University of Cambridge
Department of Architecture

(De)constructing and transforming workplace practices: Feedback as an intervention

Dimitra Dantsiou
Christ's College

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Preface

This dissertation is the result of my own work and includes nothing, which is the outcome of work done in collaboration except where specifically indicated in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as specified in the text.

This thesis does not exceed 80,000 words in length including footnotes, references and text within tables, but excluding captions, appendices and bibliography.

Dimitra Dantsiou MPhil DiplArchEng
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Cambridge

Abstract

Little empirical work has been conducted on workplace practices in university settings. Meanwhile, the impact of feedback on changing consumption patterns has been mainly studied through individualistic approaches. The academic workplace with its variety of users offers a setting that could provide a range of insights as to how practices form and change under the impact of efficiency interventions and, in turn, how relevant policies could be formed.

This research looks at workplace practices related to the regulation of indoor temperature and the use of office equipment. It examines the potential of reducing energy usage in the workplace through a case study on the understanding of and interventions in practices using consumption feedback. A framework based on social practice theory is applied where daily practices are configured by routines, technologies, knowledge and meanings.

The research takes place in a UK university building, where the provision of real-time consumption feedback through a display is employed to raise energy awareness. It follows a case study approach featuring three different office typologies and associated user groups: the shared, enclosed administrative office; the PhD open-plan office, and the post-doctoral cellular office. The study begins with an examination of the thermal characteristics and comfort preferences in the case study offices. It then examines how users shape their practices in the workplace. Finally, it observes the impact of feedback through real-time displays on the reduction of energy consumption.

A mixed methods approach is employed combining qualitative and quantitative data. Semi-structured interviews and on-site observations are cross-related to environmental conditions monitoring, electricity audits and thermal comfort diaries. Data collection takes place in two phases— (February 2014 and July 2014) —to capture differences in practices between the winter and summer as well as before and after the installation of real-time displays.

By exploring the empirical evidence through a practice theory framework, this research shows how social dynamics, the difference between the notion of comfort at home and work, and striving for productivity can prefigure ‘passive’ thermal comfort practices in the workplace. The real-time displays did not trigger change despite the fact electricity audits revealed a savings potential related to high standby use. The inadequacy of building maintenance structures, significant installation delays and the type of projected information were the main factors restricting change. The use of a practice approach advanced the understanding as to why it is so difficult to save energy at work and use feedback as a successful intervention. The combination of qualitative enquiry and energy audits meanwhile indicated the potential source of savings.

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Finally, I would like to thank my parents Demetrios and Dione for their unconditional love and encouragement and for teaching me to believe in myself and value perseverance and hard work. In a way, I owe this PhD to them.

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List of abbreviations

A/C	Air Conditioning
ABC	Attitude Behaviour Change
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BPE	Building Performance Evaluation
BPIE	Buildings Performance Institute Europe
BMS	Building Management System
CUED	Cambridge University Engineering Department
CSI	Centre for Sustainable Energy
DECC	Department of Energy and Climate Change
DTG	Digital Technology Group
ECI	Environmental Change Institute
ECRP	Energy and Carbon Reduction Project
EDDA	Engineering Department Database for Administration
FM	Facility Management
HEFCE	Higher Education Funding Council for England
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
MVHR	Mechanical Ventilation with Heat Recovery
NGO	Non Governmental Organisation
OSC	Office for Sustainable Campus
POE	Post Occupancy Evaluation
PMV	Predicted Mean Vote
PTEM	Physical-Technical-Economic Model
RH	Relative Humidity
RTD	Real Time Display
UROP	Undergraduate Research Opportunities Programme
WFT	Workplace Footprint Tracker

Participants’ pseudonyms

Participants’ pseudonyms are used throughout the thesis in order to maintain anonymity whilst preserving the human character in the text. This table serves as general reference for readers while more detailed characteristics of each participant can be found in Chapter 5.

Table 1 Participants’ pseudonyms.

Office	Participant	Gender	Occupation
A	1_Diana	F	Administrative staff
	2_Luke	M	
	3_Laura	F	
	4_Daniel	M	
	5_Oliver	M	
	6_Hannah	F	
B	1_Alexia	F	PhD Candidate
	2_Silvia	F	
	3_Ruchi	F	
	4_Peter	M	
	5_Wilhelm	M	
	6_Ben	M	
C	1_Matt	M	PhD Candidate
	2_Alan	M	
	3_Steven	M	
	4_George	M	
D	1_Robert	M	Post-doctoral research associate
	2_Sina	M	
	3_Henrik	M	
	4_John	M	
E	1_Zack	M	Post-doctoral research associate
	2_Jacob	M	

1. Introduction

1.1. Research background

In the United Kingdom, buildings account for 40.5% of the total energy use, of which the services sector holds about 13% (DECC 2015)—figures that suggest the need for urgent and immediate energy saving measures and initiatives. As a response to the energy challenge, the UK Government has set up a portfolio of strategic efficiency measures targeting new and existing buildings in order to achieve a greenhouse gas reduction target of at least 34% by 2020 and 80% by 2050, below the 1990 baseline (HM Government 2016). The scale of desired change dwarfs everything that has been hitherto achieved in this arena, with the actions expected to have the greatest impact featuring a move towards zero-carbon buildings, retrofitting of the existing building stock and promoting low carbon space and water heating alternatives (HM Government 2016, p.24). The focus of these measures is clearly technical in nature, but the significance of raising awareness of energy use and relevant emissions whilst promoting less energy-intensive lifestyles among consumers is also implied. The smart gas and electricity meters rollout, which gives people better information about and control over their energy consumption, reflects the Government's vision in this vein for households, businesses and the public sector (DECC and Ofgem 2011).

Since the oil crisis in the seventies there have been plenty of debates concerning behaviour, modern lifestyle and their environmental impact (Hayes and Cone 1977, Stern and Aronson 1984, Lutzenhiser 1992, Lopes *et al.* 2012). The change of direction noticed in the two latest Intergovernmental Panel for Climate Change (IPCC) reports confirms this notion and relevant progress. In the fourth IPCC report, technical measures are seen as the only way to abate buildings' CO_2 emissions—by approximately 29% of the projected baseline—while it is pointed out that *'the potential reduction through non-technological options is rarely assessed and the potential of policies over these is poorly understood'* (Levine *et al.* 2007, p.389). The latest report, however, suggests that behaviour, lifestyle and culture have a major effect on buildings' energy use in addition to the effect of technology and architecture (Lucon *et al.* 2014). In particular, it mentions that:

> *'Behaviour can cause 3-5 times differences in energy use for similar levels of energy services. In developed countries, evidence indicates that behaviours informed by awareness of energy and climate issues can reduce demand by 20% in the short term and 50% of present levels by 2050.'*
>
> (ibid, p.675)

The shift in focus towards a more diligent consideration of occupants' behaviour has recently gained ground in academic research (Berker and Bharathi 2012, Schweber and Leiringer 2012, Summerfield and Lowe 2012), although the need to follow a more user-centred direction has been articulated for two decades (Shove 1998, Baker 2004). The technology to reduce heat loss in buildings might be available and the theoretical understanding of its application advanced, but radical targets require debate and empirical evidence related to the user factor as well (Oreszczyn and Lowe 2009). Several studies conclude that, beyond technical considerations, user practices also effect the actual energy performance of a building, thereby amplifying the so-called 'performance gap' (Steemers and Yun 2009, Majcen *et al.* 2013, Gram-Hanssen 2014b). Evidence of a rebound effect, where people compensate for efficiency improvements by increasing energy consumption in services and differences in energy use between identical houses, is frequently cited (Herring and Sorrell 2009, Guerra Santin 2013). The converse 'prebound' effect has also been identified, where occupants consume less energy than expected by the estimated rating (Sunikka-Blank and Galvin 2012).

Similarly, in non-domestic settings—mainly in offices—there is considerable evidence of the effect of users' practices and behaviour in the 'actual' energy performance of the building (Bordass *et al.* 2001, Menezes *et al.* 2011, van Dronkelaar *et al.* 2016). Rebound effect in offices also has been identified but to a lesser extent, as discussed by Galvin (2015), who points out that the engagement of office users and the advantages of detailed energy monitoring are among the factors likely to reduce consumption. It becomes evident that in order to achieve a reduction of overall energy performance, whether in the workplace or at home, there is a need for a comprehensive approach wherein occupant behaviour and social matters are considered along with technical and contextual building factors (Tweed 2013, Sovacool 2014).

Behaviour is not simple to understand and literature on its factors of influence is vast (Jackson 2005, Darnton 2008, Lopes *et al.* 2012). There have been several disciplines—economics, sociology and psychology at the forefront—developing theories and frameworks to define how people behave and why they change their behaviour. These disciplines can be divided in two main categories: those with an individualistic approach towards behaviour (like economics and psychology) and those with a socially oriented one (including sociology and anthropology). It seems, however, that research and policies adopted during the last two decades disproportionally fall under individualistic premises that conceptualise social change primarily as a matter of individuals' behaviour and personal choice (Lutzenhiser and Shove 1999, Shove 2010, Southerton *et al.* 2011). The prevalence of 'ABC'—Attitude, Behaviour and Choice—and similar behavioural models, according to which *'the individual "decision-maker" and sometimes the context within which he or she take decisions constitute the primary targets for intervention',* comes as a result of this trend (Blue *et al.* 2016, p.47). Despite the

‘ABC’ model’s applicability and wide acceptance it has also received strong criticism since it largely omits aspects such as social context, professional cultures and institutional expectations that shape activities, practices and habits (Moezzi and Janda 2014). Hence, the need to move beyond the ‘ABC’ framework and shift the focus from individuals’ cognitive components to the fabric and texture of peoples’ daily lives as has often been highlighted (Guy and Shove 2000, Moezzi and Lutzenhiser 2010, Shove 2010).

In response, energy and building research is gradually moving towards a path were socially oriented approaches are encouraged alongside technical ones, thus encompassing a wider range of methodological approaches (Oreszczyn and Lowe 2009, Schweber and Leiringer 2012, Summerfield and Lowe 2012). A socio-technical research agenda has evolved that views society and technology as inextricably intertwined, including theories such as social practice theory (Reckwitz 2002), actor-network theory (Latour 2005) and approaches such as interactive adaptivity (Cole *et al.* 2008) and Post Occupancy Evaluation (POE) (Leaman *et al.* 2010). Among them, social practice theory as developed by Gram-Hanssen (2010b) and Shove (2003) has dominated energy and buildings research, as it can offer a deeper explanation and understanding of variations in energy consumption due to inconspicuous routines and technological structures which are difficult to explore using individualistic models or theories (Warde 2005, Shove and Walker 2014). A practice can be defined as a routinised type of behaviour, which consists of four interconnected elements—habits, knowledge, technologies and meanings—while people are the carriers of meaningful practices (e.g. driving and smoking) rather than autonomous agents (Gram-Hanssen 2010b). Consumption is seen as a by-product of every practice; and as Warde (2005, p.137) puts it, *‘a moment in almost every practice’*. Hence, when looking at energy use in buildings by focusing on the constituent ‘doings’ and ‘sayings’ of practices, it becomes easier to understand how they form, effect the everyday life of practitioners and finally their ability to change.

Although a practice ‘turn’ in energy and buildings research seems to be at hand, existing studies present a limited scope in the way practices impact energy consumption in non-domestic buildings and their ability to change in these settings. Instead, they have mainly focused on household practices (Wilhite 2008, Foulds et al 2013) with only a few examples in offices (Hargreaves 2011), educational buildings (Palm and Darby 2014) and outdoors (Dant 2004, Shove and Pantzar 2005). Similarly, studies investigating change in practices focus on the effect of feedback in domestic electricity (Gram-Hanssen 2010b, Hargreaves *et al.* 2010) and water consumption (Strengers 2011, Browne *et al.* 2014) but offer limited insight on consumption happening in the workplace (Hargreaves 2011).

Considerable work remains to be done in non-domestic settings such as universities on the grounds of their significant reduction potential and the range of efficiency initiatives implemented in their premises (HEFCE 2010, Low Carbon Innovation Coordination Group 2016). Given that universities resemble other tertiary sector buildings such as offices, colleges and private research organisations, research findings could have a wider application. Furthermore, their role within communities, their business status and the amount of resources they consume exemplifies their potential as test-beds for research and innovation. As Lombardi (2017, p.12) puts it universities are '*no longer seen as educational establishments but as laboratories for promoting innovation and capitalizing the social, economic and environmental value offered by that transformation'.* This transformative process includes the promotion of user engagement sustainability initiatives, research and enhanced teaching functions along with the implementation of building efficiency measures in their premises.

