental carbon policies coming to the fore, there is still much to gain by exploring new ways of persuading people to adopt positive energy usage behaviour whilst at work.

As indicated in grey literature [132][108][85], and governmental white papers with associated mandatory energy schemes [24][96], reducing carbon emissions is a central policy often acting as a primary intervention agent. With the negative consequences of climate change and peak oil, the transition to a society less reliant on fossil fuels is of paramount importance [62][31][188][252]. In this section, academic work will be discussed that presents a timeline of relevant studies to understand behaviour change in the context of reducing EUED in organisations.

Academic research has been undertaken for many decades in understanding behaviour and how to raise awareness of reducing energy through changing everyday practices, in both domestic and organisational settings. Relevant work stretches back to a notable period in the 1970s, when a significant global oil embargo [47][136] motivated a large body of research on behaviour change and reducing energy consumption in households [287][67][19][245][285], and commercial buildings [284][154]. This line of research carried on through the 1980s with Dwyer et al. [91] carrying out a review of the pro-environmental energy intervention literature from this period, work reviewed included the use of feedback to reduce EUED, presented through information campaigns and ‘prompt cards’ as intervention strategies [124][286]. However, Dwyer et al. [91] found that a significant body of the work did not have a sound methodological approach with limited intervention methods deployed. Nonetheless this early work paved the way for further work that was not just another reaction to oil shock prices, but towards an understanding of climate change [62][188], and sustainability through the 1990s to present day. Pro-environmental behaviour and sustainability are the keywords in framing contemporary sustainability research as it moves away from ‘energy conversation’ terminology of the 1970-80s, and embraces ‘energy efficiencies’, of which end-user behaviour change plays a pivotal role. The majority of the early work was focused on reducing domestic energy consumption, with very little explored in the organisational space, which is now discussed here.

A substantial scientific study in the domain of social psychology around engaging employees in energy related behaviour was carried out by Siero et al. [248], which demonstrated the efficacy of comparative energy feedback between groups of employees. The Siero et al. study did not use frequent or technology-led feedback (likely beyond the energy monitoring technologies available at the time), yet it was still successful, suggesting further reductions could be made by adopting a technology-enabled approach to provide more novel forms of feedback with currently available technologies, as suggested by from work by Darby [75][76]. More recent work in the social sciences by Whittle et al. [280] explores who, or what, is responsible for EUED in the workplace to better understand the relationships between employees and ‘things’ that consume energy in the workplace. This type of qualitative research is of crucial importance in understanding the socio-technical aspects of workplace EUED, as it can lead to informed and ethical organisational policies, and increased efficacy of successful interventions. Research presented in chapter 4 of this thesis mirrors this ethos and forms a large part of the core research carried out. Findings of the work by Whittle et al. [ibid] demonstrate that care and agency must be undertaken when instrumenting employee EUED, particularly avoiding the use of methods that identify end-users that can potentially bring about negative inferences in how they consume energy. This was an identifying feature of the employee discussions carried out as part of the work in this thesis, and discussed in detail in chapter 4. Energy consumption metrics don't necessarily lead to definitive 'answers' on the how and why energy is consumed, but can be used to springboard productive discussion that encourages contemplation and refection, thereby better supporting employees to act in a more sustainable manner. Additional findings of the work by Whittle et al. [ibid] identify management buy-in as being key to engaging employees around EUED – managers simply introducing measurement practices as a stick is a missed opportunity to start a useful dialogue on the relationships between employees and the things they interact with daily. Again, this point was also raised as part of the qualitative work carried out in chapter 4, appropriate management buy-in is essential for the success of interventions, not to mention engagement – if there is no visible management buy-in then this could negatively affect employee engagement. Essentially, the importance of the manager-employee relationship is at least of equal weighting to the EUED measurement itself.

Further work by Whittle [281] posits the term 'Environmental Concern' in the workplace, which conjures a more emotive concept than other work that investigates 'pro-environmental' behaviours [119][272], and focuses more on how the everyday practices of life can become both political and personal as habits, beliefs and emotions crossover between work and personal life. The organisational landscape often enforces a culture of regulation and policy, with such rules generally outside employee control – this can cause conflation between carrying out the required 'everyday' work tasks, and commitment to pro-environmental behaviours. This work again highlights the importance of qualitative approaches in collecting and analysing data to understand the important socio-technical aspects of the workplace environment in relation to EUED, and illustrates how change at the collective level (organisational) and personal level combined with social practice approaches could provide the insights necessary for change.

Other relevant work by the social sciences was carried out by Staddon et al. [254] and provides a systematic review of interventions in the workplace to reduce EUED. The review work offered findings that the most successful interventions where those with an emphasis on the socio-technical factors, over and above automated measures. Interventions that offered a good degree of control to employees, with energy feedback, including significant support to enable more sustainable practices, were the most effective. Interestingly the work highlighted three thematic intervention areas that have been under-explored in the social sciences domain: Coercion, Training, and Restriction. There are obvious issues with these under-researched themes in that they may be unethical or inappropriate for the workplace. However, in line with the research enquiry of alternative (aversive) feedback presented in chapter 6 of this thesis, these areas deserve attention as they may lead to interesting findings in terms of intervention engagement, and may actually prove useful as part of a wider sustainability behaviour change toolset. Similarly, work by Osbaldiston & Schott [215] produced a meta-analysis of work to promote pro-environmental behaviour across a range of intervention types. In relevance to this thesis, the meta-analysis results found that cognitive dissonance, goal-setting, social modelling, and prompts provide the largest, and most positive effects. Goal-setting was a core component of the study presented in this thesis in chapter 5, as it is intended to compliment suitable EUED feedback. Behavioural psychology has a long history of published work demonstrating the effectiveness of goal-setting spanning decades [185], with relatively more recent work by Lindenberg & Steg [183] looking at how goals can successfully influence environmentally-friendly behaviours.

Despite the work by Osbaldiston & Schott [215] highlighting that goal-setting and cognitive dissonance were among the most effective methods to influence pro-environmental behaviour, their meta-analysis revealed they were also studied the least. In work carried out in this thesis, alternative feedback is explored in a study reported in chapter 6. Aversive feedback is also known as negative reinforcement or aversive stimuli [158].

Instrumentation of workplace environments through systems such as intelligent Building Management Systems (BMS) [263], and other automated controls such as heating and lighting is commonplace. In the case of large organisations, the collection and reporting of energy data for mandatory government policy and regulation (UK) creates an opportunity to leverage such data for innovate interventions. The Ubicomp sustainability research community has capitalised on this opportunity, and a number of relatively recent workplace studies that tap into either BMS or smart-meter energy data to facilitate novel and engaging intervention studies have been carried out [161][100]. The work by Jahn et al. [161] went beyond energy monitoring on its own and utilised sensor deployments to monitor presence and employee interactions with lighting, heating, and windows. Post-analysis of the study revealed workers were concerned with what might be interpreted from monitoring data at this granularity. For example, there were concerns management could build detailed profiles of an employee's movements and track/infer where they have been. This mirrors employee privacy concerns revealed in the study presented in chapter 4 of this thesis. Care must be taken when monitoring employee's interactions and consumption habits in the work environment, with the work of Jahn et al. [ibid] suggesting the users (employees) should retain full control of their personal data.

Ubicomp studies tend to demonstrate that sensor deployments when appropriately deployed can save energy. However, work by Erickson and Cerpa [100] explored the use of employees as sensors to support regulating thermal comfort in an office environment. By allowing employees to vote every 10 minutes their on current thermal comfort levels, the user data generated was then used to directly adjust temperature. Over the duration of the study satisfaction levels were high for the near real-time strategy of voting, with 10.1% energy savings over the baseline. This is an interesting approach, and shows that when putting people in control, positive feedback and reduced EUED can result. It is likely the large levels of buy-in from the employees and resultant empowerment created the high engagement levels for success.

Bedwell et al. [22] carried out a review of workplace energy interventions against a backdrop of UK governmental policy on reducing carbon emissions. As identified in this thesis, carbon reduction targets are not just drivers in terms of climate and sustainability issues, but also in the context of fiscal incentivisation at the organisation level – the more carbon produced, the more an organisation will pay in carbon taxes. Findings of the review by Bedwell et al. [ibid] indicate that energy data apportioned to small groups, over the individual, is preferable in interventions. However, it is acknowledged in the work that there are complex issues in selecting between individual or group energy data feedback, with personal feedback providing motivational and personalised feedback, but potentially of concern to the individual in terms of privacy and attributing negative EUED practices. While group apportionment of energy data feedback may be motivating for group identity and improved perceptions of the instrumentation of their immediate environment. In short, Bedwell at al. [ibid] argue that the social and ethical implications of workplace interventions at both the individual and group level are important. Similarly, the work presented in chapters 4 and 5 of this thesis discusses in detail the technical issues of small group energy monitoring in a large building, and also the social and privacy concerns of employees participating in workplace interventions – of particular concern is management being able to monitor an employee's EUED and infer what they perceive as negative practices. Bedwell et al. [ibid] also conclude that understanding basic research on how to motivate individuals to reduce EUD in the workplace with an approach of incentivising rewards is still an open question. Rewards are also discussed in the study presented in chapter 4 in the context of reducing EUED. There are a number of organisational and hierarchical complexities surrounding this, particularly the difficulties around accurately apportioning EUED to small groups in large organisations across several buildings, as well as the common practice of centralised fiscal policy where the transfer of capital is not always transparent.

In other work undertaken by Bedwell at al. [23], and similar in many respects to that carried out by Schwartz et al. [243], by use of qualitative enquiry and discussion of design implications, it produced findings that highlight emergent themes of interest. The themes were energy wastage, role of company policies/negotiation of their implementation, and the bigger energy picture of procurement, construction and travel – all of which are large thematic areas of discussion and distinctive enough for singular exploration. The main take home message of the work is that more research needs to be undertaken to unpick the complexities of the relationship between stakeholders (building users) and the conflict between organisational policy, energy use, and comfort. Another headline finding was the lack of research in the HCI sustainability space that addresses energy policy in the context of integration in workplace energy interventions.

Much work has been carried out by HCI researchers on designing eco-feedback systems for the domestic space [57][112][116][223], and to a limited extent, organisational environments [178][243][186][193]. The embryonic work by Lehrer and Vasude [178], investigated the concept of using an online social network to deliver workplace energy feedback and promote and encourage energy saving practices. The authors have yet to report on the findings of their field-study; which mirrors the social media approach described in other successful domestic interventions [112][138].

As stated previously, the majority of HCI research on the design of technology for promoting sustainability has been aimed at the domestic environment. Very little previous work has investigated whether the design of domestic end-user energy interventions could be useful and applied to an organisational context. The workplace presents a very different design space from the domestic, where end-users (i.e., employees), work under regulatory and organisational rules and are generally not responsible for paying the energy bill. These identified features outline a very different design space than that targeted by domestic energy interventions, particularly on fiscal responsibility, and accountability. However, some relevant recent work has been published, notably by Lockton et al. [186] who investigate employee engagement with energy interventions. Findings highlight that feedback for near-real time energy use, and rewards in the form of points helped to engage users. However, the authors found that energy consumption was not correlated with engagement levels. Schwartz et al. [243] present findings on a series of participatory design workshops, followed-up by the deployment of smart meters and energy use visualisations in an organisation, with results suggesting that participants preferred feedback that visualised consumption related to individual devices and generated by individual users over aggregate feedback. Work in progress by Milenkovic et al. [193] reports on the outcomes of an attempt to engage office workers with personalised energy feedback [193], with the novel ability for users to provide feedback on their own comfort levels in an office or building. Early results by Milenkovic et al. [ibid] show their approach can provide a more holistic view of consumption in a building for management purposes, and also increase reflection on awareness of energy use by employees. End-user engagement is key in energy interventions, and work towards how engagement approaches can be transferred to interface and interaction design is of paramount of importance and investigated in this thesis in chapter 4.

From the literature, HCI sustainability research in the workplace has been somewhat limited in scope with the design space only beginning to be more robustly understood. Notably, Froehlich et al. [121] highlighted shortcomings in evaluation methodologies in the HCI sustainability literature, in which user studies averaged 2.5 weeks in duration, compared with 15.5 months in pro-environmental work reported by environmental psychologists [119][272]. Crucially, without longitudinal findings for behaviour change studies there is no way to validate that a particular HCI method or feedback design is effective to change behaviour. Technologies designed by the HCI community for changing behaviour would benefit from evaluation through evidence based behaviour-change methods, over psychologically significant time scales, particularly to address potential novelty effects [140][226]. Empirical studies by the HCI community tend to be small scale technology prototypes with limited inclusion of inter-disciplinary work, particularly with the behavioural sciences in areas such as behavioural, social, and environmental psychology. Overall, Froehlich et al. [121] stressed the need for HCI researchers to collaborate with behavioural and environmental psychologists in order to leverage their expertise to bring about pro-environmental behaviours. Likewise, the domains of behavioural and environmental psychology could benefit from including more user-centred methods in their work. Work by Hekler et al. [142] builds on the work by Froehlich et al [ibid] and attempts to address the silo problem between HCI and behaviour change domains in understanding the most suitable theories that are compatible with technology for behaviour change. Findings of the work offers HCI researchers guidance for interpreting, using, and to some degree, contributing to behavioural theories. Although the work was interesting, it is more of an introduction on how the begin to address the problem, with a large body of work required to better understand selecting and mapping behaviour change theory to a diverse range of technology-enabled interventions.

The HCI community has recently shown a great deal of interest in the development of interactive systems that facilitate behaviour change for sustainability and positive lifestyle practices, i.e. the design of sustainability feedback systems [121][7][112][173][116][60], and in promoting healthier lifestyles [115][64]. Much of this research has exploited ideas recently re-popularised by Thaler and Sunstein [179], in that individuals can be ‘nudged’ to make better lifestyle decisions, given the right information and the environment in which to do so. A majority of this work has focused on how individuals might improve their own private and domestic lifestyle, behaviour, and sustainable resource consumption; however, such work has rarely taken account of the fact that people spend a significant amount of their waking hours at work where they also contribute towards resource consumption, generating a significant volume of CO2 emissions.

The domains of environmental and behavioural psychology have extensively researched pro-environmental behaviours. A systematic review of the contribution environmental psychology has made to understanding pro-environmental behaviour was carried out by Steg and Vlek [255]. The review identifies target behaviours for promoting, and the correct application of interventions in changing behaviour to reduce negative environmental impact. However, there is no link back to HCI design methodologies in any of the environmental psychology literature reviewed. Despite the absence of contemporary HCI literature in environmental psychology, recent HCI work has identified the need to refer to domains such as environmental and social psychology [121] when designing sustainable interventions.

Behavioral psychology literature has carried out energy-saving intervention research in the organisational space. However, this was not always the case, with most work focusing on the domestic space up until the 1990s [169]. Work by Siero. et al. [248] in 1995 presented findings of an experimental intervention study carried out for energy behaviour-change in an organisation with some success. The work demonstrated the effectiveness of comparative feedback, by using competition between different organisational departments for promoting saving practices and perhaps most encouragingly, without the use of technology-enabled feedback. Energy feedback in this case was delivered via physical posters displayed on throughout the organisation and resulted in reductions of 6% energy saved after 6 months, highlighting the potential of more immediate, real-time feedback to enhance the approach. The work of Siero at al. [ibid] is acknowledged in this thesis, with work carried out presented in chapter 5.

Work by Staats et al. [253] conducted a longitudinal study with office workers as participants in an informational feedback study to reduce gas consumption during winter periods. Feedback was delivered via weekly posters and was successful in reducing gas consumption, with another follow-up study in the next winter period providing similar findings. Over the two-year period the work was carried out, a 6% saving in gas consumption was recorded, equal to $6000 in utility costs. The weekly poster approach was similar in method to the work by Siero et al. [ibid], as well as the energy savings realised during the intervention. Again, it is encouraging that more timely feedback through digital platforms may support further savings.

Later work by Carrico and Riemer [52] in 2011, was similar in approach to the research undertaken by Siero et al. and Staats et al. [ibid], who also used group-level feedback to employees and indirect monthly reporting as part of an energy intervention with 352 university employees. The study reported a 7% reduction in energy use over the 4-month intervention period.

More recent work by Murtagh et al. [196] in 2014 used direct feedback from plug socket monitoring technologies, and investigated the effectiveness of individual energy feedback in the office environment, in contrast to the group feedback work by Siero et al. and Staats et al. [ibid], this work found some success in reducing energy demand among office workers but issues were uncovered. Findings of the study revealed reductions during some of the intervention phases, but also uncovered some issues with engagement, and inconsistencies with energy reductions across the intervention period, revealing the complexities of deploying workplace interventions. The work was carried out over a four-month period and used an *individual* self-comparative feedback approach, with ambient feedback and temporal (to within an hour) graph feedback. Inconsistencies with energy reductions were found with levels decreasing only in the 3rd a 4th months, despite no change in the intervention condition in months 1-4. Again, this highlights the complexities of the organisational space when attempting to design and implement behaviour change strategies, with work carried out for this thesis observing similar issues which are discussed in chapters 4 and 5.

2.1.5 Research gap

With the majority of energy-saving work over the last three decades by the Behavioural Sciences and HCI focused on the domestic space, it is clear more work needs to be done in the organisational context where a very different end-user dynamic exists. Additionally, whereas the Behaviour Sciences work has successfully applied behaviour change methods in non-technological (absence of digital feedback) longitudinal studies, they have not clearly mapped behaviour change onto interaction and interface design following HCI user-centred design methods. By doing so would provide robust intervention design guidelines for digital feedback platforms, however this is easier said than done with a significant body of work required to come closer to a possible solution. From the literature a research gap exists to further explore and understand EUED in the organisational context using HCI methods to aid the design of digital EUED interventions. Methods such as participatory design, interviews and qualitative analysis would provide deep insights into end-user perceptions and daily practices around their energy use. Successful behaviour change methods as evidenced from the Behavioural Sciences literature could then be mapped onto the HCI findings for effective intervention design and deployment.

The organisational energy work presented in chapters 4 and 5 of this thesis builds upon important work cited in this review chapter. For clarity, this related work will now be summarised to clearly identify how it informed the thesis research.

Work by Shirky [247] on the power and influence of groups of people stated that institutional change can come about by employees forming simple groups around a common interest and dissemination of information. In the case of the work presented here, the common interest is sustainable behaviour, and the information shared is group awareness of energy consumption, supplemented by behaviour change attributes such as social norms and group goal setting. Shirky believed that collective action was a necessity for change in organisations, with small groups acting more effectively if given some degree of autonomy, over and above large scale 'top-down' coordination. This small-scale collective approach is similar to the organisational work in this thesis in that a small group of employees were given the opportunity to participate in an energy intervention that encouraged collective engagement through group feedback and group goal setting measures.

Work by Schwartz et al. [243] presented findings of an energy study that was initially derived from qualitative enquiry through to deployment of smart meters and simple feedback. Following a period with the smart meters, further qualitative enquiry was carried out through a workshop to enable participants assess their impact and reflect upon their consumption. A key finding was participants preferred to view their own feedback rather than aggregate, as such another phase of the study was carried out with each participant given individual appliance monitors (IAM), also known as smart plugs, to monitor their own consumption. In the final 5 weeks of the study energy levels with IAMs had dropped by around 8.4% compared to the aggregate data from the smart-meter only phase. The workplace energy work presented in thesis is similar to that of Schwartz et al. [ibid] in that it chose to adopt a qualitative approach in understanding the complex socio-technical issues at play in an organisational environment, this allows a rich narrative to take place between researchers and employees to robustly understand the design of potentially suitable interventions. However, the work of this thesis builds upon simple individual feedback by introducing more complex contingencies including group feedback and goal-setting.

Other similarities to work by Schwartz et al. [ibid] is the use of IAM's to effectively monitor EUED, although the work in this thesis did use IAMs, they were not used to provide individual energy feedback, but were used to facilitate accurate measurement of individual desk-space consumption for group aggregation of EUED data - the differentiating factor is the employee participants of this work preferred not to have individual feedback as a result of privacy and other concerns (discussed in chapter 4). The choice of individual feedback over group feedback between the work of Schwartz et al. [ibid] and the work presented here is perhaps a cultural issue (different country) or possibly attributed to the vagaries of the relatively small participant sample size of each study. In any case a fuller understanding of this is outside the scope of the research presented here, and the experimental methods selected for this work were derived from a combination of the qualitative research carried out and previous work, significantly in this case as informed by Siero et al. [248]

Work by Siero et al. [248] investigating the effectiveness of group feedback in a workplace energy intervention was perhaps the most important piece of research in providing research direction for this thesis, and from which to build and improve upon given the work was undertaken some time ago. The work by Siero et al. [ibid] successfully reduced workplace EUED simply by using physical poster information on energy use, updated asynchronously on a weekly basis. The work of Darby posits, and supports the findings of Siero et al. [ibid], that energy feedback can reduce EUED if delivered in a suitable and timely format. Darby states that savings of up to 10% can be achieved through asynchronous feedback, such as paper billing (similar format to the Siero et al. study), and even more through technology enabled feedback with savings of up to 15%.

Feedback is therefore a necessity in bringing about change and forms a core component of the technology-enabled feedback components of the studies presented in this thesis. In terms of the similarities (specifically feedback) with the organisational energy study presented in chapter 5 with the work of Siero et al. [ibid], comparative feedback was again used (group-based), with the differentiating factor of using near-real time feedback instead of indirect (asynchronous) feedback. With Siero et al. demonstrating that comparative feedback was effective, a stepwise iteration would be to enhance the feedback timeliness and frequency, as well as introduce other successful behaviour change methods such as goal-setting at the group level to encourage collective engagement.

Similar to work by Shirky [247] on the effectiveness of small groups to bring about collective change, a review of workplace energy interventions by Bedwell et al. [22] also presented findings suggesting that smaller groups participating in an energy intervention may be more motivating in reducing EUED over individual or large building-level strategies. As such, using small groups for workplace energy studies appears to be a promising and informed approach, and is adopted by the workplace study presented in chapter 5. Again, the similar format of qualitative enquiry and workshop format to better understand the socio-technical issues of workplace EUED is present in work by Bedwell et al. [23], and mirrored in the research carried out in chapter 4 of this thesis.

As a result of the research investigated in this chapter, similarities and concepts to build upon future research were identified. Subsequently, a research gap in organisational energy interventions produced the first high-level research question of interest to this thesis:

"How can we design effective technology-enabled, energy-feedback interventions in the workplace to reduce EUED through behaviour change?"

To address this overarching question and other relevant supporting questions around engagement and interface preferences, chapter 4 presents the findings of a robust qualitative study to understand EUED in the workplace and, therefore, the design of appropriate and achievable workplace digital energy intervention. This work is published in the peer-reviewed ACM CHI conference [113]. Understanding EUED in the workplace is a complex task with significant social, organisational, cultural and technical issues that cannot be easily quantified by casual inquiry. In order to help address the problem of adequately understanding employee motivations, engagement and incentivisation in workplace energy interventions, it is important, and appropriate, to carry out HCI research methods that target specific and relevant themes, as well as a wide range of end-user stakeholders. This was realised through conducting a series of facilitated in-depth workshops with employees and management from a number of different organisations. The Grounded Theory (GT) method [258] was used to understand a significant body of qualitative data from the workshops to elicit further scientific enquiry. The goal was to support a wider understanding of the employees as end-users of energy, and produce a set of design implications and guidelines on which to design and deploy technology-enabled energy interventions the employees helped to co-create.

Findings from the 1st research question are utilised to inform the design of an in-the-field workplace intervention. The intervention integrated technology-enabled group feedback and goal-setting with 16 employees from an organisational department. This field study addresses the 2nd research question of this thesis:

> *"Can group-based feedback and goal-setting in a technology-enabled workplace energy intervention reduce EUED?"*

The field study is discussed in chapter 5 with antecedent behavioural strategies implemented in the intervention including group feedback and goal setting [68][190], building upon, and enhancing, previous successful organisational energy studies [248][253][52] that did not use digital feedback, in this case with the addition of mapping group-feedback and goal setting behaviours change methods to digitally interactive feedback interfaces.

2.1.6 Summary

In summary, much academic work around energy-saving for consumers and businesses has been undertaken since the 1970s, evolving from analogue meter information to pervasive digital feedback displays combined with interventional behaviour change strategies. More recently, in the context of the UK at least, a combination of mandatory governmental policies and EU directives have created schemes that specific organisations must be members of for regulatory adherence to energy efficiencies and emission reductions. Additionally, countries around the world have acknowledged the threat and consequences of climate change and have set collective emission targets. Governmental and business grey literature has also been produced to provide basic guidelines around reducing energy consumption, going as far as the creation of government sponsored 'nudge' units for end-user behaviour change across different lifestyle facets, from energy use to physical activity. Collectively, it can be seen that a lot of work has been undertaken to bring about reductions in EUED, particularly in the domestic space, but more academic research is required to understand the socio-technical complexities of energy interventions designed from the organisational context, where a very different end-user environment exists in comparison to domestic dwellings.

2.2 Domestic Energy Consumption

In the UK, domestic energy use is the 2nd highest sector by consumption at 27% of total energy consumed, with the transport sector requiring the largest portion of total demand at 38% [81][82]. This is in contrast to UK organisational energy consumption, which as a sector consumes 13% of total demand. For comparison, the energy consumed by the transport and household sectors in the wider European Economic Area (EAA) was 32% and 27% respectively [94], reflecting a near identical consumption pattern to the UK. With household energy consuming nearly a third of total energy demand in the UK and Europe, it is critical that energy, and resultant emissions, are reduced in order to meet the UK government's global and national carbon commitments, which includes the 2008 Climate Change Act to reduce emissions by 80% by 2050 [63]. It will likely be impossible to reach a reductions target of this magnitude without significant emission reductions in households through measures including behaviour change, adoption of energy-efficient appliances, and building retrofitting such as insulation and boiler upgrades. As a result of the 2008 Act there are a number of emission-reducing incentives the UK government has developed for householders since the act was ratified, though not funded directly; funding is provided through utilities and third party commercial entities. The most recent of these initiatives include the Green Deal [270] and the Energy Company Obligation (ECO) scheme [207]. Such UK initiatives encourage householders to make energy-efficiency modifications to their homes without 'up-front' costs, but rather through commercial loans and additional costs added to utility bills. Both the Green Deal and ECO superseded the pervious, and successful, household energy programmes such as Carbon Emissions Reduction Target (CERT) [205] and the Community Energy Saving Programme (CESP) [206]. In all programs, the UK government mandated that utility companies were obligated to commit to reducing energy in the household environment, with each program offering consumers different ways in which to make their homes more energy efficient. Several of the schemes were required to target homes in low income areas and households in recipient of state benefits. In all cases the utility companies had to meet significant energy reductions targets mandated by government, realised through measures such as insulation, boiler replacement, and other retrofitting. Additionally, none of the schemes targeted behaviour change strategies, indeed it wasn't until 2011 when the UK Behavioural Change Insights team published their white paper on reducing household energy by changing behaviour [24], indicating the validity of behaviour change as an effective approach. From this it can be extrapolated that both government and utilities explored and implemented, as their primary method, the 'low-hanging fruit' energy efficiencies through retrofitting homes. The question remains however in how further savings in household emissions can be made where efficiencies such as retrofitting have already been implemented, or where they aren't yet feasible due to building constraints. It follows then that household occupants' lifestyles and EUED practices are of particular interest to bring about further savings through behaviour change.

Although the aforementioned schemes appear to be admirable in their scope and implementation to bring about reductions in EUED, work by Rosenow and Eyre [234] were critical of the potential effectiveness of the Green Deal and ECO, citing issues on contractors using newer and less understood energy efficiencies, and consumers finding the costs added to their utility bills a less than attractive approach. Essentially the utility companies are incentivised to retrofit homes with efficiency measures to meet mandated consumption targets set by government, it is however the consumer, the householder in this case, who ultimately picks up the costs of such measures. Further work by Rosenow and Eyre [235] on the schemes highlighted tensions between households in fuel poverty and the rising costs of energy associated with Green Deal and ECO.

Other UK government carbon-reducing efforts, such as behaviour change, through their behaviour insights team, and the current national smart meter rollout (through industry and utilities) [28], are designed to give householders direct feedback on their consumption practices, presented in such a way as to encourage a reduction in EUED. The current roll-out of smart meters in the UK is a major energy infrastructure project that will see the replacement or upgrading of over 50 million electricity and gas meters by 2020 [79]. By March 2016 2.6 million smart meters were operating in domestic dwellings across the UK. Given the current installation base there is some way to go to meet the target of 50 million homes by 2020, in all likelihood it's an unrealistic expectation. Smart meters are purported to bring about benefits to householders such as helping to identify energy-saving opportunities, higher engagement with billing and costs, and to engage with their energy-use practices over a longer period. Indeed, early work by Darby [75] at the Oxford Environmental Change Institute on smart meter energy feedback for energy reductions stated that savings of up to 20% may be possible

However, the underpinning theoretical work by the UK behavioural insights team on behaviour change for household energy with smart meter feedback, and the research space in general, has not yet been robustly researched at scale smart meter feedback field studies. With the national roll-out of smart meters facing delays and falling far short of meeting deadlines [217], valuable research in this space may not be forthcoming for some time to come. The Early Learning Project by Department of Energy and Climate Change carried out a qualitative study with a sample of 2,037 smart meter customers and their experience of the smart meter installation, using surveys and interviews [80]. The study provided insights into customers' engagement with the smart meter installation, satisfaction, and any reported behaviour change. It's important to note that the findings are based on survey and interview data only, with no experimental studies carried out using the smart meter as a behaviour change intervention platform. This type of research is yet to be undertaken across different experimental conditions and will provide valuable design implications in how to effectively map behaviour theory to smart meters and associated In-Home-Displays (IHD). However, some research has been carried out at scale that pilot's energy feedback as a mechanism to raise awareness of energy use and bring about positive behaviour change and shifts in attitudes.

The CHARM Project [97] carried out field work in households to reduce energy consumption through social feedback, specifically feedback on their own consumption compared to their neighbourhoods [139][138]. The trial included 400 households, each with a bespoke smart meter across three conditions: i) no feedback, ii) individual feedback, and iii) social feedback, with feedback accessed through a web portal. Findings indicated those who received feedback reduced their consumption on average by 3%, however there was no difference in the energy saved between individual and social feedback. The authors suggest if the energy feedback was presented in a less abstract way (overall view) with disaggregated feedback at the per-appliance level then the social feedback may have been more successful, with feedback targeting specific daily practices and behaviours such as doing the laundry, using their tumble drier, or turning on the central heating. Additionally, the individual feedback option was considered to be of vital importance in engaging households with their EUED, echoing other work [77], however the authors are clear that more research is needed in understanding the application of more granular feedback to target specific behaviours and practices.

The social feedback approach was carried out by the author of this thesis in previous work [112], and found the social feedback to be successful in engaging end-users and bring about reductions in EUED, albeit with a much lower sample size. Social feedback, or *social norms*, is a well understood space for behaviour change with much work carried out in the space [5][8][201][241] over several decades. The different types of feedback used in energy intervention studies are discussed further in this chapter in section 2.2.2, including direct, indirect, and social normative feedback approaches, with the under-explored *aversive* feedback type opening up an interesting and novel research gap to form part of the innovative work presented in this thesis in chapter 6.

Work by Schleich et al. [240] carried out a large scale smart meter study with ~1500 households over 12 months by providing ‘asynchronous’ energy feedback to half of the participants with the remaining half the control group. Feedback was provided as simple energy feedback with information on saving energy, with no specific behaviour change methods integrated. Feedback was somewhat convoluted in that it was not directly viewable in real-time or on the smart-meter, instead it was transmitted to the utility company who then sent it out on a monthly basis to the feedback group via a web portal or post. Results indicated average savings of 4.5% were achieved with the feedback group. It is clear the limitation of this study was the temporal nature of the feedback supplied back to the households, with further energy reductions potentially available through more timely feedback. Further field work is required with experimental studies of similar design in terms of duration and scale, as well as near real-time feedback through a smart meter & IHD combination.

Further academic work in reducing domestic EUED through behaviour change and feedback has produced a large corpus of literature with varying levels of success from the environmental psychology literature [21][42][20][35][34][273], and in HCI literature [121][7][112][173][116][60]. The environmental psychology research tended to focus more on combining empirical behaviour change methods to encourage pro-environmental behaviours, while the majority HCI research was focused more on the experiences and engagement of end users with feedback technologies. Tensions were revealed in the HCI literature between end-users and smart meters/IHD, with disengagement with the technologies occurring after a short time [222]. Further engagement issues were reported by Strengers [259], whose work suggests disengagement occurs with the monitor when a disconnect between the resource (energy-use) and the non-negotiability of daily lifestyle practices takes place, i.e. doing the washing, cooking, and consuming digital entertainment. The 'disconnect' identified by Strengers [ibid] can occur, for example, when cost alone is not motivation enough when norms and everyday social practices can be the overriding factor against change. People do not always make rational choices around being more energy efficient [56]. Irrational choices made by householders are also present in some psychology and energy research, with work by Creyts et al. [257] and Stern et al. [72] indicating that even when presented with the opportunity to make energy-saving investments at no cost with high returns in savings, they declined the uptake. Additionally, EUED is variable across households of similar demographic types due to a number of factors, which in some cases might help explain irrational energy use and failure to uptake and implement energy-efficiency measures. Energy use is influenced by the physical and technical aspects (insulation, boiler type etc.) of the home in conjunction with the householders (and other occupants) knowledge, know-how, values and daily lifestyle practices [126]. As the energy efficiency of buildings improves, we can expect the significance of 'lifestyle' factors to increase in terms of targeting interventions for behaviour. With the variability in householders' attitudes towards energy and their diverse lifestyle practices and routines, there is recognition that effective interventions need tailoring to specific individuals and circumstances [289]. As indicated in the HCI literature, a 'one size fits all' approach to energy savings is therefore likely to be unproductive [140].