In the words of John Robinson:

> *'Imagine a giant sandbox, a place in which there is the freedom to explore—creatively and collaboratively—the technological, economic and behavioural aspects of sustainability on a campus-scale, with a view to applying in the wider world what is developed in the "sandbox". In this scenario, the university turns its entire physical plant into a testing ground where the institution and its private, public and NGO partners test, study, teach, apply and share lessons learned, technologies created and policies developed.'*
>
> (Waghorn 2012)

This dissertation draws upon this potential and places the research in the context of a university building used as a case study to explore socio-technical aspects of a behavioural change initiative.

1.2. Research aims and questions

This thesis explores how workplace practices related to comfort and energy use form and their potential to change as a result of energy consumption feedback in the workplace. It introduces a practice theory approach to study the elements that shape comfort in the workplace and their commonalities with other energy consuming practices while attempting to identify barriers and opportunities for change by exploring the impact of a behavioural change scheme. A higher education building (Department of Engineering, University of Cambridge) is used as a case study and Real Time Displays (RTD) are studied as an intervention.

The study aims to:

- Investigate the performance of daily practices related to thermal comfort and energy use in the workplace.
- Explore the potential of real-time consumption feedback on changing practices in the workplace.
- Explore the applicability of social practice theory when looking at transforming practices and reducing energy use.

The objective of this study is to explore occupants' energy use in academic offices through a practice theory lens and advance the understanding of their practices as socio-technical arrangements related to social dynamics and meanings attached to the workplace as well as material infrastructure, routines and knowledge structures.

This thesis aims to answer the following research questions:

1. How to inform the theoretical practice based elements with empirical findings from the workplace?

2. What is the potential of Real Time Display feedback to transform workplace practices?

3. How can practice theory contribute to an understanding of energy use in workplaces?

Table 1.1 presents the research aims, questions and sub-questions in line with the conducted fieldwork. First, the thermal characteristics of the case study offices and the users' thermal comfort preferences are mapped to place the research in context. Next, comfort and workplace practices are deconstructed and reformed through a practice theory lens for the three different office and user groups to then explore the effect of feedback through the real-time displays as a practice-changing element.

Table 1.1 Research aims, questions and relevant chapters.

Aims	Research questions	Sub-questions	Data collection methods
Investigate the performance of daily practices related to thermal comfort and energy use in the workplace.	1. How to inform the theoretical practice based elements with empirical findings from the workplace?	- What are the thermal characteristics in an office environment? - Which are the comfort preferences of the users?	Monitoring of environmental conditions (data loggers) Comfort diaries (users) (Chapter 6)
		- What are the routines associated with them? - How and why infrastructures are implicated in workplace practices? - How does background knowledge affects them? - What kind of common meanings are embedded in them and how do they shape them?	Semi-structured interviews of users Observation Empirical reflections on the theory (Chapter 7)
Explore the potential of real-time consumption feedback on changing practices in the workplace.	2. What is the potential of Real Time Display feedback to transform workplace practices?	- How did the RTD installation process develop? - How did office users perceive energy consumption feedback through RTDs? - What is the potential for change in the workplace?	Electricity audits (conducted by the author) Semi-structured interviews of users (Chapter 8)
Explore the applicability of social practice theory when	3. How can practice theory contribute to an understanding of energy	- Which methods are useful in applying practice theory on energy demand	Reflections on theory (Conclusions)

looking at transforming practices and reducing energy use.	use in workplaces?	reduction? - What is the benefit of quantitative methods (e.g. environmental monitoring and electricity audits) when practice theory is applied in energy research?	

1.3. Research scope

As efficiency measures in buildings intensify in order to achieve carbon reduction targets, energy awareness campaigns and behavioural change interventions targeting the building occupants have become essential elements of the UK Government's green agenda (HM Government 2016). Research on the uptake of such interventions and their impact on energy consuming practices has focused on the domestic sector while little evidence exists at non-domestic settings such as the workplace (Palm and Darby 2014). In addition, existing research in organisational settings and universities follows individualistic approaches from psychology and economics (Matthies *et al.* 2011, Emeakaroha *et al.* 2012, Gul and Patidar 2015) to investigate interventions that have been similarly predicated upon rationalistic information giving interventions and behavioural change measures. However, criticism has been raised regarding their short term effects (Dam *et al.* 2010, Murtagh *et al.* 2013), narrow theoretical frameworks (Hargreaves 2011, Shove 2014) and lack of interdisciplinary methodological approaches (Sovacool 2014) indicating the need for a consideration of workplaces as socio-technical settings with an effect on the design and implementation of relevant efficiency interventions.

This thesis explores thermal comfort and energy consuming workplace practices, the elements that shape them and their potential for change. The case study takes place in five offices within an academic building, four of which have been subject to a behavioural change intervention. The scheme aimed to raise awareness on energy use and incentivise energy savings with the use of consumption feedback through an office RTD and a competition between different offices where the one with the most savings would be offered a monetary award. To overcome the challenge of the diverse user sample and different office typologies found in an academic department, three typical office types—the administrative, the PhD and the post-doctoral office—were selected as representative following a walkthrough in the building with the facilities manager. Participants were recruited voluntarily and the main data collection took place in two rounds (February 2014 and July 2014), capturing practices in the workplace in different seasons and before and after the installation of RTDs.

The research was structured in a three-stage investigation spanning over a four-year period (see Figure 4.4). The initial stage consisted of two pilot studies in two different academic departments. The first pilot study explored energy use perceptions at a university department subject to a campus wide environmental engagement campaign (Section 4.7.1) and the second the effect of a behavioural change intervention in an academic research institute with the use of an online energy consumption feedback tool (Section 4.7.2). It then focused on the case study offices where it explored the users' comfort preferences in relation to indoor thermal characteristics during winter and summer (Chapter 6) and the socio-material elements that shaped their comfort practices (Chapter 7) before the installation of the RTDs. Finally, it investigated the potential of real-time consumption feedback in transforming workplace practices by identifying opportunities and barriers to change (Chapter 8).

This thesis adopts a case study research strategy and a novel mixed methodology based on a combination of qualitative enquiry (semi-structured interviews and observation) and comfort field studies, thermal condition monitoring and electricity audits. It uses social practice theory as a theoretical framework following Gram-Hanssen's (2010b) operationalisation of practices on its four constituent elements (know-how and embodied habits, technologies, knowledge and meanings) (Section 2.3.2). The potential of mixed methodologies in such empirical studies has often been suggested given that practice literature has mainly used historical narratives and a qualitative methodology (Browne *et al.* 2014). By offering a combination of qualitative and quantitative methods this study aims to address the actual impact of practices in consumption in a systematic way and track their change over time.

1.4. Thesis structure

The thesis is structured as follows (Figure 1.1):

Chapter 2. Disciplinary perspectives on energy use in buildings' research gives an overview of the existing theoretical approaches looking at energy use behaviour, pointing out the distinction between the individualistic, socially oriented and socio-technical research paradigm. It then introduces social practice theory as a socio-technical approach to study occupants' energy consuming practices and Gram-Hanssen's (2010b) analytical framework. Thermal comfort is discussed through different theoretical perspectives and the chapter finishes with a review of empirical studies looking at comfort as a socio-technical construct.

Chapter 3. Transforming energy use practices in the workplace discusses the energy saving potential of behavioural change interventions with a focus on energy consumption feedback in university and organisational settings based on a literature review. It explains how changes take place from a practice theory perspective and why practitioners may defect from taking up a certain practice. Finally, it reviews empirical studies related to awareness raising initiatives and feedback in universities.

Chapter 4. Research design and methodology describes the rationale behind the research design and the methodological choices for this thesis. It looks at the interdisciplinary research perspective, the adopted theoretical framework, the case study approach, the data collection and analysis methods and finally comments on methodological limitations. It then outlines the research design and study phases.

Chapter 5. The case study is a detailed review of the case study building (Engineering Department, University of Cambridge) and the typological and user characteristics of the three office groups: the administrative shared enclosed office; the PhD open-plan office, and the post-doctoral cellular office.

Chapter 6. Thermal characteristics and comfort preferences of users presents the results of the indoor thermal conditions monitoring and comfort diaries for each case study office during winter and summer season. First, it looks at indoor temperature and relative humidity conditions for each office and next it correlates them with users' thermal sensation, preference and acceptability.

Chapter 7. Framing workplace practices presents the findings on how existing socio-material arrangements in the three types of case-study offices shape workplace practices related to thermal comfort and the use of the office equipment. Findings are structured in four thematic sections: Know-how and embodied habits; technologies; knowledge, and meanings.

Chapter 8. Transforming practices: Real-time consumption feedback as an intervention looks at the potential of feedback through RTDs to transform energy consuming practices in the case study offices. Through an examination of the information projected by the RTD's, actual electricity consumption figures, the users' views on energy saving in the workplace and the first impressions from their installation, the chapter identifies barriers and opportunities for change.

Chapter 9. Conclusions summarises the main findings of this research related to the three research questions. Implications for different stakeholders are discussed while limitations of the study and directions for future research are set out.

Appendices include additional information related to the above chapters.

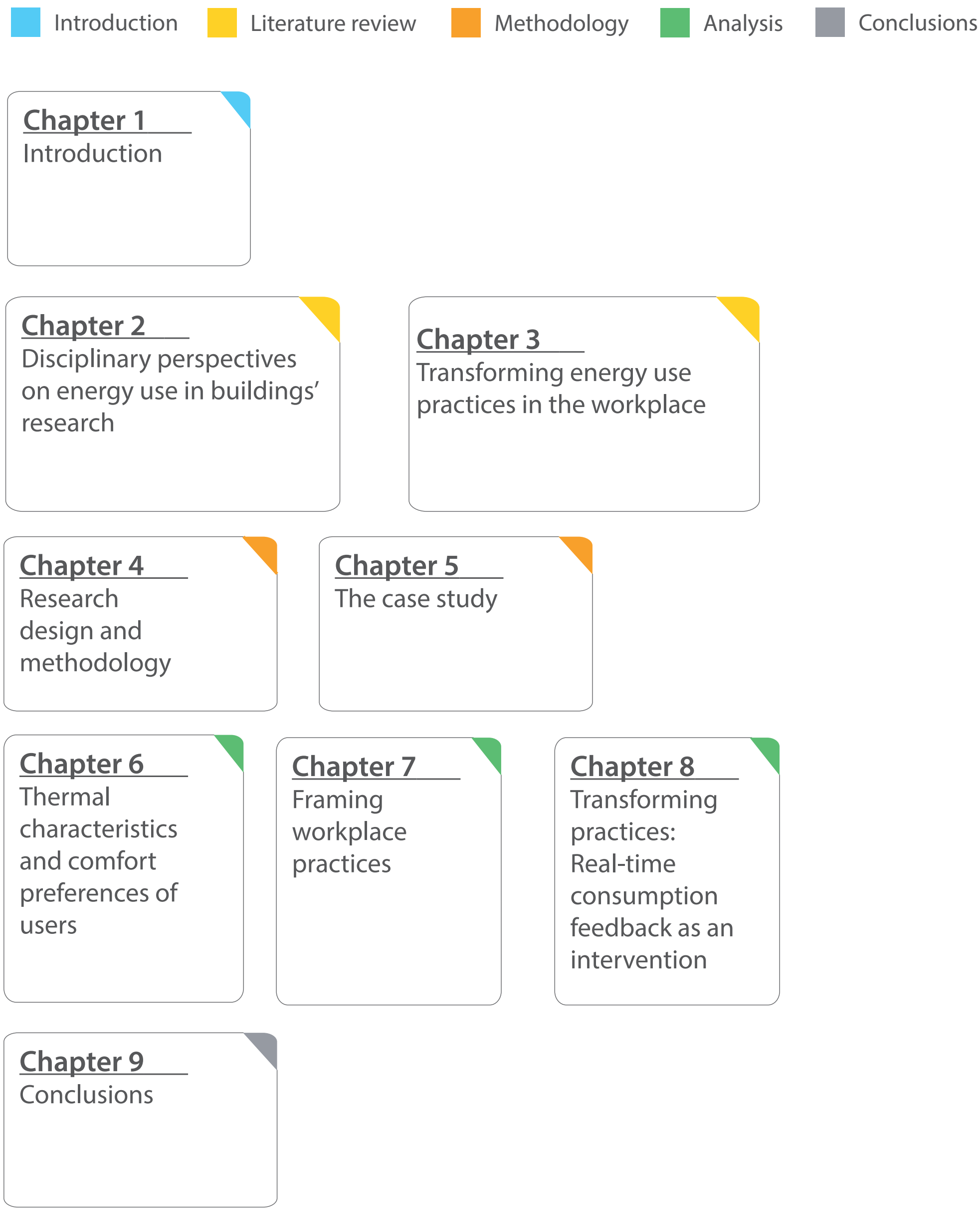

Figure 1.1 Thesis structure.

2. Disciplinary perspectives on energy use in buildings' research

2.1. Introduction

This chapter begins with an overview of the main theoretical disciplines looking at behaviour and energy use (Section 2.2). It examines the two dominant paradigms and associated models—individualistic and socially oriented—outlining their strengths, limitations and methodological characteristics. Section 2.3 introduces social practice theory as a socio-technical approach that complements the existing techno-economic and socially oriented models. It then discusses the concept of 'practices' and presents Gram-Hanssen's (2010b) analytical framework, which is adopted by this thesis and indicates how practice theory can be developed for use in empirical research. Next, it looks at the link between practices and energy consumption and discusses key examples from a literature review of empirical studies in domestic and non-domestic settings. Section 2.4 is a commentary on thermal comfort and its interpretation through physiological, psychological and socio-technical perspectives. It reviews socio-technical comfort studies highlighting considerations for future research. The summary (Section 2.5) points out the potential of a socio-technical systems approach and social practice theory as a theoretical framework in empirical studies looking at comfort and energy use.

2.2. 'Energy use behaviour' through different theoretical lenses

2.2.1 Disciplinary perspectives

Knowing how people think and make decisions is important in research that seeks to understand energy consumption from a user perspective. Trying to understand the way people behave in their daily life and in different contexts has been the subject of several academic disciplines. Through theories and models of behaviour they explore how people shape their views and approaches towards the world and what is it that influences their present decisions and future plans.

Table 2.1 outlines the main academic disciplines and research traditions-spanning from engineering to political science, architecture and anthropology-relating them to the dominant themes they use to understand efficiency, energy use and social change. Among all these disciplinary perspectives, the four most commonly used are located in the disciplines of engineering (physics), economics, psychology and sociology (Chatterton 2011, Moezzi and Janda 2014).

Table 2.1 Disciplines and fields; themes and vocabularies (Moezzi and Janda 2014).

Research tradition	Some dominant themes and vocabularies
Engineering	Technical energy efficiency, physics, services, asset ratings, user behaviour
Economics	Investments and cost-effectiveness, demand elasticity, utility, externalities
Behavioural economics	Choice architecture, nudges
Psychology	Attitudes, values, commitments, beliefs, goals, behaviours, decisions
Social psychology	Norms, contexts, habits
User-centred design/human factors	Users, device design, micro-interactions connecting to behavioural and social sciences
Energy planning	Supply forecasting, urban forms, spatial organisation, transportation, embodied and indirect energy use
Architecture	Building design, passive solar, passive house, intelligent building, user interaction
Sociology	Practices, habitus, social groups, communities, shared social meaning of consumption
Political Science	Political party platforms, state and none-state actors
Anthropology	Cultures, power structures, interactions with physical world
Social studies of technology	Social interpretation of devices and structures, social construction, scripts, assemblages, regimes, systems of provision

Engineering and economics have hitherto dominated the research and policy considerations on energy use and efficiency in buildings (Moezzi and Janda 2014). Engineering focuses on the efficiency of technologies and the technical potential of energy savings employing analysis methods such as energy modelling and simulations, energy audits and load quantification (Swan and Ugursal 2009, Kavgic *et al.* 2010). Although it is very useful to develop innovative solutions on 'how' to be more efficient, this approach is criticised upon its failure to answer questions related to 'why' efficiency is not achieved even though it is technically possible (Crosbie 2006). This case is often expressed as the 'performance gap' and comes as a result of inadequate commissioning, poor maintenance and inefficient facility management amongst other reasons (de Wilde 2014). The economic discipline follows, looking at the impacts of economic criteria on energy consumption with studies on monetary incentives and cost-effectiveness of goods. Individuals are considered rational decision-makers, forming their behavioural choices based on provided information, energy prices and financial incentives. It seems, though, that some of the aspects this approach ignores are the differences in consumers' attitudes and the ability to understand people as more than consumers so *'puzzlement abounds when reason fails to materialise'* (Lutzenhiser 2014, p.142).

Psychological approaches in the context of energy use—often supporting research in economics—try to shed light on the behavioural attributes that make people adopt certain efficiency measures that are not solely economic. Individual perceptions, attitudes and social norms are considered key factors that influence behavioural choices. When combined with economics, the discipline of Behavioural Economics emerges, focusing on why people deviate from rational choice and how these deviations can be alleviated. Both psychology and economics make use of surveys and large statistical databases to understand and break down behavioural processes.

Finally, the discipline of sociology shifts the focus away from the 'actor' and places it on the 'actions' and the 'context'. The main difference between sociology and the other three disciplines is that the central unit of analysis is not the individual, but rather the individual's attitudes and expectations, which are placed in social, institutional, material and organisational contexts (Breukers *et al.* 2011). To understand variability in behavioural patterns and their social origin, these studies often make use of interviews, observations and focus groups.

Theories emerging from these disciplines are used in research and policy in the form of applicable models that illuminate the elements that form, and the processes that are used in one's decision-making. However, given that theories provide abstract ways of understanding a phenomenon rather than an absolute representation of reality, it should be noted that none is completely accurate. Regarding their methodological orientation, individualistic approaches germane to the fields of engineering, economics and psychology focus on positivistic methodologies using quantitative methods, while socially oriented ones related to the disciplines of sociology and anthropology are linked to qualitative tradition. Individualistic approaches place the focus on technology and individuals as decision-makers whose behaviour is influenced through device efficiency, information and economic incentives. Socially oriented approaches, on the other hand, try to shed light on the wider socio-material context that determines how energy is used by looking at the interactions between people with a range of top, middle and bottom actors (e.g. families, communities, NGOs) and the interaction of those actors amongst each other, energy efficiency products and systems of provision (e.g. utility companies).

An outline of the two main philosophical perspectives, the academic disciplines that follow them, the way they position the consumer, their understanding of energy use and its determinants, their primary research objectives and their assessment and analysis tools is presented in Table 2.2. As previously explained, looking at energy consumption through individualistic lenses and positivistic methodologies offers statistical accuracy and objectivity while human-centred methods offer descriptive, explanatory and predictive benefits. However, the irrationality of energy use where technology and society intertwine often calls for interdisciplinary collaborations and comparative analysis. Analysing fifteen years of research material in the energy and buildings field, Sovacool (2014) revealed that only 19.6% of authors had a training in social sciences and 12.6% of the (4444) research articles utilised qualitative methods. The need for incorporation of more qualitative and human-centred methods in current methodological approaches and the enhancement of research topics in

Table 2.2 Comparison of theoretical approaches of energy use behaviour from engineering and the social sciences (Adapted from: Shove 2004, Wilson and Dowlatabadi 2007, Chatterton 2011, Lopes *et al.* 2012, Moezzi and Janda 2014).

Philosophical perspective	**Position of consumer**	**Discipline**	**Understanding of energy**	**Primary research objectives**	**Determinants of energy use**	**Main research methods**
Individualistic	Decision-maker: exercising environmental choice	Engineering, Physics	Energy use is related to the efficiency of technologies and the building fabric	Understand and increase device and thermal efficiency	Device and thermal efficiency	Quantitative (modelling and load quantification)
		Economics	Energy is a commodity and consumers will adapt their usage in response to price changes	Understand and use price signals to influence consumer action	Energy prices, billing information, explanatory literature, socio-economic characteristics, attitudes	Quantitative (surveys, statistics)
		Psychology	Energy use can be affected by stimulus-response mechanisms and by engaging attention	Understand and influence individual perceptions about and actions related to energy use, energy services, or their environmental effects		
Socially oriented	Practitioner: reproducing more and less sustainable ways of life	Sociology, Anthropology, Social studies of technology	Energy use is largely invisible, energy systems are complex, and daily practices significant	Understand variability and patterns of consumption and the social origins of those patterns	Families, households, energy supply companies, companies selling efficiency products and services, communities, NGOs, government	Qualitative (interviews, observation)

order to address the social significance of energy use becomes apparent (Berker and Bharathi 2012, Lopes *et al.* 2012, Schweber and Leiringer 2012). As a response, the socio-technical research regime aims to combine elements and methods from the individualistic and socially oriented approaches and offer an interdisciplinary and complementary research perspective (Section 2.2.2).

2.2.2 A socio-technical systems approach

It has been commonly accepted that a Physical-Technical-Economic Model (PTEM) of energy use has dominated contemporary energy research and relevant efficiency policies. Subsequently, attempts to influence behaviour have largely relied on either legislative prohibition or financial measures to guide people into certain behavioural trajectories (Chatterton 2011, Janda 2011). As a result, the focus has been placed on the interaction of the individual consumer with efficient technologies, innovative devices and the building envelope, largely omitting social contexts, professional cultures, institutional expectations and larger technological landscapes that affect peoples' energy use behaviour, habits and practices (Guy and Shove 2000, Wilhite *et al.* 2000). As Shove and Lutzenhiser (1999, p.217) describe:

> *'Rather than seeing human choice as critical and controlling in energy use and technology choice, the conventional paradigm focuses on physical-mechanical systems in which human factors are of concern only in terms of possible injury, discomfort or mis-operation of equipment. In the 25 years since the first energy crisis, this perspective has changed remarkably little, despite its weaknesses.'*

The main limitations of this dominant approach as summarised by Moezzi and Janda (2014) arise from three common assumptions: a) the emphasis on information and individual choice; b) the expectations that financial incentives and moral benefits will influence energy consumption behaviour; and c) the focus on how energy is used at home rather than in non-domestic environments. They also remarked that the explicit nature and ease of implementation of a techno-economic line of thought eased its way in the policy agenda despite warning signs from the buildings' 'performance gap' phenomenon, which highlighted a lack of understanding of occupants' behaviour (Stevenson and Leaman 2010, Menezes *et al.* 2011).

To overcome these limitations, literature suggests that existing research and policy frameworks need to expand towards a socio-technical approach that would encompass social sciences along with various technical paradigms in order to illuminate the processes that produce certain behavioural patterns (Lutzenhiser and Shove 1999, Schweber and Leiringer 2012, Tweed 2013). As a result, the socio-technical systems perspective evolved through the science and technology studies opposing 'technological determinism', instead regarding technology and society as inextricably intertwined (Hinton 2010). It consists of a philosophical perspective that incorporates a series of approaches such as actor-network theory, social practice theory, social studies of technology, socio-technical transition scholarship, systems of provision, and transitions to sustainability (Lutzenhiser 2014). Its main strength lies in its ability to demystify the social nature of consumption and the social structuring of demand; hence, it coheres with the broadening line of thought currently shaping our understanding of energy use activities. As such, ST systems encounters the current theoretical and policy 'barriers' not as a sign of failure, but rather as fundamental elements of social structure and action (ibid).

There are not many studies in energy and buildings research that seek to cross disciplines following a socio-technical approach and geared to addressing the complexity of energy use behaviour (Lopes *et al.* 2012). Post Occupancy Evaluation (POE) and Building Performance Evaluation (BPE) studies can be considered as a starting point for this undertaking in the UK. These studies were initially technically-oriented, utilising building monitoring, energy audits, simulations and BUS (Building Use Studies) questionnaire surveys as their data collection methods (Leaman and Bordass 2007, Leaman *et al.* 2010). Over time, they have evolved to incorporate the building user and his behaviour through observation and interview techniques (Gupta and Chandiwala 2010, Stevenson and Rijal 2010), but their lack of a social science theoretical basis and their often 'commercialised' nature obstructed a clear analytical structure and view of behaviour. A socio-technical approach that has been recently introduced in energy research is social practice theory (Shove and Pantzar 2005). It enhances the understanding of behaviour looking at people as carriers of practices rather than autonomous agents of choice, while acknowledging the impact of social, material and cultural structures.

The next section introduces practice theory and its theoretical background along with a discussion of how it can be used in empirical studies. It is followed by a description of the empirical material that has influenced this study with a focus on comfort and energy consuming practices in both domestic and non-domestic settings.