Further issues around householders understanding EUED in the home was carried out by Kempton who studied two theories of how householders understand thermostat control operation in the home for heating [168]. This is of particular importance as space heating in the home accounts for 62% of total domestic consumption. A householder's understanding of thermostats and other high energy consumption appliances may originate from other people, or can be self-conceived in the form of folk theories or urban myths regarding appliance energy use in the home [86]. This may lead to forming incorrect or inefficient behaviours when using energy-consuming appliances in the home, particularly as incorrect practical or recommendation advice may come from friends or colleagues who are influential sources [278]. One of the theories put forward by Kempton [ibid] was coined 'Valve Theory', and describes the incorrect use of the thermostat control in the home, with an estimated 25%-50% of US household occupants holding an incorrect theory on how the thermostat operated. Valve Theory describes the misconception that if the thermostat control is set to a higher temperature than desired to heat a cold room up it will heat the room up quicker. As this mental model of system operation is incorrect, it is likely that more energy is consumed as the temperature will ultimately reach the higher temperature, with the occupant then turning it back down to the required temperature. An earlier study found that 62% of 38 households also stated they would turn the thermostat on full to heat a room up believing it to be quicker [203].

Although the aforementioned research on thermostat control use may be rather old, ranging from 1982-2000, the thermostat control on contemporary heating systems has not been through a major transitional change. Most modern systems still employ a rotary dial for temperature adjustment, while others use a digital display with numerical values that can be set up or down. An occupant may still go through the same application of 'Valve Theory' on a modern system by the same temperature adjustment method.

More recent research exploring cutting edge 'intelligent' thermostat systems in the home has been carried out by Yang and Newman [291]. A qualitative study was carried out using interviews to understand how householders perceive and use intelligent thermostats such as the Nest [198], the technology used in the study. Their findings were interesting in that despite decades of technological advancement since the development of 'valve theory', householders still had great difficulty in understanding how a so called intelligent thermostat operates, with workaround strategies developed which could defeat the purpose and intent behind such intelligent systems.

Innovative research in the ubicomp sustainability research community by Bates et al. [12][13] was carried out in student dorms that moves beyond solely using a sensor network to monitor and display EUED. The work approaches energy-use 'as a service', with such services involving every day activities and lifestyle habits to encapsulate the use of lighting, cleaning, comfort, and cooking – the types of services that comprise daily social practices. To glean a deeper understanding of the how the services were used in conjunction with the collected energy data, qualitative interviews were carried out, and supplemented with near-real time mini queries during the study phase. Findings indicated improved insights of energy use in domestic or living spaces such as student dorms can be derived by moving energy analysis to the concept of services. This approach can provide a more holistic view and an alternative approach for intervention design considerations – where multiple energy appliances are often used together in daily practices such as consumption of digital entertainment and cooking.

Further research into folk theories on how energy behaviours and practices was carried out in the 2000 study [56] and exposes myths such as leaving lights, computers and televisions switched on constantly consumes less energy than frequently turning them on and off. The seemingly widespread belief of folk stories surrounding EUED in the US, as evidenced through the aforementioned studies, illustrates problematic mental models that are at odds with the correct engineering operation, and impact upon energy efficient behaviours. Emergent technologies for the home environment that have the potential to eliminate the effects of Value Theory, are technologies based on the Internet of Things [131] and Connected Home concepts [244], to fully automate (through learning heating behaviour patterns) and remotely connect an end-user to their household's heating system. Systems such as Nest [198] and Hive [146] employ an array of sensors that learn the heating patterns of a household and automatically schedules as appropriate. To our knowledge, no academic user-study work has yet been carried into these systems and how they can potentially save energy. However, some white paper studies have shown the systems in a positive light for energy savings [271][199].

Similar to research carried out in the organisational energy space with smart meter feedback which revealed inconsistencies of consumption patterns [196], work by [42] revealed that in some cases household energy interventions with feedback can increase consumption if the end-user's consumption was of a low-level prior to the feedback. Given the complex socio-technical backdrop of energy use, more research is required to unpick energy behaviours and practices to provide an insight into why consumption may go up when feedback is provided. Work presented in chapter 5 of this thesis discusses this phenomenon further, albeit in an organisational context, as it was observed in the results of an in-the-field study.

It is clear from the work discussed in this chapter covering UK Government and European policies, independent white papers/grey literature, and academic work, that the research landscape for household energy interventions is diverse and challenging, requiring a multi-disciplinary approach to unpick the socio-technical challenges threaded throughout all aspects of EUED. There is an identified need for households to reduce their CO2 emissions, and with smart meters likely to become a ubiquitous piece of equipment in the near future, they should afford researchers an ideal platform to explore the mapping of behaviour change theory onto technology for energy interventions. However, researchers should be mindful of the previously identified tensions and implications of energy feedback interventions in relevant HCI and behavioural psychology literature.

2.2.1 EUED in the home

The distinction in how energy is used in households is very different from organisational use, and additionally, is also very different from the way household energy was consumed in the 1970s. Most homes now have central heating, usually fuelled by natural gas, and most households also have a large number of appliances such as fridges, freezers, washing machines, dishwashers, tumble dryers, PCs and games consoles. In the period of 1970-2012 household energy use in the UK rose by 16% [216]. The estimated percentage of energy use for each of the main household usage areas in 2009 was: i) space heating (62%), ii) hot water (18%), iii) lighting (3%), iv) appliances (14%), and v) cooking 3% [ibid], see figure 2.2-1 for a comparison of these to 1970 percentage values.

A large increase in a wide range of appliance ownership is evidenced, including exponential growth in smartphone and portable computing equipment such as tablets and laptops that require daily charging [ibid]. However, a drop in energy is seen in hot water generation and cooking, likely through the use of more energy-efficient appliances and methods, more on this shortly.

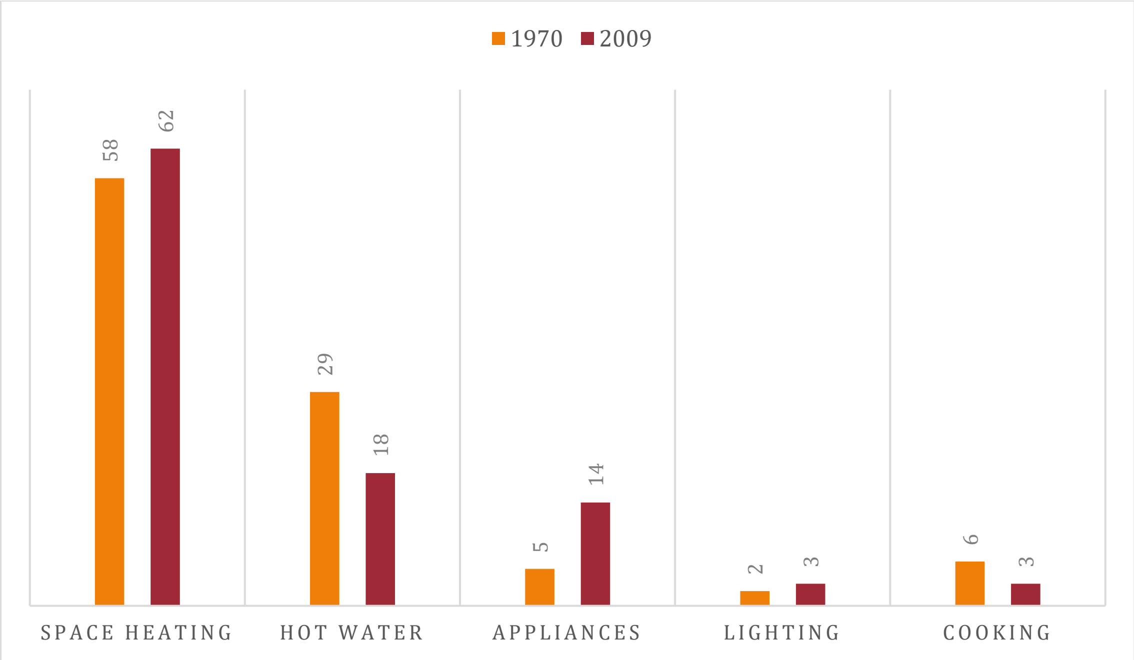

Figure 2.2-1 - % areas of UK household energy use comparing 1970 to 2009.

The householder is responsible for the purchase and operation of such appliances with choice of selecting energy-efficient models, and ultimately responsible for paying the energy costs. In the workplace environment, equipment such as computers, projectors, photocopiers and any portable heating are normally purchased centrally, the employee end-user generally has no control over the procurement process of potential energy-efficient options, and importantly neither are they responsible for paying the energy costs of using said workplace equipment. With little to no control over equipment procured and utilised, and no responsibility to pay the energy costs, it is clear organisational energy interventions are a challenging area of research for developing successful energy interventions. It may be argued that as a result of the significantly more challenging space to carry out research, there is an imbalance of work carried out in understanding organisational energy interventions.

Work by Beck [18] identifies increasingly individualized forms of living such as: “living alone, single parenthood, non-marital cohabitation, childless marriage, serial marriage” and “living apart together”, where partners live in separate dwellings. The impacts of these trends are social but also environmental in that one person living alone uses more energy than two in the same household [39]. Essentially, the fewer people living in a household, the less energy efficient it is. Rising energy consumption currently means increased CO2 emissions, which is very much a global problem with climate change perhaps the greatest threat to human civilisation and the global ecosystem [62].

2.2.2 Feedback

The concept of using feedback in the home for displaying EUED is a well-researched area, spanning multiple disciplines, i.e. in the behavioural sciences [57][240][20][35][34][273], and HCI [239][112][220][222][259][57]. Different types of energy feedback have been categorised throughout the literature, with work by Darby defining the main categories evidenced as *direct* and *indirect* feedback [75][74], which can be deployed as part of empirical behaviour change methods such as antecedent or consequence strategies [68], and social norms [201][241]. In terms of displaying/reporting EUED, direct feedback is generally available on demand in near real-time through a smart meter or IHD at whole house level, or in more sophisticated devices at disaggregated per-appliance level, though this is currently rare. Indirect feedback is generally more asynchronous in nature, for example through monthly paper or electronic billing.

Social norm feedback in the context of energy use is based on nudging end-users towards positive behaviour change. Nudging can be explained in terms of social norming effects where an individual will adjust their behaviour to align with peers, or what is perceived as a normative measure [229]. A *descriptive norm* feedback message may be delivered for example on how much energy a household has used compared to other households, offering a comparative measure, while an *injunctive norm* feedback message indicates if the amount of energy used is good or bad, or within the ‘norm’ range of peers [58][59], see figure 2.2-2. A combination of descriptive and injunctive norm feedback is advised to help avoid a *boomerang* effect [241]. For example, if a householder is already abstaining from excessive energy use and is given the descriptive energy feedback of peers who are using substantially more energy, then they may increase their energy consumption by viewing the peers EUED as an appropriate standard [ibid][42]. Thus, to minimise the possibility of undesirable behaviour increasing due to provided feedback, the injunctive message (whether the behaviour is good or bad) should accompany the descriptive message. Work by Alcott [5] also reported evidence of the boomerang effect when social norms were deployed in a large scale household energy intervention with 80,000 homes through paper billing. Another application of social norms in an attempt to reduce alcohol consumption produced differential results in participants, leading to increased consumption in some individuals [51]. In summary, social norms require the utmost consideration in their application to ensure that any unintended effects are satisfactorily mitigated.

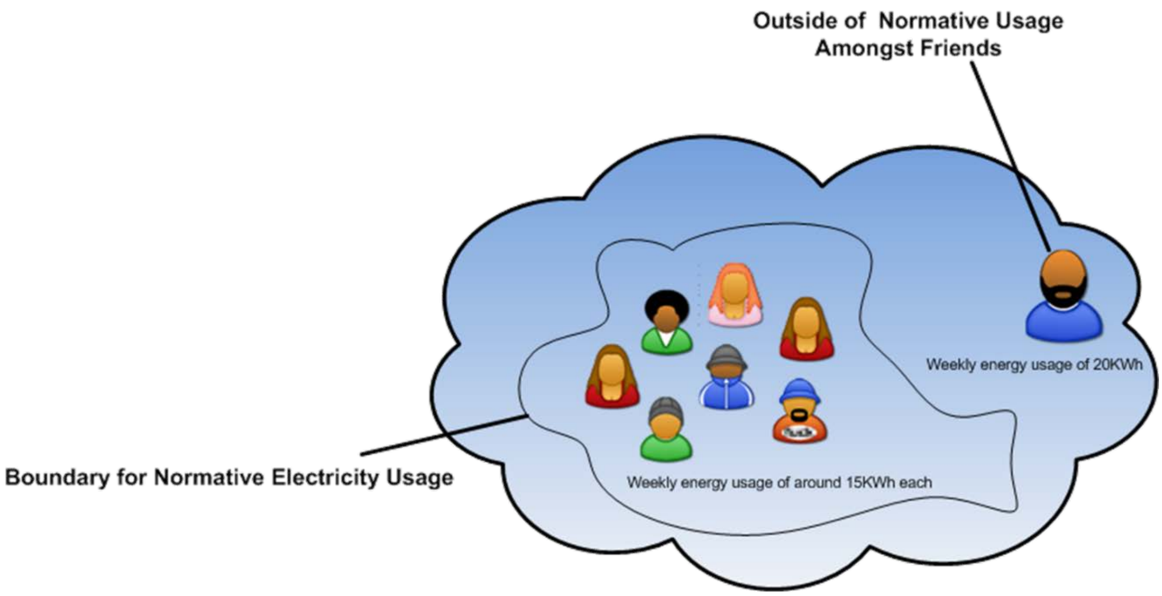

Figure 2.2-2: Social normative feedback with a group of friends comparing EUED.

Much research has been carried out in facilitating the nudging of people towards positive changes in eating, fitness and health [26], and more recently through persuasive technologies with feedback playing a crucial role. So, what exactly is a 'persuasive technology'? BJ Fogg coined the term in his book *'Persuasive Technology'* [109] and described it as:

"Persuasive technology is broadly defined as technology that is designed to change attitudes or behaviours of the users through persuasion and social influence, but not through coercion"

Work in ‘persuading’ individuals through using technology-enabled feedback in the context of energy saving has since progressed rapidly with greater emphasis on understanding the underpinning social and behavioural sciences methodologies that may be employed successfully in energy interventions. Perhaps the key phrase in Fogg’s description of persuasive technologies is social influence, again we see the power of social norms at work as the catalyst for behaviour change, now delivered through emergent web and mobile platforms.

With a great deal of work carried out in utilising social norm feedback for household energy interventions by the behavioural and social sciences, as well as basic informational-only feedback interventions without integrated behaviour modification methods, there is one feedback mechanism that has been little explored, particularly in the HCI space – aversive feedback.

Much attention by the HCI community has been given to the role of technology such as mobile phones, the Internet, computer games and social networking sites in helping stimulate behaviour change in users. As well as the aforementioned energy intervention studies, technology-based behavioural interventions have been developed in the fields of diet and exercise [9][10][45][50][65] chronic disease management [122][180] and HIV prevention [283]. Although these technologies are designed with the specific aim of effecting change in user behaviour by providing positive information and feedback, very few have implemented empirically established methods for doing so [249]. Indeed, very little of the published work on persuasive technology by the HCI community gives any specific insights into the processes involved in behaviour change, nor specific examples on how to apply these processes. Negative information, or aversive feedback is particularly notable by its absence in HCI persuasive work. This is despite behavioural psychology research stating that negative feedback universally has a stronger effect, and that negative feedback is normally processed more intensely than positive feedback [14][236][250]. This strong effect could potentially be leveraged in the context of sustainability, by persuading end-users to be more pro-environment in their attitude and behaviours, and help support reductions in EUED. The consequence of inaction has a negative impact on the environment, and an increase in personal costs through utility billing. Essentially, negative feedback signals a need for a change in behaviour, and thus may be more effective than positive feedback if carefully considered in its design, deployment, and frequency.

Aversive feedback can be delivered as part of an energy intervention with empirical behaviour modification methods in the form of operant conditioning, encompassing positive reinforcement, negative reinforcement and punishment [249]. Most persuasive technology applications aim to effect behaviour change simply through offering simple rewards or *appetitive feedback* (i.e. badges and points) to users. Appetitive feedback is rewarding, and as a result is attractive and has potential to motivate and make us exert more effort to reach the reward goal. In the context of an intervention, rewards can induce approach or appetitive behaviours, as demonstrated by work by Schultz et al. [242], with the primary rewards for reducing domestic EUED a reduction in direct costs (billing), and a positive impact on the environment (less emissions). Appetitive or positive feedback is all well and good, but what if an end-user (householder) is not saving energy, or meeting goals, and is in fact consuming far more than required, simply through habitual consumption practices? It would seem appropriate that the end-user should also consume negative feedback as a consequence, that communicates a suitable message about their 'undesirable' behaviour. In other words, there is a consequence to their actions and behaviours by delivering this type of feedback.

People can learn from the consequences of their actions, and energy feedback that contains an aversive message could be effective if deployed appropriately. In line with operant conditioning, being able to evaluate feedback information, delivered in an energy intervention, and using it to guide future actions are important for changing behaviour. Work in the neuroscience space by Nieuwenhuis et al. [200] reports that such learning depends on the ability of the brain to discriminate between positive feedback, indicating that the behaviour was appropriate, and negative feedback indicating that the behaviour was inappropriate. Other work by Huang and Rongjun [152] explored the concept of feedback-related negativity (FRN) and its impact upon subsequent behaviours. In the context of their usefulness in HCI sustainability and persuasive work, the take home message of the aforementioned studies by the neuro and behavioural sciences is negative feedback as a consequence of undesirable behaviour is important feedback for consideration in an intervention, but must be carefully designed and evaluated before deployment. Poorly designed negative feedback could lead to intervention disengagement and an increase in negativity around daily energy consumption practices.

In the case of energy interventions, it may be argued that to be effective and consistent, both positive and negative feedback should be communicated to end users, however this has rarely been implemented in the HCI research space. It is rare to find a persuasive application that takes advantage of the full capabilities of operant conditioning, despite the fact that a combination of positive reinforcement, negative reinforcement and punishment is a fundamental aspect of how behaviour is learned and maintained in the natural environment [ibid]. For example, in an office a person will work hard in order to achieve a salary and the approval of colleagues (positive reinforcement). However, that person's performance is also maintained by the aversive stimuli that they are avoiding such as peer disproval, suspension, termination of employment (forms of punishment) and poverty (working to escape poverty is an example of negative reinforcement), which will be delivered if the person does not work hard.

One significant problem with designing behaviour change interventions that offer only rewards is that when a reward is not obtained, there is no meaningful feedback delivered to the user at all – there is an absence of aversive stimuli, effectively there are no consequences. It is difficult to evaluate what a person learns from a complete lack of feedback upon failure to meet targets, for example a weekly energy saving target. Additionally, when feedback is not presented, the control over what the person learns is taken out of the hands of the intervention program designer and can lead to the development of problematic "folk theories", as discussed in this chapter. This work suggests that persuasive technologies may benefit from the delivery of aversive stimuli when a user does not meet behavioural targets, as this will increase the overall frequency of feedback delivered to users and, consequently, the control of the intervention over the user's behaviour.

Embryonic work by Cowan et al. [71] explored the use of aversive feedback as a consequence strategy to address habitual 'bad consumption practices' when using an intensive energy appliance in the kitchen – the common kettle. To address behaviour such as consistently overfilling the kettle beyond the required quantity of water and thereby wasting energy, the work designed a study that presented a form of aversive feedback if the kettle was used incorrectly. If the kettle was overfilled the user is forced to undertake a mundane task, commensurate with the quantity of overfilled water. Although the approach may raise awareness of the targeted bad behaviour, it can be argued that a more direct approach of being forced to enter the correct amount of water before it is heated may be a better approach in helping to enforce the correct behaviour.

Other early HCI sustainability work by Dillahunt et al. [87] argued that a type of aversive feedback, in the form of a visualisation comprising a polar bear on top of shrinking ice floes, may increase pro-environmental behaviours. In their study, participants who made more sustainable commitments where shown a polar bear on top a larger ice floe, less commitments resulted in a smaller ice floe, with an increased negative effect on the bear. However, the study was not deployed in-the-field as part of an energy intervention, but rather exploratory research. Work by Midden et al. [192] conducted a lab study exploring the use of negative feedback on modifying per-appliance consumption behaviours. A specialised software dashboard was designed in which participants interacted with mock-ups of appliances such as washing machine controls. Results of the study found that negative feedback induced more sustainable actions compared to positive feedback. A field deployment based on the results of the Midden et al. [ibid] study would provide valuable findings to help inform the design of aversive feedback systems in the context of energy consumption.

From the literature surveyed, there is a clear research gap in exploring the use and effectiveness of aversive stimuli in energy interventions in both the household and workplace environments. This route of academic inquiry forms part of the novel research contribution presented in this thesis and is further defined in section 2.2.4, and presented in chapter 6.

2.2.3 Monitoring technologies for the home

Much of the terminology to describe energy monitoring for the home is similar to that used in the context of organisational monitoring. However, whereas much of the large-scale organisational hardware is headless with no separate feedback display, household technologies typically comprise accessible in home displays (IHD) to display energy feedback directly to the householder, either at whole household or disaggregated at per-appliance level.

Over the last few decades there has been a clear evolution of the venerable analogue energy meter itself, gradually morphing into the modern smart meter unit with multiple capabilities, including data storage and transmission, and in some cases over-the-air (OTA) tariff switching. Since the 2000s, the older type of analogue energy meter installed in most homes was gradually being replaced by their digital counterparts, at least this is the case in the UK. For the first time various types of energy data feedback could be rotated through a monochrome display. Of course the householder would still have to view the display from wherever the energy meter was located, which might be outside the building. Figure 2.2-3 shows the transition to a basic digital energy meter, offering an early form of 'situated' feedback.

Figure 2.2-3: Household meters, older analogue meter on left, digital meter on right.

Household energy monitoring in the US and UK has gained traction through utilities bundling free energy monitors with specific tariffs as a response to consumers desiring more information on their consumption habits. The technologies available at the time of the free bundling offered compatibility with both analogue and digital meters, using a magnetic clamp for the former, and a more accurate optical sensor for the latter. The monitors themselves were generally of a table-top design, with a basic display showing energy used in kWh units with associated cost, see figure 2.2-4. Literature by Pierce et al. [222][223] suggests that this type of energy monitor is quickly discarded after the novelty effect wears off, while work by Strengers [259] suggests disengagement occurs with the monitor when a disconnect between the resource (energy) and the non-negotiability of daily energy-use practices takes place.

Figure 2.2-4 Current Cost and Owl Energy table top energy monitors.

Other types of home energy monitors have been developed with a more ambient approach in mind by using light as feedback such as the Wattson monitor in figure 2.2-5, and the Power Aware chord in figure 2.2-6. These deviations from the standard IHD units were an attempt to make the monitors more desirable for the home setting and better fit with furnishing; thus potentially increasing engagement and interaction levels with consumption practices.

Limited interaction with IHD monitors, including lack of internet connectivity for enabling richer online user experiences, will also contribute to high disengagement levels. Effectively, many of IHD units in the home are small data silos, typically storing around one month of energy data, accessible through the display alone. The inherently closed nature of this data inhibits opportunities for providing consumers with compelling, provocative and persuasive experiences around their energy consumption. Enabling the publishing of open, timely and optionally private energy data, for use by third party developers is an important first step in effectively engaging end-users with their consumption practices. The availability of open online energy data means monitoring usage in the home is not reliant upon physical table-top monitors to capture the attention of the end-user, paving the way for remote anywhere anytime access.

Figure 2.2-5: The Wattson energy monitor from DIY Kyoto.

Indeed, some companies in the UK and the US [43] [213] are producing monitoring and software service kits that are internet enabled, providing access to proprietary online services such as live and historical energy dashboards. Generally speaking, these monitors are based on emergent Internet of Things (IoT) platforms [131], with utilities securely collecting and storing large volumes of consumer energy data from smart meters. This data, commonly termed ‘Big Data’, will be mined and analysed by utility providers for understanding the consumption practices of millions of households. Such analysis can help feed into the strategic planning in the wider energy grid in understanding peak demand.

With space heating in UK homes accounting for around 62% of total household energy consumption, a number of intelligent thermostat systems have evolved over the last few years in an attempt to bring about automated savings on comfort heating, while taking account of peak demand times. The technology taps into machine learning to learn household consumption patterns over a period of time, and gradually schedules the most economical mode of operation and time periods in which to heat the home. This can also involve input from external sensors that factor in outside temperature and weather, when adjusting for the most economical mode of operation. Examples of such systems are Nest [198] and Hive [146], both of which are capable of employing an array of sensors that learn the heating patterns of a household and automatically schedules as appropriate. White paper studies have been carried out using Nest and Hive, with findings indicating the systems show promise for generating energy savings [271][199].

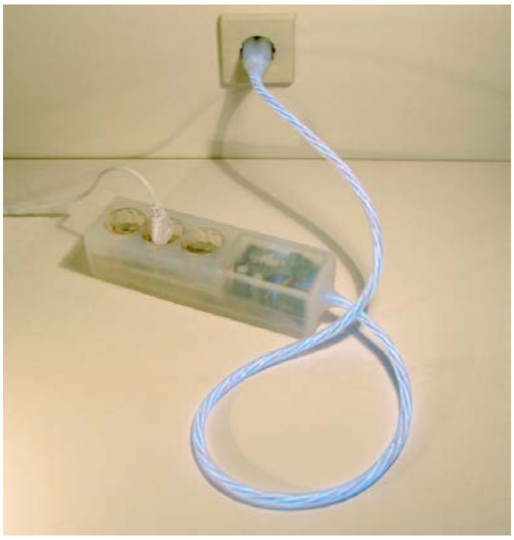

Figure 2.2-6: The power-aware cord, emitting light to indicate energy consumption.

However, for the most part, mass-produced consumer off-the-shelf systems do not provide the householder, or the wider developer community access to developing third party service creation, with accompanying access to fully open energy data. Proprietary ‘added-value’ services from utilities are also often an additional cost to householders through yearly subscriptions. In many cases the online energy services are just slightly more interactive versions of the table-top display. Some inroads have been made by UK based company Current Cost with its NetSmart device **[73]**, and the Open Energy Project [211], both of which supply energy monitoring hardware capable of publishing online, fully open energy data. The NetSmart device utilises a large scale IoT platform to provide reliable API access, enabling open energy data publishing and access. This approach facilitates developer friendly eco-systems to be built offering a compelling range of energy monitoring applications including integration of social media channels. When undertaking academic in-the-field energy studies, it is often necessary to build bespoke monitoring services to enable experimental studies to take place. Without access to open energy data, such studies would be difficult to undertake, and would likely require the partnering of a utility company with a smart meter service - a costly and time-consuming endeavour.

The ideal experimental platform from which to carry out energy feedback studies is having energy monitoring hardware in homes publishing timely consumption data online in a secure fashion, to non-proprietary open data platforms. By doing so allows researchers to investigate how to engage householders around their EUED using novel approaches, outside the context of a static IHD and proprietary services. This is the approach developed in this thesis in the context of deploying a workplace energy intervention (chapter 5), and aversive feedback in a household energy monitoring system (chapter 6).

2.2.4 Research gap

As previously discussed, the majority of energy-saving work over the last three decades and more by Environmental and Behaviour Psychology, and HCI research communities, has been focused on the domestic space. Research undertaken is centred on positive reinforcement through positive feedback, with little attention given to negative reinforcement and punishment through aversive feedback, thereby taking advantage of the full model of operant conditioning. A meta-analysis of pro-environmental behaviour studies was carried out by Osbaldiston and Schott [215]. Findings indicated that under-utilised methods such as cognitive dissonance when applied in an intervention were potentially effective techniques for interventions. Similar to cognitive dissonance, aversive stimuli can create a negative association with an undesirable behaviour, in this case behaviours that are not pro-environmentally.

From the literature it is clear more work needs to be done in understanding how aversive stimuli can be safely integrated into feedback delivered through technology-enabled energy interventions, while considering the needs of end-users, and limiting the opposite effect of increasing negativity around target behaviours. An HCI research approach that adopts methods such as participatory design and qualitative analysis, would provide deep insights into end-user perceptions and daily practices around their energy use, facilitating the careful design of aversive stimuli to be used in an intervention.

The potential inadvertent misuse of aversive feedback, and subsequent negative impact, is not to be under-estimated when considering intervention design. As such, and from a more positive ethical stance, the use of aversive feedback in the research presented in this thesis will be from a novel, and perhaps most importantly, *playful* approach. Justification in this respect is to prevent disengagement where it's possible to do so, and to provide a more lightweight approach in engaging end-users around their energy consumption, whilst communicating aversive feedback.

As a result of the identified research gap in using aversive feedback with domestic energy interventions, the 3rd and final research question of interest to this thesis is as follows:

"How can we design and deploy effective, yet playful, aversive feedback in a domestic energy intervention?"

An in-the-field study was carried out with several households to address this research question, with findings presented in chapter 6.

2.2.5 Summary

In summary, the role of appetitive, or positive, feedback has been the mainstay of providing feedback in domestic energy intervention research, with a significantly large corpus of work undertaken across behavioural psychology and HCI disciplines. As a result, there is a lack of academic research in how to effectively use aversive feedback as part of an energy intervention, where the consequences of over-consumption are communicated. However, despite the opportunities afforded to the two areas of behavioural psychology and HCI in creating a synergy of methods to better understand how to map behaviour change theory onto technology design, there has been little evidence of this to date. In some cases, it can be observed that industry is taking the lead with some major utility providers taking a pro-active approach. Opower with its millions of customers, is employing research methods of the behavioural and social sciences as part of their customer smart-meter packages, and claimed energy savings in excess of 11 terrawatt-hours, saving customers $1.1billion in billing costs [212]. The concept of attempting to reduce consumption during 'peak-demand' with dynamic energy tariffs was explored by Rodden et al. [232]. However, the associated dynamic energy tariffs for client-side peak demand management are only possible through the large scale adoption of smart-metering infrastructure. In the UK at least, such an infrastructure is several years away from reaching the majority of domestic dwellings connected to the national grid. In the intermediate time before dynamic tariffs come online to the masses, behaviour modification is a useful tool in the box to bring about emission savings now.

With the UK committed to emissions reductions of 80% by 2050 over 1990 levels to address climate change, it is imperative that savings are made in overall domestic EUED to support meeting this target, without doing so the target will be impossible to achieve. In support of this a number of UK household energy-optimisations initiatives are in place, as well as work being carried out in developing behaviour change strategies through government funded ‘nudge’ units, with all such endeavours supporting the UK government’s efforts to shift to a low-carbon economy.

Given the immediate concerns of climate change, and the associated impact of emissions from domestic dwellings, academic research into reducing EUED through behaviour change is a societal level challenge, and therefore of paramount importance for researchers from multiple disciplines to work together and investigate. This thesis presents a research study in chapter 6 that investigates the under-explored space of designing and applying aversive feedback in domestic energy interventions.

3 METHODOLOGY

This thesis presents three case studies, each with a distinct research question aimed at increasing an understanding and contribute to the research knowledge of designing technology-enabled interventions with empirical behaviour modification methods.

The first two case studies are linked and focused on the organisational environment, with a qualitative study first conducted to better understand the end-users and space of interest, with a follow-up field study that implements findings from the qualitative study. For the final case study an experiment is conducted to carry out a domestic intervention with the key exploratory area of looking at the effectiveness of aversive feedback to engage users around their energy consumption. Common to all three studies is the selection and deployment of HCI methods to conduct all main research components to understand end-users and their engagement with EUED. HCI methods, particularly those that embody a strong user-centred design approach, are suitable for the entire research framework of this thesis in that they facilitate a deep understanding of how people use technology, commonly by adopting a mixed-methods approach.

In order to design effective and engaging interventions it is critical that end-users are well understood in terms of their values, requirements, situated environment, context of activities, and interaction with various technologies throughout their daily practices.

HCI is a multi-disciplinary subject and has grown out of computer science and psychology, addressing a need to understand through empirical observation how people interact with technology. Over time the discipline has adopted methods from the social sciences, organisational theories, and ergonomics, to name but a few. As a result, it is difficult, if not impossible to define the boundaries of HCI - there is so much overlap and methodological contribution from other disciplines. What HCI does provide is an array of contextualised methods that can be used to make a valuable contribution to the body of HCI knowledge. Having a wider understanding of such methods enables researchers to avoid a narrow approach to the subject of interest, as working towards an understanding of humans interacting with technology benefits greatly from a mixed-methods approach, encompassing the most suitable HCI methods.

This chapter will outline the common HCI research framework used in this thesis, with focus on the primary user-centred approach and methods used. Following this the methods selected and deployed for each of the case studies will be discussed. Behaviour change methods used are discussed in detail in each of the dedicated case study chapters.

3.1 Research Framework

3.1.1 Case study approach

A case study approach is used to present the multiple research questions addressed in this thesis. Case studies are well understood in their use as an effective research method [295][292]. In the case of this thesis, they demonstrate research conducted by the author that uses HCI methods in conjunction with behaviour change theory to understand and inform the design of energy interventions. Each case study addresses, in an appropriate fashion, the research question asked, how the work was carried out to meet the question, and the observed findings. A discussion then follows each case study to unpick the results and provide a narrative that provides a useful research contribution to the body of HCI sustainability knowledge. Work by Zainal [ibid] argues that a case study approach to research provides a more holistic view, which in fact sits well with qualitative HCI methods in understanding the fuller spectrum of users' needs and values, and goes beyond the narrow view and limitations of a quantitative-only approach. Further work by Tellis [261] argues that a researcher that includes both quantitative and qualitative data, essentially describing a 'full' case study, helps explain both the process and outcome of the research topic of interest through complete observation, reconstruction and analysis of the experimental attributes under investigation. Although not explicitly described as the 'case study' method in many HCI studies, it is clear from the many instances of a mixed-method approach that this is indeed a common and valid approach to presenting hypothesis through a more simplistic what, how, and why narrative.

Yin [292] defines the case study research method "as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used.”. This thesis presents multiple case studies that were carried out in a non-lab, real-life context, providing evidence in the form of a research contribution to the HCI sustainability research community.

3.1.1.1 Published work as case studies

Each of the three case studies presented are based on peer-reviewed published work fully carried out and written by the author of this thesis. These are as follows:

Case Study 1: The work is published as a full peer-reviewed paper in ACM CHI 2012 conference, titled “*'Watts in it for me?' Design implications for implementing effective energy interventions in organisations*” [113];

Case Study 2: The work is published as a full peer-reviewed paper in ACM Academic MindTrek 2014 conference, titled “*Effects of group performance feedback and goal-setting in an organisational energy intervention*” [114];

Case Study 3: The work is published as an extended abstract at the ACM CHI 2011 conference, titled “Power ballads: deploying aversive energy feedback in social media” [116].