2.3. Social practice theory

2.3.1 The 'practice turn'

The application of practice theory in consumption studies (the 'practice turn') stems from a recent trend in sociology to go beyond the existing individualistic line of thought and its focus on the lifestyle and post-modern symbolic identity (Gronow and Warde 2001, Schatzki *et al.* 2001). It is considered as a particularly useful analytical framework when looking at energy use in buildings since it places the attention on the social, regulatory and material context of daily activities, thus achieving a balance between the contextual and the technical (Foulds *et al.* 2013). Its application does not only focus on building and energy research, but it spans in the domains of public health (Blue *et al.* 2016), ecological economics (Røpke 2009), social and political anthropology (Evens and Handelman 2014) and media ethnography (Postill 2010).

As Reckwitz (2002, p.257) posits, practice theory, similar to other versions of social and cultural theories *'offers a contingent system of interpretation which enables us to make certain empirical statements'*, or else a conceptual framework that *'opens up a certain way of seeing and analysing* *social phenomena'*. One of its main strengths is that, although it aligns with the wider socio-technical research framework, it does not reject the established individualistic perspectives where individuals receive new knowledge and relate their consumption to financial incentives (Gram-Hanssen 2010a). In the words of Warde (2005, p.136), its difference and main attraction compared to other socio-technical theories is that:

> *'Practice theories are neither individualist nor holist; they portray social organisation as something other than individuals making contracts, yet are not dependent on a holistic notion of culture or societal totality.'*

Theories of practice have developed incrementally over two distinctive generations of theorists. Giddens and Bourdieu laid the foundations in the late 1970s through the philosophical concepts of structuration (Giddens 1984) and the notion of 'habitus'[1] (Bourdieu 1984), followed by a second generation of thinkers, among whom are Schatzki and Reckwitz. Through their work it was pointed out how practices are key elements underpinning the social realm. In the words of Giddens (1984, p.2):

> *'The basic domain of study of the social sciences, according to the theory of structuration, is neither the experience of the individual actor, nor the existence of any form of societal totality, but social practices ordered across space and time.'*

The important point of these theories is that practices are seen as entities that exist through routine reproduction, but they are also thoroughly social in the sense that they lack a consideration of material objects and infrastructures (Shove and Pantzar 2005). There is, however, an ambiguity in terms of their use of 'rules' as a condition of human action, given that rules are both rejected by the notion of 'habitus' and habituated skills and re-emerged through the argument of rule-based socio-economic motivators for change (Galvin and Sunikka-Blank 2016).

A second generation of thinkers represented by Schatzki (2001), Knorr Cetina, von Savigny (Schatzki *et al.* 2001) and Reckwitz (2002), expanded upon previous work in this vein by adding materials, meanings and competences to the concept of practices. According to Schatzki (2001), a practice is a dynamic combination of *'doings'* and *'sayings'* performed by individuals as daily routines but formed and sustained by collectively shared elements—*'embodied, materially mediated arrays, and shared meanings'* (ibid, p.3). In the same direction Reckwitz (2002, p.249), in his definition of practices, explains that:

> *'A "practice" (…) is a routinized type of behaviour which consists of several elements, interconnected to one another: forms of bodily activities, forms of mental activities, "things" and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge.'*

[1] '*Intuition formed during childhood determining one's tastes, habits, dreams and wishes.'* (Gram-Hanssen 2010b, p.153).

These formulations move beyond the logical and philosophical flaws residing in Bourdieu's and Giddens's schemata of practices to form *'a robust starting point for social theorising'* where people have the ability to effectively coordinate in complex social and practical situations, even as society influences them to act in the way they do (Galvin and Sunikka-Blank 2016, p.65).

Finally, a more coherent analytical framework has emerged through the recent work by Warde (2005), Shove (2003, 2010, Shove *et al.* 2012) and Gram-Hanssen (2010b). This work led to the operationalisation of the theory and its main components in order to be easily applied in empirical studies of energy consumption and is detailed in the following section (2.3.2).

2.3.2 Practices and their constituent elements

The starting point and main unit of analysis of practice theory is that people perform meaningful practices rather than individual behaviours. Behaviour is no longer seen as the expression of someone's values, beliefs and attitudes, but as the observable expression of socially shared sets of meanings, knowledge and skills (Shove *et al.* 2012). For example doing exercise, cooking and driving constitute practices that can be *'reproduced and transformed through their re-enactment and performance'* and are *'coordinated and synchronized across space and time'* (Blue *et al.* 2016, p.38). These socially shared domains of human activity—practices-as-entities—are not absolute and sterile but within each of them there is a variety of ways that a practice can perform—the so called practice-as-performance (Shove *et al.* 2012).

Practices are configured by a set of interconnected elements that hold them together and power their constant reproduction within society. The current discussion surrounding the elements from which practices are formed has been ongoing since the end of the 1990s (Gronow and Warde 2001). Due to the loose philosophical nature of the theory, the absolute interpretations of its elements vary; a comparison of the understanding of practices derived from the work of recent theorists is presented in Table 2.3.

Table 2.3 Key elements in the understanding of practices from recent theorists (Adapted from: Gram-Hanssen, 2010b, p.154).

Schatzki (2002)	**Warde (2005)**	**Shove and Pantzar (2005)**	**Reckwitzt (2002)**	**Kirsten Gram-Hanssen (2010b)**
Practical understanding	Understandings	Competences	Body	Know-how and embodied habits
			Mind	
Rules	Procedures		The agent	Institutionalized knowledge
			Structure/ Process	
Teleo-affective structures	Engagements	Meanings	Knowledge Discourse/ Language	Engagements
	Items of consumption	Products	Things	Technologies

The most commonly used models in recent empirical research in the context of energy use in buildings have been those of Shove and Pantzar (2005) and Gram-Hanssen (2010b) due to their practical and methodological considerations. For Shove and Pantzar (2005), a practice is defined as an entity consisting of three elements: equipment (material), images (meanings) and competence (skills) as illustrated in Figure 2.1. A practice-as-entity is a set of bodily and mental activities or, in other words, heterogeneous elements held together by this three-element structure. Looking at the re-emergence of Nordic walking, they point out how practices develop upon the interaction of these elements, a process in which both consumers and producers are involved (ibid).

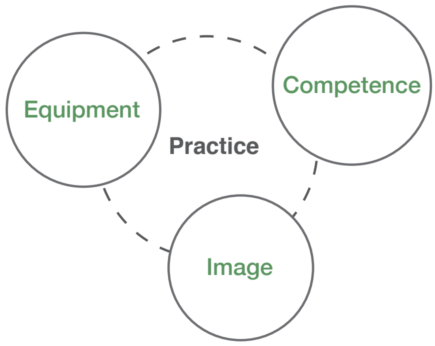

Figure 2.1 Elements of practice based on Shove and Pantzar's (2005) approach.

Gram-Hanssen (2011, p.64) defines practices as *'coordinated entities of sayings and doings that are held together by different elements and that are also what make practices collectively shared across time and space'*. She has recently revised Shove and Pantzar's three-element framework, suggesting that the term 'competence' can be too general to differentiate between tacit knowledge—that is, embodied habits and know-how—and explicit rules that deem research related to energy consumption dissatisfactory (Gram-Hanssen 2010a). In her attempt to operationalise the theory for empirical use, she proposes an extended version where competence is broken down into institutionalised knowledge and embodied habits (Figure 2.2). In this case practices are seen as a composition of: know-how and embodied habits; technologies; institutionalized knowledge, and engagements. A description of each element is outlined below while an example of cooking practice and its constituent elements is presented in Table 2.4.

- **Know-how and embodied habits** may refer to past experiences and life routines that resulted in unconscious ways of performing actions. Others are generic (e.g. the ability to read) while others are more specialised (e.g. bedtime reading).
- **Technologies** reflect the physical environment that surrounds us, including electrical devices, physical objects and infrastructure.
- **Institutionalised knowledge** refers to the level of general knowledge and the way it has been provided. Institutions such as schools, universities, governmental bodies, NGOs, utility providers and local authorities provide it.
- **Engagements** are meanings carried by certain actions or behaviours, which may influence the motivation of individuals; for example, doing something that is considered to be healthy.

Their impetus may come from different sources, such as social norms, aspirations and symbolic concepts and they are seen connected to the practice rather than to the individuals.

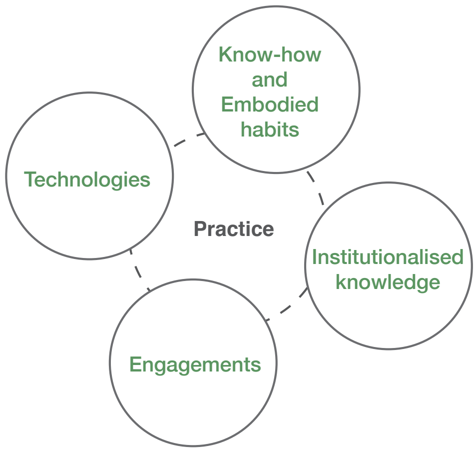

Figure 2.2 Elements of practice based on Gram-Hanssen's (2010b) approach.

Table 2.4 Elements of practice (Foulds et al. 2013, p.625).

Element	Cooking practice
Know-how and embodied habits	Sense of smell/taste; managing the hottest part of the oven; how to react to it all going wrong; complementary dishes / ingredients
Technologies	Oven; hobs; microwave; saucepans; energy; energy supply infrastructure; oven gloves; apron
Institutionalised knowledge	Recipes; appliance manuals; energy efficiency advice; dietary advice; weights and measures; serving suggestions
Engagements	Being healthy; wordy; part of a family unit; sustainable; a good host; affectionate; nationalistic; a shrewd cost saver

The advantage of such a framework lies in the fact that it provides a structural understanding of everyday practices, *'though it is still open for interpreting differences in the way different actors take part in a practice'* (Gram-Hanssen 2010a, p.186). Each element is a structure that sustains practices while at the same time these elements are sustained and developed by the practitioners performing the practices (ibid). If one of these elements is subject to change then new inter-element relationships emerge which often change the practice itself (Gram-Hanssen 2011). Despite their common structure, practices are also dynamic and can be internally differentiated and 'translated' in disparate ways by different people at the same situation. For some a practice can be related to the *'pursuit of excellence and a degree of competition'* while for others it is a case of maintaining certain performance standards that leads them to pursue *'acceptable (…) equipment, experience and provision'* (Warde 2005, p.141). The contribution of practice theory in this case is that it helps illuminate the reasons for these deviations (apart from personal choice and culture) and therefore helps in devising ways to address them (see Section 3.4).

This thesis follows Gram-Hanssen's (2010b) four-element framework as an analytical tool in the empirical study of workplace practices and the use of real time consumption feedback as an intervention. A consideration of its methodological affordances is located in Section 4.4.

2.3.3 Practices and energy consumption

In social practice theory, looking at people as consumers is rarely meaningful in comparison to cultural theories of consumption where people are considered to be the victims of market forces (Røpke 2009). Energy consumption is not a cause or consequence of social systems (political, economic, technical), but an ingredient of the social practices and complexes of practice of which societies are composed (Shove and Walker 2014). According to Warde (2005, p.137) consumption is considered a by-product of daily practices and thus *'a moment in almost every practice'* since *'being a competent practitioner requires appropriate consumption of goods and services'* (ibid, p.145). Gram-Hanssen (2014a) also explains that energy consumption does not constitute a practice in and of itself, but rather is all the different things that people do when consuming energy (e.g. cooking, cleaning and heating a space), which are guided by different elements. Thus, the organisation of a practice, the items related with its performance and the engagement in it, are the reasons for consumption rather than an individual's personal choice.

Røpke (2009) further suggests that the motivations behind consumption are related to the meanings (intrinsic pleasures) and the skills (competences) associated with practices. Associated meanings could include such things as attracting a new partner, being a good student, being healthy, being a competent driver, etc. Similarly, Shove *et al.* (2007) highlight that the importance of the skills associated with 'doings' is linked to the concept that things are beneficial only to those who know how to use them. Therefore, consumption can be seen as *'the expression of capabilities and project-oriented ambitions of knowledgeable actors'* (ibid, p.43). For Warde (2005, p.145), in addition to know-how and commitment to the value of a practice, *'a competent practitioner requires appropriate consumption of goods and services'*. These considerations are usually tightly bound to practices, suggesting that much consumption occurs without prior calculations—a phenomenon characterised as *'inconspicuous consumption'* (Gronow and Warde 2001, Shove and Warde 2002).

2.3.4 Practice-oriented empirical studies

Daily practices and their relationship to energy use have been examined by a series of studies. Table 2.5 outlines some key examples of existing empirical research both in domestic and non-domestic settings. For this thesis, useful methodological and analytical insights on daily practices and how they relate to energy use were identified in studies by Gram-Hanssen (2010a, 2010b), Foulds *et al.* (2013) and Palm and Darby (2014), and therefore deserve further consideration.