3.1.2 HCI methods for designing energy interventions

After reviewing numerous HCI studies on domestic energy research in chapter 2, it is clear that the majority of studies were of a short duration - the average was 2.5 weeks [121] – meaning they are sometimes not designed in a way that allows them to fully reach their full potential. Regardless of the context in which they have been implemented, or the intervention design strategy adopted, there are very few examples in the HCI literature of technology-led energy interventions either sustaining user engagement or, more importantly, facilitating long-term reductions in energy usage [ibid][99]. Some researchers i.e., [121][184], suggest the failure of these systems for longitudinal effect are due to a lack of understanding on the part of designers of the complex ways electricity usage fits within and impacts peoples lived experience. Energy use is entwined in daily and social practices, habitual, and in some cases the very act of consuming energy for pleasure, for example baking a cake, would not provide the same enjoyment if carried out in a more economical fashion [48][56]. In this respect, there appears to be a disconnection between how technology mediated behaviour change works in theory and in practice when applied to energy interventions.

The initial stages of the design of energy interventions often involve social science-style research with small groups of potential participants and end-users, in order to adapt and build upon currently developed “theories” of energy usage. Prototype software systems are commonly built following such design ‘sessions’, to implement those abstracted concepts based on the known theories. Interestingly, the practice of abstracting data gathered in small-scale user studies to form theories that inform a design process has been much criticized recently. For example, Ghassan and Blythe [125], suggest that this approach is characteristic of researchers not discriminating the “minor science” of design practitioners with the “royal science” of basic researchers. Work by Gaver et al. [123], criticised the scientific analysis, using theories, of user data as diminishing the connection between designer and end-users. Additionally, work by Olivier and Wallace [210] argue that reducing users’ experiences to a set of objective data can diminish our understanding, and subsequent valuing, of human heterogeneity. This approach does not sit well with the practically unlimited diversity of everyday practices, particularly when interacting with energy through a myriad of devices and appliances. In this thesis the research approach to understanding the design of interventions is not based on abstracted theories, but rather is grounded in the data in the form of experiences and reflections from participants. Importantly, in the context of designing interventions with a view to intentionally impacting upon people’s lives, it seems especially important to engage with participants at an experiential level [210][265].

The work presented in this thesis is largely undertaken in the first instance through a qualitative lens, with focus on understanding the underlying reflective experiences of potential end-users. HCI methods used in this context are now discussed.

3.1.3 Experience-centered design

In recent years, computing technology has developed from something primarily used in organizations to facilitate commerce, to something that impacts upon all aspects of our personal, social and cultural lives [191][290]. This is particularly evident with computing devices now small enough to fit into our pockets in the form of smartphones. The study of human interaction with computers has moved away from analyses of human cognitive abilities and interface usability, or traditional HCI and ergonomics, and towards a more holistic understanding of the complex interactions between technology and the human experience [191]. The process of designing technology based on understanding the subjective experiences of users is referred to as experience-centred design [290].

Unsurprisingly, there is little agreement on how best to understand the experiences of people as part of the design process. For example, Forlizzi and Ford [265] proposed *subconscious, cognition, narrative,* and *storytelling* as useful facets for analyses. Wright and McCarthy [290] identified *emotional, sensual, compositional* and *spatio-temporal* as elements of experience. Norman's follow up work to the hugely influential 'The design of Everyday Things' book, breaks experience into *visceral, behavioural* and *reflective* [290]. Despite this lack of consensus, there does seem to be an overall commitment to understanding interaction from a holistic rather than reductive perspective. As a result, qualitative methods for data collection and analysis are common for carrying out HCI research, and are normally inductive approaches. Qualitative data collection and analysis are carried out in all three case studies presented in this thesis, and forms the basis for understanding end-users, and informing intervention design.

In addition to the lack of philosophical consensus in the aforementioned experience-centred research, there is also no agreed-upon best-practice research method for sampling experience as part of the design process. However, Wright and McCarthy [ibid] emphasise that the most fundamental requirement is a commitment to dialogue between designers, users and communities, which is the approach used in the work presented in this thesis, using qualitative methods. Hence, research methods drawn from the social sciences seem most appropriate. With experience-centred design a method adopted in this thesis, the next appropriate method to be used is participatory design, and is discussed in the next section.

3.1.4 Participatory design

Participatory design is a process long established in both research and industry. It's not to be confused with the approach of contextual inquiry [202], although there are similarities in that there is core participation between designer and end-user to understand practices of interest. Participatory design is an approach that invites the people and end-users who will benefit from, or be impacted by, a technology to participate in its design, with the intention of empowering those communities. By empowerment a great deal of 'buy-in' should persist throughout the design of the technology, due to the investment in time, and values alignment. There is also an assumption that involving participants in the design process should lead to more acceptable, useable and useful technology [290][275].The practical act of creating prototype solutions to intervention design challenges can also be seen as a means for eliciting more realistic contributions from participants than is possible with simple interviews and focus groups alone [49], which often produce vague, or unrealistic and biased results, or suffer from effects of social acceptability. Further, due to the potentially intrusive nature of energy interventions, it is important to adopt a participatory approach to the intervention design work across all field studies presented in this thesis, as domestic energy field work may request access to people's private homes. In the context of organisation energy work, participatory design will also help to breakdown the organisational hierarchy, where the 'norm' may be challenging to unpick, and where certain job roles may involve the operation of energy-intensive appliances as part of daily and mandatory job functions.

3.2 Case Study 1: Understanding the Design of Organisational Energy Interventions

This case study (CS1) is fully presented in chapter 4 and is comprised primarily of a qualitative study carried out across a series of interactive workshops to robustly explore end-user employee's perceptions, values, and attitudes towards theirs, and that of their colleagues, energy consumption practices in the workplace. Additionally, data is collected and analysed on the co-design of appropriate workplace energy interventions, through participatory design tasks.

The research question directing this study is:

"How can we design effective technology-enabled, energy-feedback interventions in the workplace to reduce EUED through behaviour change?"

3.2.1 Method overview

A number of HCI methods were deployed in this study for data collection and analyses, with the overarching user-centred approach encompassing participatory and experience-centred design. A series of three workshops were run in conjunction with the Open to Change project [162], with participants taking part from industry and university organisations. Participant backgrounds comprised a wide range of roles, from office administrators to senior leadership, and employees from the energy sector. The workshops were advertised through relevant email lists through the JISC Greening ICT programme [163]. The workshops themselves would provide two separate and distinct data collection opportunities – qualitative data collection for the work presented in this study (CS1), and also for the researchers of the Open to Change project whose interest was in collecting data from a survey during the workshops. A fuller description of the study details is in chapter 4, section 4.3. In total 65 people took part in the workshops at two distinct geographical locations. The theme of the workshops was communicated to potential participants as working towards an understanding of workplace energy interventions. Audio recording was carried out for the duration of each workshop, with some parallel recordings for informal 1-1 discussions taking place with participants, providing greater context in points of interest. Each workshop followed the below format:

Table 3.2-1: Energy workshop structure for case study 1.

1.	Welcome
2.	Survey
3.	Refreshment break
4.	Presentation
5.	Design exercise in three groups
6.	Lunch
7.	Common goods activity
8.	Discussion on activity and brief look at survey results

The Survey item listed in Table 3.2-1 was designed to set the scene for participants and was carried out at the beginning of the workshop, and featured a series of quantitative questions on rating energy feedback visualisations. It should be noted the survey data was not used as part of the qualitative data analysis component of case study 1 in this thesis, the focus of the work was on a qualitative approach with data collected on participant's experiences and from the participatory design exercise. The Open to Change project [162] used the survey data extensively, independently of the work presented here. Only the participants job role data is used from the survey to provide background information on participants. The design exercise focused on empowering employees to design an effective 12-month workplace energy intervention in groups, to support their values and address possible organisational constraints, such as management buy-in.

Audio and written data was collected from: i) participatory design exercise, ii) group discussions, and iii) 1-1 discussions between researcher and participant. Upon completion of all workshops, the collected data was transcribed using the Nvivo software tool [288], and then analysed using the GT method [258], providing a suitable approach to making sense of the data. The goal of using GT was not the construction of an explicit final theory, or by relating findings to other established theories, but rather it was to support the generation of design implications and guidelines derived from data on the participants own daily experiences in the workplace, and through interaction with the participatory design exercise.

The GT method was further justified for its suitability in supporting further research enquiry when analysing a large corpus of qualitative data. Other positives are its usefulness for developing research hypotheses from little understood domains, as well as its effectiveness when working with qualitative text or audio data. In this work, at a basic level, it allows us to understand employees' energy usage habits and their relationship with the technologies they use at work. At an advanced level, it allows us to understand their personal levels of trust and openness in their organisation when asked to engage with a workplace energy intervention. When combined we can develop a fuller understanding of energy as a 'resource' in an organisational context and how employees interact with and perceive this resource. Upon completion of the GT analysis, it provides design insights that aid an informed approach for intervention design. A full and detailed discussion on the use of GT in this study is presented in chapter 4, section 4.4.

In summary, the HCI qualitative research methods deployed in this study were experience and participatory design, and grounded theory.

3.3 Case Study 2: Group Goal-setting and Feedback in an Organisational Energy Intervention

The work carried out in this study (CS2) builds upon the findings of CS1. Design implications and guidelines identified are mapped onto antecedent behaviour change strategies in a workplace energy intervention. The previous work from the CS1 produced a number of key themes detailing user perceptions and workplace energy intervention design considerations, with some of the factors echoing grey literature produced for energy efficiency strategies in businesses [246][132][108]. The findings provided a scaffolding for the design of engaging and effective workplace interventions, with each theme representing an abstracted intervention component. A 4-month energy intervention was designed and deployed using a bespoke, near-real-time energy monitoring system in an organisational department with 16 employees. The employee participants were recruited through targeted email invitations to a specific organisational department – an 'Estates' department. An information session was also facilitated, giving participants the opportunity to ask general questions about the study and the equipment to be used. Senior management who oversee the department of interest authorised the study deployment first, and was generally seen as a good indicator of management buy-in for the employee participants. Group feedback and group goal-setting were integrated in the intervention as antecedent contingencies, with work fully presented in chapter 5.

The research question directing this study is:

"Can group-based feedback and goal-setting in a technology-enabled workplace energy intervention reduce EUED?"

3.3.1 Method overview

A prototype application was trialled across four phases (pre-study baseline, group feedback, group goal setting, and post-study baseline) over a four-month period with 16 participants, thereby creating a robust intervention that builds upon an extends components of work by Siero et al. [248], Staats et al. [253], and Carrico and Riemer [52]. In this case further research is undertaken by adopting a technology-led approach in providing near-real-time feedback with group goal-setting. Being an organisational intervention, it targets the individual employee as well as the collective (departmental members) through a common performance-related goal – the reduction of EUED.

Supporting research questions to evaluate the effects of the selected feedback and antecedent contingencies were:

- Does frequent group feedback reduce energy consumption?
- Does group goal-setting reduce energy consumption?
- Do engagement levels change with each condition?
- What are the interface preferences for energy feedback?

The primary research question for this case study, and above supporting questions are addressed through analysing the energy consumption data using descriptive and inferential statistical methods. Qualitative data was also collected post-study through informal semi-structured interviews to glean an understanding of the employees' experiences while participating in the intervention, and how their responses compare to the actual quantitative consumption data evidenced.

3.4 Case Study 3: Designing Aversive Feedback in a Domestic Energy Intervention

The case study (CS3) described in this section differs from the work in CS1 and CS2 in that it is a standalone study that is focused on the domestic space, as opposed to the organisational space explored in CS1 and CS2. Building on the small body of HCI research work to date that has explored the use of aversive, or negative feedback [71][87][192], this study presents findings from a domestic energy intervention, termed 'Power Ballads', with nine households. Work by other HCI researchers in persuasive technologies has previously suggested the use of aversive feedback should be avoided as it may lead to user disengagement [140][66]. However, given that work by the behavioural sciences indicates full consideration of operant conditioning should be given when designing interventions [166], it opens up an interesting research space for HCI sustainability research. The case study work outlined here is presented in chapter 6.

The main research question directing this study is as follows:

“How can we design and deploy effective, yet playful, aversive feedback in a domestic energy intervention?”

3.4.1 Method overview

To address the research question above, aversive feedback was delivered through an online social application using the Facebook developer platform [104], to display playful, yet aversive feedback on users’ household energy consumption. Design of the feedback investigates a ‘designing for coolness’ approach and acknowledges the importance of the critical design space for creating novel and engaging user experiences [150][148]. Following this, the work evaluates whether playful punishment of non-desirable behaviour discourages users from engaging with a persuasive application and whether energy reductions are possible. Nine households were recruited using a mix of purposive and convenience sampling to use the Power Ballads application over a period of five weeks. An off-the-shelf energy monitor was installed in each home, linked to an internet-enabled ‘bridge’ that published the energy data every few minutes to a web service. The Power Ballads Facebook application could then consume the web service and display the household energy consumption of the logged in Facebook user.

Supporting research questions are as follows:

- Do participants disengage when presented with aversive feedback?
- Do participants reduce their EUED following exposure to aversive feedback?
- Do participants and non-participants interact with the aversive feedback?

Results of the study indicated the use of aversive feedback did not act as a deterrent to regularly interacting with the application through evaluating user engagement and some reductions in EUED were evidenced in the time period following the aversive feedback.

4 Case Study (1) - Understanding the Design of Organisational Energy Interventions

4.1 Introduction

In this case study, understanding the design of technological interventions to motivate behaviour-based reductions in workplace EUED is the locus of activity, with findings making a significant contribution to the HCI sustainability community. Over the last ten years a significant body of work has been produced by HCI sustainability researchers on reducing energy consumption, particularly in the domestic space, with little work carried out in an organisational context – see section 2.1 for an in-depth review of relevant academic work from behavioural and environmental psychology, as well as HCI. Typically, the majority of work on energy interventions across all research disciplines have focused on domestic energy consumption. By contrast, the work presented in this study focuses on the workplace context, which presents very different opportunities and challenges. For instance, financial consequences, which have proved successful as motivators in the domestic environment, are generally not present in the workplace in the context of employees. Additionally, other barriers to saving energy are wrapped up in the organisational hierarchy, from an employee perspective it may not be clear at all who is responsible for their organisation's consumption and subsequent emissions footprint.

This study makes a significant contribution to the HCI sustainability community by producing a set of design guidelines for workplace energy interventions. It describes the outcomes of a series of workshops that focussed on understanding employee perceptions of energy use in the workplace, with participatory design activities generating novel ideas and strategies around energy intervention design. Using a Grounded Theory (GT) analysis of data collected during the workshops, a set of design implications and guidelines was produced derived from themes that emerged from the data coding process of the GT analysis. The themes detailed user perceptions and values on energy consumption, and from these appropriate intervention design considerations were articulated and consolidated for each theme. The results offer valuable insights into employee values and practices around energy demand, to inform the design of technology-enabled workplace energy interventions.

4.2 The workplace as an intervention space

Designing an energy intervention for the workplace presents challenges for the interaction design process which must address issues ranging from the motivational, to the social, organisational, and technical. For instance, for most people cost is the primary motivating reason to reduce their energy use in the domestic environment (for instance see Chetty et al. [57]). In essence a decrease in cost is the reward for reducing consumption in a household. In the workplace, however, employees are typically not responsible for paying energy bills, therefore creating a problem in how to incentivise positive behaviour change. Furthermore, there are challenges inherent in understanding and gaining access to organisational cultures, with incumbent cultural constraints, that are not present in the domestic domain. In order to meet this challenge, it is prudent to employ a qualitative research methodology to provide a rich account of the users and the design space.

Given that the working population spends a significant amount of time in organisational and institutional settings, it’s important that behaviour in these environments is not overlooked at both individual and organisational collective levels [165]. From this standpoint it is clearly justified that a qualitative approach to understanding this complex space would likely provide a more holistic understanding of people’s behaviour whilst at work.

Work by Heerwage [141] discusses the impact of ‘green’ buildings in producing positive economic and organisational benefits, including improving employee well-being. It is not a leap of faith in understanding this is likely down to a few factors, including transparency and acting collectively for an organisation's common good.

An important factor to consider for energy interventions is the personal control the employee has over their immediate working environment, this includes workstation space and the operation of other appliances and environment controls such as heating and ventilation. For employees with little degree of personal control whilst carrying out their role, it likely constrains their ability to engage with, and ultimately make energy savings. For example, work by Brager and Dear [41] found that employees who had control over environmental conditions such as heating, lighting, and ventilation had an enhanced performance profile over those who had no control. However, it is now very common for new buildings, or retrofitted older builders, to have this control removed in those 'comfort' areas through automated energy efficiencies, in practice this does not always improve employee satisfaction or productivity [174]. Indeed, in this research it was found that some participants did not want to relinquish their locus of control around comfort controls. These participants stated it was common in their work space to circumvent, or 'subvert', automated measures such as thermostat control in order to increase/decrease temperature manually.

It can be argued employees, when at home as household occupants, have much greater agency and freedom to decide the level of comfort in the home for heating, lighting and ventilation, as well as the perceived convenient operation of equipment such as computers. As such, tensions can exist between daily work practices and what is acceptable in the home. For example, work by King et al. [171] indicated that employees would circumvent lighting controls to stop them from automatically switching off, and in work by Langensiepen et al. [175], employees were observed subverting mechanisms to ensure their computer stayed on, thereby avoiding the 'inconvenience' of having to slowly boot up their computer each day. The latter instance of undesirable behaviour through subversion was also evidenced in this case study.

From the literature, it is clear that when employees still have some agency over controlling environmental considerations, even to a small degree, it results in a more satisfied workforce [100]. However, the complex socio-technical interplay between organisational convention, employee comfort, and the conflicting freedom of agency when at home, results in a challenging landscape to unpick for understanding the design of workplace energy interventions. It is from this highly contextualised starting point the work in this case study begins to explore through qualitative enquiry. A purely quantitative approach may have produced some generalisations, for example from the workshop survey data, but due to the complexities of daily work and personal life, and patterns of energy consumption, a wider perspective of the issues needs to be understood for greater contextual depth.

From the HCI literature the author believes there is a basic research knowledge gap present in understanding the end-users of energy in the workplace and, therefore, the design of appropriate and achievable workplace energy interventions, particularly those that encompass novel ways of encouraging people to adopt positive energy usage behaviour whilst at work. Understanding EUED in the workplace is a complex task with significant social, organisational, cultural and technical issues that cannot be easily quantified by casual inquiry. In order to help address the problem of adequately understanding employee motivations, engagement and incentivisation in workplace energy interventions, it is important to carry out basic research targeting specific relevant themes. To address these issues, a series of facilitated in-depth workshops were carried out in conjunction with the 'Open to Change' project [162]. The workshops are discussed in the next section. Workshop data collection and analysis had the specific aim of supporting the principal research question of this thesis:

"How can we design effective technology-enabled, energy-feedback interventions in the workplace to reduce EUED through behaviour change?"

As stated previously, the selected approach of deploying the GT method to elicit further scientific enquiry into this question enabled the creation of a robust set of design guidelines, generated from workshop data. This supported an understanding of both the employees as end-users, and the design space of workplace energy interventions.

4.3 Workshops

Three day-long workshops were run across three locations with a total of 65 participants from five universities and a number of businesses in the energy industry. The structure of the workshop is outlined in section 3.2.1. The job roles of participants covered a diverse range including administration, managers, marketing, engineering, librarians, IT support and institutional leaders. Table 4.3-1 lists the job roles recorded from the workshop survey from the 31 participants who completed it. The workshops were run to facilitate parallel, and distinct, data collection for two projects: i) the Open to Change project [162], and ii) the independent work presented in the study in this chapter. The Open to Change project focus was on quantitative survey data (scale-rating of mock energy dashboard visualisations), while the study presented in this chapter (CS1) was focused on qualitative data collection to understand participant attitudes and perceptions of EUED in the workplace, and how an effective workplace energy intervention could be designed. To reach potential participants, the workshops were advertised through the JISC Greening ICT programme [155] email lists. In total 65 people took part in the workshops at two distinct geographical locations, 23 participants identified their job roles. The overall theme of the workshops was communicated to potential participants as working towards an understanding of workplace energy interventions.

Table 4.3-1: Workshop participant job roles

Job Role	No. Participants
Administrative	2
IT Support	2
Librarian	2
Project Manager	3
Institutional Leader	2
Other (manually specified)	12 - Public Engagement Officer, Communications Officer, Energy Engineer, Communications Manager, Sustainable Development Officer, Operations Manager, Supervisor (Clothes Shop), Carbon Reduction Manager, Energy and Climate Change Officer, Environmental Manager, Energy Officer, Lecturer.

Although a large number of participants were from universities, students were not present at the workshops as they are a different type of end-user, usually not subject to the same organisational structures and rules as employees. Many of the workshop participants were senior members of staff with long careers in managing institutional change. Their responses were based on many years of experience of implementing new policies and managing staff.

The main workshop task for the purposes of this study was to generate discussion on EUED in the workplace in the context of sustainable practices, leading on to carrying out the participatory design of a 12-month energy intervention for the workplace. The latter task was done in smaller groups. The substantial written and audio accounts from the task comprised the data for use in the GT analysis of this study. Participants were passionate during discussion with heated debate taking place on topics such as automating (taking control away) vs. behaviour change (retaining control) energy reduction strategies. A descriptive, yet insightful, snapshot of the type of content discussed at one of the workshops is illustrated figure 4.3-1, the commonality of many of the presented concepts across the workshops is evidenced. All three word clouds, one for each workshop are available to view in Appendix 1.

Figure 4.3-1: Workshop word cloud generated from focus group discussions.

4.3.1 Participatory design task

Participants were briefed on the design task requirements and asked to think in terms of deployment in their own organisation. Specifically, the task was to design a 12-month intervention, using technologies of their choosing, to reduce energy consumption in the workplace. Basic non-visual details of possible concepts to consider for inclusion in an intervention were given to promote advanced reflection on the task, these were: a) recruitment strategies b) energy feedback and c) sustaining beyond the intervention. Participants were randomly split into smaller focus groups at each workshop (4-5 people) with 2 hours given to complete the task. For each group audio and written accounts of the task were recorded for later analysis. Figure 4.3-2 shows examples of the intervention strategy sketches that were developed by the small focus groups.

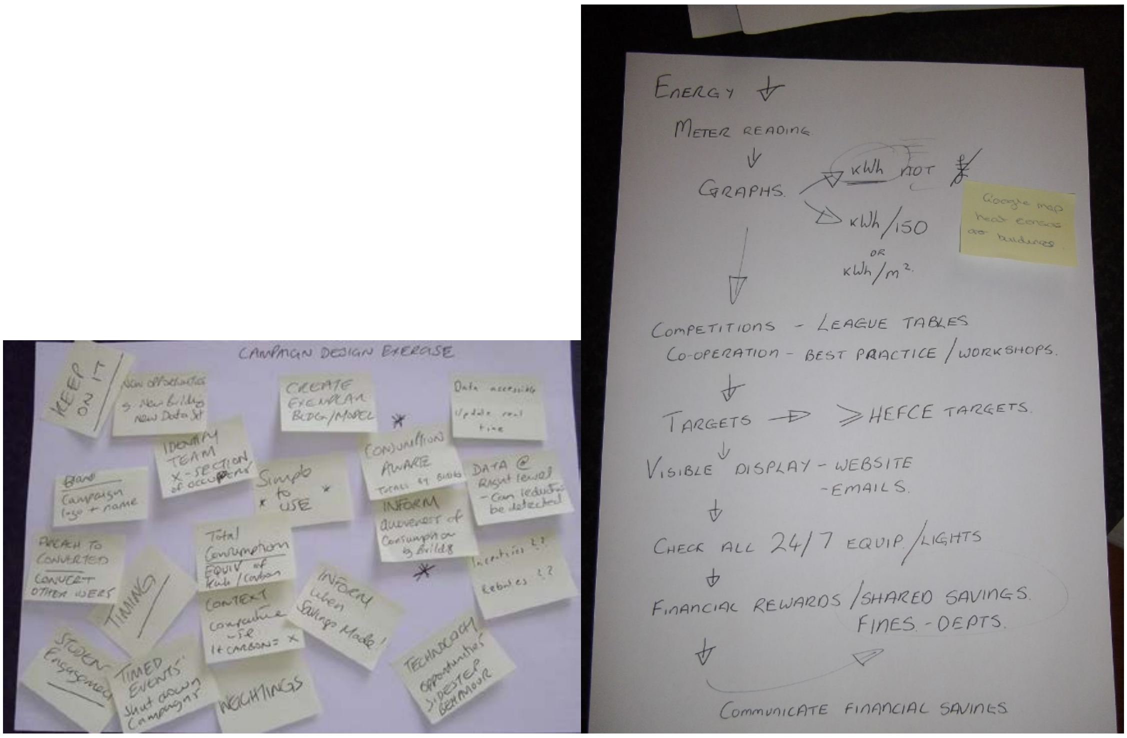

Figure 4.3-2: Participatory design task - designing a 12-month intervention.

4.4 Results of Grounded Theory

The Grounded Theory method was selected in this study as it employs inductive analysis as its primary technique against a large corpus of qualitative data pertaining to a particular phenomenon of interest [258]– in this case understanding the complex socio-technical aspects of EUED and sustainable practices in a workplace environment. In this work, at a basic level, the GT analysis allows us to understand employees' energy usage habits and their relationship with the technologies they use at work. At an advanced level, it allows researchers to understand their personal levels of trust and openness in their organisation when asked to engage with workplace energy interventions. When combined we can develop a fuller understanding of energy as a ‘resource’ in an organisational context and how employees interact with and perceive this resource. With the GT analysis complete, it provides a series of design implications and guidelines that form the contribution of the research question outlined at the beginning of this chapter. Researchers in the HCI community have adopted the GT approach to analyse and explain phenomena such as digital performance spaces [37], new technology responses on media platforms [38], and to inform design [260] – all of which are difficult to quantify through statistical analysis alone.

In terms of the GT analysis presented in this study, the contribution provides valuable insights and information on workplace energy intervention design guidelines.

There are three main steps to undertake the process of GT:

- Open Coding - 1st pass of data to draw out conceptual labels or ‘codes’, see figure 4.4-1 for some open code examples;
- Axial Coding - Saturation of open coding, final categories (themes) are formed by collapsing of 1st pass categories;
- Selective Coding - Central theme is derived by bringing all categories (themes) together, providing a narrative that best describes the data and the relationships linking the themes.

It is important to note that the terminology in Grounded Theory for categorising data is frequently interchanged between ‘categories’ and ‘themes’ in the literature [55], in most cases there is no distinction between them. The Nvivo qualitative research software suite [16] was used to code and transcribe the recorded workshop data (including transcribed recordings and post-it notes, examples of which are shown in figure 4.3-2), providing an efficient means to collect, analyse and present the data.

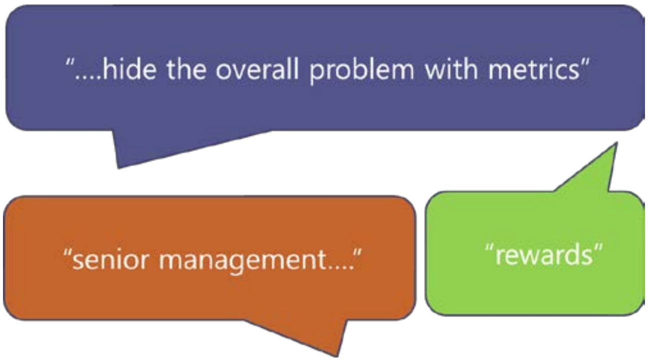

Figure 4.4-1: Open coding example data from the design task.

4.4.1 Open coding

The first phase of developing GT is open coding, which includes manually trawling for conceptual labels (codes) relating to energy usage from the corpus of design task data. Open coding is required as the analysis of the empirical data starts with no pre-defined sets of codes or categories. A total of 631 codes were compared and grouped into 35 learned abstracted categories, these '1st' pass categories are listed in Table 4.4-1, with the count of codes/labels grouped under each category. Concept granularity was at the word or sentence level with examples coded such as 'hide the overall problem with metrics', 'senior management' and 'rewards'. Further refining of the codes into key hierarchal categories is carried out in the next step.

Table 4.4-1: Open coding - 1st pass of grouping 631 codes to 35 categories.

1st Pass Category	Count	1st Pass Category	Count
Accountability	8	Openness	8
Climate Change	4	Organisational Role	20
Communication	31	Play	8
Competition	30	Pledge	6
Constraints	23	Positive Feedback	6
Control	17	Publicity	3
Delegation	1	Recruitment	25
Education	24	Relationships	12
Enforcement	15	Renewables	2
Engagement	26	Representation	85
Fair Comparison	2	Role Conflict	2

Fear	8	Savings	27
Hierarchy	2	Small Steps	10
Incentives	47	Targets	41
Maintenance	19	Technology	27
Management Buy-in	32	Trust	16
Marketing	32	Us and Them	5
Negative Feedback	7	Total:	631

4.4.2 Axial coding

Abstract categories from open coding were amalgamated to create a more defined hierarchy forming key related categories. At this stage theoretical saturation occurs with no new concepts or categories emerging from the corpus of data. The resultant axial categories are the central themes formed from the participants' discussion and activities for the design task and determine which design insights and requirements can be drawn out. From these key categories a 'core' category is developed using selective coding that integrates and connects to all others. Six key axial categories were identified and are illustrated in figure 4.4-2, all categories are interlinked.

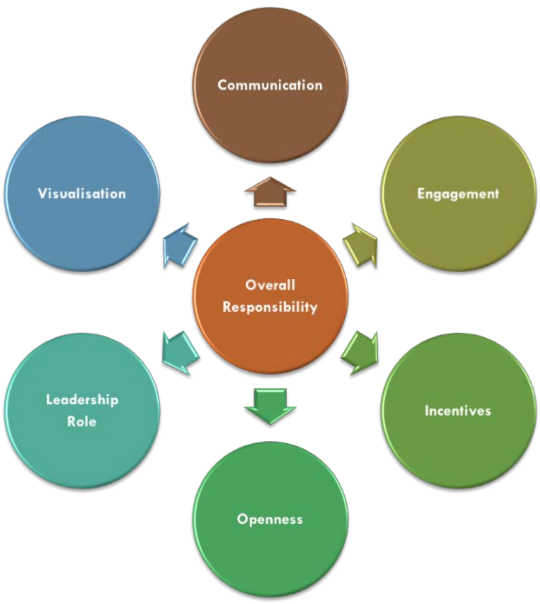

Figure 4.4-2: Axial coding derived key categories.

The percentage of codes allocated to the final axial categories is illustrated in figure 4.4-3 (note: there is no categorisation by colour scheme). The most common category was engagement, with 167 codes. This is unsurprising as engagement with any intervention is critical to its success. However, engagement in this context was not just important to the individual employee, but also to their immediate peers and senior management. As such, particular attention should be given to the sensitivities and meaning of the engagement category, as clearly it carries considerable weight, as identified from the data. The six derived categories from the analysis are described in the next section, including supporting quotes from participants.

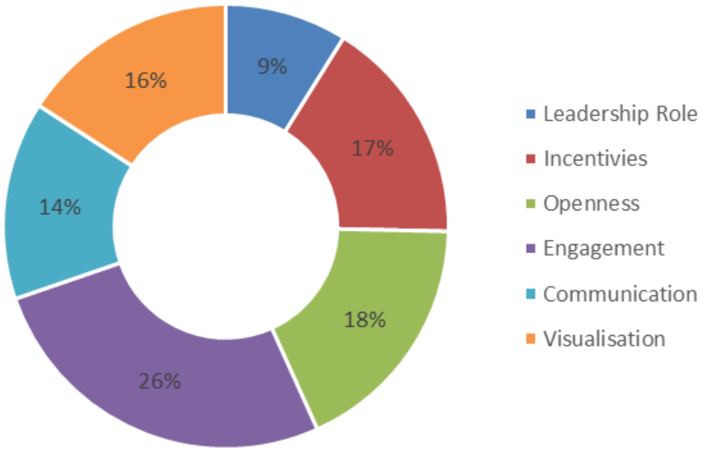

Figure 4.4-3: % of codes grouped to each axial category.

4.4.3 Selective Coding

The final stage of a GT is "selective coding" where illustrative quotes are selected to form a narrative [258]. Here an overarching GT "theory" is developed which brings together the axial codes, also known as the *themes*. In this case, the final theory is not generated from the viewpoint of explicit theory construction, instead the analysis presents a rich narrative and broader description of the participant's experiences and practices, rather than a predictive theoretical model [55], and provide insights and valuable information to understand and inform the successful design of workplace energy interventions.

The central theme of 'overall responsibility' emerged from the data, and can be seen as an overarching concern, and brings together all other identified themes. Throughout the workshops participants would return to the notion of responsibility. Many of the other themes in the discussions were strongly related to this concern. In this way mundane organisational concerns such as current performance indicators which might conflict with energy targets became drivers of the discussions. Throughout the participant discussions there was a strong undercurrent of feeling that without management buy-in or leadership engagement with an energy intervention it would very likely fail, the general sentiment was if senior management didn't support them and engage, then there was little incentive for them to do so.

Each of the six main themes identified from the analysis will now be discussed.

4.4.3.1 Incentives

Many of the workshop participants approached the problem of motivating employees by asking on their behalf: '*What's in it for me?*' They argued that employees want to be incentivised by negotiated rewards. This involves selecting the intrinsic 'value' of savings, examples were saving funds for student bursaries or a free Christmas party. Participant quotes of tangible rewards were:

W1P2: *"we can offer them a party at the end of the year, that's an incentive"* and **W1P6**: *"free meals in the canteen would be good as a reward"*

Other quotes indicated positive and negative financial incentives that were devolved back to a department:

W2P2: *"the proportion of what you save comes back to you"* and **W1P3**: *"if you go over energy budget it will hit you hard financially and have to come out department's budget"*

Interestingly, employing extra people with savings made was seen as a viable incentive:

W2P6: *"sit them - management - down and say look this is why it matters and [this is] how [it] is going to affect your budget, this is how many more people you can employ through savings"*

However, simply by saving money through energy reductions, and then recruiting new members of staff is tantamount to the boomerang effect – savings made are channelled into new resources resulting in higher emissions. The effect is well understood in the literature [241], particularly in domestic energy consumption studies. The incentive suggestions were disparate and ranged from small and seemingly innate rewards such as free meals to sweeping high impact, high value rewards like employing more staff. Whatever the reward was, participants argued that it would have to be highly visible with frequent progress updates. Incentives were closely related to Engagement.

4.4.3.2 Openness

Trust was seen as an important issue for employee engagement with energy interventions. For the programme to be engaging employees would have to accept the reasons why savings were required without being cynical. Having confidence that the organisation was acting in the employee's best interest was a key theme. The foremost question participants wanted to ask in response to taking part in a workplace energy intervention was: *'Why am I doing this?'* embodied in the following quotes:

W1P6: *"got to ask who benefits from savings, me personally, the department, the company, the government?"* and **W2P3**: *"why am I doing this who am I doing it for?"* and **W3P11**: *"if head office are putting the money in (returning savings), it's whether or not they will do it"*.

This indicates the importance of a transparent response in the reasons why they should commit to an intervention. Employees placing trust in their employing organisation was of course not straight forward:

W3P12: *"we had quite a lot of serious redundancies which we were told was because X amount of money needed to be saved, within a year we were told that money saved had been given to students in bursaries, so there is always a danger of politics behind the scenes"* and **W2P10**: *"it is useful to define what the value of the savings is going to be, if you don't, you won't have any confidence in your institution to do what they say they will with savings"*

Trust in the context of automated energy interventions such as air-conditioning thermostat controls and powering off desktop computers outside working hours was discussed.

Employees had little trust in such systems and voiced concerns they don’t always support their best interests and comfort at work:

W1P9: *“If you take all control off me (automated system), I’m going to feel completely disempowered”* and **W3P21**: *“If working conditions are uncomfortable, [I] will 'switch off' from energy saving, and not going engage at all in energy interventions if you can’t heat my office”* and **W2P7**: *“[management] have got to convince me that it’s reliable (automated powering off computer)”*

Anecdotal stories regarding employees circumventing automated measures were mentioned, very closely resonating with the work of King et al. [171] and Langensiepen et al. [175]:

W2P3: *“there was one lady in our office who would attach ice cubes to a thermostat to turn heating on, and if it was too hot they would put an electric heater on near it”* and **W1P4**: *“…found a way to get around (automated system) switching my computer off, so I didn’t have to wait for it booting up when I came back in the morning”*

Lastly, participants indicated privacy was important, with respect to identifying individuals’ consumption levels:

W3P13: *“…it’s also about getting into the wrong hands (personal energy data), don’t want other people making inferences about how I do my job”* and **W3P5**: *“if it was anonymised (personal energy data) I really don’t mind, as long as there is something that would stop me from being identified”*

Without trust in the organisation, participants indicated participation in an intervention would be lacklustre at best and likely to fail. An intervention should begin with transparency at the offset by detailing the motivations for reductions. Demonstrations of how savings have been allocated and utilised could be achieved through frequent feedback and by the potential use of public social media, thereby offering public-facing openness and alternative modes of communicating feedback.

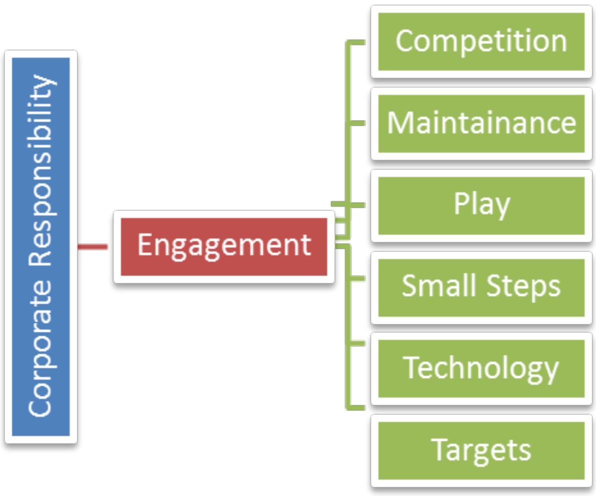

Figure 4.4-4: Axial category - Engagement - with thematic sub-categories.

4.4.3.3 Engagement

Competition and negotiated targets were favoured to both lower barriers to participation and engage with an intervention; with particular emphasis on achievable targets. Unrealistic targets, inability to set targets and unfair competition were highly cited for bringing about potential disengagement. Engagement is critical for success in any intervention and understanding its role in an organisational setting is important. A detailed illustrative breakdown of this key category is shown in figure 4.4-4.

A lofty goal that is out of reach is likely to cause disengagement, with behavioural psychology research suggesting a combination of regular feedback and realistic goal-setting may prove a useful approach in promoting behaviour change [68][190]. However, according to the work of Abraham and Michie [3], there is no standardised behaviour change approach in applying goal-setting to an intervention, in terms of combining it with other techniques such as feedback or self-monitoring mechanism. As such care should be taken when designing a goal-setting framework as part of an intervention, in this case understanding the end-users is of paramount importance.

Participants were vocal on negotiated targets with small incremental steps deemed important for an intervention's uptake and adherence:

W1P7: *"people who are involved in negotiating the basis of the target is an interesting way of getting people to buy in, better than just saying here's your target, this is from the government"* and **W3P14**: *"It's about setting targets, it's about sitting down at a meeting and saying what can be the best achievable target with what we have got at the moment"*

Participants agreed that competition could be very effective and suggested using league tables:

W1P5: *"everybody likes a bit of competitiveness and like to compare themselves against each other"* and **W2P9**: *"introducing competition to people like the [anonymised] cycle challenge, sent an email and within an hour 20 people had logged into the cycling site and uploaded all their trips, we went from way down in league table to the 5th best"*

Although competition was favoured, it was observed that consideration should be made of the granularity and disclosure of performance data. Participants indicated points relating to performance data such as a) data at individual or department level, b) choosing to opt in, and c) implications of publicly disclosing organisational performance data.
Play was also present in the engagement dialogue, manifesting itself as game mechanics such as campaign challenges with rewards and punishments:

W3P4: *"could play Hangman – if you are over target it's one extra piece, could hang the manager!"* and the idea of aversive feedback: **W3P6**: *"you can kind of reset the challenge by saying look this is atrocious you've slipped by 60%, shame on you in a slightly friendly way"*

Friendly admonishment or teasing was also a theme in previous studies which allowed Facebook friends to check on one another's energy consumption rates. It is possible there is space for the kind of friendly, but aversive banter, participants suggest may be provided through social media communication. Behavioural psychology work indicates that negative feedback or consequences are an integral part of operant conditioning, with positive and negative feedback required for effective behaviour change [166]. The work presented in case study 3 in chapter 6 explores the design of aversive feedback for use in energy interventions.

4.4.3.4 Communication

Communication was seen as critical at all stages of an intervention. Discussion encompassed running workshops for educating employees on energy as a finite resource, effective marketing campaigns for recruitment, and continuous feedback using multiple channels for all aspects of energy use in the organisation. Lines of communication should be open up and down in the organisation with quality of the message, not the mode of communication, seen as the important factor. Grassroots movements at work were also discussed to raise awareness, and the necessity of having ‘green warriors’ in the organisation, although it was voiced that this could quickly become a disengaging factor if ‘preached’ to.

Communication via online social media was discussed in detail:

W2P5: *“a lot of the students and academics will be on twitter and that kind of stuff, if you are just admin in the office you are not meant to have your mobile switched on so texting would be useless and you are not looking at Facebook and Twitter”* and **W2P6**: *“the thing as well about Facebook and using it at work is some of these channels you could be getting at home at the weekends and that’s the blur between work and play…..it might affect not only what you do at work but at home as well”* and **W3P16**: “*if you were looking at Facebook while at work that would be frowned upon, you aren’t doing your job”*

These quotes highlight the polarisation of social media use within an organisation such as a university; organisational culture is present in the form of constraining communication with different rules for different groups of employees. Communication restrictions placed on specific job roles can limit an intervention’s outreach and effectiveness, raising further design implications. For example, an employee managing an organisation’s ‘green’ social media accounts may not be allowed to post negative information on their corporate footprint or other resource consumption that could be construed in a negative light – with this type of knowledge how are people to understand the issues and act?

Participants indicated that the quality of a communicated message is important:

W2P8: *“even email….if you get so much you don’t read it, we have actually had a comment if it’s important please can you send me a hard copy”* and **W2P4**: *“can I just emphasise the quality of the message and not the media being used is important, I think* *the biggest problem is the quality of the message… a bad message is a bad message"* and **W1P7**: *"communication is about communicating in a relatively personal way how different that is from just showing a bunch of numbers"*

Communicating an 'energy awareness' message in an organisation to seed behaviour change is a difficult task. It is not just concerned with conveying messages to an individual but rather groups of people. Employees may have been in roles for long durations where their daily tasks have become routine and deeply embedded in the organisation's culture, in other words old (often inefficient) habits and routine. Communication therefore needs careful consideration not only of the content of the message but the chosen medium to deliver it. This raises other questions of interest: '*Which employees can we reach effectively and collectively, and through which communication channels?'* and 'Are online social networks appropriate for organisational use as part of energy interventions?'

Communication is closely linked to the visualisation category, which communicates energy consumption through visual representations.

4.4.3.5 Visualisation

Representation of energy i.e. bar graphs and other abstract visualisations was one of the most debated themes in the workshops. However, it was the least understood by participants with regards to technical feasibility, and what their own organisation's policies would allow them to do with their energy data. The overarching finding was there is no single solution or 'one size fits all' representation for displaying energy feedback. Instead, a visualisation or 'dashboard' that embeds the attributes of the other five key axial categories in the analysis may be the most suitable.

Participants understood the value of visualising energy data but also realised that there is no simple method to generalise a visualisation to all audiences:

W3P8: *"…it depends on your learning style, whether you respond to text or images or in some ways again it's like who the audience is, there is no one silver bullet response, different people need different things"*

Presenting progress feedback towards an energy target was also important for visualising: **W1P3:** *"[we] need to see where we are going you can't just say let's reduce energy as that's a bit woolly"* and **W1P7:** *"people feed into it from all the departments…..which means you could have a separate target for each department"* and **W2P6**: *"I'd be more motivated if I can see the figures actually working with regards to a target, could we not compare a department's progress against their own individual's targets?"*

Energy feedback granularity was considered important, with energy data at departmental level suggested as more useful instead of abstracted to whole organisation level:

W3P13: *"…..would like to have office level metering, it's because we have the power to influence what is going on"* and **W3P20:** *"coming back to motivation, it's hard to look at a whole organisation and think I'm going to make a difference"*

Displaying fiscal units mapped onto energy consumed and saved was deemed to be a useful metric in making the resource more tangible:

W2P4: *"I think putting monetary value on it is really useful, though it's not saying anything about whether it's high or low"* and **W2P9:** "*the thing for me was that you could actually put pounds and pence to something"*

Lastly, the timeliness of energy feedback was discussed:

W1P3: *"realtime (energy feedback) has got the potential to be brilliant…. you have a feeling of control and there is direct cause and effect, you can see that happening in real time"* and **W2P5**: "*live data (energy feedback)…..we could plot all our stuff that is on, how many computers throughout the day and stuff*"

However, it is important to note that the timeliness and detail attributes of a visualisation is largely dictated by the format of the energy data being fed into it, as well as the physical smart meter infrastructure. Energy data provenance is examined further in the discussion section.

4.4.3.6 Leadership Role

The role of leadership was a thread woven throughout much of the collected workshop data. Without “management commitment” employees feared their efforts would be frustrated, that results would be trivial and interventions destined to fail. Charismatic leadership and leading change from the top were cited as being the most motivating factors in engaging with and adhering to interventions, with change “trickling down”.

Participants indicated having good leadership and management behind an energy intervention was important:

W1P3: *“first point you have to make when creating any campaign is getting senior management buy-in”* and **W1P4:** *“….you would need a carbon management plan and somebody leading that project”* and **W3P5:** *“if senior management aren’t in then they can’t motivate people, you might have…….certain leaders buying in and certain ones don’t, so you are still seeing variable behaviour”*

Some quotes also discussed convincing management of the benefits of a successful intervention:

W2P4: *“…approach their manager and say the same thing – look, this is good for you, when you tell them the rewards that they could be saving, that’s when senior management will go 'oh yes!’”* and **W2P7:** *“sit them [management] down and say look this is why it matters”*

Leadership was unanimously seen as an essential component of a workplace energy intervention, whether leading from the local level or from the top of the organisation. However, it does allow us to identify possible anomalies in the data, for example the ‘Leadership Role’ category had the lowest frequency in terms of open coding count but was communicated during the design task as the single most important attribute for intervention success. Participants likely felt uncomfortable describing management practices due to the hierarchical nature of the organisational structure, with senior colleagues present at the workshop. Indeed, this was voiced during the workshops by some participants whose managers weren’t present, stating they wouldn’t be so open in their criticism of current workplace practices that could impede intervention.

4.5 Overall Responsibility

From analysing the data and interpreting the emergent themes, the theme of 'Overall Responsibility' best describes the essence of the data, by linking all the categories together. Therefore, the theme of overall responsibility can readily be seen as the main theme from the perspective of corporate responsibility. This broadly encompasses trust, ethical values, sustainable practices, and transparency in an organisation's commercial and social activities and acts as the main driver for key themes identified from the data such as openness, communication and leadership role. Corporate responsibility applies to the whole organisational structure from top to bottom conveying the message that all levels of staff have to be engaged in realising sustainability-themed change.

From the GT analysis, the emergent themes as previously discussed in detail in section 4.4, provide the main attributes for designing successful workplace energy interventions:

- **Theme - Leadership Role:** Providing strong leadership and "management buy-in" to ensure all departments and employees are part of the initial outreach as well sustaining engagement long term;
- **Theme – Openness:** Promoting trust by ensuring that no part of the organisational structure is exempt;
- **Theme – Communication:** Ensuring transparency so that the reasons behind the intervention are clearly and openly communicated;
- **Theme – Engagement:** Involving employees in setting energy consumption targets;
- **Theme – Incentives:** Negotiating incentives mapped to any energy savings made either at the departmental or organisational level;
- **Theme – Visualisation:** Energy feedback was a contentious issue in that it was very much desirable, though it had to be carefully managed to address sensitivities around data privacy, particularly around being able to identify a single employee's energy consumption and practices.

In terms of the six themes listed above, the socio-technical aspects of organisational culture and corporate responsibility are complex, work by Benn at al. [29] states that more traditional organisations are inherently unsustainable in their practices, given the resource constraints of the modern world, society acceptance, and climate issues. In so much as large companies and corporations are part of the emissions problem, they are also part of the solution, by transforming their business processes and practices to a sustainable model. Such transformation is demanded by modern society with consumers showing greater interest in the carbon footprint of products and services. In the context of this work, energy reduction interventions, as part of corporate governance and responsibility, are a way to gain trust and engagement not only with their employees, but the wider public.

The identified themes provide a robust set of design guidelines to support successful energy interventions, with the intention to enhance an organisations sustainability efforts and reducing their carbon footprint. However, as evidenced from the data, the challenges are non-trivial, and not all of the design guidelines may be suitable for inclusion in an intervention.

4.6 Prototype Interface

From the findings of the GT data analysis, a prototype intervention design interface was created. Identified themes informed the design of the prototype interface, and was derived from diagrams, textual and audio accounts which were coded to each of the 6 key categories (themes) developed in the GT axial coding stage. From the concept of each category and their descriptive content, it is possible to determine the basic design of a workplace energy intervention when delivered as a web application or desktop widget. The basic design should attempt to include each of the following themes: Visualisations, Incentives, Engagement, Leadership, Communication and Openness to help maximise engagement. The prototype designs are available to view in chapter 5, section 5.3.

4.7 Discussion

The findings presented in this case study provide a background for understanding the challenges of organisational change in reducing energy usage. The issues discussed here, although organisational rather than technical, are relevant to the HCI community as important context for creating energy interventions in the workplace. A summary is now provided that first highlight the findings of our analysis, followed by a discussion on their relevance to the design space.

A large amount of the workshop discussion was directed towards defining the level at which energy should be monitored, i.e. individual, office, department or organisation. The departmental level was deemed the most accessible level to identify with in terms of an employee's ability to perceive and influence energy usage. Privacy concerns were raised when identifying an individual's consumption with organisational level deemed too coarse to relate to. Employees felt uncomfortable with others being able to make inferences about how they use energy while carrying out daily work tasks. Granularity of energy data is a technical issue and determines the scope of an energy intervention in terms of ability to run fine grain departmental level or coarse organisation level interventions. Energy sub-metering is generally required for office or department level. For example, some organisations may only have building level metering that is recorded once every 24-hours, making most office or departmental level interventions difficult and raising further implications for design when considering the effectiveness of comparative or competitive measures.

The smart meter infrastructure installed throughout an organisation's premises will largely dictate the granularity and frequency of energy data capture and availability. For example, it would be difficult to run an intervention with competing departments in a single building if only one smart meter is capturing data for the entire building. In this case the data is classed as 'coarse'. Additionally, the energy data may not be transmitted to a storage service frequently, new data may only be available on a 24-hour basis for the preceding day. Coarse and infrequent smart meter data collection will keep costs down but will still allow an organisation to fully comply with all mandatory governmental carbon policies. As long as the data is captured at 30 minute intervals for large organisations they are fully compliant. Whether or not the data is available frequently for external consumption is irrelevant for compliance purposes. Essentially this creates a barrier around creating interventions that would be more engaging and effective with higher-frequency data available; however, there is significant costs associated with opening up data in a timely and interoperable fashion.

Surprisingly the participants didn't think it was important for the energy feedback to be pleasing aesthetically. Typical organisational style bar and line graphs with set energy targets overlaid were deemed to be suitable for understanding usage, an approach also recommended by Tufte [269] when presenting simple, quantitative data. Suggested metrics for visualising EUED were cost and the kilowatt hour energy unit. Although the kilowatt unit was not generally understood by all participants, it still gave an indication as to high and low consumption. As with the work by Chetty et al. [57] understanding energy itself is a difficult concept, and with the added temporal element of time such as the kilowatt hour, it adds yet another layer of complexity for intervention participants to unravel. It can be assumed that a simple bar or line chart presenting high/low values is sufficient, providing a window of understanding on an otherwise intangible resource. Alternative tangible offset measurements were suggested to sit alongside energy, such as the number of cars that could be taken off road. Frequent feedback was important with near-real time preferred, allowing employees to see a more tangible impact of their actions.

Engagement and maintaining interest in an intervention were highlighted as critical to lasting success. Competition through sharing performance data with others and setting targets to self were frequently suggested as a means of preventing disengagement. Equally, the creation of pledge-enabled incentives where energy savings are piped into a cause or reward was desirable. Frequently suggested intervention attributes were league tables, timely progress feedback and pledging boards. It is of course no accident that these mechanisms are those most commonly used in the public sector for managing any organisational change and monitoring performance.

Another important aspect of engagement was employees' desire and motivations for empowerment to bring about green and sustainable practices. They wanted to negotiate the terms of an energy intervention, not just as individuals but as a collective group, which in many cases could be the entire organisation. Key to this empowerment was negotiation of energy targets and what should be done with any energy savings made. Work by Dourish [89] suggests scaling issues can occur with sustainable practices unless you have community wide and upwards participation. With empowerment present it alleviates the scaling concerns as employees from top to bottom in the organisation are rallying together collectively, not just a few motivated individuals or small silos of 'green warrior' employees.

The workshop participants were predominantly administrators and managers. It is clear that during these workshops they applied the strategies that they typically used to monitor organisational performance to the problem of reducing energy consumption. The performance of institutions in the public sector such as universities and hospitals has for the past twenty years been measured by indicators like league tables. Measurable targets (e.g. student numbers, increased recruitment and retention rate) are set and counted annually. Research is ranked and rated by the number of publications in conferences and journals. The discussions then centred not only on suggestions for implementing similar mechanisms to achieve energy change, but also on the kinds of problems encountered when using such systems.

Participants were from both the public and private sectors, often quite senior managers, who were aware of the problems of this kind of approach to organisational change. Unintended consequences of new performance indicators and league tables are well documented. For example, the introduction of waiting time targets in UK Accident and Emergency wards appeared to speed up the queues but further investigation revealed that people were being kept in ambulances, discharged early or sent to the wrong department so that administrators could meet their targets [157]. Similarly, in education whenever exam results have been used as performance indicators marks have improved but not necessarily because the pupils were learning more (ibid). In large Health and Education organisations the introduction of new performance indicators has resulted in managers and employees gaming the system. For many participants then a frequent concern was accountability and the ways that blame might be managed in the event of a failure to reach targets.

In summary, two emotively charged questions were posited by the participants in terms of engagement with a workplace energy intervention: i) *What's in it for me?,* and ii) *Where does the buck stop?* In other words, what do I gain from taking part, and who is to blame if it doesn't work or something goes wrong? The discussions presented here highlight the importance of considering the impact of organisational culture in the design of energy reduction interventions. This case study makes a significant contribution to the HCI sustainability literature in understanding the design of organisational energy interventions, while considering the socio-technical implications. HCI researchers can adopt and build on the design guidelines presented through the grounded theory analysis and resultant six thematic areas of i) incentives, ii) openness, iii) engagement, iv) communication, v) visualisation, and vi) leadership.

The next steps in this research will be to apply the GT findings to a workplace energy intervention. In the next chapter, work is presented that adopted the developed design guidelines in a 4-month intervention with 16 employee participants from a professional services department in a large organisation.

5 Case study (2) – Group Goal-setting and Group Feedback in an Organisational Energy Intervention

5.1 Introduction

End-user energy demand (EUED) in the workplace is affected by a complex interplay between behavioural, social, technological, design, regulatory and organisational factors. Therefore, designing technology-led interventions to encourage pro-environmental behaviour that acknowledge and support this complexity is a significant challenge. Academic and government-led work in this space is discussed in detail in chapter 2, section 2.1, of which this case study acknowledges and builds upon. Presented here is work carried out for the design, implementation, and evaluation of a four-month EUED intervention, deployed as a field study in a professional services department with 16 employees at a UK university. The intervention was based on the design guidelines developed from case study 1 in chapter 4, and consisted of integrating two behaviour change methods, group feedback and group goal-setting, both of which are based on established techniques from the behavioural sciences.

The design of the field study allowed the clear monitoring of any changes in mid-term energy use behaviour during and beyond intervention. Findings suggest that, surprisingly, participant energy consumption increased during the intervention period compared to baseline conditions. The results demonstrate that simple group-based behaviour change methods can be counter-productive in the workplace, illustrating the complex and unpredictable nature of intervention in this design space. Findings also reflect similarities in intervention field work by Murtagh et al. [196], who carried out a larger workplace energy intervention which also evidenced inconsistencies with energy reductions and employee engagement during the intervention phases.

5.2 Informed Design from Case Study 1findings

In order to adequately design, develop, and deploy a workplace energy intervention using HCI methods, the author draws upon the research findings presented in case study 1, which undertook a rigorous qualitative study involving 65 employees from a number of organisations. The main objective of case study 1 was to understand the design challenges for organisational energy interventions. Using grounded theory, the resultant analysis produced a framework of key themes detailing user perceptions and energy intervention design considerations, with some of the considerations echoing grey literature produced for energy efficiency strategies in businesses [24]. For a full description and analysis of each theme please see chapter 4 for case study 1, section 4.4. Each theme represented an abstract intervention attribute for consideration as part of an intervention strategy. In this study, five of the six themes were implemented – a limitation of the study. The author was constrained by organisational policy and did not have sufficient management buy-in to implement the *incentives* theme, this would have required a long and drawn out process with no clear pathway for a successful outcome or manageable solution. From a research perspective, even though it was a study limitation, it validated some of the findings from case study 1 as management buy-in for an intervention was deemed to be a real challenge.

Two of the themes from the design guidelines - *engagement* and *visualisation* – were identified as requiring behaviour change methods to engage participants with their energy practices, and attempt to reduce their energy use. The behaviour contingencies chosen were group feedback and group goal-setting. This approach can be seen as mapping theory to design, in this case the design of software as a digitally-enabled intervention. The application of the selected behaviour change methods is discussed in section 5.3 - Study Design.

The selected five themes will now be briefly summarised in the following sub-sections.

5.2.1 Engagement

Competition and negotiated targets (goal-setting) in an intervention were favoured to both lower barriers to participation and to engage with an intervention; with particular emphasis on achievable targets and goals. Unrealistic targets, inability to set targets, and unfair competition were highly cited for bringing about potential disengagement.

5.2.2 Openness

Trust and privacy were seen as important issues for employee engagement with energy interventions. For the intervention to be engaging, employees would have to accept the reasons why savings were required without being cynical. Having confidence that the organisation was acting in the employee's best interest was a key theme. Participant privacy, in the context of presenting only group feedback as opposed to individual, was cited as being important to preserve anonymity.

5.2.3 Leadership role

Without "management commitment" employees feared their efforts in an intervention would be frustrated, that results would be trivial and interventions destined to fail. Charismatic leadership and leading change from the top were cited as being the most motivating factors in engaging with and adhering to interventions, with change "trickling down".

5.2.4 Communication

This was seen as critical at all stages of an intervention. Communication encompassed workshops for educating employees on energy as a finite resource, effective marketing campaigns for recruitment, and continuous feedback using multiple channels for all aspects of energy use in the organisation. Quality of the message, not the mode of communication, was seen as the important factor.

5.2.5 Visualisation

Representation of energy i.e., bar graphs (group feedback) and other abstract visualisations is a contentious issue. It is dependent on the technically feasible and organisational policies in the context of energy data ownership. There was a preference for bar charts, line graphs and metrics such as cost; typical organisation-centric representations.

5.3 Study Design

A prototype desktop widget application was run across four phases (pre-study baseline, group feedback, group goal-setting, and post-study baseline) over a four-month period with 16 participants in a professional services department in a UK university. The widget automatically loaded on desktop computers used by the participants, who were all based in the same large, open office space.

In the literature review carried out in chapter 2 of this thesis, there was an absence of evaluation strategies in the HCI sustainability work appropriate for evaluating the long term effectiveness of workplace energy interventions. Significantly, the design of digitally mediated energy interventions reported in the HCI literature is also lacking in solid foundation in behavioural science, highlighting the complexities of mapping design to behaviour theory, and to date there is still a body of work to do in understanding the space. However, some HCI work has acknowledged this problem and are investigating social & behavioural psychology frameworks [121][140] in an attempt to map appropriate behaviour methods onto design.

The science of behaviour modification spans decades of research [68]. It defines rigorous evidence-based methods for intervention through quantification and controlled experimentation, and is immediately and practically useful for anyone designing technology-mediated behavioural interventions. For example, the psychology research suggests a combination of regular feedback and realistic goal-setting may prove a useful approach in promoting behaviour change and maintaining intervention engagement and adherence [68]. In the work reported in this case study, group feedback is implemented through the design of energy visualisations, and applying goal-setting through weekly group-based goal setting tasks [68][190]. The group contingencies implemented are based solidly in those reported in the behaviour modification literature, and are discussed in study phases presented in this chapter.

A mixed methods approach was undertaken for the study, which facilitated the deployment of quantitative and qualitative methods throughout the study where appropriate. Descriptive and inferential statistics were used to analyse the energy data, while qualitative techniques were adopted to collect data that offered supporting qualitative explanations on how participants engaged with the study.

The quantitative and qualitative research questions were:

- Does group-based feedback reduce energy consumption?
- Does group goal-setting reduce energy consumption?
- Do engagement levels change with each condition?
- What are the interface preferences for energy feedback?

An online, pre-study questionnaire was distributed to participants to collect information on their basic preferences for viewing visualisations and for any energy-saving tips they felt were pertinent to their immediate working environment. Additionally, for post-study data collection, semi-structured interviews were carried out with two main open questions asked to provide an account of participants' reflections on engaging with the study. The open questions used to drive the discussion were i) "*Overall, do you feel the office used more or less energy as a group during the study?"* and ii) "*Could you discuss which parts of the study you felt were the most effective in terms of engagement?*" The pre-study questionnaire with responses is available to view in appendix 2.

Ideally, the planned workplace intervention for this case study would have aimed to include all of the six intervention design themes resulting from the work of case study 1. However, constraints were experienced by the policies of the organisation with whom the author was working with to deploy the intervention. Specifically, there was no sufficient management buy-in to implement the incentives theme – as a result no rewards scheme was available for reductions observed in energy consumption made by the participants. However, rather than a limitation of our study, this constraint demonstrates the realistic and valid challenges faced when designing technology-mediated energy interventions for organisations. Indeed, lack of buy-in from people in leadership roles was identified in case study 1 as potentially detrimental to employee engagement with any workplace intervention. Participants previously expressed concern over; '*where do any energy savings go*?', and '*is there any management buy-in*? *if not then why should we take part?*' The final design of the intervention widget interfaces was based on sketching and paper-prototyping produced from findings in case study 1. It's important to note that simple numeric illustrations and graphs were desired. The initial wireframe design and further developed hi-fidelity design are illustrated in figures 5.3-1 and 5.3-2 respectively.

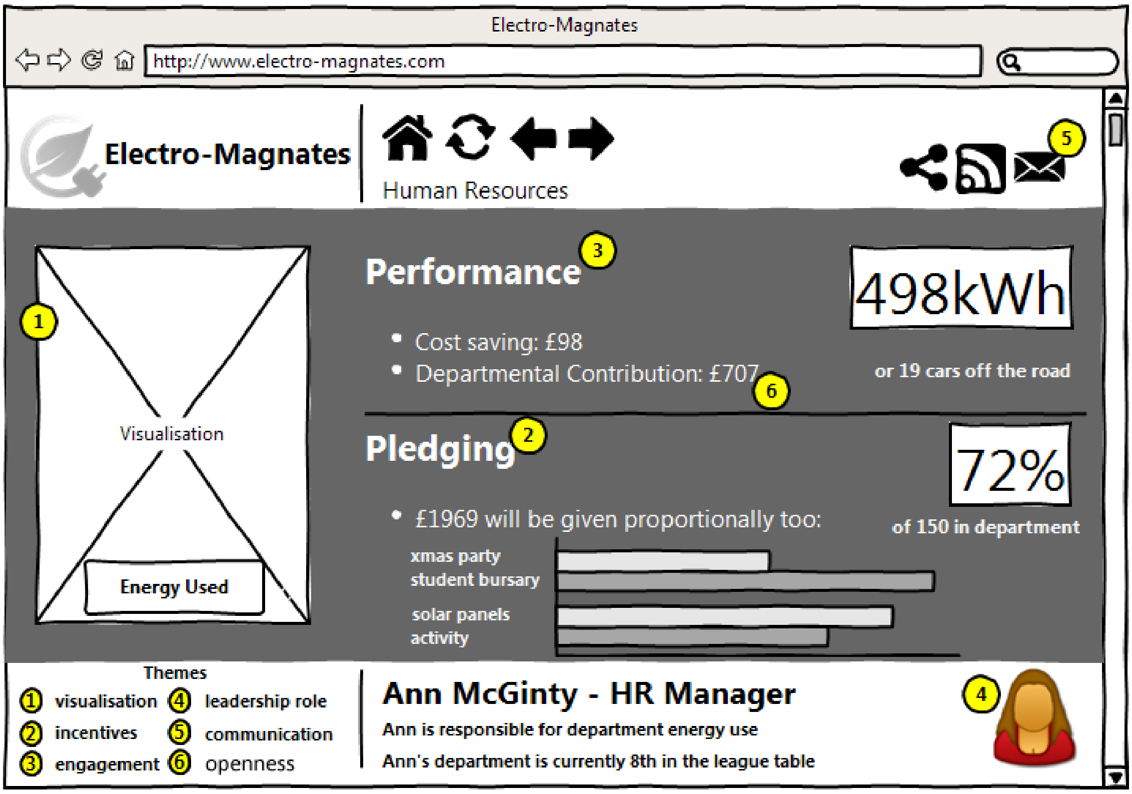

Figure 5.3-1: Wireframe prototype visualising the GT themes.

Figure 5.3-2: Hi-fidelity prototype visualising the GT themes.

In the following sub-sections, each of the field study phases are described in detail.

5.3.1 Baseline (pre-study)

To measure baseline energy consumption (non-intervention phase) an energy appliance monitor was installed for each participant (n=16), to monitor total energy consumption at their personal desk space once every minute. Energy data was sent wirelessly to a base-station which relayed it to a database server and the COSM Internet of Things storage platform. Baseline data was collected for a period of 1 month before and after the intervention phases. Additionally, an online questionnaire was developed and distributed via email to all staff working in the department before the study started. The questionnaire aimed to elicit basic responses in how employees perceive and consume energy in workplace practices. Interviews were also carried out post-study to help unpick how participants engaged with the intervention

5.3.2 Group feedback (intervention part 1)

The first stage of the intervention delivered energy consumption feedback at the group, rather than individual, level. This decision was primarily made because of concerns expressed over openness and visualisation themes during the workshops described in case study 1. Participants requested energy consumption feedback be delivered at the group level, rather than the individual, because of worries about how such data could be used by others to draw inferences about how they do their job.

In designing ‘group-based’ interventions, this case study was influenced by the work of Siero et al. [248], who designed energy feedback mechanisms appropriate for groups of employees in an organisation setting. Siero et al. [ibid] focussed on bringing about collective behaviour change in a group using comparative feedback by providing performance feedback on other groups and comparing it to own group. Indeed, behavioural psychology research, more generally, has shown that group contingencies, when properly managed, can bring about effective results [68].

The dependent group contingency method was selected as it allows a whole group to share a positive reward, even if it is just an individual or a small number of users within the group whose performance is responsible for reducing their energy consumption. In other words, this type of group contingency means consequences are delivered to the entire group based on the performance of one participant, or a subset of the larger group. This directly supports goal attainment feedback as discussed in the next section. Group feedback was delivered for 6 weeks. Crucially, the first two weeks of energy data in this condition was removed from the data set analysed, due to the potential for novelty effects.

5.3.3 Group goal-setting (intervention part 2)

The second stage of the intervention again delivered energy consumption feedback at the group level, and also allowed for the collective setting of weekly goals for reductions in energy consumption. Group goal-setting was designed to support the communication, engagement, and visualisation design themes of the intervention. Goals were designed that were public, provided timely progress feedback, and had a completion deadline [190]. At the start of each working week (Monday), when in the goal setting condition, participants were prompted to view the widget and select an optional energy saving goal. Participants were able to set a savings goal between 1-5% of the total energy used in the previous week. Participants indicated their desired goal target individually, and a final goal for that week was calculated based on an average of all goal values submitted by participants. The group goal-setting condition was delivered for 6 weeks, again with the first two weeks removed from data analysis for potential novelty effects. Feedback was displayed to participants on goal progress, with final goal positive/negative attainment feedback displayed at the end of the working week (Friday at noon).