Gram-Hanssen (2010b) looks at the standby energy consumption of ten households and uses practice theory as a socio-technical medium to provide insights on the elements that bind a practice and constitute possibilities for change. She points out how rationality alone cannot explain the extent to which people can change their practices in relation to standby consumption and that there is a need to also understand *'the way technology is used, configured and designed'* (ibid, p.162). In another study, she employs practice theory to explain how everyday residential thermal comfort practices are formed in order to understand why different levels of energy consumption exist in identical houses (Gram-Hanssen 2010a). Methodologically, she goes a step further by introducing a framework for empirical studies related to energy use in buildings (see Section 2.3.2). She also stresses the importance of using a mixed methodology that juxtaposes qualitative interviews with measured data to validate users' 'doings' and 'sayings'.

Foulds *et al.* (2013) explore daily practices in an affordable UK Passive house, highlighting the potential of mixed methodology—in this case, building monitoring and qualitative enquiry—in practice-oriented studies. The authors suggest that indoor conditions monitoring can prove particularly useful in examining the impact of technological interventions in the study of practices. They also remark that precisely recording internal conditions in relation to time is useful for tracking implications of change in a practice's trajectory in space and time. Using the case of the passive house, they show how monitoring helped illuminate the effects of seasonality in the performance of practices, and the changes in comfort when passive technologies become mainstream. Given that technological improvements are at the forefront of policy, the paper concludes that the use of practice theory and monitoring can provide a useful analytical tool for energy consuming practices especially when they are linked to certain technological aspects.

Similarly, Morley and Hazas (2011) in their attempt to investigate occupant-related variations in energy consumption of homogeneous samples of households, developed a framework based on practices as a structure to relate details of micro-variations to a macro-level understanding of the dynamics of energy demand. They also argue that qualitative data on user practices need to be complemented by micro-level energy profile data in order to explain the aggregate levels of energy consumption. Finally, they suggest that it is easier to understand and interpret variations in domestic energy consumption through such a framework and, by extension, to challenge the existing view that this is mainly due to differences of individual behaviour.

Studies with a practice theory approach have mainly focused on domestic settings, but there are few examples in offices and purpose-built research buildings. Palm and Darby (2014) explore how a practice theory approach can improve the understanding of energy use in a research lab and a passive house setting to lead into energy savings. They show how the tight configuration of technologies and the meanings associated with scientific activity preconfigure practices and overwhelm energy considerations in research laboratories. The case is reversed in the residential setting, where occupants more easily adapt their practices to the passive house environment. Findings indicate that to reduce energy consumption in buildings of a special use such as research labs, there is a need for further consideration of the ways in which scientific research is practiced from the design to the operation and maintenance stage.

Table 2.5 Key empirical studies on energy use with a social practice theory perspective identified for this research.

Author	Study title	Target	Methodology	Region
		Domestic studies		
Behar (2015)	A socio-technical perspective on ventilation practices; Design, everyday life and change	Ventilation practices	- Interviews - Prompting activities - Walkthroughs - Photography - Document review	United Kingdom
Foulds *et al.* (2013)	Investigating the performance of everyday domestic practices using building monitoring	Domestic practices	- Building monitoring (Temp, RH, CO_2, Electricity) - Interviews - Planned observation of key events	United Kingdom
French (2011)	Comfort, control and change: occupant control and the socio-technical construction of thermal comfort in lower socio-economic Argentine dwellings	Thermal comfort	- Building monitoring (Temp, RH) - Comfort field studies - Interviews	Argentina
Gram-Hanssen (2010a)	Residential heat comfort practices: understanding users	Water, electricity and heat comfort practices	- Interviews	Denmark
Gram-Hanssen (2010b)	Standby consumption in households analysed with a practice theory approach	Standby electricity consumption	- Interviews	Denmark
Hargreaves *et al.* (2010).	Making energy visible: A qualitative field study of how householders intract with feedback from smart energy monitors	Electricity consumption	- Interviews	United Kingdom
Morley and Hazas (2011)	The significance of difference: Understanding variation in household energy consumption.	Electricity and gas consumption	- Interviews - Electricity monitoring	United Kingdom
Strengers (2010)	Negotiating everyday life: the role of energy and water consumption feedback	Energy and water consumption	- Interviews - Walkthroughs	Australia
Sweeney and Kresling (2013)	Energy saving behaviours: Development of a practice-based model	Energy saving at home	- Focus groups	Australia
Topouzi (2015)	Occupants' interaction with low-carbon retrofitted homes and its impact on energy use	Energy consumption	- Energy audits and energy assessment surveys, fabric tests - Building monitoring (Temp, RH, CO_2, Electricity) - Questionnaire surveys - Interviews - Focus groups - User diaries	United Kingdom
		Non-domestic/ Mixed studies		
Hargreaves (2011)	Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change	Pro-environmental behaviour	- Participant observation - Interviews	United Kingdom
Morgenstern (2016)	Understanding hospital electricity use: an end-use(r) perspective	Electricity consumption	- Half-hourly electricity data - Monitoring of equipment and occupancy schedules - Lighting and	United Kingdom

			appliances audit - Walkthroughs - Interviews - Analysis of policy documents	
Palm and Darby (2014)	The meanings of Practices for energy consumption - a comparison for homes and workplaces	Energy consumption	- Interviews - Indoor temperature measurements	Sweden
			- Interviews - Observational material - Surveys - Electricity sub-metering	United Kingdom

Another set of studies that use a socio-technical framework with insights from social practice theory comes from the research of French (2011), Behar (2015) and Kuijer (2014). French (2011), examines the physiological, behavioural and psychological dimensions of thermal comfort by looking at thermal performance and comfort perception in lower socio-economic houses in Argentina. His study highlights the fact that comfort is a socio-technical construct and demonstrates how the built environment configures it through scripting expectations and thermal lifestyles. In terms of methodology, the use of indoor conditions monitoring (temperature and humidity) and comfort field studies complement his interview data, thereby providing a holistic understanding of comfort practices in the studied setting.

Behar (2015) drew upon Gram-Hanssen's (2010b) analytical framework to examine domestic ventilation practices and how they may be enabled and constrained. Using a case study approach and qualitative methodology she points out that ventilation activities do not always follow the design intent and the process of change can be slow and unpredictable. Based on interviews both with designers and users she concludes that designers lack the understanding of household practices where incompatible or inflexible technologies are introduced that cannot deliver the intended energy savings. Finally, she asserts that focus needs to be shifted in the design, construction and handover building phases since practices can be shaped during these early stages.

Another study using a practice orientation is Kuijer's (2014) doctoral thesis, which examines how practices instead of interactions can be a unit of analysis for approaches to sustainable design. Through empirical studies of bathing and indoor heating practices she argues that a practice-oriented framework can be more effective in addressing issues of rising energy consumption compared to other frameworks on account of four key characteristics: a) the attention to history and diversity of the practice under analysis; b) the focus on improvisation and experimentation; c) bodily performances being the focus of design; and d) the drive towards open design.

Among the above-mentioned studies there are two analytical streams in terms of the version of practice theory followed. Foulds *et al.* (2013), Palm and Darby (2014), Behar (2015) and Topouzi (2015) follow Gram-Hanssen's (2010b) theoretical framework (Figure 2.2) while French (2011) and Kuijer (2014) base their analyses on Shove and Pantzar's (2005) version of practices (Figure 2.1).

The orientation of most of the studies towards domestic rather than non-domestic settings is clear. In addition, in some cases (French 2011, Kuijer 2014, Behar 2015) the focus is on a specific practice e.g. ventilation, heat comfort, bathing while in other the focus shifts in the interaction between a set of domestic (Hargreaves *et al.* 2010, Topouzi 2015, Foulds *et al.* 2013) or workplace practices (Palm and Darby 2014). A methodological tendency towards the combined use of building and energy monitoring, along with interviews and observations is featured in Foulds *et al.* (2013), French's (2011) and Gram-Hanssen's (2010a) studies. By adopting a mixed methodological approach, they demonstrate its potential to track practice change over time, reflect the bundling of practices with energy use and help their practical interpretation in policy.

2.4. Reconsidering comfort and consumption

Although there is much research done on the 'ideal' comfort conditions, the specification of thermal comfort is one of the most controversial issues in buildings science (Nicol et al. 2012). One generally accepted definition of thermal comfort is that it constitutes *'that state of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation'* (ANSI/ASHRAE 2013, p.4). This definition, however, has been interpreted through different theoretical perspectives, which range from the technical, psychological, sociological and socio-technical literatures. Whilst the technical approach focuses on physiological responses to certain temperature conditions achieved through technological means, the psychological approach takes into account the individual's stimulus-response mechanism and the sociological approach emphasises contextual and social structures. Finally, the socio-technical approach recognises the interplay between each of the above elements, networked together to account for socio-cultural regimes, technological configurations and individual agency.

This section sets out an account of the two mainstream approaches to comfort—the heat balance approach and the adaptive approach—and discusses its notion through a socio-technical perspective. It then outlines relevant socio-technical and practice-oriented empirical studies in domestic and non-domestic settings.

2.4.1 The comfort controversy: Heat balance vs. adaptive approach

Technically oriented studies focus on an interpretation of comfort as a physiological construct that is influenced by certain environmental parameters; given its 'standardised' nature, optimisation can be achieved through technological arrangements. This tradition has been dominated by two approaches: a) the heat-balance approach and b) the adaptive approach. The heat-balance model, rooted in physics and human physiology, relates thermal sensation to the balance between heat generated by the body's metabolic activity to that transferred away and into the environment. This model results in a great number of thermal indices (Auliciems and Szocolay 2007), the most important of which is the Predicted Mean Vote (PMV) developed by Fanger (1970) in the 1970s. The PMV model is based on a mathematical equation of human physiology that is calibrated against sensation votes reported by people in climate chamber conditions (CIBSE 2006, pp.1-7). It contends that the main physical parameters (which constitute the thermal environment affecting a person's sensation of warmth) include air temperature, radiant temperature, air speed along with personal parameters, such as the metabolic heat production (related to the activity undertaken) and clothing level. This approach has gained widespread recognition and has been adopted by national and international comfort standards regarding the regulation of the indoor conditions of air-conditioned buildings such as those used by ASHRAE[2] (Fanger 1973) and ISO (2013).

As a response to the optimum conditions suggested by the heat-balance model, a series of field studies took place, which demonstrated that people are satisfied with a wider range of temperatures. They indicated that building users' evaluation of the indoor thermal environment is context-dependent and can vary with time (Humphreys 1995, Humphreys 1997, Brager and de Dear 1998). Hence, the adaptive approach to comfort emerged as an alternative to the conventional comfort theory in the mid-1970's. This approach posits that by giving people more control over their thermal environment and keeping indoor temperatures close to outdoor temperatures can improve comfort and reduce energy consumption. In this way, *'if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'* (Nicol and Roaf 2005, p.340). It also moved beyond the physics of the body acknowledging that *'thermal perception in "real world" settings is influenced by the complexities of past thermal history and cultural and technical practices'* (Brager and de Dear 1998, p.93).

Looking at an example of existing comfort standards for an office setting, the PMV model suggests a temperature range between 21°C and 23°C in winter and 22°C to 24°C in summer, while humidity values ranging from 40-70% are generally acceptable (CIBSE 2006). In the case of the adaptive comfort model, there are no fixed standards, and the width of the comfort 'zone' depends on the balance between the possibilities for change and the actual temperatures achieved (Nicol and Humphreys 2002). When there is no possibility of changing clothes, activity or air movement levels, the comfort zone may be as narrow as ± 2°C from the comfort range suggested above; when these opportunities are available, however, it becomes considerably wider (ibid). In the adaptive approach the building is expected to provide opportunities for change in order for occupants to adjust the conditions.