5.3.4 Baseline (post-study)

Upon completion of the intervention phases the widget was removed from participants' computers by means of an automated script. Energy data was collected for 1 month to provide a post-study measurement. Participants were given the opportunity to take part in a semi-structured interview with open questions. Data collected would provide further qualitative insights into how they engaged with the study.

5.4 Implementation

In the early stages of planning the intervention, the possibility of using the building's smart-meter infrastructure where the employee participants worked was explored, with a view to upgrading the current configuration to a smart-meter on each floor with further disaggregation to large office spaces. At that time, a single smart-meter was installed in the building, a common setup across the organisation. The author undertook work to understand the current smart-meter hardware and software configuration with a view to capturing and publishing energy data from it, with interoperability the main objective. Figure 5.4-1 illustrates the target organisation's setup with the added enhancement by the author to enable open publishing of the energy data via the COSM IoT platform. The use of COSM would enhance the data by providing descriptive metadata so that other 3rd party users can make better sense of it, and understand any inherent limitations, such as gaps in the data. Work in open data research by Corsar and Edwards [70] describes the concept of 'data provenance', and argues that by publishing data with contextual information and 'provenance' it will allow others to validate and compare it for usefulness. For energy data this would provide a further level of transparency and means that datasets from similar institutions, in this case UK universities, could be compared and understood better.

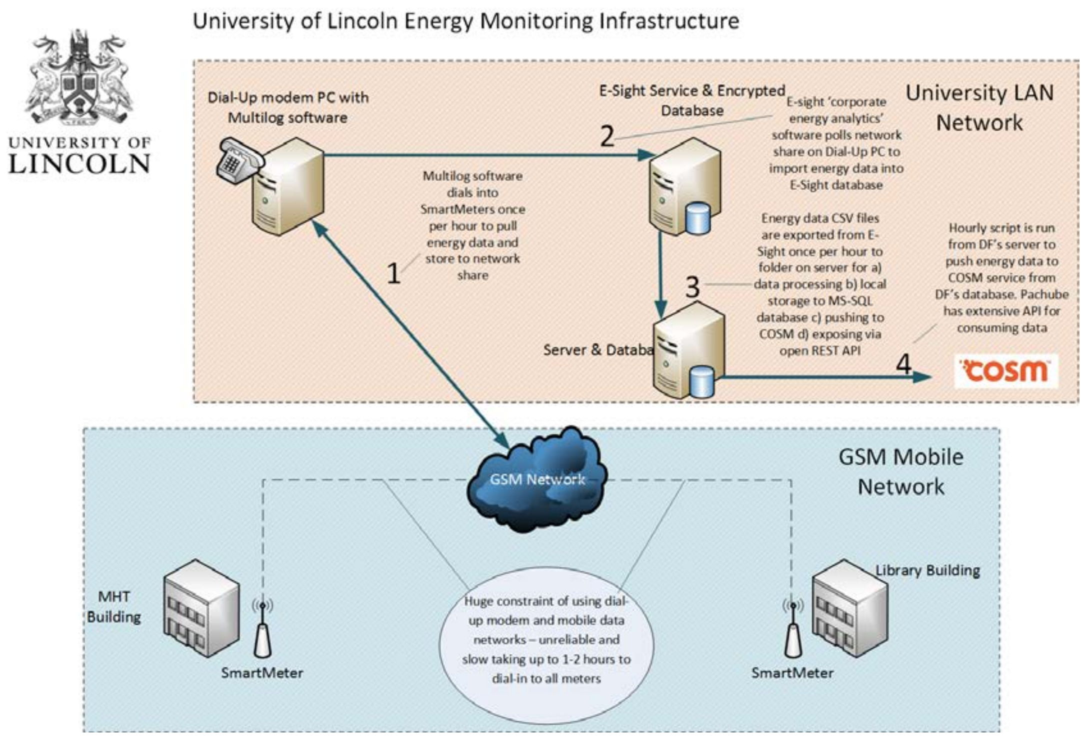

Figure 5.4-1: -Target organisation's smart-meter infrastructure with enhancements.

Perhaps the largest constraint of the organisation's smart-meters was reliable data collection, as GSM modems were attached to each meter for data transmission – this proved to be unreliable in practice. This type of smart-meter infrastructure is a barrier to creating interventions that would to some degree rely on data being delivered in a timely fashion. However, as an example for other researchers, it is possible to publish open energy from a setup similar to that presented in figure 5.4-1, albeit with limitations. A full RESTful API was built to expose the data for consumption by third party applications, documentation for this is supplied in appendix 3.

Upon testing, the enhancements to the smart-meter infrastructure and publishing of the open energy data were deemed to be unsuitable to support the planned intervention. Instead, a bespoke energy monitoring system was developed that would fully support group feedback and group-goal setting, and provide timely energy feedback. This system is discussed later in this section.

A number of other technical challenges were addressed to deploy the intervention widget to participant's desktop computers. In order to drive engagement and limit the complexity of interacting with the widget, it was deployed as part of the organisation's corporate network domain. This meant when each participant logged onto their computer with their domain credentials, the widget would automatically load on their desktop. This required senior-management buy-in at the highest level and was a positive step forward for intervention engagement, it also addressed the requirement of the *leadership-role* theme for intervention design.

When initially logged in the widget would move first through a 'loading screen', then the 'main screen', with a number of supporting screens available to click through for further information, energy tips, and switching the feedback view between fiscal and kWh units. A detailed illustration of the widget's features is shown in figure 5.4-2. The loading screen imparts feedback and energy saving tips (comparing work to home energy use) and information on whether or not the group is saving energy compared to the same time period last week, with the main screen displaying total energy used in the current weekly time period, updated automatically every minute.

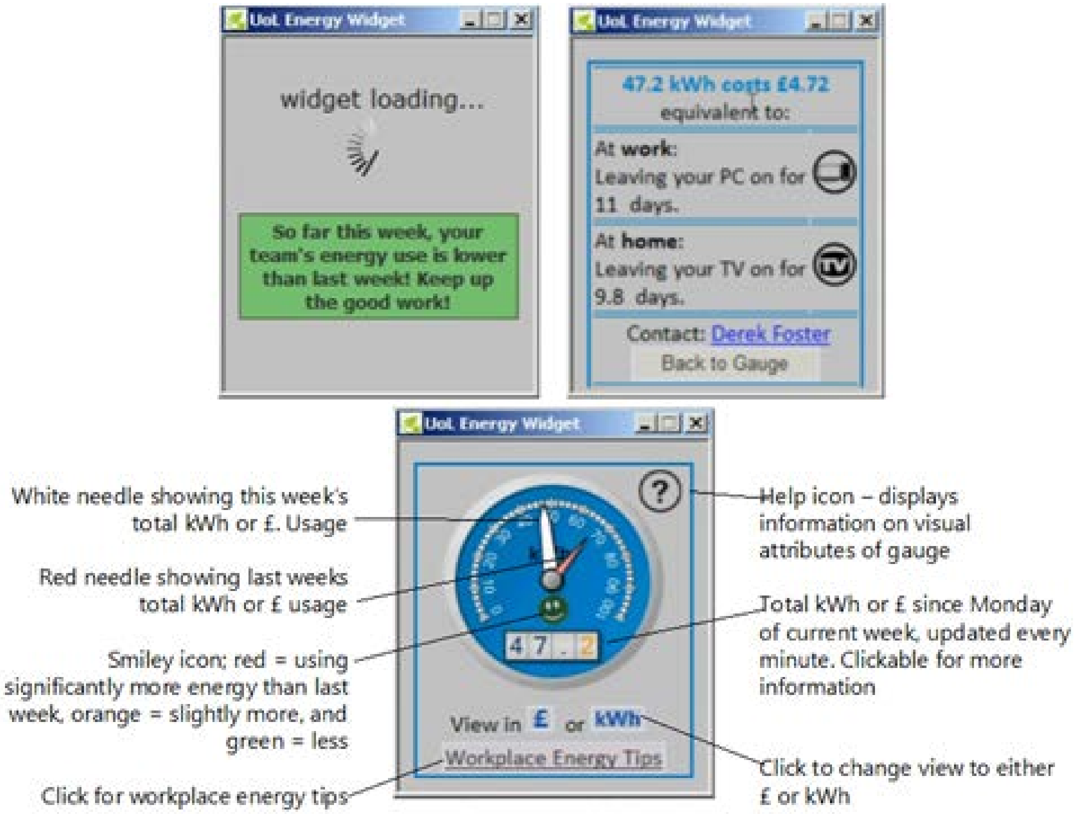

Figure 5.4-2: Desktop top energy widget interfaces.

To accurately measure each participant's energy use we configured each desk's electrical power sockets in such a way that they mapped onto an individual participant's desk area. This ensured an aggregate energy reading for all electrical appliances a participant used. Participants had a great deal of control over the number and type of equipment and devices they could utilise at their desk space; for example, portable heaters, multiple chargers, secondary computers such as laptops, desk lights, and even rechargeable power tools were all evident on site visits.

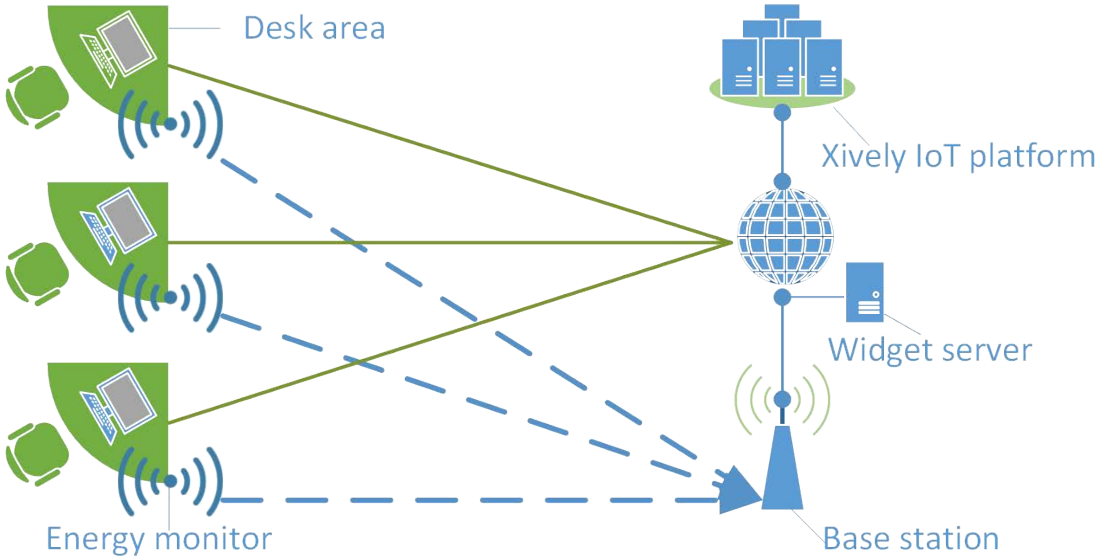

Figure 5.4-3: Technical energy monitoring implementation.

5.4.1 Equipment

Appliance monitoring devices [73], measured each desk's total energy consumption every 60 seconds and transmitted the data wirelessly to a base station. The base station was connected via a serial cable to a low power computer running a custom service to publish the energy data to the COSM IoT platform (now Xively) [187]. Approximately 3.5m energy and interaction data-points were generated for analysis. See figure 5.4-3 for the technical implementation diagram.

5.5 Experimental Method

Deployment of the intervention field study featured employees as participants from a professional services department in a UK university. The employees all worked in a large open-plan office with diverse roles including engineers, space development, and residential services. The main aim of the study was to observe if the intervention phases influenced the department's group energy consumption.

5.5.1 Participants

Sixteen employees were recruited as participants to take part in the study and trial the energy widget, 5 were female. They were comprised of a diverse range of roles including engineers, general admin, space management, building control, and from various levels of organisational management. All participants used a work-supplied computer connected to the corporate network domain. Participants were invited to join the study and full informed consent was given by 16 employees. It was clearly communicated that they were free to opt-out of the study at any time without question.

5.5.2 Design

The field trial study followed a single-subjects A-B-A design commonly used in the behavioural sciences to evaluate the effects of intervention upon a behaviour of interest (see [5]). A baseline condition was used to determine an expected level and variance of the behaviour of interest. Two intervention conditions (group feedback and goal-setting) were introduced with the intention of impacting upon that behaviour. A post-study baseline was used to judge whether any observed changes in behaviour during intervention were stable, generalisable and long-term, or whether behaviour returned to baseline levels when intervention conditions were removed.

To clarify the independent variable had four conditions, baseline, group feedback, group goal-setting and baseline, while the main dependent variable is the energy used in kWh for each condition with other dependent variables to measure engagement and interaction levels. In the group feedback condition participants could view the group's energy consumption in near real-time, and compare it to the previous week. In the group goal-setting condition participants could suggest an energy savings goal, with progress towards the goal displayed.

In order to address the likelihood of intervention conditions producing a novelty or halo effect [19] when taking part in a study and presented with new technology, it was decided to remove the first two weeks of energy data from each condition in our analysis. This was also a requirement for equal time epochs for meaningful descriptive and inferential analysis to be made.

As well as eliminating the first two weeks of energy data, weekend data was removed, as staff were not normally contracted to work over the weekend period. This produced a final dataset that covered 80 days of energy consumption data for analysis.

5.6 Results

The main metric of measurement was kWh, calculated from snapshots of watt-seconds once per minute, using the formula '(power * 60) / 3600000' to calculate kWh. To put the energy use into context, the average daily total consumption by a participant across each of the study phases was: pre-study = 1.0517 kWh, feedback condition = 1.1846kWh, goal-setting condition = 1.1894kWh, and post-study = 1,155kWh. During the baseline pre-study phase, this equated to around 5.08kWh consumed by each participant during Monday-Friday. Comparatively, 5.08kWh is approximately half the daily energy use of the average UK household [206]. The descriptive data clearly indicates participants used more energy in the intervention conditions. The absolute total consumption in kWh for each month from the raw data was month 1: 336.5, month 2: 378.9, month 3: 380.5, and month 4: 356.8. Figure 5.6-1 illustrates the daily total average EUED for participants, with the mean shown for each month of the study, while a sample of participants (n=5) was used to graph absolute daily consumption totals over the entire study, see figure 5.6-2.

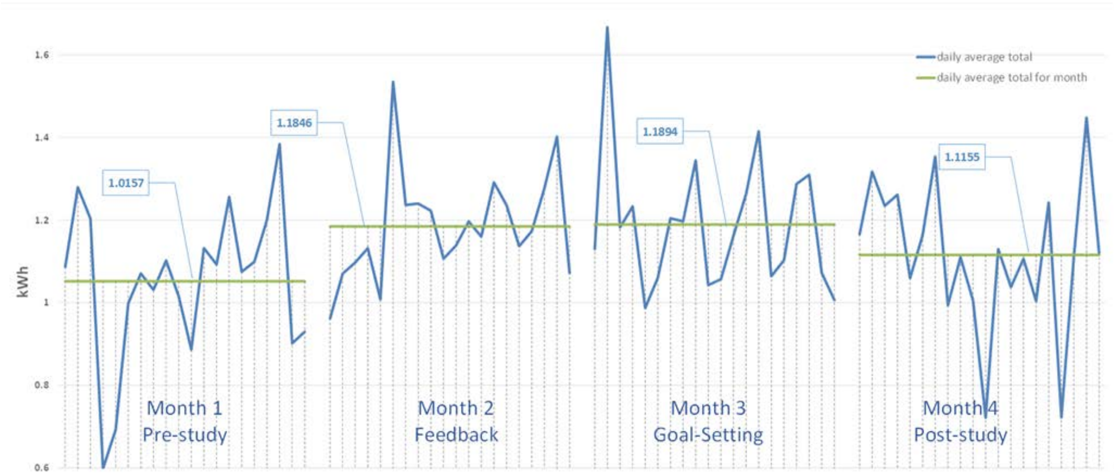

Figure 5.6-1: Total daily average participant consumption across all phases of study.

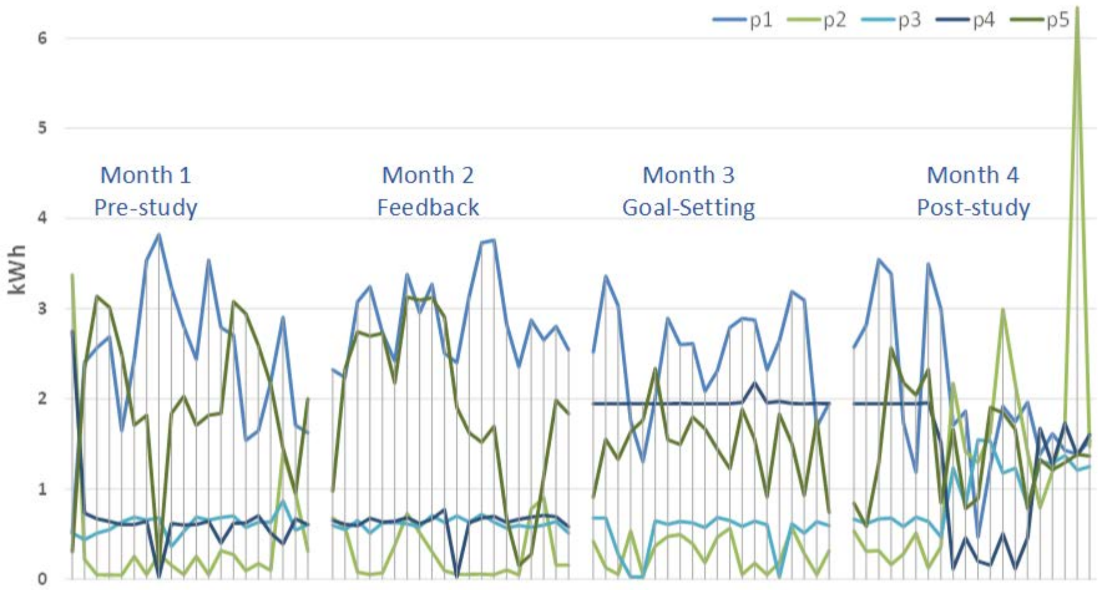

Figure 5.6-2: Sample participants' (n=5) daily energy use in each month.

5.6.1 Statistical significance

With the descriptive results indicating more energy was used in the intervention conditions over the baseline measurement a repeated measures ANOVA was carried out to check for significance in the findings. The daily absolute values for total kWh used by each participant were used as the input data for the ANOVA analysis. Results indicated assumptions of sphericity had been violated $\chi2(5) = 30.42$, $p = 0.00$, which was corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = .94$). The results of the ANOVA show that the effects of the intervention were significant in increasing EUED $F(2.81, 894.85) = 3.16$, $p = 0.27$. Drilling down further using a pairwise comparison, it was found pre-study vs. feedback ($p = 0.034$) and pre-study vs. goal-setting ($p = 0.023$) were significant. However, the conditions: feedback vs. goal-setting ($p = 1$) and pre-study vs. post-study (p = 1) were found to be non- significant.

Although the data indicated the null hypothesis of feedback and goal-setting conditions have no effect over pre-study measurements could be discarded, the evidence presented was that participant energy had actually increased by statistically significant levels. In other words, the intervention conditions appear to have had the opposite of the intended effect of reducing energy consumption. Qualitative data to support unpicking this interesting finding is presented in the interview data later in this section.

5.6.2 Engagement

In order for an intervention to be successful, adequate engagement is required. Engagement and interaction with the energy widget was tracked covering:

- Duration widget was displayed during working day;
- Selection of interface type (kWh vs. fiscal), and use of energy tips with further information;
- Goal-setting activity.

5.6.2.1 Widget viewing and energy tips

To understand the daily use of the widget when it initially loads and whether it is left running on the desktop or simply closed by a participant, engagement and interaction statistics were automatically recorded through the widget. Overall there was relatively high levels of engagement, with the widget displayed for an average of 7.7 hours for each participant in the feedback condition, and 6 hours a day in the goal-setting condition. See figure 5.6-3. For viewing energy tips there was little uptake, which essentially provided more contextual information on the current weekly energy total. A total of 44 energy tips views were recorded from 8 participants.

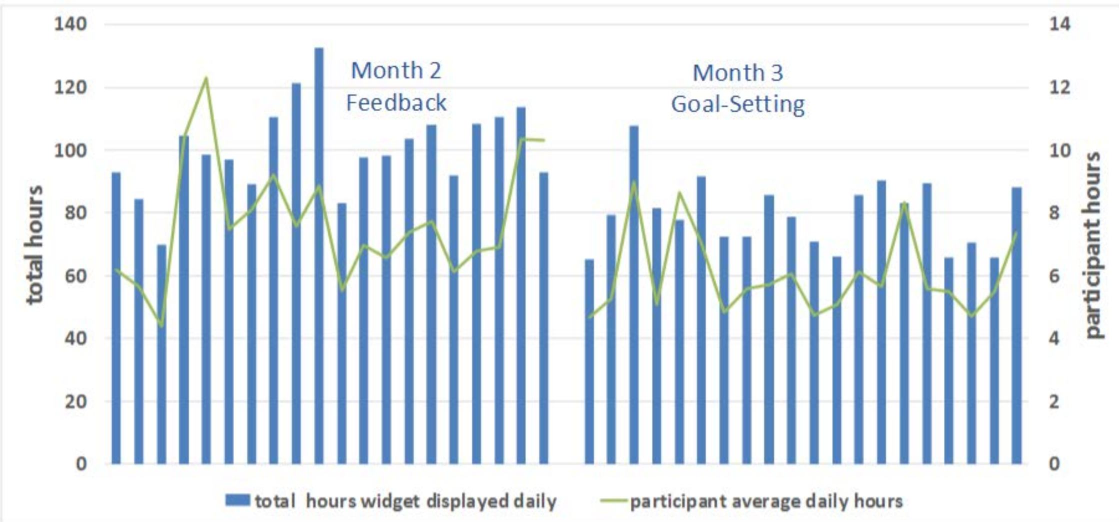

Figure 5.6-3: Energy widget daily engagement levels in each intervention condition.

5.6.2.2 Choice of kWh or Fiscal units

The widget provided the functionality to swap between kWh and fiscal cost units, allowing participants to choose the interface they preferred at any time. The default selection was kWh with very little deviation, however 11 participants did try the fiscal view over a few days.

5.6.2.3 Goal-setting

Four group goal-setting events were carried out in the goal- setting condition (one per week), with goal activity recorded including data on goal achievement. Table 5.6-1 shows that two goals were met (goals 1 and 4), with the remaining two goals not met by using more energy than the previous week. Encouragingly the number of participants taking part in goal-setting never fell below 50%, given that goal-setting was optional. Engagement with goal setting was fairly positive with at least 50% of participants submitting a target savings goal.

Table 5.6-1: Participant goal-setting engagement

	Participants	Target Goal	Saving
Goal 1	10	3.87 kWh, 4%	14%
Goal 2	8	1.67 kWh, 2%	-7%
Goal 3	9	2.80 kWh, 3%	-2%
Goal 4	11	2.86 kWh, 3%	3%

In summary, the descriptive and inferential statistics show participants used significantly more energy in the intervention feedback and goal-setting conditions when compared to the baseline pre-study measurement. Post-study measures indicated energy consumption fell to near pre-study levels, in other words it was a return to baseline measures, indicating there was a clear impact during the group feedback and group goal-setting conditions. Overall engagement levels with the widget were high. The findings are discussed in more detail in the discussion section of this case study.

5.6.3 Questionnaire data

A short pre-study questionnaire was distributed to all participants with 8 responses from a potential of 16, the questionnaire can be viewed in appendix 2. The pre-study questionnaire data is used primarily in this study to compare responses with intervention engagement levels and to further understand the potential implications of the design themes used in the intervention, as well as those that weren't implemented. As the groundwork and analysis was undertaken in case study 1 to understand employee awareness and attitudes on workplace energy consumption, there was no need to develop a significant, quantitative based questionnaire. Responses from a sample of the questions are presented here, with full results in appendix 2.

A simple opening question, question 1, asked *"What unit of measurement do you prefer to see energy consumption displayed?"* The options were: 1) Cost (£), 2) Energy (kWh), and 3) No preference. Four responses preferred the cost unit, one participant preferred energy and the remainder having no preference. When asked Question 2:

"Please indicate how EFFECTIVE you think the following communication channels would be for communicating energy use during an energy saving campaign

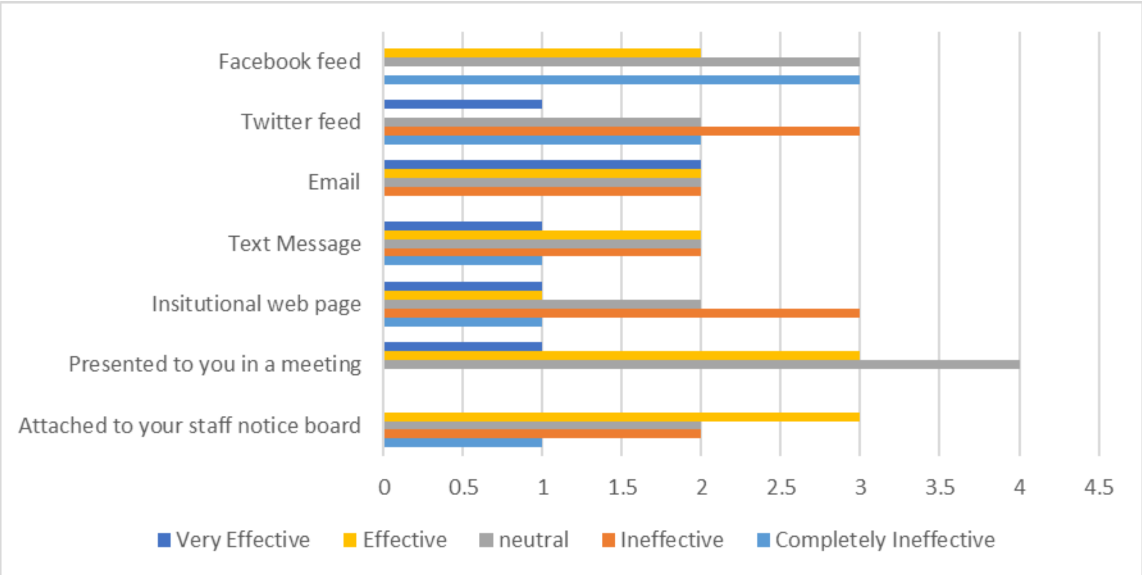

Figure 5.6-4: Questionnaire responses to effective methods to display energy use.

Choice and responses are shown in figure 5.6.4, it was clear that social media channels were not a popular choice for the organisational environmental. This is not surprising as being seen on these platforms whilst at work could easily be misconstrued as carrying out a leisure pastime whilst at work.

When asked Question 5:

"Please rank the following approaches for bringing about organisational change where you work"

The responses presented the view that effective communication, clear rewards and punishment, and financial incentives were shown to be the preferred mechanism to bring about organisational change, see figure 5.6-5.

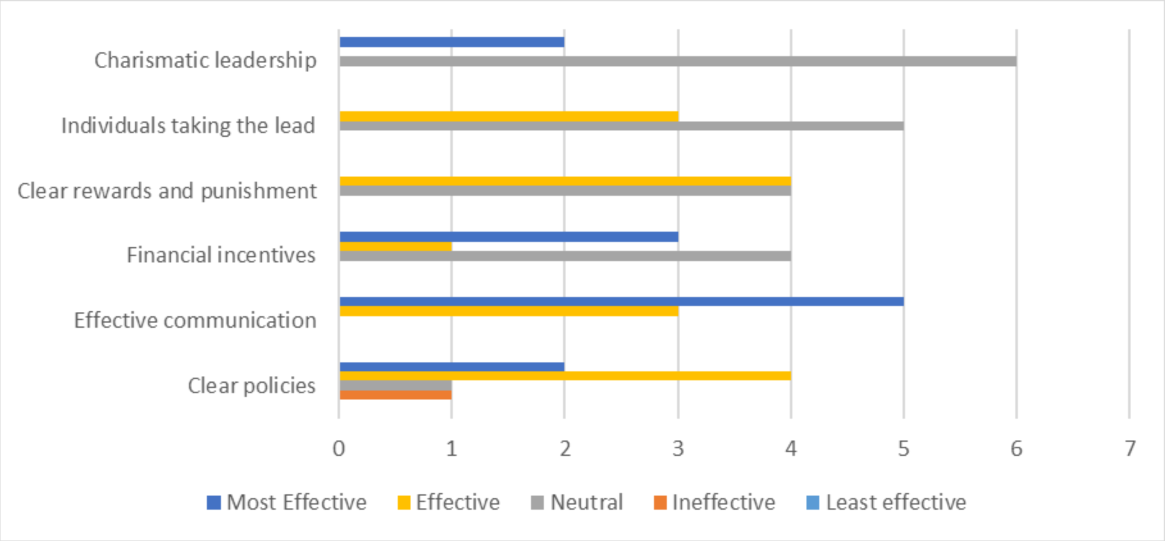

Figure 5.6-5: Responses on organisational change approaches.

Overall the pre-study data didn't contribute a great deal to the findings of case study 1, rather it corroborates the work by validating the intervention themes. To examine possible explanations for increased consumption in the intervention conditions, the next section will present the post-study interview data.

5.6.4 Interview data

To provide a richer, and more insightful narrative on participant engagement with the study over and above quantitative energy use alone, post-study semi-structured interviews were carried out with six participants. The interview data presented here supports unpicking what ensued during the intervention phases, with data analysed using a small-scale grounded theory approach [258] . The first two stages of grounded theory were utilised, namely open-coding and axial-coding. Axial coding provides the emergent themes from grouping and categorizing open codes. Each theme offers an interpretation of the data to give insight, and to help explain attitudes and actions by participants during the study. Four themes emerged from the data: i) Non-negotiable practices; ii) Technology constraints; iii) Efficiency awareness; and iv) Circumvention. Each theme is now discussed in turn with supporting conversational segments.

5.6.4.1 Non-negotiable practices

This theme focused on the dissonance between pro-environmental behaviour and carrying out necessary activities specific to a job role **P1:** *"It is my view that the reasons behaviours do not change is on the basis of our job role practices being more deeply ingrained, like job priorities and habits."*, and **P4:** *"I didn't really change my pattern of work during the study as I had my usual stuff to do"*. These comments suggest work routine conflicted with action to make energy savings.

5.6.4.2 Technology constraints

Participants were vocal in describing how current technologies they use at work impede making reductions: **P2:** *"I felt that there was no way to minimise the energy used due to the current way that remote access works at the university i.e., you have to have your PC on all the time you wish to work remotely"*, and **P1:** *"new equipment was installed (such as the new Cisco video phones which have replaced the already over-egged display phones we had. I just need a simple phone, preferably one powered from the phone line, not with its own transformer using unnecessary electricity!)"*. Technology constraints highlight lack of employee control and ownership of equipment used at work, linked to employees normally being excluded from the procurement process. In support of P2's claim of remote working requiring a PC be switched on constantly, the data identified power signatures in the data consistent with this.

5.6.4.3 Efficiency awareness

This theme highlighted divisive feelings on the usefulness of widget energy tips. Some felt they were not useful - **P5:** "I rated tips as the least effective because this is basic information that all people already know", and **P1:** *"I didn't look at the energy tips as I* *already do all I can"*, while others were more positive, **P6***: "The feedback and energy tips were useful. Also just having the widget generated discussion in the office about energy saving."*, and **P3:** "I do think it will have encouraged a few colleagues to be more energy aware and perhaps switch off more often than before".

5.6.4.4 Circumvention

The field study was located in a single department over a large floor space. The area incorporated automated controls for lighting and heating with no way to override them locally. However, suggestions were made that some participants were using portable heaters and lighting at their desk space – **P1:** *"some of my colleagues use personal heaters in the morning at their desk on colder days"*, and **P4:** *"the new LED lighting isn't very nice, its an unnatural kind of light so we sometimes bring in desk lights"*. It can be reasonably assumed that circumventing automated controls can lead to higher consumption overall. Indeed, P1's claim of portable heaters being deployed for personal use is supported in the energy data, with short energy spikes identified early morning at some of the desk spaces.

To summarise, the derived themes are linked in that for the most part they offer a series of 'organisational-led' reasons from participants in how they perceived savings could not be made. These findings propose potential explanations for the energy use evidenced in the intervention phases, particular around the tension between being able to carry out work tasks that by default will consume more power (i.e. remote working), and a range of comfort contingencies such as personal lighting and heating appliances. However, given the scope of our qualitative evaluation, and the complexities of employee work demands, it is not easy to draw out conclusive findings, but rather offer a reflection upon further design implications of such interventions, and the findings of other similar work.

5.7 Discussion

It is generally accepted that feedback is a useful tool to bring about reductions in energy use. For example, work by Darby [75][76] found that reductions of up to 15% are possible when feedback is displayed frequently. The findings of the current study, where energy use significantly increased over baseline levels during each intervention condition, do not reflect those of Darby. However, most of the studies covered by Darby [ibid] in the reviewing literature are focused on the domestic domain, where it might be less of a socio-technical challenge to deploy effective interventions.

Notably, the experimental design used in this case study, allowing for analysis of ‘return to baseline’ was, in the context of HCI sustainability research, uniquely suited to detect stable changes in participant behaviour. ‘Return to baseline’ is a concept commonly used in behavioural science to evaluate the effectiveness of an intervention [68]. In this method, an intervention is removed and the effects upon behaviour are observed. If behaviour remains stable despite the removal of intervention contingencies, it can be inferred that the participant has learned, and that the new behaviour is stable and has generalised. However, if the behaviour returns to the level recorded at pre-intervention baseline, it can be inferred that the intervention itself was maintaining that behaviour and that no long term learning, or change in behaviour, has occurred. In this study a clear return to baseline effect was observed. Thus, while goal-setting and feedback did not have the intended effect of lowering consumption, it did have a psychologically significant short-term effect on energy use behaviour.

Importantly, the findings of this study do not necessarily mean that a group-based approach to feedback and goal-setting is ineffective to reduce energy consumption in workplaces. Rather, it is possible that a more suitable implementation of a group contingency would be more effective. The findings suggest that dependent group contingencies [68], which were used in the current study, are not an appropriate means for delivering group feedback and goal-setting in this context. However, this intervention design is the simplest possible type of group intervention available. It was decided it was prudent to use the simplest possible intervention design for the study.

Given the findings presented, the interdependent group contingency [68] may be more suitable design for future studies [170] for the HCI sustainability research community to explore. Specifically, dependent group contingencies allow all group participants to share the success of receiving positive nominal feedback and achieving goals, even if the success is attributed to an individual or a small group of the larger group. Essentially this means that not all participants have to engage and save energy to achieve the goal, and can be carried along with their more sustainability-minded colleagues. In the case of the interdependent group contingency approach, all group members need to meet the criteria of reducing their own consumption, as well as that of the group goal, when compared to the previous week's performance. This enforces participants to work together to achieve a common goal, in this case a reduction in energy use. An applied example of an interdependent group contingency study was carried out by Poplin & Skinner [225] with success. Of course, manipulation of the intervention design is a logical stepwise process, and the author has learned through this study that dependent contingencies appear not to be appropriate in this context. Consideration should also be given to the independent group contingency [167], this approach may be better suited if the *incentives* theme were implemented in the intervention. Alternate group contingencies are discussed in further detail for future iterations of this study in the chapter 7, section 7.1.

5.7.1 Limitations and future work

Great care and consideration was given to the study presented in this chapter, however there are several limitations that are worth mentioning which provide further insight into the findings. As the study was conducted during the period of September to January, seasonality influence (Winter) could have been a factor for the increased consumption in the goal-setting intervention phase, this is discussed in further detail in the discussion section 7.1, chapter 7.

In terms of the more outlying impacts participants had on the outcome of the study, it emerged that some employees would need remote access to their computers as part of their job role, thereby facilitating the need for a VPN client to be installed on their computer. As a result, this could mean their computer being powered on for long periods to enable remote access, thereby consuming more energy. Although the intention to save energy may of course be desirable to these particular participants, they still need to be able to carry out tasks incumbent to their job role. This need to carry out job tasks was identified in data collected in the energy workshops from chapter 4, and in some cases was presented as a barrier in behaving in a pro-environmental fashion. It may be safe to assume that for some this may present a conflict of interests – expressing a desire to save energy but not being able to do so. From the questionnaire data in this study, it was manifested as several participants voicing the opinion their job tasks take priority, and clearly communicated as: "*I still had my usual stuff to do.*". This interesting aspect of the study is discussed further in the conclusion chapter.

The study duration itself, although longer than most HCI sustainability studies according to HCI work by Froehlich [121], still does not have the longitudinal reach of sustainability studies in disciplines such as environmental psychology [121]. An example being the similar piece of work (to this study) by Murtagh et al. [196] which was conducted over an 8-month period. It could be argued that a longer study would provide more internal/external validity. If the study were to span two summer and winter periods not only would it provide more reliable data, but it would allow more insight into the potential impact of seasonal influences, as well as understanding trends in the data more robustly. However, there are challenges around running interventions in an organisational space for long periods of time, management buy-in and employee engagement to name but a few. There are also significant challenges for HCI researchers to gain access to resources for running longitudinal studies.

Finally, the stats indicated that engagement levels with the study were significant, however this is mostly from the quantitative perspective. Arguably, we would need to understand what 'engagement' means for the purposes of a workplace energy intervention before we can measure it appropriately to garner deeper understanding from an employee's personal perspective, as well as from an organisational level.

As mentioned, quantitative stats provide raw measurement (i.e. number of times energy widget is viewed, closed, and energy consumption) but this does not inform the researcher of what EUED practices the participant is engaging in, and whether they reflected upon better ways to reduce their energy use. There are opportunities for data capture through post-study activities such as interviews and questionnaires, but these may miss the capture of vital 'in-the-moment' thoughts and reflections as employees carry out their daily work-related practices. To support capturing such information, it may be possible to include the use of qualitative energy diaries in future work, allowing participants to capture their thoughts as close to EUED events as possible.

A diary approach has been used in previous domestic energy studies [74],[268], but no research was found in the organisational space at this time. The practicalities and potential privacy concerns of asking employees to carry around a diary and record information on their activities is problematic. Nonetheless, barriers and constraints that may not be evident in the domestic space, but are of importance in the workplace, should not stop researchers from pursuing basic research in the space. Additionally, of particular interest to understanding engagement 'during' an intervention is a domestic study by Bates et al. [12] that used near-time 'mini-accounts' to gather data as close as possible to a point of interest during the study. Such data capture during an energy study would be invaluable to help unpick EUED practices, and enable researchers to better understand engagement and the complexities of the workplace. Again, the aspect of monitoring technologies (i.e. cameras) to initiate the capture of a mini-account are problematic for a workplace environment.

As it stands, this study provides a significant contribution to the HCI sustainability literature in understanding the application of behaviour change methods to an in-the-field workplace energy intervention - essentially how to map behaviour theory to intervention design. At the same time, it also recognises the limitations of carrying out such a study, including the use of specific methods and resource constraints. Despite this, the study offers basic research findings in an un under-researched space. A four-month intervention was deployed that provided valuable insights into employee engagement with an energy intervention.

Further discussion to conclude the work of this case study is presented in the final discussions chapter, section 7.3.

6 Case Study (3) - Designing Aversive Feedback in a Domestic Energy Intervention

6.1 Introduction

In this work the author investigates whether playful aversive stimuli can function as an integral part of an application designed to help users monitor and reduce their domestic energy consumption. Careful consideration had to be given to the design of the message content in the aversive stimuli without pushing the boundaries of the ethically challenging and negative feedback that proves to be a cause of disengagement. To this end the approach undertaken was to look at how to effectively create playful and cool aversive feedback, by drawing upon literature that attempts to understand and define 'cool' from the viewpoint of design and HCI disciplines as well as popular culture [230][148][176].

Creating novel user experiences in online applications around domestic energy data is problematic, in that most energy monitoring systems use simple in home display units with limited interactivity; frequently the energy data from these small inexpensive systems is not easily exposed for consumption by third party applications and often uses proprietary data formats. To address this issue, this work utilized COSM (now known as Xively) [187], a cutting-edge Internet of Things (IoT) [131] data brokerage platform used in conjunction with monitoring hardware to facilitate publishing of open energy data at five minute intervals.

The contribution of the work presented in this case study is an understanding of playful aversive stimuli applied in the context of energy feedback, and whether users disengage when confronted with the stimuli. It was found that aversive feedback did not deter users from logging in and using the Power Ballads application, even though they could have avoided the aversive feedback entirely by not choosing to run the application. Our findings indicate that designers of sustainability technologies (enhanced by IoT platforms) should consider the use of alternative feedback that not only rewards positive behaviour, but acknowledges and responds to negative behaviour.

6.2 Designing for coolness

The concept of cool is nebulous in nature, spans different cultures with different contexts, with cool in one demographic uncool in another. For example, work by Willis in the 60's [282] identified two distinct cultural groups at the time in the UK, bikers and hippies, and described their styles or 'coolness' as being a shared material experience. More recently we can see cultural groups such as hipsters whose exploitation of cool involves seemingly arbitrary objects with limited utility such as fixie bikes and the adoption of dated technology. Cool could then be seen as inherently local to a cultural group, with its manifestations seemingly random or strange to an outsider.

At a basic level cool could be perceived as a manifestation of the human need to belong that leads to a strong desire for social acceptance [15]. Work by DeWall and Bushman [84] provides an overview of social acceptance and rejection against people's fundamental need for positive and lasting relationships. In their work, they define social acceptance as being the 'sweet' that satisfies the desire to belong (in groups this can be seen as a mutual concern for one another) and social rejection as 'bitter', where individuals experience a negative state if they do not receive the benefits of inclusion through social acceptance.

In the context of understanding cool as part of social acceptance, people are attracted to groups that align with their beliefs and ideals to the extent that some groups may be perceived as 'cool' and the first step to achieving the status of cool themselves is social acceptance by the group. To clarify this further work by Leary states that social acceptance means that people in other groups signal they wish to include you in their groups and relationships [177]. Essentially, anything that is cool is *desirable*, and its desirability that can lead to greater levels of engagement with a group or object. In the context of applying cool to this study, end-user engagement is important to its success.

As such, the interactions designed for this study's software were primarily focused on creating a 'cool' experience, with a view to keeping end-users from disengaging.

Moving beyond cool for the sole purpose of social acceptance, it has also been explored as a method to enhance brand awareness in marketing – essentially the creation of outwardly 'cool' products in marketing is the ultimate goal [197]. In their work, they define cool as 'the favoured language of popular culture'. However, the word itself – cool - is almost meaningless, but the concept is powerful, so much so that work in the book 'The Conquest of Cool' [118], believes that advertising agencies have created 'Hip consumerism', with consumption a kind of pleasure-seeking cool. If groups of individuals can portray cool, yet ephemeral, characteristics that are desirable to others for social acceptance, and marketing can create cool 'products', thereby by crossing into the physical and tangible, what then of software technologies? This raises an important question on the concept of cool for this study - is designing software technologies that embody attributes of cool possible?

Cool technology products, hardware or software, are not defined purely by functional and aesthetic concerns, but are bound up with their place within a social and cultural context and the positive user experiences they offer. Frustratingly for HCI practitioners, the most efficient and effective products frequently fail because they lack some mysterious measure of "cool" that engages users. Therefore, it is of great importance to the field of HCI to begin to understand what makes things cool, and more pressingly, how we can create coolness in our products which ultimately trickle down to create novel user experiences. However, this is by no means trivial, and the author explored other relevant HCI literature in the space of understanding cool in relation to technology.

In recent studies and explorations of coolness as it relates to HCI, one particular aspect appears to continually resurface as an important aspect of cool – playfulness. Cool products "make work feel like play" [149], and that joy forms "the absolute centre of cool" [148]. Playfulness, as a valuable aspect of design, is not a new area of interest. Game Studies, as a field of inquiry, has long sought to understand playfulness and its impact in terms of fun and enjoyment in games, both digital and on the table-top that may be applicable [92]. Unfortunately, game design is difficult and designing for fun and playfulness is more complicated than it seems. As such, there is no single agreed model or methodology within game studies that can fully illuminate playfulness in a manner that can support designing for cool in the context of the study presented here; however, there is a long history of literature that can support these continuing explorations.

Work by Bartle [11] developed a model on informing game design and was recently re-interpreted in the HCI space to explore the potential connection between games that are fun and products that are cool [172]. This opens up the potential value of game studies literature in understanding the appeal and design possibilities of applying cool attribute to aversive feedback, so as to minimise the potential for user disengagement.

In the context of ‘coolness’ for more serious ends, and highly relevant for this study, recent work by Read et al. [228] and Fitton et al. [107] in designing cool sustainability technologies for teenagers revealed they wanted to tap into specific group dynamics such as peer pressure, personal goals and achievement, with emphasis on personalisation. They also found clear age and gender differences on perceptions of cool. Social identity plays an integral part of being seen as cool by peers, also mirrored in contemporary hipsters' highly personalised and unique appearance. While cool may be defined within a cultural group with its own rules and guidelines, designing for coolness is a challenging area of research, although playfulness appears to be a more common attribute, as it encourages engagement. It is the *playful* attribute that this work attempts to integrate with aversive feedback to create a *cool end-user interaction* through the Powerballads application, with a view to reducing potential disengagement issues with the study.

6.3 Can eco-feedback be cool?

Traditionally eco-feedback was the domain of carbon managers and large organisations adopting corporate responsibility policies; time-stamped bar and line charts were the norm, exposing efficiencies/inefficiencies for fiscal metrics. Indeed, this approach is still very much in existence, with previous energy feedback work in the corporate space indicating many participants still preferred the use of bar charts as they fit with the rest of the reporting measures across their organisation [113]. Similarly, up until recently, the UK's Department for Energy and Climate Change (DECC) prominently displayed the nation's energy consumption as a bar chart on their web site's landing page [80].

Figure 6.3-1: Basic IHD energy information display.

Energy monitoring in the home is commonly carried out using IHD's characterised for the most part by their distinctly utilitarian form factors and 'calculator' like displays; figure 6.3-1 is indicative of such design. IHD's such as these offer little in the way of novel interactivity with the dominant form factor designed for table-top placement. An IHD with poor physical aesthetics it is unlikely to be placed in a prominent area of the home and destined for a short 'time-to-drawer' shelve life. Indeed, work by Piece et al. [222] found a large portion of IHD users no longer regularly interacted with them after a short novelty period passes. Further work by Strengers [259] found that disinterest around the IHD was common when a disconnect between the resource (energy) and the non-negotiability of daily energy-consuming practices takes place. It follows that when designing with the intent to engage users with their incumbent energy consumption, we need to step outside the confines of the 'uncool' IHD and look at alternative ways to compellingly engages users with their energy consumption practices.

Other work in designing sustainable technologies has used ambient prototypes that are aesthetically pleasing and might be termed 'cool' over their commercial IHD counterparts. Work by Gustafsson and Gyllenward [134] produced the 'Power Aware Cord', an innovative approach to ambient per-appliance energy monitoring. The cord utilised feedback in the form of emitting ambient light to indicate an appliance's current consumption level. The view might be taken that 'ambient' technologies provide an alternative or 'cooler' way of monitoring energy consumption, allowing owners of such devices to express their sustainable interests outside conventional, static, IHDs.

In summary, currently available IHDs for energy monitoring have yet to evolve into technologies that seamlessly fit into the home environment and don't adopt the appearance of yet another technical 'beige box' design. Further still, they have yet to break out of their 'closed-system' ethos and integrate functionality that allows the transparent publishing of open energy data online, effectively opening the design space for energy interventions offering more than the static context of an IHD readout.

6.4 Internet of Things and the energy intervention design space

Given the prevalence of closed IHDs, how can householders engage with innovative energy intervention technologies? Emerging energy monitoring systems are leveraging IoT data brokerage platforms that connect online a range of monitoring equipment. Examples of manufacturers producing IoT ready energy monitors in the UK and the US from Current Cost and OPower [73][213], with both offering online dashboards and mobile applications to monitor home energy usage. Although not offering completely open data solutions, they are early steps to move focus away from the IHD and onto connected devices such as smartphone applications and remote displays away from home.

The availability of open online energy data is critical for the creation of online energy interventions that do not solely rely on IHD feedback. Effectively the IHD in the home is a small data silo, storing around 30 days of data at most, accessible through the display alone. This makes the availability of apps offering novel and compelling user experiences around energy data almost non-existent for the average consumer as the energy data is simply not available to developers to produce value-added services. Instead, householders in most instances are left with little choice but static, closed displays. Essentially, applications such as Power Ballads presented here will only be possible outside of prototyping when open energy data is ubiquitous with minimal constraints in access, for example through an open energy API. The technical implementation of this study is discussed further in section 6.5.1, and involves the use of a number of different web services, including the IoT COSM platform.

In 2009 Google launched a free open data energy service called Google Powermeter which allowed consumers to track their energy consumption, with the idea it would help raise awareness of their usage habits and become more efficient. Householders' energy data on the service was easily accessed and could be integrated into Google's visualisation widgets, see figure 6.4-1. The service published open data through its highly scalable RESTful approaches. In 2011 Google announced it was retiring Powermeter as it hadn't experienced the uptake Google had envisioned [44]. Despite Google retiring Powermeter there are now a number of emergent commercial systems that offer similar services, though at extra cost.

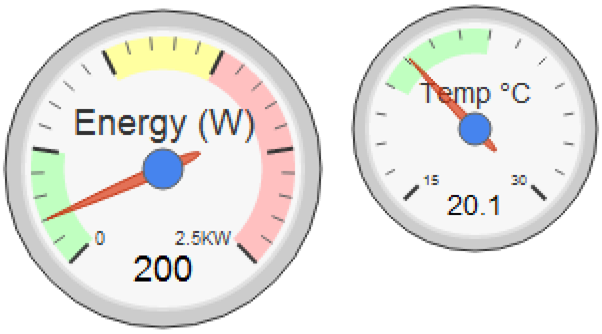

Figure 6.4-1: Google Powermeter data with Google javascript visualisations.

The policy of large scale deployments of smart meters in millions of homes in the UK [208], and the US and China [182] should see the open availability of household energy data increase in the future, however privacy and ownership issues around the data will be problematic, potentially resulting in secure, and closed data collection systems. This is particularly important around the security of the smart meter hardware/communication in terms of vulnerabilities and hacking [61]. Issues such as maliciously switching off power to a household, or snooping on data to determine if anyone is home are all viable concerns, and can damage trust between consumers and utilities. In some cases, the potential impact of such scenarios can be life-threatening in the context of vulnerable members of society.

Although the security aspects of smart meters for households are outside the scope of the study presented here, it is common for privacy concerns to be aired during household energy interventions around the sharing of consumption data. Research in the organisational energy space by the author, and presented in chapter 4 [114], found that employees were worried about their colleagues making inferences on the amount of energy they used, and would prefer their personal data to be anonymised. Similarly, work by Molina-Markham et al. [195] demonstrates that with a few months of data from a smart meter it is possible to make accurate inferences about a household's daily pattern of practices, such as when people are home, sleeping, and cooking.

This work exposes a gap in the design space for supporting a ‘designing for coolness’ approach in sustainability energy interventions. By using innovative and unexpected forms of energy feedback, enabled by emerging IoT platforms and open energy data, compelling user experiences can be created. The work offers a contribution by exploring the concept of playful aversive feedback, integrated through social media in a sustainability intervention. In summary, to support the main line of research inquiry of the efficacy of aversive feedback, a number of supporting areas of investigation are as follows:

- Do users disengage when presented with aversive feedback?
- Do users reduce their energy use following exposure to aversive feedback?
- Do users interact with the aversive feedback?

6.5 Power Ballads

To test our designing for coolness approach, an application was designed with the intention of promoting behaviour change and engagement primarily through playful aversive feedback. This aversive feedback embodied playfulness as the *cool* factor, with the intention of making it desirable for participants to engage and interact with.

The design of the Power Ballads application, though basic, was largely inspired by the author’s previous conceptual work in playful embodied agents for energy monitoring [173], and previous sustainability work in the domestic space that used social norms as an intervention mechanism [112]. In particular, it was the aversive feedback messages from the embodied agent that the author found interesting and engaging, and were not short of ‘tongue in cheek’ moments. An illustration of the conceptual system showing the embodied agent deliver a dire warning on the effects of using too much energy is shown in Figure 6.5-1.

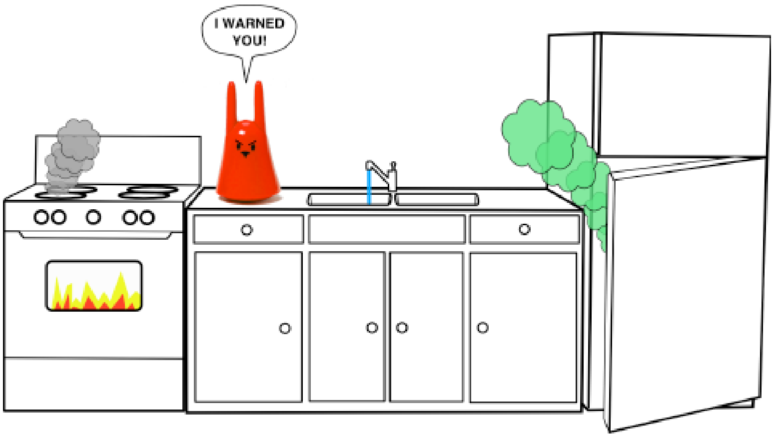

Figure 6.5-1 Embodied agent energy monitoring concept

The embodied agent work also demonstrated that different reinforcement techniques (i.e as applied in computer games) can increase engagement, and could be used to motivate behaviour change. This was the main motivation behind using aversive feedback, with the added element of playfulness. Further conversation with the author's supervisor consolidated the conceptual ideas from the embodied agent, with a firm view that aversive feedback could provide useful negative reinforcement in the context of EUED, and would be a good avenue of research to pursue. The agreed upon caveat with the author's supervisor was the aversive feedback must be carefully applied so as to not risk participant disengagement – it was to this end that the aversive stimuli (content of the feedback), must be of a playful nature.

The Power Ballads Facebook application presented a basic interface which delivered feedback on participants' comparative energy use, by time splicing the previous 48 hours of usage. A commercial off-the-shelf home energy monitoring system consisting of a Current Cost ENVI IHD (figure 6.3-1), connected to the IoT NetSmart Bridge [73] (Figure 6.5-2). Energy data is sent to the ENVI IHD unit from the electricity meter clamp sensor, which in turn is sent to the Netsmart bridge connected by wire to a home internet router. This is a somewhat convoluted configuration and takes a significant degree of technical competence, even though it's targeted at consumers. A more detailed description of the technical architecture is given in section 6.5-1.

Figure 6.5-2: Current Cost NetSmart internet bridge device.

When a participant visited the Power Ballads application from their Facebook account, the application interface informs them of their energy use by means of a large notification displaying ‘Yes!’ if they have saved energy or ‘No!’ if they have increased their usage, see Figure 6.5-3. A line-graph illustrating the last 24 hours of energy use is also shown, which could potentially highlight any peaks of EUED and when they happened. The comparative values are comprised of first checking the total energy used in the previous 24-hour time period, then comparing it with the directly preceding 24-hour period. If the participant increased their energy consumption they were playfully punished by the application automatically publishing aversive feedback in the form of a public post to their Facebook newsfeed, as shown in the example in Figure 6.5-4. The post would then be viewable by all the participant’s Facebook friends. The aversive post example highlights the participant is using more energy over the past 24 hours compared to the previous 24-hour period, effectively disclosing their high usage, or undesirable behaviour to their peers.

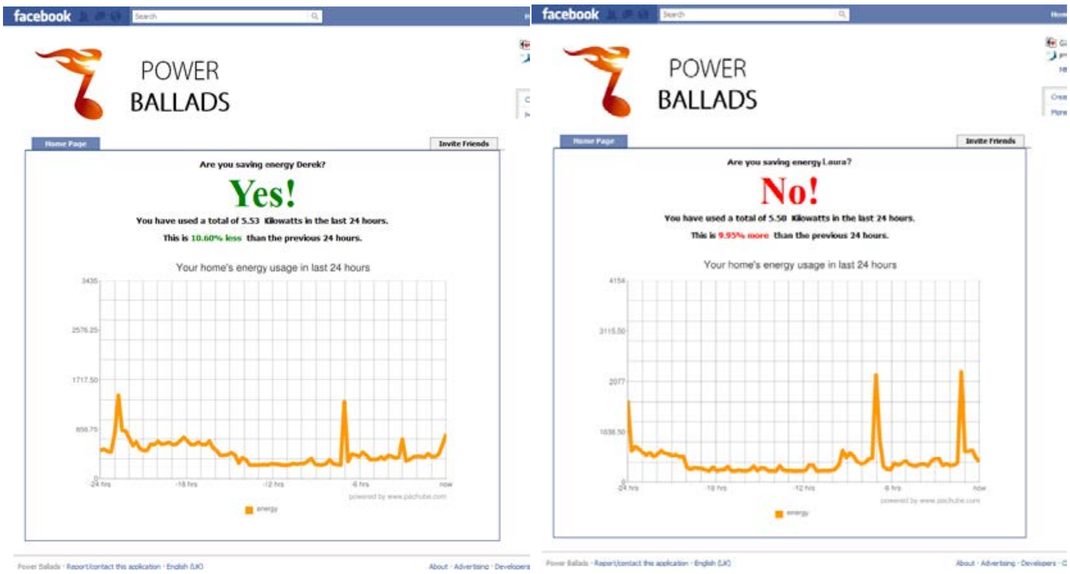

Figure 6.5-3: Power Ballads comparative energy feedback notification

As energy usage is wrapped up in highly personal consumption habits and daily lifestyle practices in households, it was apparent that the publishing of aversive feedback about excessive usage on participants' Facebook page may be undesirable and could lead to the type of disengagement discussed in [140][66]. The author was interested in exploring whether presenting this information in a playful manner may avoid the problem of disengagement. To this end, the chosen approach to present popular UK chart music as the aversive stimuli posted on participants Facebook wall. Participants were initially screened and accepted based on their strong disliking of this type of popular chart music.

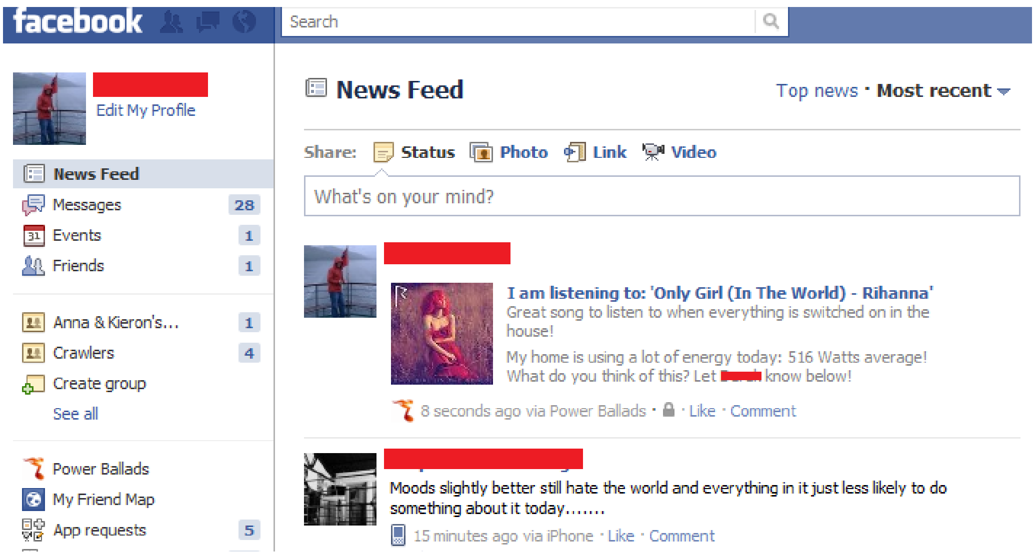

Figure 6.5-4: Playful aversive feedback post example.

6.5.1 Implementation

Development and implementation of Power Ballads utilised both the Facebook Developer and COSM development platforms through their respective API’s [104][187], to display participants’ live online energy data on their respective Facebook member accounts. The Netsmart bridge and ENVI IHD display were the selected energy monitor components to collect data from each of the householders’ electricity meters. At the time of the study they were one of the low cost solutions available that would support the design and deployment of Power Ballads. The Netsmart bridge provides the capability to send energy data directly online to the COSM platform storage service via participants’ home routers, where it is published for consumption by third party applications.

COSM is an IoT data brokerage store and provides an online REST API that allows authorised web applications to query and store large volumes of sensor data, both public and privately. This approach an important step forward in the evolution of home energy monitoring as most monitors at the time of the study with similar functionality require separate PC software (with powered-on PC) to send energy data online where it can be used by third party applications.

Once the energy data is published on COSM it is available for consumption via RESTful calls in three highly interoperable data formats: json, xml, and csv. A simple HTTP GET call is made to COSM to return a specific energy data point, or an array of points. For example, you can request the last 24 hours of energy data, a lightweight and scalable approach.

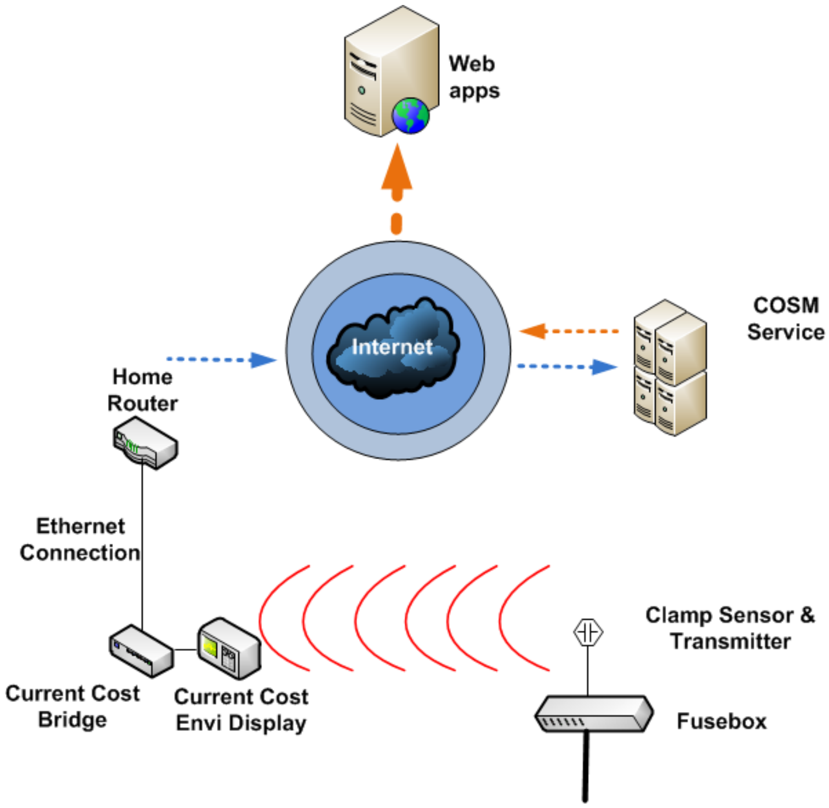

Figure 6.5-5: Power Ballads hardware/software Architecture.

The hardware and software architecture to support Power Ballads is shown in Figure 6.5-5. The process of procuring energy data from the standard household energy meter is outlined below:

i) Magnetic clamp sensor/transmitter attached to mains power cable a fuse-box/meter;
ii) Transmitter wireless sends clamp energy reading to the IHD;
iii) IHD sends data to bridge device via wired Ethernet cable;
iv) Bridge device sends energy data to COSM platform via wired Ethernet connection to home router;
v) Energy data on COSM now available to all authenticated 3rd party applications (Power Ballads in this case) using open data formats.

With the hardware configuration validated for facilitating the design of Power Ballads, a dynamic approach to generating the aversive feedback content was explored. This would provide new, and ongoing feedback without relying on a static database of predefined content. This required a web service mash-up [294] of several online data sources using

Yahoo Pipes with Yahoo Query Language (YQL) [164] and data scraped from the BBC Music Charts website [17]. Work by Benslimane et al. [30] further defined mashups:

"It simply indicates a way to create new Web applications by combining existing Web resources utilizing data and Web APIs. Mashups are about information sharing and aggregation to support content publishing for a new generation of Web applications."

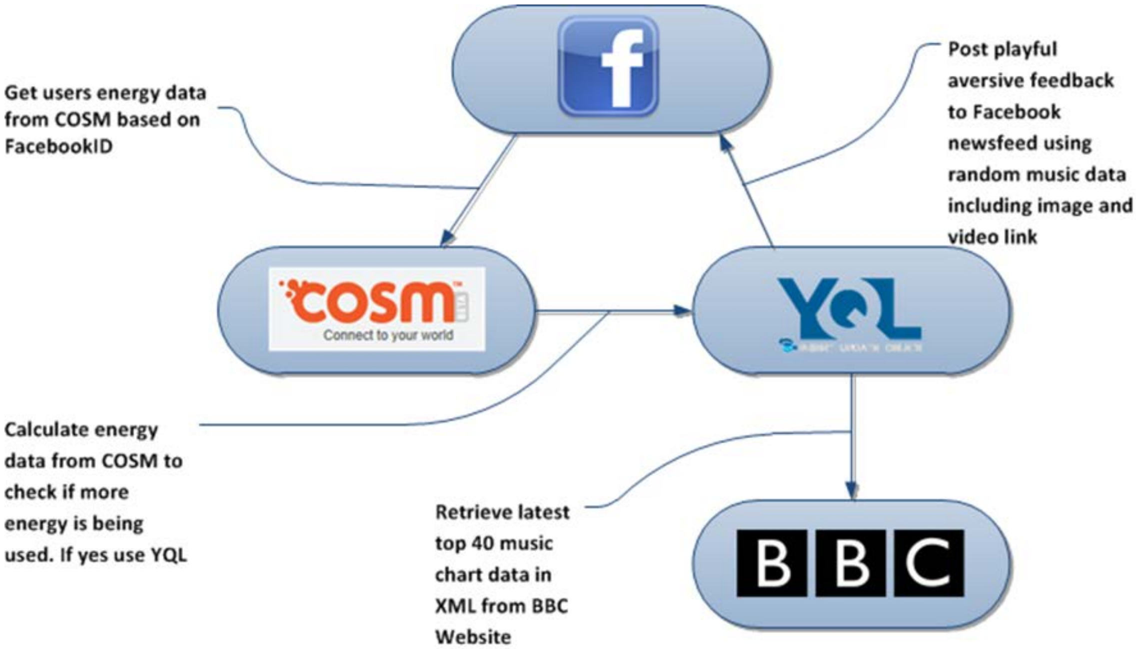

Figure 6.5-6: Power Ballads data mashup flow.

The logic and process of automatically generating the aversive feedback content is outlined below:

i) Participant logs into their Facebook account and clicks to load the Power Ballads application;

ii) Power Ballads application logic queries COSM for participant's energy data to compare the two previous 24 hour periods;

iii) Participant is presented with either a 'Yes' or 'No' notification, dependent on their consumption values, as shown in Figure 6.5-3;

iv) If participant is using more energy the application logic runs the configured Yahoo pipe to scrape music metadata from the BBC charts website, data is returned as an xml file;

v) Application logic then published an aversive feedback post, as shown in Figure 6.5-4, on the participant's Facebook news feed stating they are have increased their energy use and that they are listening to a music single from the popular charts. The music single is selected at random.

vi) The participant's Facebook friends can view and interact with the pubic aversive feedback post.

A mash-up approach to generating and delivering the aversive feedback content was deemed appropriate and low maintenance for posting to Facebook. It was also felt that by providing up-to-date data automatically, it would enhance the experience of using the application. Figure 6.5-6 shows the flow of the open data sources used in Power Ballads. Code snippets are available to view in appendix 4 for the code logic supporting the flow of data in the application.

6.6 Experimental Design

6.6.1 Aims

The aim of the study was to understand how to design engaging and effective aversive feedback in a household energy intervention. Supporting research was undertaken to

- Investigate if participants disengage with the application when presented with the aversive feedback;
- Investigate if participants and non-participants interact with the aversive feedback, and with each other;
- Investigate if participants reduce their EUED following exposure to the aversive feedback;
- Analyse and derive meaning and emergent themes from user-generated comments that could then be exploited in subsequent iterations of Power Ballads and other eco-feedback applications.