There is no consensus about which comfort model should be generally applied. As things stand, the PMV model has been developed for air-conditioned buildings, while the adaptive model is mainly applicable to naturally ventilated buildings. Advocates of the adaptive approach argue that the inability of the laboratory based heat-balance models to take into account contextual elements, culture and behaviour can make them unduly normative (Darby and White 2005). Comfort standards enshrined in

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[2] ASHRAE stands for the American Society of Heating, Refrigerating and Air-Conditioning Engineers. British standards are set by CIBSE (Chartered Institution for Building Service Engineers).

these models were initially developed for buildings controlled by centralised HVAC systems and their universality often leads to the normalisation of these conditions across building types, climates and populations (Brager and de Dear 1998). As Humphreys (1995, p.10) suggests:

> *'If a building is set, regularly at, say, 22°C…(and)…if enough buildings are controlled at this temperature, it becomes a norm for that society at that period of its history, and anything different is regarded as "uncomfortable".'*

2.4.2 Thermal comfort as a socio-technical construct

Comfort and, in particular, the practice of seeking (thermal) comfort through the use of heating, air-conditioning or natural ventilation is not only related to physiological and psychological factors, but it is also a socio-technical construct (Wilhite *et al.* 1996, Shove 2003, Gram-Hanssen 2010a, Hinton 2010, Foulds *et al.* 2013). As such, it is no longer seen a result of individual preference or technically specified conditions, but as a collective practice influenced by technologies and spatial configurations, social situations and histories associated with the use of certain objects. According to Chappells and Shove (2005, p.34) comfort is a *'provisional and always precarious'* socio-cultural construct that could unlock unsustainable social and technical trajectories if it would be considered as such. The difference between the two theoretical positions—the one that wants to see comfort as a standardised condition and the other that looks at it as a sociocultural achievement—in terms of their implication in policy and practice are outlined in Table 2.6.

Table 2.6 Contrasting concepts of comfort and what they mean for policy and practice (Chappells and Shove 2005, p.34).

	Comfort as a universally definable state of affairs	**Comfort as a socio-cultural achievement**
Theory of comfort	Heat balance model	Historically and culturally specific experience
Characteristics of comfort	Definable universal condition	Social phenomenon
How to provide comfort	Deliver specified comfort conditions	Provide opportunities in which people make themselves comfortable, whatever that means
Policy response to the challenges of climate change	Develop and promote technical fixes and so increase the efficiency with which comfortable conditions are provided	Debate and explore diverse meanings of comfort; construct new and varied infrastructures, contexts and experiences of comfort

An influential approach has been that of Shove (2003), where comfort is viewed as a socio-historical artefact. She explains how its meaning has changed historically, being subject to the proliferation of indoor climate technologies (mainly the appropriation of air-conditioning) and the universal dominance of technical comfort standards. The use of air-conditioning became commonplace both in houses and in offices in order to achieve certain temperatures considered comfortable. She contends that people do not consciously shape comfort expectations but that these are part of a process, which entails a range of activities that people understand to constitute 'normality'. In that sense, design standards are 'self-fulfilling' because they construct, reify and reproduce concepts and conventions of comfort and *‘whether or not they can achieve it, people increasingly expect and have become accustomed to the same conditions indoors, in cars, offices, hotels and shops’* (Chappells and Shove 2005, p.37).

Another socio-technical position is one of comfort as an achievement, which embraces engagement and interaction between people and thermal conditions, systems and technologies. It shifts from the automatic and standardised comfort assumption to a view that individuals have the agency to manage comfort through a dynamic, integrated and participatory approach. This approach points towards an updated meaning of comfort where the building and the user are dynamically connected with technologies and fabric to enhance its adaptive and participatory aspect (Cole *et al.* 2008). This emphasis on the agency of individuals to control and change their comfort practices challenges Shove’s consideration of people being locked in unsustainable patterns of consumption and points towards the interactive and dynamic nature of socio-technical systems (Spaargaren 2005).

This thesis adopts a socio-technical perspective of comfort wherein it is considered the result of socio-cultural regimes, technological configurations and individual agency. These elements co-evolve over space and time given the right stimulus. As Hinton (2010, p.40) posits, comfort is no longer seen an attribute but as an achievement that *‘may involve a range of technologies (…); a range of spaces (…); a range of social situations (…); and a range of objects, which may be associated with particular social histories (and futures) of acquisition and divestment’*.

2.4.3 Empirical studies of comfort

Existing literature has looked at the notion of comfort as a socio-technical construct both in office and domestic settings. The most relevant studies to this thesis are discussed in this section and provide information on how the level of control and existing technological infrastructure, the organisational culture, and socio-cultural considerations influence temperatures that are considered as comfortable to work and live in.

A study conducted between homes and offices in Finland by Karjalainen (2009) indicated how people tend to have lower comfort levels—and thus feel hot and cold more often—in their workplace as compared to their homes. The perceived level of control, which was much lower in offices, and the lack of knowledge on the heating and ventilation systems were found to be the main reasons for this difference. The impact of control in comfort levels in the workplace has also been pointed out by other studies. Wagner *et al.* (2007), in a field study of thermal comfort in naturally ventilated office buildings in Germany, found that actual comfort range was much wider compared to the temperature range set for buildings with A/C. In particular, comfort temperatures were higher especially in winter where occupants had a higher control over temperature. Similarly, Raja *et al.* (2001) confirmed that the use of controls are related to thermal sensation and their availability and appropriate use is a significant part of adaptive behaviour that can improve both building performance and occupant satisfaction.

There are also contextual factors and meanings attached to comfort that can influence satisfaction with indoor climate and in different environments (Brager and de Dear 1998). Differences in comfort temperatures between homes and offices have been reported by Oseland (1995) in a study where he observed neutral temperatures of the same participants in their home, office and a climate chamber. He found that participants felt warmer in their home than their office and warmer in their office than a climate chamber even with identical indoor temperatures, clothing and activity levels. Thus, the context and related comfort requirements dictated comfort expectations instead of the environmental conditions. The socio-cultural meanings attached to comfort practices are evident in an ethnographic study by Wilhite *et al.* (1996) that compares space heating, lighting and water heating between Japan and Norway. Indoor comfort practices were found to be more frugal in Japan than in Norway where using space heating and lighting for longer hours and in more rooms was considered as a sign of 'coziness' and social significance. On the other hand, space cooling in Japan using air-conditioning saw a great increase in popularity since it became a symbolic indicator of socially appropriate indoor climate and, in a more general sense, of a suitable home.

Looking at comfort studies in the workplace, Cole *et al.* (2008) discuss the need to re-contextualise the notion of comfort from an individual to a collective experience. Their study stresses the fact that in commercial buildings 'inhabitants' may have a less degree of control compared to residences but the social setting creates more interactions and interdependencies. The sense of collective responsibility and agency for the control of heating and cooling systems as well as the need to improve interaction, comprehension and engagement with the buildings' systems are some of the main issues highlighted that call for further consideration.

Practice theory as a theoretical and analytical framework has been used by Gram-Hanssen (2010a) to understand how (residential) comfort practices are collectively structured through habits, technology, knowledge and meanings. Going through the impact of each element in the heating regulation practice, she shows how the layout of the house and the heating and ventilation system prefigure certain usage patterns. She then remarks on the influence of experiences gained in the workplace and childhood memories in shaping heating and cooling habits and the similar effect of knowledge gained through feedback (bills and taxes), environmental campaigns and television programmes. Next, the importance of meanings attached to the environment, money saving, technical achievement and homeliness are discussed. She concludes by pointing out the advantage of practice theory to understand heat comfort practices and explains how the variations between different households are due to their different socio-technical configurations.

These studies point to several further considerations, such as the collective nature of comfort and how it varies due to different socio-technical configurations and between identical or different settings (e.g. the office and home), the symbolic meanings that it carries and the social significance of certain thermal comfort standards, associated habits and related equipment. Furthermore, the sense of collective agency and responsibility, the hierarchies and social dynamics as well as the opportunities that the organisational structure offers in relation to workplace comfort and energy use are issues that could be further investigated in practice-oriented energy and buildings research.

2.5. Summary

This chapter situates the current study within its theoretical and empirical context. It looks at energy use behaviour and comfort through different theoretical perspectives, pointing out the benefits of a socio-technical approach. It then introduces social practice theory, setting out the theoretical and analytical framework of the thesis. Through a review of socio-technical literature it places comfort and energy consuming daily practices within a larger socio-technical and socio-cultural system where agency is distributed throughout. As adopted from Gram-Hanssen (2010b), practices are understood as dynamic combinations of 'doings' and 'sayings' that are held together by habits, technologies, knowledge and engagements. Next, a literature review of empirical studies indicated the usefulness of building monitoring along with qualitative enquiry to track changes in the performance of practices through time and pointed out the lack of studies in non-domestic settings. Another useful consideration was how meanings associated with certain types of buildings (such as research labs and lower socio-economic dwellings) can prefigure practices related to energy consumption, comfort and expectations for certain lifestyles. Even though comfort and consumption are well theorised and have been the subject of numerous studies, there seems to be a lack of empirical studies looking at ways to influence and change these practices and, in particular, in non-domestic settings.

3. Transforming energy use practices in the workplace

3.1. Introduction

The previous chapter reviewed the two dominant disciplinary perspectives looking at energy use behaviour-the individualistic and the socially oriented. It then introduced social practice theory as an alternative socio-technical approach to understanding users' practices and discussed their configuration based on a combination of social and material elements—routines, technologies, knowledge and meanings. This chapter discusses the literature on changing practices with a focus on the workplace setting. The impact of behavioural interventions within organisations and universities is examined from both a practice theory and social psychology perspective. Section 3.2 demonstrates the potential of raising awareness on energy consumption in the workplace and its impact on energy savings. It then outlines different types of interventions with a focus on feedback provision. The next section (3.3) sets out findings from empirical studies that examine behavioural change through feedback in universities, which is considered useful for understanding the impact of social and contextual factors in the particular setting. The last section (3.4) comments on how change in practices can occur, and investigates why some people defect from certain practices and how passive practitioners can be recruited.

3.2. Energy use in the workplace

Non-domestic buildings currently account for approximately 18% of the total greenhouse gas emissions in the UK (DECC 2015). They constitute a significant part of the existing building stock and vary in typologies, sizes and uses, forming a complex and heterogeneous sector. At a European level, the non-residential sector is mainly composed of retail and wholesale buildings (28%); offices are the second largest category group (23%) with educational buildings following (17%), which corresponds to approximately a fifth of the total non-residential floor-space (BPIE 2011) (Figure 3.1). This sector presents a significant carbon saving potential and is expected to achieve a 35% reduction in carbon emissions by 2020 and a 75% by 2050 based on the extent to which efficiency measures will be successfully applied (Low Carbon Innovation Coordination Group 2016). Among the wide range of areas in which energy savings can occur—such as efficient systems and technologies, energy audits and use of advanced BMS systems—occupant engagement constitutes a significant determinant (CSI and ECI 2012). As stated in the latest IPCC report, behaviour and lifestyle changes can cause up to a tenfold difference in office buildings with the same climate and building functions (Lucon et al. 2014).

Energy use in the workplace is mainly related to the regulation of indoor thermal conditions through the use of the existing heating, cooling and ventilation systems, the use of office equipment such as computers, printers and photocopiers and the use of lights (Staats *et al.* 2000, Cox *et al.* 2012). Røpke (2004) states that the office configuration in terms of room size and furnishing, provision of daily meals and beverages, business trips and facilities related to indoor sport activities integrated in the working hours could also be considered as additional forms of consumption.

Figure 3.1 A picture of the European building stock (BPIE 2011).

Although the opportunities to save energy in the workplace are similar to the domestic setting, it constitutes a totally different context given that its potential for and barriers towards energy savings are linked to its inherent social, material and organisational characteristics. A key point is that employees usually do not have the same financial incentive to save energy at work as they do at home (Carrico and Riemer 2011). The motivation to engage in energy efficient patterns is therefore different and mainly relies on corporate and social responsibility (European Environment Agency 2013). In addition, the fact that in many cases the facilities and equipment are shared has been found to influence motivation towards change given the small level of control that users have over them (Bedwell *et al.* 2014). On the other hand, their institutional character can exemplify patterns of desirable behaviour, their communal nature allows their occupants to interact and develop social norms and the fact that they constitute single sites with regular attendance make them effective communication channels, thus adding to their efficiency potential (Cox *et al.* 2012). Even though home and workplace are two different settings, a crossover between initiatives might exist. For example, Røpke (2004) suggests that the consumption that occurs in the workplace and at home is largely intertwined and work-related factors can influence domestic consumption.

As a response to the research evidence that highlights the impact of occupants on the energy use of buildings (CarbonBuzz 2012), a series of programmes and initiatives that aim to raise awareness of energy consumption (predominantly at home and subsequently in the workplace) begun to get implemented. The array of behavioural change interventions available in literature is broad and their impact is documented through a range of studies in organisations such as retail buildings (Christina *et al.* 2014), offices (Hargreaves 2011, Galvin and Terry 2016) and universities (Matthies *et al.* 2011, Gul and Patidar 2015). The general categories that efficiency initiatives fit are communication and engagement (e.g. feedback, training, prompts), economic incentives and disincentives (e.g. subsidies, taxes, bonuses), and regulatory measures (e.g. general laws and rules, dynamic versus regulated energy prices) (European Environment Agency 2013). Of these, the first category and, in particular, feedback on energy consumption will be further investigated in this study.

Existing literature on the design and impact of behavioural change initiatives in the workplace has been dominated by information-giving interventions and a rationalistic approach (CSI and ECI 2012, Staddon *et al.* 2016). It comes predominantly from the discipline of social and environmental psychology with only a few examples documenting a socio-technical approach (Chatterton 2011) (Table 3.1). This dominant PTEM perspective (see Section 2.2.2) has been critiqued for its short-term effects and narrow theoretical view (Dam *et al.* 2010, Murtagh *et al.* 2013). However, some of these studies—with a focus on energy use feedback—are reviewed in Section 3.4 and the key 'intervention functions' of the Behaviour Change Wheel framework (Michie *et al.* 2014) are presented in Table 3.2 as it constitutes *'one of the most rigorous and coherent frameworks to date'* (Staddon *et al.* 2016, p.33). They were considered relevant for this thesis, as they account for both physical and social opportunities and provide insights on social and organisational elements of energy saving interventions in office-type workplaces.

Table 3.1 Summary of the different conceptualisations of agency and related types of intervention into comfort practices that are associated with social, technical and socio-technical approaches (Hinton 2010, p.40).

Disciplinary view	Agency	Potential types of intervention
Psychological	Individuals act primarily based on their attitudes and values.	Awareness raising and information-based, delivered to individuals who are broadly considered to act in isolation.
Sociological	Individual agency is influenced by social and cultural structures.	Awareness raising and information-based delivered to individuals in social groups and possibly incorporating vernacular or folk knowledge.
Technical	Individuals are relatively passive; technologies of different kinds are relatively active.	Interventions focus on technologies within the home, and their optimal control to produce comfort.
Socio-technical	Both individuals and technologies are active, and arranged in socio-technical assemblages; agency is distributed across different levels, form the socio-technical regime to the household or the workplace, including practices themselves.	Interventions focus at multiple levels to attempt to drive change within the socio-technical regime.

The workplace domain offers a promising setting to examine occupants' energy consumption and its potential for change, but has received little attention from a practice theory perspective (Hargreaves 2011, Shove 2014). For savings to occur, interventions need to be aligned with its technical, social and organisational parameters (Bedwell *et al.* 2014, Galvin and Terry 2016). As Breukers et al. (2011, p.2176) point out, *'a conceptualisation of energy behavioural change is needed as nested within and interacting with broader social processes'.* It is important to consider workplaces as socio-technical regimes and change interventions to be designed accordingly. Key elements to consider are the financial incentive to save energy at work, the impact of social dynamics and the setting's organisational structure and identity. Finally, the relationship between practices at home and in the workplace practices should also be considered.

Table 3.2 Behavioural change intervention functions (Michie *et al.* 2014, p.111).

Intervention function	Definition
Education	Increasing knowledge or understanding e.g. by providing relevant information.
Persuasion	Using communication to induce positive or negative feelings or stimulate action e.g. by using imagery.
Incentivisation	Creating expectation of reward e.g. using prize draws.
Coercion	Creating expectation of punishment or cost e.g. raising financial cost of an activity.
Training	Imparting skills through advanced training.
Restriction	Using rules to reduce the opportunity to engage in the target behaviour (or to increase the target behaviour by reducing the opportunity to engage in competing behaviours).
Environmental restructuring	Changing the physical or social context e.g. providing on-screen prompts for inducing certain behaviours.
Modelling	Providing an example for people to aspire or imitate.
Enablement	Increasing means/reducing barriers to increase capability or opportunity e.g. behavioural support or provision of relevant medication, tools, etc.

3.3. Behavioural change initiatives in the workplace: effect of energy consumption feedback

3.3.1 Energy consumption feedback

Feedback is considered a necessary element of effective learning and has been broadly used in behavioural change initiatives. Its ability to raise awareness on energy consumption and change energy use patterns and practices has been documented by several studies in both domestic (Darby 2010, Hargreaves *et al.* 2010) and non-domestic settings (Coleman *et al.* 2013). There are several types of energy consumption feedback which can broadly be categorised as either direct, indirect, inadvertent or as energy audits (Darby 2006) (Table 3.3). Direct feedback can be provided through venues such as RTDs, smart meters and cost plugs. Indirect feedback is related to bills sent by the utility companies. The difference between these two types of feedback is that while indirect is most likely to give a general account of what is happening to the heating load, *'instantaneous direct feedback gives a more clear picture of smaller end-uses'* (ibid, p.4). Finally, inadvertent feedback could be related to community projects and social learning, while energy audits could be carried out by the consumer himself, an energy surveyor or take the form of an energy certificate.

Policies adopted in recent years support a change in consumers' consumption behaviour and the rollout of smart meters and energy (electricity and gas) utilisation feedback through user displays is one of the technologies aiming to increase awareness and control over energy use and lead to the reduction of its demand. The mass roll-out of these technologies in the UK is due to take place between 2015 and 2020, with the installation of smart devices in approximately twenty-three million homes and two million businesses (DECC 2013). The increased potential of such a measure has triggered research looking at its implications to energy policy and the consumer-utilities relationship

(Darby 2008); smart meters interface and home-owners engagement (Darby 2010, Hargreaves *et al.* 2010); and the impact of feedback on energy use behaviour over the medium and long term (Dam *et al.* 2010). Despite the range of existing studies, there are gaps in knowledge regarding the behavioural processes through which energy savings are achieved over time, particularly in non-domestic settings.

Table 3.3 Types of feedback on energy consumption (Darby 2006, p.8).

Types of feedback	

Direct feedback
Learning by looking or paying
	• Direct displays
	• Interactive feedback via a PC
	• Smart meters
	  o Operated by smart cards
	  o Two-way metering
	• Trigger devices/consumption limiters
	• Prepayment meters
	• Self-meter reading
	• Meter reading with an adviser
	• Cost plugs

Indirect feedback-raw data processed by the utility and sent out to costumers **Learning by reading and reflecting**	• More frequent bills based on meter readings • Frequent bills based on readings plus historical feedback • Frequent bills based on readings plus normative feedback (comparison with similar households) • Frequent bills plus disaggregated feedback • Frequent bills plus offers of audits or discounts on efficiency measures • Frequent bills plus detailed annual or quarterly energy reports
Inadvertent **Learning by association**	• New energy-using equipment • Distributed renewable energy generation • Community energy-conservation projects and the potential for social learning
Energy audits	• Undertaken by a surveyor on the client's initiative • Undertaken as part of a house sale/purchase or other mandatory survey • Carried out on an informal basis by the consumer

Discussing the future of feedback, Darby (2006) highlights the need to carefully consider a variety of elements when planning interventions. Such elements include the socio-material context, the scale and timing of usage related to the target behaviour or technology, synergies between feedback and other information and the timing of the intervention itself. For example, households require different treatment compared to non-domestic buildings. In addition, billing or other periodic feedback is better when looking at long-term effects (e.g. the effect of heating system replacement), while RTDs are better for targeting behaviour at the present time. Hence, although feedback is an intervention carrying much potential, it requires careful planning and consideration of contextual and technical parameters.

3.3.2 Empirical studies of behavioural change initiatives in the workplace

This section discusses studies that look at the impact of energy saving initiatives in the workplace from a psychological and organisational theory perspective. Despite the fact that energy behaviours in individualistic studies are highly diverse, they are also patterned in systematic ways based on the size of an organisation, its sector, and its local and national context (CSI and ECI 2012). Thus, a review of findings from such studies provides useful insights on social and contextual parameters that might influence workplace practices. First, interventions in organisational workplaces that have been found to be successful will be outlined followed by findings from studies that investigate the effect of feedback within universities.

Staddon et *al.* (2016) examined different types of behavioural change interventions for workplaces through an extensive literature review and suggest that those creating social and physical opportunities for employees to save energy are the most successful. They point out that the communal nature of the workplace demands a scrutinising approach to understand the effect of social dynamics that are a key parameter towards change. Specifically, interventions that promote employee 'enablement' through increasing the means for change and reducing barriers to it (e.g. access to behavioural support), 'environmental restructuring' through changes in the physical or social context (e.g. on-screen prompts) and 'modelling' of intended behaviours were found to have the biggest impact on changing behaviours. Finally, interventions using 'coercion' through expectations of punishment or cost, 'restriction' of the target behaviour through official rules and the provision of 'training' to impart certain skills were considered to carry the most potential for further development.

A response from policy makers was also identified in literature. A report by the UK's Department of Energy and Climate Change (CSI and ECI 2012) reviewed existing government policies and organisational strategies to improve energy efficiency behaviours in the workplace. It suggested that making energy use visible through effective environmental management systems, visible to senior management as well as employees, is an important first step for energy efficiency to become a strategic objective. Policies should encourage monitoring and reporting practices and combine the energy use messaging with a broader eco-friendly agenda. Another report on the impact of workplace initiatives from the Scottish Government (Cox *et al.* 2012) pointed out the need to consider the issue of behaviour change in the workplace through a perspective where 'material inputs' are aligned with individual and social factors in a holistic and coherent programme. Thus, a combination of educational activities, relevant changes in organisational policies and infrastructure upgrades are important elements for a balanced and sustained change in behaviours. The most successful studies were the ones that managed to build shared individual and organisational values through a combination of employee involvement and senior management commitment (ibid). In addition, elements of successful projects were found to include the involvement of staff at the earliest possible stage of the intervention and joining up different kinds of low carbon activities (e.g. waste management and savings from electricity use and transport).

With regards to behavioural interventions in universities, past research has indicated savings through feedback on energy use of approximately 4-8% for electricity and 1-6% for heating (Table 3.5). Matthies et al. (2011) suggest that energy reductions in university buildings can occur through changes in the heating, cooling and ventilation practices of the staff, which is made possible through the provision of information based on each group's characteristics. A pre-survey that tailored information on an empirical basis is deemed necessary to improve the relevance of the intervention programme. In another study looking at the effect of individual feedback in desk electricity consumption, Murtagh *et al.* (2013) found a small but statistically significant reduction in energy use, but point out that was only sustained short-term. Although participants engaged with feedback during the field trial, the absence of motivation to effect change beyond that of energy reduction was evident and quickly led them back to their normal patterns. Carrico and Riemer (2011) challenge the importance of economic incentive by trialling the effectiveness of energy use feedback and peer influence in settings where variable pricing schemes may be politically unpopular, such as universities. Collective feedback using bulletin boards combined with individual feedback on thermostat settings and the use of heating resulted in a reduction of 7% while peer education reduced energy use by 4%.

Table 3.4 Studies on behavioural change using feedback in universities identified for this thesis.

Author	**Target behaviour**	**Intervention type**	**Energy savings**	**Intervention functions**
Carrico and Riemer (2011)	Electricity use	Feedback Peer education	7% 4%	Education Persuasion
Dixon *et al.* (2015)	Electricity use	Comparative feedback	6.5%	USA
Matthies *et al.* (2011)	Electricity use and heating	Prompts Commitment	Electricity 8% Heating 1%	Germany
Murtagh *et al.* (2013)	Electricity use	Feedback	<1.5%	United Kingdom
Staats *et al.* (2000)	Heating	Feedback	6%	USA

Despite the fact that a considerable investment has been made in the promotion of behavioural change strategies by national and local authorities, utilities and consumer associations, its effect on changing behaviours has been moderate (Lopes *et al.* 2012). Studies suggest that the impact of feedback cannot be sustained in the long-term and further research is required. In addition, studies conducted in a university context indicate a potential for savings, but found a lack of motivation to support sustainable patterns of consumption. The potential for energy savings from behavioural change and the identified implementation barriers point towards the need for a differentiated approach with regards to the design, application and aftercare of relevant initiatives (Chatterton 2011, European Environment Agency 2013, Janda 2014). Furthermore, new research *'on the factors at the organisational level that promote or inhibit the greater uptake of energy-saving technologies and practices, as well as the division of responsibilities surrounding decisions to enact change'* is suggested (Axon *et al.* 2012, p.470).

3.4. Transformation of practices

Practices are repetitive—and not static—activities while innovation and change are embedded in their nature. Being recognisable entities—like cleaning, cooking and working—they set out the framework of *'a secure and liveable everyday life'* (Gram-Hanssen 2008, p.1182) without necessarily being conducted with a great degree of awareness or reflection from the side of the practitioners. However, their performance is not always the same but varies as their elements can be *'differentially distributed among and observed by its practitioners'* who *'adapt, improvise and experiment'* (Warde 2005, p.141). These variations are also the seeds for their change. The dynamic, progressive and changeable nature of practices raises two types of questions: a) how can change occur in a practice? and b) why do certain practitioners take up or withdraw from practices compared to others that remain stable?