6.6.2 Participants

Using a mixture of purposive and convenience sampling, nine lead participants were recruited: 4 of which were female, from nine households. The study recruited participants through advertising to two local Facebook groups that targeted two distinct geographical areas. Such groups are generally community driven and discuss topics of interest to the area, events, and other related activities taking place within that specific location. The recruitment process through the Facebook groups supported reaching out to potential participants who met the study requirements of first being a Facebook member, and secondly living at specific locations that were reachable to the researchers to install and support the installation of energy monitoring equipment. In terms of relationships between participants, its possible some were friends on Facebook, some of the comments posted through the study Facebook application appeared to support this linkage. However, no existing relationships between participants where known at the time of the study recruitment.

6.6.3 Study design

Each household was given monitoring equipment for a period of 5 weeks. Each participant gave informed consent, and installed the equipment in their own home, help and support was offered to do this. At the end of the first week participants were given access to the Power Ballads application on Facebook and could then view their previous 24hr energy usage in graph form and view energy notifications based on whether or not they were saving energy compared the preceding 24-hour period.

In order to view Power Ballads each participant was required to first login to Facebook and start the application. Aversive feedback would only be delivered when logged in to Facebook, and then purposely loading the application. These required steps for accessing the application enabled the author to examine whether participants were engaging with the application or simply avoiding punishment by not using it.

At the end of the study participants were given the opportunity to complete a short, online qualitative questionnaire designed to elicit their subjective experiences of interacting with the Power Ballads application. The following questions were asked:

- Q1. Do you like popular chart music?

- Q2. How did you feel about the posts Power Ballads made to your own Facebook Newsfeed?
- Q3. Did Power Ballads change your thinking about how you use energy in the home?

Participants energy data was collected for subsequent analysis from COSM. Facebook Insights and Google Analytics data was collected to further support quantitative measurement of participant's engagement throughout the study. The Google analytics service was able to supplement Facebook's Insights service to record the number of Facebook application page views for each of the Power Ballads application interfaces.

6.7 Results

During the course of the study five participants (five households) actively used Power Ballads - one participant did not realise they had to log into the application to view feedback and three had compatibility problems with their home routers when collecting and transmitting energy data. Compatibility issues were sourced to a firmware issue with the Netsmart bridge when syncing data packets during comms with the router. Thus, data from five of the nine original participants is presented here.

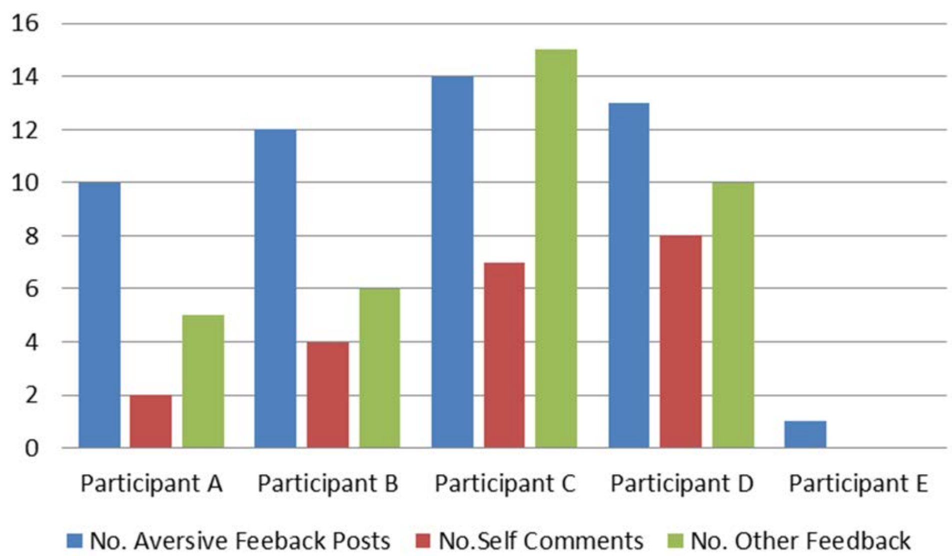

Figure 6.7-1: Participant engagement with aversive feedback.

6.7.1 Engagement

Due to the relatively low number of participants, but by no means unusual for an HCI study of this type, this section presents descriptive statistics over inferential. A small qualitative analysis was also undertaken on the questionnaire and Facebook comments data.

It was important to record basic engagement in terms of participants selecting to run the Power Ballads Facebook application, as this was a manual process on their part. If a participant did not select the Power Ballads app from within Facebook then they could completely avoid any aversive feedback, or any energy feedback for that matter. Therefore, the act of manually running the Power Ballads application was a solid metric to measure engagement, it was entirely within the participant's power not to engage. As illustrated in Figure 6.7-1, all participant's engaged with Power Ballads over the study period, and received a number of aversive posts, as well as positive reinforcement in the form of feedback indicating they had saved energy.

In total, the participants made 167 visits (75% in the first two weeks) to the Power Ballads application, with 50 aversive newsfeed items publicly posted to participants' Facebook news feeds. This equates to around 30% of all visits to the application resulting in a playful punishment post, with the remaining 70% bringing about a notification indicating they were saving energy. It highlights participants were engaging with the application by logging in and therefore not trying to avoid punishment. From the 50 aversive newsfeed posts an additional total of 57 user-generated content items were created consisting of 41 comments and 16 'Like' clicks suggesting that playful dialogue took place. These user generated comments were created by participants and non-participants who were Facebook friends.

Figure 6.7-2: Participant and non-participant interaction with aversive feedback.

Figure 6.7-1 highlights participant engagement throughout the study. The graph illustrates the number of aversive posts created for each participant as well as the number of comments they made in response to aversive feedback directed at them. Also shown is the total number of other feedback items made, pertaining to the aversive feedback posts. This includes comments and 'like' impressions from study participant and non-participant Facebook users. An example of engagement with an aversive feedback post is shown in figure 6.7-2. The results show that participants engaged with their own and others' aversive feedback.

Although interaction with the app does taper off after around 2 weeks, there is steady engagement for the remainder of the study. Given the relatively low numbers of participants it is difficult to draw any conclusive deductions from this. It is clear however that participants did not completely disengage when confronted with their first aversive feedback post, which is promising.

6.8 Energy Consumption

The energy used by all participants was constantly monitored and stored on the COSM platform throughout the duration of the study. Snapshots of energy use from each participant where stored at 5 minute intervals. Analysis of the energy data found that of the 50 aversive posts generated, 31 (62%) resulted in energy reductions over the ensuing 24-hour period. Figure 6.8-1 shows for each participant the number of aversive posts made and the accompanying number of instances they reduced consumption in the ensuing 24-hours following the time the post was generated.

Although the energy consumption results are encouraging, it’s was not conclusive that aversive stimuli will be effective in most instances based on these early descriptive findings. This is discussed in further detail in the next section, with a qualitative analysis and appraisal of the questionnaire and Facebook comments.

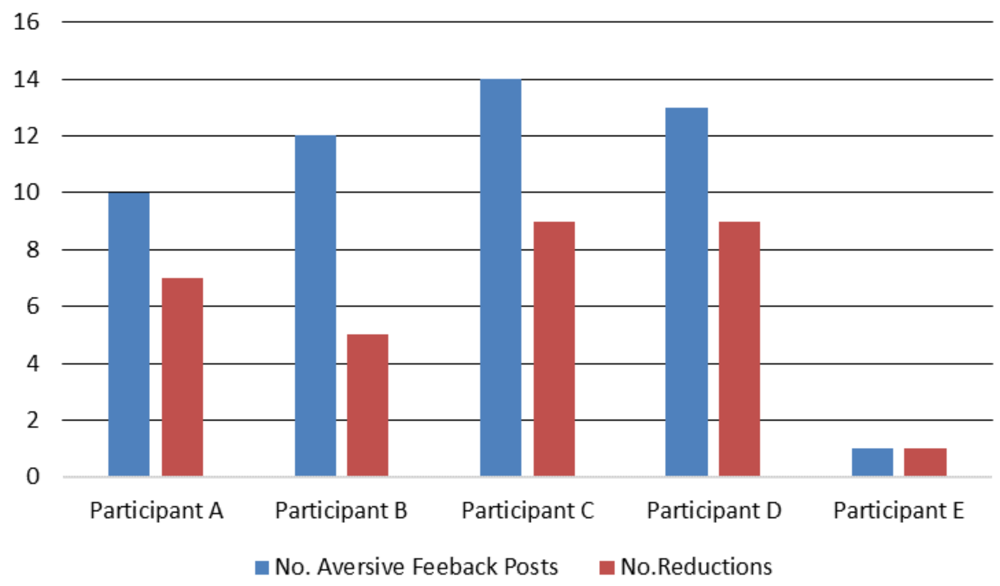

Figure 6.8-1: Instance count of energy reductions observed following aversive feedback.

6.9 Discussion

To summarise, our results suggest that aversive feedback may be effective in successfully engaging users (or at least does not disengage them), and could potentially support reductions in energy consumption. In this study it is important to explore the qualitative aspects of the data, including the user-generated comments that were created based on the aversive posts, as well as the questionnaire responses.

The aversive feedback was intended to be playful and cool, even embarrassing, with participants indicating this in the questionnaire responses:

Participant C: *"I was already using an energy meter from British Gas to minimize our electricity usage. cool idea though! perhaps could be personalised towards things that people would find more embarrassing within their peer groups…"*

Participant B: *"it made a post when we had to use the washing machine a lot one day... I had never heard of the artist/song that was posted on my FB feed, was more baffled than anything else but thought I could show off a bit! :)"*.

Participant A: *"I was rather amused by all these strange posts!"*

When asked question 3 – *"Did Power Ballads change your thinking about how you use energy in the home?* participants responded with some interesting comments. Generally, it was observed participant's felt the application did encourage them to think more about how they use energy:

Participant A: *"It helped me realise the overall figures, average consumption quantities etc. In general I am concerned about the 'green issues' at home so this was definitely useful."*

Participant E: *"…it did raise may awareness of power usage and I did consciously switch TV's and room lights off where possible."*

Participant D: *"Power Ballads got me thinking more about what had a big impact on my energy usage. I now know what appliances in my home are not all that efficient. I do try to be efficient in my home already and power ballads confirmed that i as doing quite well. It's a shame i have to give the meter back, it's been very informative just having that."*

Engagement from Facebook posts around understanding the significance of high/low energy use was present:

Participant C: *"277...are you sat in the dark?"* with **Participant B** responding with*: "is 277 fairly low? It is not extremely bright in here, but still can recognise furniture and [anonymised]!"* Similarly, another dialogue, **Participant C:** *"313 average and you have* *used more today? Did you sit in the house with the lights off yesterday?"* with **Participant D** responding: *"Yesterday it was 233 and that was higher than before that! Not sure what's been different today though."*

Interestingly, some of the Facebook dialogue was based on determining which appliances may be causing the aversive feedback, effectively exposing social practices around household energy:

Participant D: "*You're using the most out of [anonymised] you and me today! Washing day?!"* with **Participant A** responding, *"Funnily enough yeah…the washing machine, caught up on a load of washing!! Just shows you"*. **Participant D** responded directly to the aversive feedback when their personal usage peaked at its maximum with *"Oh good god! I guess that's what i get for having the oven on :(....but i also get home-made bread...not sure it's worth my reputation though!!"*

Engagement suggesting the use of chart music was playfully averse was present by non-participating Facebook friends, **Non-participant:** *"jls???"* [teenage boy band] with **Participant D** responding: "*There needs to be a smiley for hanging your head in shame!!"*. Additionally, the quote, *"Oh no, what are you doing to my reputation!"* by **Participant C** was a direct response to an aversive feedback post.

The majority of responses to the aversive stimuli were centred on two main themes; the first based around energy use practices and the specific appliances potentially responsible for causing the aversive post. The second theme focused around friendly banter related to the chart music displayed in the posts. These two emergent themes were mirrored in our questionnaire data. Overall the qualitative questionnaire and Facebook post data suggest participants not only engaged with their energy feedback, but enjoyed the playful content of the aversive posts. This raises interesting issues around understanding the effects of playful feedback with aversive attributes, particularly when delivered in response to undesirable behaviour.

As pointed out in the background chapter 2 of this thesis, aversive stimuli requires careful consideration of the message content for delivery. This is in line with other lifestyle interventions to help prevent disengagement and detrimental effects on participants, for example in the delivery of aversive feedback in dietary interventions. Work by Thieme et al. [262] investigated raising awareness of food waste and recycling through a provocative and personal approach by appropriating household bins and placing internet enabled cameras inside. The cameras publicly published photos of waste to social media site Facebook, effectively delivering a form of aversive feedback when photos contained excessive food waste or recyclable materials. Despite the photos allowing the potential directing of negative inferences about others' lifestyles, results from the study indicated users had a raised awareness of their waste habits with increased motivation to change.

The idea of generating new and engaging experiences with energy, that steps outside the norm of appetitive feedback, has gained traction in the HCI sustainability community. Design work by Paulos [219] coined the term 'energy parasites' for physical objects that effectively leech energy from natural sources such as wind and water and store it for future 'expressing' in public urban spaces. New experiences such as this are an encouraging approach and prompt users into thinking more of their relationship with energy as a tangible and finite resource [221].

6.9.1 Limitations and future work

This work carried out best efforts to support the validity the study findings, however the Power Ballads study comes with some limitations that provide opportunities for future research.

Firstly, the present study is embryonic work in understanding the application of aversive feedback to raise awareness of energy consumption in the domestic environment. As such, a limitation is the number of participants recruited, as well as possible selection bias in participants volunteering. With any sustainability study, there is always the possibility it will attract participants who are already pro-environmentally minded – essentially preaching to the converted. For future work, where a larger group is recruited for another potential iteration of the study, it would be useful to deploy a pre-study questionnaire to screen for pro-environmental behaviours to help reduce selection bias. One such questionnaire is the E-RCQ (Environmental Readiness to Change Questionnaire) [266] as adapted from work by Forsberg et al, [111] in developing readiness to change questionnaires.

A second limitation is perhaps the choice of engagement metrics for the study, covering both quantitative and qualitative. In terms of quantitative, the main metric was collecting data on application use – essentially did the participants regularly choose to run the app from within the Facebook platform? The answer to this is yes, participants did engage in this respect. However, this requires effort over time, specifically a participant would need to remember to run the app, it is not realistic to assume this is sustainable over a longer period beyond the study duration. A more robust approach could include a phase where participants' energy consumption is automatically calculated over a period, and as a result either positive or aversive feedback is automatically and publicly posted to Facebook, with no manual input required by the participant.

This leads to a future research question that explores whether or not participants would carry on engaging with the study with their locus of control removed, or remove/block the Power Ballads application. The Facebook application platform offers application metrics that can collect data on application blocks/removals, providing further data for discourse.

In terms of measuring engagement using qualitative techniques, the study performed a small-scale analysis of Facebook posts (in direct response to aversive feedback) and a short post-study questionnaire. However, these methods took place after the study had finished. As previously suggested in the limitations section for Case Study 2, a more salient method could take place *during* the study to capture near-time information on participants' thoughts directly after experiencing an aversive feedback post. The Facebook application platform could facilitate direct communication or messaging to convey information back to researchers, providing a richer account of the participant's experience. The conclusion chapter of this thesis provides further discussion on the type and content of the aversive feedback message, in terms of adding an additional experimental condition.

In summary, Power Ballads was a novel and somewhat bold study on designing and deploying aversive feedback in a household energy intervention. At the time of the field trial it pushed the boundaries of currently available monitoring technologies, and at the same time challenged what was deemed to be 'acceptable' use of feedback in the HCI literature, for use in an intervention. The results indicate that users did not disengage when presented with aversive feedback, with reductions in energy also evidenced following delivery of the feedback. However, despite the promising outcomes, and the limitations of the study in terms of participant’s numbers and study duration, it offers a contribution of useful early work that can be built upon in future research.

7 GENERAL DISCUSSION & CONCLUSION

This chapter provides a summary of the case studies presented in this thesis to reflect upon their empirical findings. The presented work forms a significant contribution to HCI sustainability research, contextualised to understanding the design of workplace and domestic energy interventions. It further discusses implications for applying behaviour change theory, and alternative forms of feedback, to support energy interventions from an HCI sustainability research perspective. A discussion is also presented on the deployed qualitative research methods, their limitations, and how they can be effectively used as part of an exploratory toolkit for the HCI researcher to understand the complex nature of EUED for designing energy interventions.

In summary, this thesis contributes findings to support the design of feedback systems in organisational and home settings. HCI researchers are provided with a substantive contribution in the form of a set of design guidelines on which to build workplace energy interventions. The guidelines also support workplace managers in the delivery of such interventions by recommending supporting attributes such as leadership, trust, and engagement. A contribution is also made in research findings from deploying a 4-month duration, group-based feedback and foal setting workplace intervention.

For the home environment, HCI researchers are provided with a research contribution on how aversive feedback can be useful in engaging users as part of domestic energy interventions, contrary to previous HCI research that states negative feedback may induce users to disengage. Finally, the chapter is concluded with a future work discussion.

7.1 Discussion

The idea of improving energy ‘technological’ efficiency is a promising way forward in countering the increase in global energy consumption [54], however the reality of an ever growing consumerist and technology-focused landscape makes this extremely challenging. Commonly, energy savings made at home and the workplace are often offset by there being ‘more’ devices consuming energy, known as the rebound effect [127][224].

There is another way to improve energy efficiency, which is through improving end-user practices in the context of EUED. The behaviour of individuals in workplace and home environments, in terms of how they perceive and use energy, can have a significant impact on the quantity of energy used. End-users who don’t have a clear understanding of the optimal way to interact and use energy-intensive appliances can lead to an increase in unnecessary energy consumption. Smart metering infrastructures and other feedback systems can now provide information back to end-users with a view to giving static or even tailored information to improve their energy efficiency. However, an individual’s motivations to demonstrate pro-environmental behaviours may not be the same for the home (cost-benefit considerations) and workplace (options for more efficient behaviour possibly overridden by required work tasks and central procurement policies) environments.

As the HCI literature indicates, feedback systems are not a ‘one size fits all’ [140] strategy, with work in the social sciences indicating the negative consequences of such an approach [241]. Following this, the approach this thesis suggests and carries out is that interventions for the workplace and home will differ in design, possibly significantly. As such the methods adopted in this thesis are largely qualitative in nature for data collection and analysis, and focus on understanding end-users for specific energy contexts. Behaviour change methods are also used, as well as quantitative descriptive and inferential statistics to support evaluation aspects of the case studies presented. It is prudent to state that qualitative methods form the bedrock of the research undertaken in this thesis.

The research contexts of interest were twofold: energy use in the workplace, and energy use at home. Qualitative methods were used to understand users in both environments, with the majority of focus on the organisational workplace space, covering the substantial body of work carried and presented in chapters 4 and 5. GT was the main research method deployed. The research methods used in this thesis will now be discussed to conclude their effectiveness, and limitations.

For Case Study 1 (CS1) presented in chapter 4 (Understanding the Design of Organisational Energy Intervention), a GT data analysis method was used due to its emphasis on data induction and emergence, where themes emerge from the data collected from observing/interacting with the phenomena of interest [258]. Work by Patton [218] describes attributes of inductive data analysis as 'themes and categories emerge from the data, and are not imposed on the data', in this respect there is no predefined schema or taxonomy used prior to the data collection and analysis. Generally, the goal of carrying out GT is to produce a theory, or narrative, that can produce information to increase understanding of complex phenomena. In this instance the GT method is used to understand EUED practices in the workplace, where there is much multifaceted interplay between stakeholders.

An example of utilising GT for understanding complex phenomena is discussed by Brown et al. [46], where they discuss its use to increase educators' understanding of complex interactions between students and college environments. Themes emerge from the data during the data coding of GT analysis, with similar categories collapsed to produce an overarching theme, of which there may be multiple instances. Essentially, the identified themes capture the essence of related chunks of data. Collectively, the themes may yield explicit theory construction, or provide a rich narrative, or story, that attempts to describe the relationships between the identified themes [55]. The story *describes* the theory at a conceptual level, describing and relating the themes, and thus providing insightful information to support further understanding of the phenomena of interest.

The data analysis work in CS1 uses GT as a method to support the generation of a set of design guidelines for workplace energy interventions, derived directly from interpreting the emergent conceptual themes. In support of qualitative analysis to provide design guidelines for technology, work by Hekler et al. [142] refers to the term 'design guidelines' as "*principles formulated by HCI researchers to make behavioural theory and empirical findings actionable for designing behavior change technologies*". In this context the design guidelines were derived by qualitative analysis.

To clarify further - it is not always necessary to move beyond identifying key themes and the generation of a 'descriptive' or explanatory narrative as the 'final theory', to then progress onto developing an underlying predictive or explicit theory. HCI work by Blythe and Cairns in analysing qualitative Youtube 'comments' data [37],[38], illustrated their resultant GT analysis 'theory' was comprised of a broader description of emergent themes from their data, derived from user quotes. This was sufficient to glean a significant understanding of the investigated phenomena.

In-depth work on understanding the construction of GT by Charmaz [55] discusses the issues around explicit theory construction that may contain objective elements, and suggests that throughout the literature there is a diverse range of opinion on what a 'finished' grounded theory actually is. Views on such final theories have been presented as explanations, a description/narrative (as presented in the work by Blythe & Cairns [37],[38]), a final category/theme, or an empirical generalisation. As such, it is likely there is much conflation amongst researchers, particularly between disciplines, on the format of a final theory.

Perhaps a limitation of CS1 was that no explicit theory was constructed from the data, rather the narrative of overall responsibility in the organisational 'corporate' sense was seen to be overlaid and linked across the main themes generated from the data. In short, the selective coding phase of the GT yielded a descriptive narrative of the phenomena of interest (EUED in the workplace), rather than a generalisable theory that could be applied to a wider range of EUED contexts, outside of the workplace environment. That's not to say that generating an explicit and generalisable theory for designing workplace energy interventions is not possible, but it was not achievable in this work, and would require a much larger sample size of participants for analysis. In any case, construction of explicit theory was not the goal of CS1, instead the emergent themes from the axial coding stage would generate robust requirements for designing a workplace energy intervention, with the selective theory narrative providing an overarching description that links the themes.

The most interesting reflection on the group contingency behaviour change method deployed in Case Study 2 (Group Goal-setting and Group Feedback in an Organisational Energy Setting), was the use of the dependent group contingency in delivering goal-setting. The study took the approach of using the most basic, suitable, group goal-setting technique available from the academic literature [68]. The use of the dependent group contingency technique meant that reducing energy consumption, or achieving the set goal, was dependent on an individual or a small group with the whole participant group. Essentially this meant that it was possible only one participant (unlikely) or a small number of people (more likely) would need to save energy to meet the goal. This type of approach is often associated with the term ‘Hero Procedure’ - in this case those who are more inclined towards pro-environmental or ‘green’ behaviours are seen in a positive light as the ‘heroes’, who can carry the group towards achieving the goal, so that everyone shares the reward.

The dependent group contingency has seen success when used in education [6],[170], however there is no known use of the contingency in the context of an in-the-field sustainability study. There are two other group contingency methods that are worth briefly reflecting upon as possible methods to use in future deployments – the independent group contingency, and the interdependent group contingency [68].

The independent type means that the same rules of reducing energy and achieving the goal still apply to everyone – in this case participants must still reduce energy consumption, but only those who meet the goal of saving energy receive the reward. An example of the independent type is the Token Economy concept [167]. This form of behaviour modification is designed to increase desirable behaviours with the use of tokens. Individuals will receive tokens after displaying desirable behaviours, in the context of the study in this chapter it means tokens would be received by individuals if they reduced their energy consumption. The tokens can then be exchanged for something meaningful to the participants, for example an object or privilege.

The idea of a Token Economy for sustainability purposes fits well with the ‘Incentives’ theme that emerged from the GT analysis, in that workshop participants were keen energy savings translated into the likes of more staff, employed, bursaries, and social events like free Christmas parties. As such, designing a workplace study that uses the Token Economy as part of an independent group contingency would be a worthwhile avenue of research to follow up for future work. It was not possible to implement an independent-group contingency in CS2 due to constraints in using incentives – effectively the incentives theme from the design guidelines could not be used. This is a clear approach for future work.

The third group contingency to consider is the interdependent group contingency. This technique stipulates that all members of a group must meet the criteria (individually) of saving energy, and achieving the goal. It could be considered the most ‘fair’ of all the aforementioned group contingencies, however it may also be the most challenging in terms of sustaining engagement. It’s not difficult to envisage just a few participants disengaging and therefore having a negative impact on the group as a whole. However, this technique could prove effective to induce appropriate peer pressure to encourage positive pro-environmental behaviours. Like the independent group approach, the interdependent technique has seen success when applied to education [225],[238]. From the academic literature, the indicators are both the independent and interdependent contingency techniques would be suitable for future experimental iterations of CS2.

In Case Study 3 (Designing Aversive Feedback in a Domestic Energy Intervention), the main method the study focused on was aversive stimuli for behaviour change, more commonly recognised in the literature as negative reinforcement. Perhaps a limiting factor in the use of aversive feedback in CS3 was that it was not strictly a ‘negative’ punishment, by the somewhat ‘playful’ measure of the aversive feedback posts. This is in comparison to a more serious punishment (or negative reinforcement) when undesirable behaviour (more energy consumed) is observed. For example, a serious message that conveys your EUED practices are damaging the planet’s eco-system and endangering the lives of future generations. However, such a serious message may potentially lead to user disengagement as identified in HCI work exploring the use of behaviour change theory [140].

A future iteration of the Power Ballads study could include an experimental condition that conveys a more serious message for negative reinforcement, with engagement levels measured for analysis and comparison with playful aversive feedback. Other related work that has used negative reinforcement as a form of punishment has been carried out in relation to EUED, one example is the ‘stroppy kettle’ study that aimed to break the bad habit of overfilling a kettle unnecessarily [71]. The punishment component involved the user having to wait longer for the kettle to boil if overfilled. Negative feedback has also been used in an energy study using embodied agents to deliver feedback on appliance energy use [192], findings indicated there was a significant effort to conserve energy following the negative feedback. The methods available to deploy aversive or negative feedback are well documented in the literature by the behavioural sciences as part of operant conditioning, and demonstrated to show promise to engage users in the related HCI sustainability work discussed in this section, and the work by this thesis in chapter 6.

The research presented in this thesis through case studies makes extensive use of qualitative data collection methods including participatory design, focus groups, interviews, and questionnaires. Additionally, the bulk of data collected from CS1, was analysed using the Grounded Theory method. As such the work of this thesis makes a methodological contribution that demonstrates the methods used were effective in understanding the research space, and led to experimental field studies with further empirical data collected and evaluated.

7.2 Implications for Design

The 1st research question of thesis was investigated in case study one, and was focused on the following question:

"How can we design effective technology-enabled, energy-feedback interventions in the workplace to reduce EUED through behaviour change?"

The qualitative analysis presented in case study 1 addressed this question by providing a rich account of employee and management perspectives of current energy usage practices, and how to design effective interventions. Although the insights described are largely concerned with organisational cultures, understanding these contexts will be crucial in the development of a successful energy intervention in such a challenging environment. The Scandinavian traditions of participatory design originated in a Union led insistence that workers should be involved in the design of the tools they used, and in this work participatory design was a key catalyst in engaging employees around the concept of workplace interventions, and the finer nuances of changing behaviour through approaches appropriate for the workplace.

There is little doubt that the workplace is a special environment in terms of designing interventions when compared to the home setting. Present are corporate policies and legal obligations, and hierarchal social structures (management) that are not present in the household space. The problem therefore is neither solely a human nor engineering issue, but rather socio-technical in nature. The concept of social-technical was coined in early systems thinking work by Trist [267] where he defined within it three distinct layers: i) primary work system, ii) the whole organisation, and iii) macrosocial phenomena. All three levels impact on the viability of workplace energy interventions. For context - the *primary work system* can be identified as an organisations department or unit created for a specific function, the *whole organisation* can be seen at the corporate or organisational identity, and it is the *macrosocial phenomena* that encompasses communication and engagement across hierarchal structures. Although there is interplay between all levels, it is particularly vital to understand the macrosocial phenomena for intervention design, if not by ethnography or contextual inquiry then by other modes of qualitative study, for example using HCI methods, it is the latter approach undertaken in case study 1.

The concept of socio-technical has evolved into the more contemporary term of Socio-Technical Systems Thinking (STST) [117], and advocates consideration of both technical and social factors when seeking to promote change within an organisation, whether it is in the design of new software or a business change programme such as an energy intervention. Organisations can be considered complex systems, made up of many inter-dependent factors (e.g., people, processes and procedures, goals, culture, technology, and buildings). Designing a change to one part, without considering how this might affect, or require change in the other aspects of the system, can limit effectiveness and engagement [143], echoing the design implications emergent from case study 1. In essence, there is no such thing in an organisation as “it’s just an energy intervention”. Such interventions will often be dependent upon other factors such as changes to work practices, management buy-in, regulatory framework [293], or acceptance by users. Again, these themes were emergent from the workshop data.

Reductions in workplace EUED will be reliant upon individuals acting upon the information provided by management and the intervention itself, and in some cases making changes to work and building technologies, working practices and employee behaviour. Software-based interventions on their own are unlikely to produce the desired

EUED reductions without due consideration of related behavioural and organisational factors – which was addressed in this work. In particular, an understanding of how to engage employees and management in any necessary behaviour change; how to integrate the intervention with existing business processes and demands; and how to equip users to make best use of the presented information. Failure to appreciate how employees will respond to interventions can lead to unintended consequences and possibly inefficient practices. For example, in technologically advanced buildings: "Some of the oft-cited ecological benefits of green buildings are dependent on the ability to correctly predict user behaviour". Exactly this type of automated-efficiencies approach was seen as negative to many of the participants in the workshops:

W1P9: *"If you take all control off me (automated system), I'm going to feel completely disempowered"* and **W3P21**: *"If working conditions are uncomfortable, [I] will 'switch off' from energy saving, not going engage at all in energy interventions if you can't heat my office"* and **W2P7**: *"[management] have got to convince me that its reliable (automated powering off computer)"*

Not only does it remove locus of control from employees, it also creates comfort issues with a propensity to subvert systems [171][175], thereby creating unintended consequences. Many such technological innovations turn out to be much less effective in practice, than when they were conceived [279].

Given the complex structures at play within an organisation, it may be argued that the organisational intervention space is significantly more challenging than the domestic arena, where ultimate responsibility for energy management lies with the householder, as an employee responsibility may not be clear at all unless it is communicated adequately.

Understanding work environments will be no less important in the context of designing interventions which encourage employees to use less rather than more technology. However, with known organisational resource issues such as the rebound effect reported in the energy policy and ecological research literature, it is not always clear that if savings are made, they remain so [127][224]. This is also an issue of transparency, and one of the key themes emergent from the analysis – *openness*.

The findings of CS1 study 1 argue that the design of interventions intended to reduce energy consumption must address issues of corporate responsibility. Throughout the workshops the participants returned to issues of personal, departmental and institutional responsibility: who was to be responsible for setting targets? Were they achievable? What would happen if they were not achieved? Who was to be held accountable? Where, in other words did the buck stop? Here or near? The design of energy reduction interventions must be carried out with particular sensitivity to institutional cultures of accountability and blame management - very much a socio-technical research challenge.

In summary the 1st research question was addressed robustly, with a contribution to the HCI sustainability community, in the form of a set of design guidelines and implications for workplace energy interventions.

7.3 Practical Implications

This section discusses the implications of deploying a workplace energy intervention informed by the findings of case study 1, with a sub-section on the design considerations of aversive feedback for domestic settings. From the findings it is clear that researchers must also take into account the participant experience in order to uncover more complex issues that can hinder intervention success. Crucially, for any energy intervention to achieve a degree of success there has to be adequate levels of participant engagement. In the study, relatively high levels of engagement were evidenced, with the intervention widget being displayed for a significant part of the working day. There was no significant diminishment of engagement with feedback over time with an average of 7.7 hours and 6 hours of daily widget viewing time in the feedback and goal-setting conditions respectively. Goal-setting activity was also carried out by at least 50% of participants. In no way do the results suggest any disengagement took place that may contribute to higher consumption levels.

Other similar research to case study 2 was carried out by Murtagh et al.[196], with a four-month study that used an *individual* self-comparative feedback approach, with ambient feedback and temporal (to within an hour) graphs. The researchers found inconsistencies with energy reductions with levels decreasing only in the 3rd a 4th months, despite no change in the intervention condition in months 1-4.

Perhaps the most striking similarity with this work and that of Murtagh et al. [ibid] is the recurring element of employees offering explanations on why energy savings can't be made, a phenomenon the researchers. termed 'a syndrome of reasons'. This finding is not too dissimilar from some of the data evidenced in the workshops of case study 1, in that employees were reluctant to engage with an intervention if there was little management buy-in, employees were worried they would be blamed if energy reductions weren't made. For the most part, the reasons offered were shifted away from the employee and focussed instead on the organisational context. In other words, responsibility to make savings appeared to be shifted from the individual and onto the organisational entity. This finding further compounds the difficulties in designing appropriate interventions in this particular design space, and highlights the complex relationship between feedback and behaviour in organisations.

Indeed, in addition to the aforementioned issues, a number of external confounding factors may influence a workplace energy intervention such as staffing levels and seasonal weather effects. As such it is difficult to draw all-encompassing conclusions on best practice application of behaviour change methods for feedback and goal-setting in a work place intervention. Even more so when very little rigorous work has been carried out to date. Rather, work should draw upon valuable qualitative accounts and empirical behaviour modification research and adopt an iterative approach in the stepwise implementation of selected behaviour change methods. In this case future research building on this work should logically explore the next suitable group-contingency method – either the independent or the interdependent group contingency [68] – with a decision made based on the resources available to the researchers. A description of this method and how it could be applied was discussed earlier in this chapter in section 7.1.

Another possible cause for increasing the energy consumption during the intervention phases, and one that is well understood in the literature, is the boomerang effect [241]. For example, and at a basic level, if a participant is saving energy during an intervention, and then observes through feedback that their peers are using more energy, they may adjust their behaviour and increase consumption in line with the perceived 'norm' of said peers. This effect has been observed in multiple domestic energy studies [ibid][5][8]. However, evidencing the boomerang effect normally implies an individual has access to others' individual feedback to make a personal comparison. In the case of this study, the individual feedback of others was not available, only group aggregate feedback.

There is also the potential issue of the 'rebound effect' [127] to increase consumption, where savings made with the introduction of new technologies, i.e. the software intervention in the context of this study, can quickly be offset by an adverse behavioural response by end-users, such as consuming more energy or circumventing automated air conditioning/heating controls [224]. In the interview data it was found that participants were using personal equipment for environmental comfort, thereby overriding the automated lighting and heating controls. There is also the possibility that after viewing the group feedback consumption, participants deemed the quantity and associated cost lower than expected, and as a result consumed more.

Findings from the qualitative interview data offer more granular design implications that could support the main design themes from CS1. However, given the evidence of this study and other relevant published work [196], the unpredictable nature of such interventions remains a challenging obstacle. Careful consideration of experimental design, coupled with robust design considerations paves the way forward for future research.

It is not unusual for employees in different departments of the same organisation to have a dissimilar structure, in some cases they may even have a flat hierarchy, and will likely be focused on very different aspects of the organisations daily business. In terms of the group of participants who took part in this study, they were a mix of individuals with a diverse range of skillsets, this mix included engineers and desk-based office support staff. It was reported by the participants (post-study) that their colleagues (also participants in the study) used personal heaters on occasion, which would have increased the consumption levels, particularly as the goal-setting intervention phase took place in November where temperatures would have been lower.

In the energy stats there were unexplained 'spikes' in specific periods that could explain portable heater use. However, this is a just a possibility, and not by any means conclusive. Another study attribute that could be considered a limitation is the omission of monitoring the energy of 'social appliances' such as printers, coffee makers, and kettles. As the department of interest was in a large building with partitioned floor space occupied by other departments, facilities such as kitchens and printers were shared resources. As such, the aforementioned appliances were used by many different departments, making it difficult to track and apportion energy consumption of these appliances to any specific department. In the case of printers, these were in open spaces (outside any specific departments area), with kitchens also placed outside of any department's remit or area.

As there is little homogeneity between departments housed in the same building as the department that participated in this study, the concept of an intervention that compares departments could be challenging. This type of comparative feedback method is the approach of the workplace energy work by Siero et al. [248], and it was deemed to be effective. However, the participating departments in the Siero et al. study were of a similar structure, making it more palatable to directly compare consumption. Introducing competitive aspects would be difficult in another iteration of this study, from the point of view of ensuring there is an equitable metric of measurement to compare different departments' energy consumption.

It might be possible to consider not comparing direct EUED at the department level, but rather comparing if each department had met its own distinct savings target. The interdependent group-contingency method would be suitable in this respect [68][225]. Insofar as using the design guidelines from CS1 to design an intervention at the building level (as a group unit), they should be effective in supporting this. However, careful consideration on a suitable metric for a comparative feedback approach, and the type of group contingency (dependent, independent, or interdependent) would need to be given.

In summary, while the intervention deployed in CS2 did not have the intended effect of lowering participant energy consumption, the advantage of basing the design and evaluation on established methodologies is clear; it was demonstrated that the simple intervention trialled here was not appropriate in this particular context. Further, based on our understanding of the behavioural science literature and findings in this study, a clear plan for moving forward is known, based on the implementation of more nuanced group feedback methodologies that has been demonstrated as effective in other, similar, contexts.

7.3.1 Practicalities of deploying aversive feedback

The section discusses the design, and subsequent impact, of deploying aversive feedback in a domestic energy intervention as presented in CS3. The wider goal of this study was to evaluate whether punishment of non-desirable behaviour can function as a useful part of larger future studies – this is the main contribution of the work.

From the empirical findings, it is apparent that this type of feedback does not necessarily lead to disengagement by users if presented carefully. In no way does the author suggest that presenting only aversive feedback is an ideal method of designing a persuasive application for changing behaviour; indeed, the qualitative questionnaire data revealed that some participants would have liked supplementary reward (positive feedback) posts when saving energy. This is correct in that a fully designed, large scale intervention would likely be more effective by following the full model of operant conditioning when presenting feedback [166]. However, this work demonstrated that aversive feedback does not necessarily bring about disengagement. Rather, as the psychology literature suggests, aversive stimuli can function as a valuable component in behaviour change interventions. Findings demonstrated that it does not necessarily lead to participant disengagement, and the author therefore concludes that it is important that this type of feedback should not be simply ignored when designing persuasive applications, as has been suggested by other researchers in the HCI literature.

A common critique of technology-enabled sustainability interventions is that they use non-sustainable resources themselves. The realisation that more technology is being used in an attempt to reduce the consumption of other technologies alludes to the rebound effect in action [127][224]. Furthermore, many persuasive technology studies that are designed to motivate reduction in energy use have been shown to be successful in the interim. Despite this, more often than not they tend to require feedback to be delivered permanently, albeit at a lower frequency over a prolonged duration [173]. It could be argued that technology-enabled interventions which combine aversive and appetitive feedback could engage users over the longer term, and could help eliminate the need for consistent and permanent feedback to be delivered if the target behaviour has been adopted.

An interesting quote from a study participant on baking bread is below:

"Oh good god! I guess that's what i get for having the oven on :(....but i also get home-made bread...not sure it's worth my reputation though!!"

This resonates with the findings in work by Burrows et al. [48], who described energy use as being entwined in daily and social practices, and in some cases the very act of consuming energy for pleasure, for example baking a cake, would not provide the same enjoyment if carried out in a more economical fashion [56]. Clearly participant D was enjoying baking home-made bread and the reaction of guilt for having the oven on as a result of the aversive feedback was perhaps unfair at best, and damaging at worst.

Research by Light [181] underpinned the value of using a form of critical design influenced by queer theory, which combats her suggestion that the majority of HCI work is designed to 'up' human productivity and create more efficient machines. As evidenced in the findings of this case study and other relevant work, perhaps the most efficient way of doing things, particularly in some cases of energy consumption, isn't the most satisfying approach in that it does not reflect the user values. Researchers and designers of interventions should be mindful of this. Light suggests that the HCI community needs to take responsibility for undertaking research that is both radical and challenges user conceptions of the way they expect technologies to work. Light argues this approach would allow a fuller understanding of the cultural impact of technologies. Indeed, the author believes the use of aversive stimuli in certain design scenarios, particularly involving behaviour change, could directly support this form of critical design, with the feedback delivered in Power Ballads a good example of this.

A limitation of this study was its relatively small scale, however, this is in line with most HCI household energy field studies [121], particularly those which are developing embryonic work. The findings contribute to a growing body of eco-feedback work in HCI, with emphasis on understanding the practical application of aversive feedback in sustainability interventions when applied through online social media.

7.4 Future research

Beyond generating new research hypothesis from the limitations identified in each of the case studies, there is considerable scope to combine behaviour change theory with technology-enabled interventions that are tailored based on information derived from the rigour of a GT analysis. The organisational space is inherently complex for any intervention, whether that be reducing paper waste [276], with the work in the study carried using GT as their main method, or for understanding thermal comfort and satisfaction in low-energy buildings [137]. In reducing workplace energy consumption, work by Murtagh et al. [196] made the striking comment ‘a syndrome of reasons’ in the context of the recurring theme of employees offering explanations on why they couldn’t change behaviour to make energy savings. Employee’s as participants present a challenge to researchers, the underlying organisational structures and hierarchies must be fully understood, and at the same time sensitive concerns such as data privacy and job role activities must be managed carefully.

The design guidelines produced in this thesis for workplace energy interventions provide a solid and well informed foundation on which to build upon. A key theme that could not be implemented in the intervention study presented in chapter 5 was the *incentives* theme. Future work that includes this in an experimental study iteration would provide valuable data in its effectiveness to engage employees with the intervention, and might also raise trust and transparency in the target organisation, as it would genuinely show that management has ‘bought into’ the intervention’s vision.

For the domestic space, the work in this thesis has demonstrated that aversive feedback shows promise in engaging users with their consumption practices. Future work in this space would be the improvement of the experimental design presented in chapter 5. Enhancements could include the addition of a ‘serious’ negative reinforcement message to supplement the playful aversive feedback. Findings in this respect would provide valuable information on the type (context) and content (message) of negative feedback that participants would accept, and more importantly what is likely to bring about disengagement.

Lastly, it would be worth improving on the longitudinal aspects of all the case studies presented in this work, since the effects of an intervention diminish over time, future research should test different strategies for maintaining the effects over time to prevent disengagement. Longitudinal studies would also collect more data, for instance being able to compare data from one month to the same month in the subsequent year would enable researchers to adjust for external factors such as seasonal discrepancies.

7.5 Conclusion

To conclude the research presented in this thesis, the results have developed an approach to design workplace energy intervention by means of a set of robust design guidelines. The guidelines demonstrate best practice design considerations when designing, deploying and maintaining effective workplace energy interventions. They can support management and employees in developing energy intervention programmes in organisations at scale. Additionally, they also provide HCI sustainability researchers with design considerations and implications to build future organisational-focused EUED reduction interventions.

Results from the work also provide a contribution from findings from the deployment of an organisational intervention using the developed design guidelines. Future work in this space should carefully consider the application of behaviour change methods when applied to groups in an organisational setting, with a thorough understanding of the socio-technical aspects of the target environment. Incorrect application of group behavioural contingencies can lead to unintended consequences, which may lead to increased consumption or inconsistencies in energy reductions during intervention phases. This was evidenced in this work, as well as being observed in other similar energy research.

Other results in this thesis contribute findings that aversive feedback should not be avoided as part of an intervention to change behaviour. Previous HCI work in designing persuasive applications has suggested that aversive stimuli should be avoided as it can lead to user disengagement. However, the findings presented in this thesis from a field study make a valuable research contribution in providing evidence that aversive feedback does not lead to disengagement – in the context of an energy study. This is in line with the established behavioural sciences approach of applying all components of operant conditioning for effective behaviour change. A combination of positive and aversive feedback holds the potential of playing a significant role in designing effective and engaging technology-enabled energy interventions. HCI researchers will find these findings useful in the design of future interventions across a range of persuasively themed applications.

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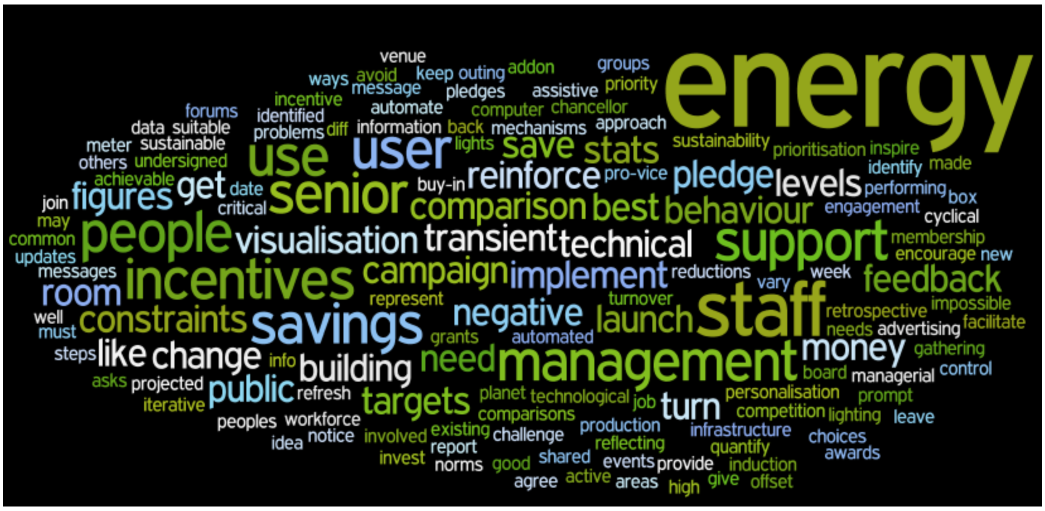
9 APPENDICES

APPENDIX 1 CASE STUDY (1) WORKSHOP WORD CLOUDS



Top to bottom, workshops 1-3 word clouds generated from participatory design task.

APPENDIX 2 CASE STUDY (2) PRE-SURVEY QUESTIONNAIRE & DATA

Pre-study Questionnaire

Energy Widget Pre-Study Questionnaire

Thank you for taking the time to complete this short questionnaire, it should only take around 5 minutes to complete. If you have any queries then please get in touch with Derek Foster defoster@lincoln.ac.uk. Completed questionnaires will be entered into a prize draw for a £25 iTunes voucher with a winner chosen at random by the end of September.

Energy as a resource is difficult for most people to quantify and visualise with its intangible attributes. This is further compounded in organisational settings where most employees are not responsible for energy costs. As such, it's impact in terms of both cost and to the environment may seem to be the responsibility of others.

This short questionnaire aims to elicit basic responses in how employees perceive energy-use in the workplace and how it it might be effectively communicated.

*Required

What unit of measurement do you prefer to see energy consumption displayed? *

- Energy (kWh)
- Cost (£)
- No preference

Please indicate how EFFECTIVE you think the following communication channels would be for communicating energy use during an energy saving campaign: *

5 being very effective with 1 being completely ineffective

	1 - Completely Ineffective	2	3	4	5 - Very Effective
Attached to your staff notice board					
Presented to you in a meeting					
Institutional web page					
Text message					
Email					
Twitter feed					
Facebook feed					

How effective do you think the following ways to express a saving in energy are? *

5 being very effective with 1 being completely ineffective

	1 Completely Ineffective	2	3	4	5 - Very Effective
Your office has saved N kWh of electricity					
Your office has saved enough energy to take N cars off the road					
Your office has saved N pounds (£)					
Your office has saved enough pounds to pay N salaries					
Your office has reduced consumption by N per employee					

How concerned are you about the effects of climate change? *

- Very concerned
- Quite concerned
- Neutral
- Unconcerned
- It's a hoax

Please rank the following approaches for bringing about organisational change where you work *

5 being the most effective and 1 being the least effective

	1 - Least Effective	2	3	4	5 - Most Effective
Clear policies					
Effective communication					
Financial incentives					
Clear rewards and punishment					
Individuals taking the lead					
Charismatic leadership					

Please list your top tips for saving energy in the home.

This is not mandatory.

Please list your top tips for saving energy in the workplace.

This is not mandatory.

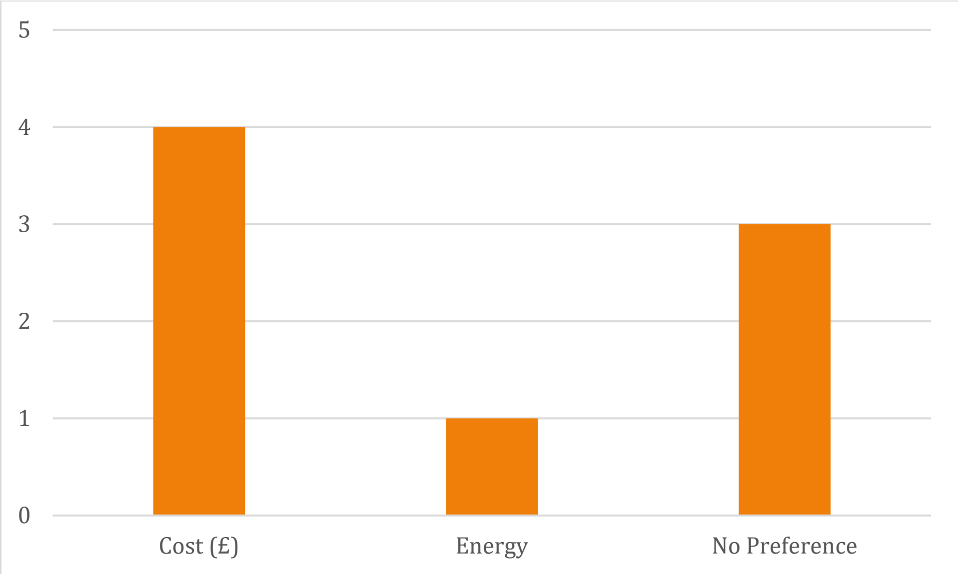
Please enter your email address if you wish to be entered into the prize draw for a £25 iTunes voucher.

Submit

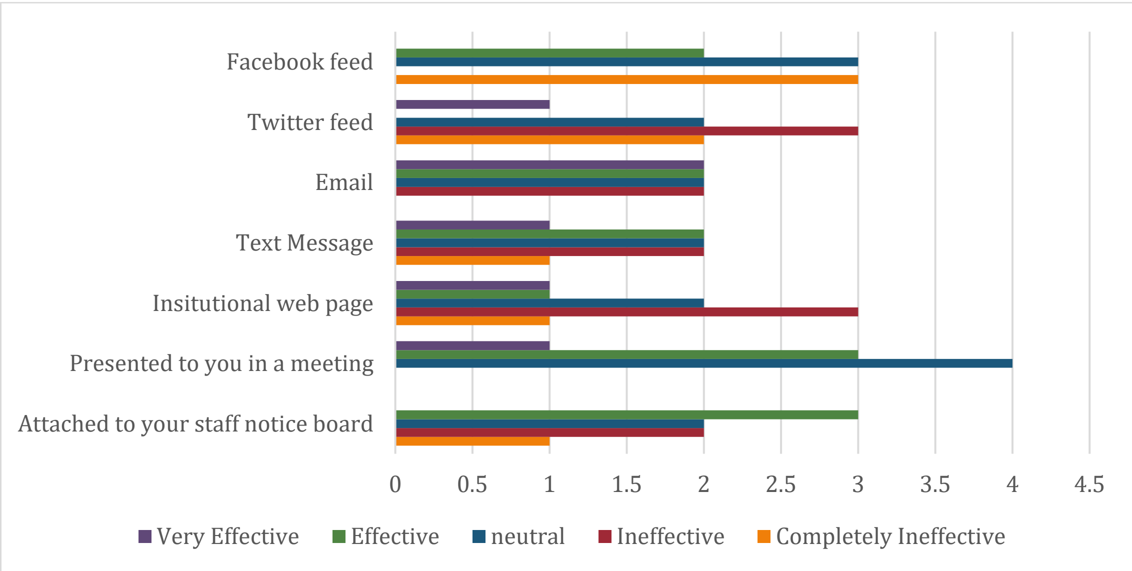
Never submit passwords through Google Forms.

Pre-study questionnaire responses

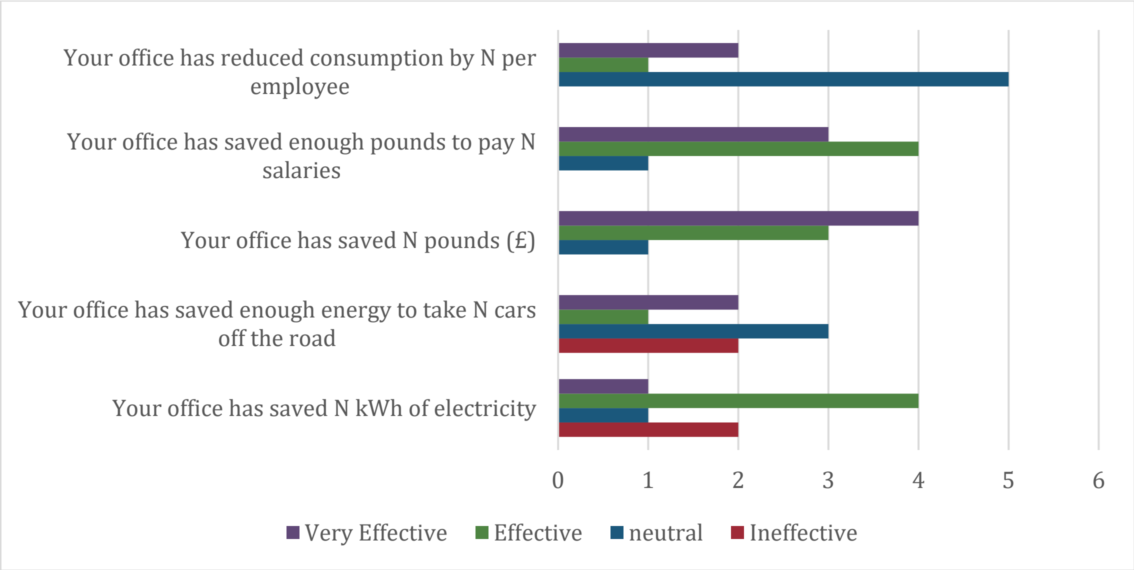
Q1 - What unit of measurement do you prefer to see energy consumption displayed?



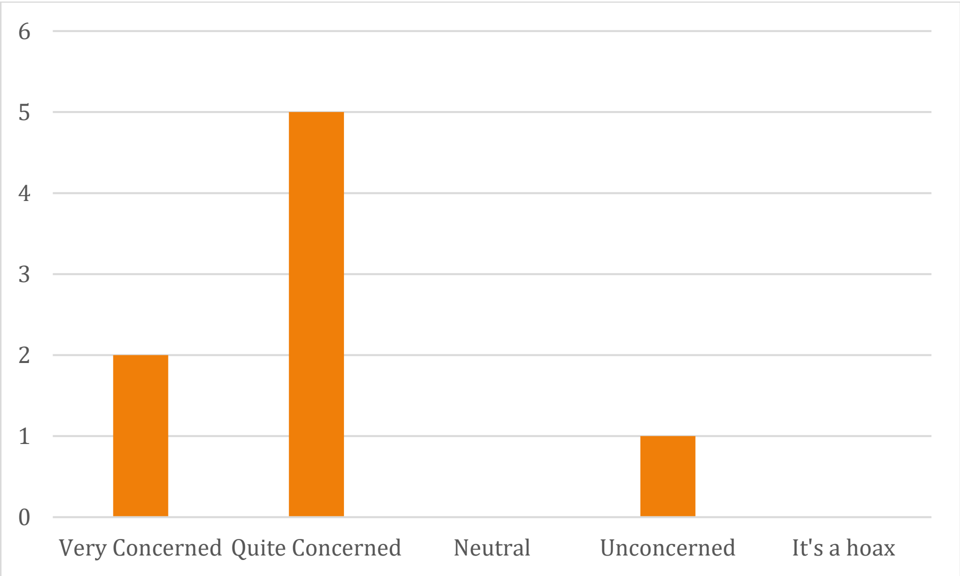
Q2 - Please indicate how EFFECTIVE you think the following communication channels would be for communicating energy use during an energy saving campaign:



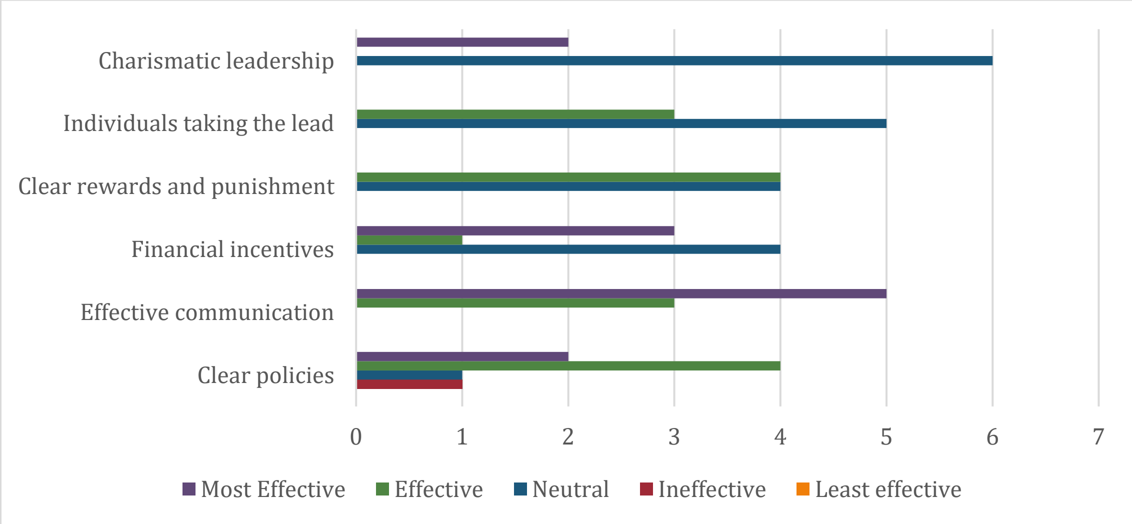
Q3 - How effective do you think the following ways to express a saving in energy are?



Q4 - How concerned are you about the effects of climate change?



Q5 - Please rank the following approaches for bringing about organisational change where you work:



Q6 - Please list your top tips for saving energy in the home:

Put TV, amp, consoles etc onto one plug and switch off at wall when not using.
Use energy saving light bulbs. Switch lights off when not required.
Turn everything off at the socket when not in use.
Install effective insulation and double glazing.
Defrost the freezer regularly and keep as full as possible.
Loft insulation.
Cavity wall installation.
Turning off lights.
Energy saving bulbs.
Do not light or heat any unused room.
When making a hot drink boil just enough water.
Shower instead of bath.
Make sure washing machine and dishwasher are full before using so no half loads.

Q7 - Please list your top tips for saving energy in the workplace:

Switch computer, monitor and lights every evening.
Ensure windows are closed at night.
Only switch on lights when necessary.
Don't waste paper.
Turning heating down.
Closing windows.
Do not light or heat any unused room.
Turn PC off when not in use.
Do not open windows when heating is on.
If too warm (with no heating) open windows instead of using air-con.
Turn any portable appliance off after use.
Switch off PC at night.
Turning off computers when leaving work instead of just logging off and switching the monitors off.
Only have lights on when needed.
Have energy saving devices, eg printers.

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APPENDIX 3 CASE STUDY (2) REST API DOCUMENTATION

UoL energy data is accessible via a RESTful API in open data formats JSON and XML. Specific buildings or entire campus energy values can be returned, for individual building data please see building list, datetime values are UTC format.

The baseURI is `/RestService/RestServiceImpl.svc/` which exposes 4 main functions detailed below.

Return energy for specific building using date range

```
baseURI +
energy?format={format}&building={building}&dateStart={dateStart}&dateEnd={dateEnd}
```

Parameters:

{format} = return energy data format, can be either **XML** or **JSON** (uppercase!)

{building} = building name (see list)

{dateStart} = UTC datetime to start energy data query: yyyy-mm-dd hh:mm:ss

{dateEnd} = UTC datetime to end energy data query: yyyy-mm-dd hh:mm:ss

Example usage:

```
http://baseURI/energy?format=XML&building=mainAdmin&dateStart=2012-01-
31%2000:00:00&dateEnd=2012-01-31%2023:00:00
```

Return energy for specific building using pre-defined time period

```
baseURI + energyPeriod?format={format}&building={building}&period={period}
```

Parameters:

{format} = return energy data format, can be either **XML** or **JSON** (uppercase!)

{building} = building name (see list)

{period} = time period to return energy data

24 = previous 24 hours

48 = previous 48 hours

168 = last 7 days

Example usage:

```
http://baseURI/energyPeriod?format=XML&building=mainAdmin&period=24
```

Return energy total (sum) for all UOL buildings on specified date range

```
baseURI + energy_all?format={format}&dateStart={dateStart}&dateEnd={dateEnd}
```

Parameters:

{format} = return energy data format, can be either **XML** or **JSON** (uppercase!)

{dateStart} = UTC datetime to start energy data query: yyyy-mm-dd hh:mm:ss

{dateEnd} = UTC datetime to end energy data query: yyyy-mm-dd hh:mm:ss

Example usage:

```
http://baseURI/energy_all?format=XML&dateStart=2012-01-31%2000:00:00&dateEnd=2012-
01-31%2023:00:00
```

Return total energy values comparing yesterday and today (datetime.now) for specific building

```
baseURI + energy_total?format={format}&building={building}
```

Parameters:

{format} = return energy data format, can be either **XML** or **JSON** (uppercase!)

{building} = building name (see list)

Example usage:

```
http://baseURI/energy_compare?format=XML&building=mainAdmin
```

The list of UoL buildings with available open energy data are below, the building parameter for inclusion when making a REST call are in bold:

Campus buildings:

Architecture Building : **archi**

Bridge House : **brideHouse**

Canoe Club : **canoeClub**

EMMTEC Building : **emmtec**

Engine Shed : **engineShed**

Harrison House : **harrison**

LPAC : **lpac**

Main Admin Building : **mainAdmin**

MHT Building : **mht**

Science Centre : **scienceCentre**

Spark House : **sparkHouse**

Sports Centre : **sportsCentre**

Main Library : **library**

Village Hall : **villageHall**

Witham House : **withamHouse**

Students Accommodation Courts:

Student Court 1 : **court1**

Student Court 2 : **court2**

Student Court 3 : **court3**

Student Court 4 : **court4**

Student Court 5 : **court5**

Student Court 6 : **court6**

Student Court 7 : **court7**

Student Court 8 : **court8**

Student Court 9 : **court9**

Student Court 10 : **court10**

Student Court 11 : **court11**

Student Court 12 : **court12**

Student Court 13 : **court13**

Student Court 14 : **court14**

Student Court 15 : **court15**

Student Court 16 : **court16**

Student Court 17 : **court17**

APPENDIX 4 CASE STUDY (3) CODE METHOD SNIPPETS

Code Snippet [1]: Get last 48-hour periods energy data from COSM for use in Power Ballads

```
private void ReadCsv()

{

DateTime last24 = DateTime.Now.AddDays(-1);

DateTime last48 = DateTime.Now.AddDays(-2);

string last24hours = last24.ToString("s");

string last48hours = last48.ToString("s");

//Create a WebRequest for last 24 hours

WebRequest fetchCsv = WebRequest.Create("http://api.pachube.com/v2/feeds/" +
feedidString + "/datastreams/1.csv?key=" + apiKeyString + "&start=" + last24hours +
"&interval=60&per_page=500");

//Create a Proxy

WebProxy px = new WebProxy("http://api.pachube.com/v2/feeds/" + feedidString +
"/datastreams/1.csv?key=" + apiKeyString + "&start=" + last24hours +
"&interval=60&per_page=500", true);

//Assign the proxy to the WebRequest

fetchCsv.Proxy = px;

//Set the timeout in Seconds for the WebRequest – important when pachube playing up!

fetchCsv.Timeout = 15000;

//Get the WebResponse

WebResponse rep = fetchCsv.GetResponse();

//Read the Response in a streamReader

System.IO.StreamReader strReader = new
System.IO.StreamReader(rep.GetResponseStream());

// Create the local file

string test = @"C:\inetpub\wwwroot\watttunes\App_Data\last24hours" + feedidString +
".csv";
```

```
FileInfo f1 = new FileInfo(test);

StreamWriter sw = f1.CreateText();

//write response data to csv file

sw.Write(strReader.ReadToEnd());

//close stream

sw.Close();

strReader.Close();

}
```

Code Snippet [2]: Mashup music data, get top 40 chart music data using Yahoo Pipes and YQL

Execute chart music YQL Query, node selection using xpath to get song description and image source:

```
SELECT alt,src FROM html WHERE url="http://www.bbc.co.uk/radio1/chart/singles/" AND xpath="//li/img" LIMIT 40
```

Embed REST Query to return XML:

```
http://query.yahooapis.com/v1/public/yql?q=SELECT%20alt%2Csrc%20FROM%20html%20WHERE%20url%3D%22http%3A%2F%2Fwww.bbc.co.uk%2Fradio1%2Fchart%2Fsingles%2F%22%20AND%20xpath%3D%22%2F%2Fli%2Fimg%22%20LIMIT%2040%0A&diagnostics=true
```

Returns XML for consuming (data shorted in this example):


```
<?xml version="1.0" encoding="UTF-8"?>

<query xmlns:yahoo="http://www.yahooapis.com/v1/base.rng"

    yahoo:count="40" yahoo:created="2011-03-08T08:48:50Z" yahoo:lang="en-US">

    <diagnostics>

        <publiclyCallable>true</publiclyCallable>
```

```
        <redirect from="http://www.bbc.co.uk/radio1/chart/singles/"
status="301"><![CDATA[http://www.bbc.co.uk/radio1/chart/singles]]></redirect>

        <url execution-time="49"
proxy="DEFAULT"><![CDATA[http://www.bbc.co.uk/radio1/chart/singles/]]></url>

        <user-time>60</user-time>

        <service-time>49</service-time>

        <build-version>11323</build-version>

    </diagnostics>

    <results>

        <img alt="Someone Like You - Adele"
src="http://www.bbc.co.uk/radio1/chart/artwork/gbbks1000351.jpg"/>

        <img alt="Price Tag (feat. B.o.B) - Jessie J"
src="http://open.live.bbc.co.uk/dynamic_images/radio1_70x70/http://www.bbc.co.uk/1
xtra/chart/artwork/jessiej_pricetag.jpg"/>

        <img alt="S&amp;M (Come On) - Rihanna"
src="http://open.live.bbc.co.uk/dynamic_images/radio1_70x70/http://www.bbc.co.uk/ra
dio1/chart/artwork/usum71026591.jpg"/>

</query>
```

Code Snippet [3]: Post aversive feedback to Facebook newsfeed using mashup data

Facebook newsfeed post when using more energy, gets data from Yahoo YQL generated XML:

```
XmlNode node =
xmlDocumentInstance.SelectSingleNode("response/songs/song/artist_name/text()");

XmlNode node2 =
xmlDocumentInstance.SelectSingleNode("response/songs/song/title/text()");

private void PublishFBStream()

        {

            last24avg = last24avg * 1000;

            attachment attachment = new attachment();
```

```
attachment.caption = "This song is comparable to my home's average energy today, " + Convert.ToInt32(last24avg) + "Watts!";

attachment.name = "I am listening to '" + songTitle + "' by " + artist;

attachment.href = "http://www.facebook.com/apps/application.php?id=148673945179479#!/apps/application.php?id=148673945179479&v=info";

attachment.description = "oh yeah!";

attachment.media = new List<attachment_media>(){new attachment_media_image()

                {

                    src = "http://thesocialapp.internal.lincoln.ac.uk/watttunes/images/streamlogosmall.png",

                    href = "http://www.facebook.com/apps/application.php?id=148673945179479#!/apps/application.php?id=148673945179479&v=info"

                }};

Api.Stream.Publish("", attachment, null, base.Api.Session.UserId.ToString(), Convert.ToInt32(base.Api.Session.UserId.ToString()));

DateTime yesterday1 = DateTime.Now.AddDays(-1);

}
```