Apropos to the first question, Shove and Pantzar (2005, p.45) note that for a new practice to emerge the *'relations between material objects, associated images and forms of competence are of defining importance'*. Thus, new practices are the result of a differentiation in the configurations between existing elements, or new ones that occurred in combination with those already existing. Looking at the re-emergence of Nordic walking in Finland, they explain how the components of walking as a habit, the availability of walking sticks as material infrastructure and the meanings of fun and health are connected to reinvent the practice at a certain point in time. They point, however, to the importance of the context and already existing routines, as practices tend to be *'home-grown'*, consisting of new and old ingredients interwoven *'against the backdrop of previous, related and associated ways of "doing"'* (ibid, p.62).

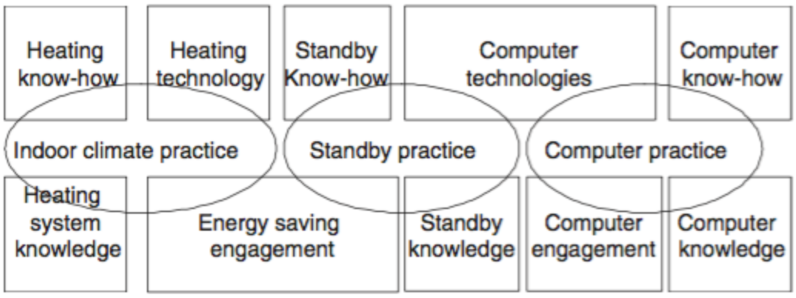


Figure 3.2 Illustration of three practices and the elements holding each of them together (Gram-Hanssen 2011, p.62).

Warde (2005) offers another vital insight on the issue by discussing how everyday life is a synthesis of different practices and that when these practices meet they affect each other. This view has been further developed by Gram-Hanssen (2011) who comments on how energy consumption is a part of several practices expressed through different, but also shared elements; hence, changes in one practice can have implications for the others. For example, Figure 3.2 illustrates how a change in engagement towards more energy saving standby practices has an impact on other practices such as regulating the indoor climate or working with the use of a computer. By exploring transition and domestication theories she places the emphasis on technologies as *'an inevitable element in holding practices together (…) and bringing changes'* (ibid, p.62). She discusses how technologies co-evolve with social elements at various levels resulting in technological changes in major sectors—housing, transport, etc.—and how when people interact with technologies on the micro-scale, internalise and domesticate them in their daily routines. She then suggests that practices could change through changes in the engagement of individuals that might come from the introduction of new technologies or knowledge on how to use them correctly.

Another point for consideration when thinking of change in practices is the influence of the social dynamics and the various symbolic meanings associated with them. Transitioning from the domestic to the office setting, Hargreaves (2011) observed the impact of a behavioural change initiative on existing workplace practises. He found that deep green environmental meanings would be *'dismissed as inappropriate in the workplace'* (ibid, p.89) and replaced by the issues of professional status and competence. The office members preferred to follow already well-established meanings related to energy saving rather than challenge them out of fear of underdelivering. This example suggests that *'environmental socialisation that practices bring about (or fail to), in which new social identities, interactions and relations are forged'* (ibid, p.96) are more resistant to challenge and change compared to skills and technologies. For Røpke (2009, p.2496), environmental considerations are usually missing in daily practices as the environmental impact *'is not embedded as an aspect of their meaning, and routines are not so easily called into question'*. In addition, the environmental relevance of scarcity of time is highlighted, given that in modern society, there is a tendency towards a high intensity of activities per unit of time, which is usually linked to high material intensity (Røpke and Godskesen 2007). Hence, to increase environmental awareness, relevant meanings within a practice need to be visible and serve as a symbolic indicator while not conflicting with other aspects of practices such as time efficiency.

But what happens to the various practitioners when a certain practice is to be promoted or banned and how is it that the uptake of certain practices varies between different people? Blue *et al.* (2016) used smoking as an example of an unhealthy practice, and discuss relevant processes of recruitment and defection. Similarly to Gram-Hanssen (2011) and Warde (2005), they point out that the success of such an intervention depends first of all on the good understanding of the alliances between the elements within the practice itself and other relevant practices, such as drinking alcohol or socializing. On the chances of someone becoming a practitioner, they clarify that it depends on: a) what the practice itself demands, b) previous life histories (know how) and c) resources (material elements) accumulated during one's lifetime. It is stressed however that *'the structuring of opportunities and access to requisite elements is not random but is instead closely linked to (…) "wider determinants" (contextual or structural conditions)'* (Blue *et al.* 2016, p.44). As such, the above elements *'are not evenly distributed across society'* and these socio-economic inequalities are the reason why it is easier for some people who have access to them to be recruited compared to others that would defect (ibid, p.44). This participation is not always sustained on the long term and practitioners defect due to loosing access to one or more of the interconnected elements.

To summarise the above, practices are not static performances but are subject to change. Transformation in practices comes as a result of the differentiation between their existing elements or newly occurring ones combined with those already in existence (Shove and Pantzar 2005). As practices are interconnected, changes in one can affect the other (Warde 2005, Gram-Hanssen 2011). Therefore, these alliances need to be considered in the design of change interventions as relevant practices might promote or block the circulation of certain practice elements. Finally, in terms of the uptake or defection of such interventions, the types of resources and commitments they command and their availability in the specified context need to be considered.

3.5. Summary

In this chapter studies investigating energy saving interventions and the effect of energy use feedback in the workplace were reviewed. It was pointed out that the majority of existing studies look at the design and effectiveness of behavioural change initiatives from an individualistic perspective, while there is a lack of practice-oriented empirical studies. The university workplace was identified as a promising but complex setting to save energy given its inherent social, technical and organisational characteristics. In looking at energy awareness interventions, energy use feedback was found to carry much potential even though studies suggested its long-term impact is low, while the expected savings are often not achieved. Accommodating a social practice theory perspective when looking at behavioural change initiatives could shed light on the meanings of energy saving for the various stakeholders and the elements that prevent further savings to be achieved.

4. Research design and methodology

'Our analytic ventures are a blend of strategic mindfulness and unexpected discovery.'
Lindlof and Taylor (2011, p.242)

4.1. Introduction

This chapter discusses the rationale behind the adopted research design and its methodological choices and is divided into seven sections. It starts by introducing the interdisciplinary perspective germane to architectural research (4.2) that is advocated by this thesis. In Section 4.3, the research is situated within an ontologically constructivist and an epistemologically pragmatic perspective, which calls for an inductive process of reasoning. The next section (4.4) discusses the theoretical foundation of this research in social practice theory and the analytical and methodological implications it portends. This is followed by an explanation of why a case study research design has been adopted (4.5) and how it was organised into two main stages: a) preparation, and b) fieldwork and data analysis. Section 4.6 reviews the mixed research methodology with its qualitative and quantitative data collection and analysis components. Participant observation and the interview coding process are explained in detail, as are the electricity audits, monitoring of thermal conditions and comfort diaries. Section 4.7 sets out the various stages of this research, including a brief account of the two pilot studies and main data collection phases. The case study selection criteria and the data collection protocol are outlined in Section 4.8. Finally, Section 4.9 considers the study's methodological limitations.

4.2. An interdisciplinary approach

In a general definition, architectural research can be described as an understanding of the built environment. Architecture is an *'ever-developing body of knowledge concerned with how we use space: how we dwell and occupy, establishing meaningful places and giving form to the world around us'* (Lucas 2016, p.8). Conducting research within the discipline of architecture is not a singular undertaking, but rather is as multifaceted as architecture itself. It often crosses disciplinary barriers to draw upon methods and theories of other fields that share an interest in the topic of the built environment, but from different perspectives.

In light of the fact that this study examines both the energy use and comfort of people, it benefits from a socio-technical perspective that utilises theories from sociology and engineering. As previously explained in Section 2.2.2, a socio-technical systems approach contends that technology and society are intertwined and physical infrastructure, things, people, institutions and their immediate physical and social context are considered as a system (Hinton 2010). However, due to the complexity and epistemological challenges it carries, focus tends to shift either towards the technical or the behavioural potential of energy efficiency, thereby creating gaps in performance and the holistic understanding of energy use in buildings (Berker and Bharathi 2012).

To address existing efficiency challenges realistically there is a need for a middle ground and a multidisciplinary spectrum (Moezzi and Janda 2014). In this vein, Sovacool (2014, p.2) advocates the need for *'more human-centred research methods, interdisciplinary collaborations and comparative analysis'*. Reflecting on the existing research gaps and methodological directions, this study follows an *interdisciplinary* path where both sociological and technical elements contribute to an understanding of energy use from the perspective of the user. The following sections show how this decision is applied to the study's practice theory theoretical framework and its mixed methods approach.

4.3. The research framework

To understand the research process employed in this study, it is important to break it down into its main components—the elements and key decisions that frame it. Groat and Wang (2013) explain how the conceptual framework within which methodology in architectural research is situated consists of five nested clusters (Figure 4.1). The outer frames refer to the theoretical position of the research while the inner ones refer to its practical considerations. The outermost cluster, called ontology, represents the worldview—the broad philosophical assumptions about the nature of reality, knowledge and being that provide the research context and inform the rest of the process (Creswell 2014). Next comes epistemology, or 'school of thought', which indicated the general theoretical perspective that influences research. Epistemology directs the nature of the questions asked and the mode of analysis used. Moving on the next level, methodology refers to the research design or study structure followed by methods or tactics that refer to the use of specific tools and techniques for data collection and analysis.

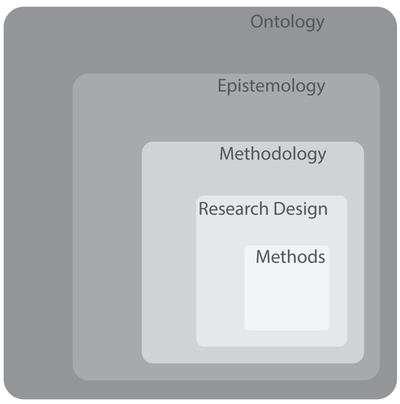


Figure 4.1 Research components.

4.3.1 In-between constructivism and objectivism with a pragmatic epistemology

The assumptions about the nature of social phenomena, whether they are 'inert and objective realities' or 'social constructions' dependent of social actors, are referred to respectively as objectivism and constructivism (Bryman 2012). They engender ontological considerations of organisation and culture, and try to answer the question '*What is the nature of reality?*', thus influencing the perspective of the research design and analysis. The ontological perspective of this research is between *constructivism and objectivism*.

The assumptions regarding the way research should be done in a discipline are influenced by the research process, and are referred to as epistemological considerations (ibid). They try to answer questions such as '*How should research be done?*' and '*What is the relationship of the researcher to that being researched?*'. The two main positions are positivism, which advocates a more objective view of social reality and is historically bound to scientific disciplines and interpretivism, which requires the researcher to *'grasp the subjective meaning of social action'* (p.30). In other words, the first is concerned with the cause of social phenomena while the second tries to understand the meanings that they carry and their effect on people.

An emergent perspective based on a more 'pragmatic' approach rejects the previous views in their absolute terms. It posits that *'through multiple stages and methods of data collection and/ or analysis, researchers can arrive at a better understanding of a phenomenon by combining the reliability of empirical counts with the validity of lived experience'* (Wheeldon and Ahlberg 2012, p.7); this is the central philosophy advanced by mixed method scholars (Tashakkori and Teddlie 2003). This *pragmatic* epistemological perspective aligns with the position of this study, where the reliability of empirical knowledge (e.g. building monitoring) is combined with the validity of social reality (e.g. interviews and observation) in the study of daily practices and energy consumption.

4.3.2 An inductive reasoning

The ontological and epistemological decisions previously discussed influence the process of reasoning used in this study. The nature of the relationship between theory and research—whether theory guides research (deductive) or whether it is an outcome of observations (inductive)—determines the research approach (Bryman 2012). In this study, the research process began with two pilot studies that allowed the specific areas of investigation to be gradually identified. Although the literature review assisted the development of a theoretical foundation, the lack of existing empirical evidence obviated the use of deductive reasoning. There was a need for an explorative method that would allow unanticipated findings to come across. Throughout data collection, findings were consolidated and the final conclusions were arrived at, by weaving back and forth between the data acquired and the research questions used to acquire it (Figure 4.2). Therefore, this study follows a combination of inductive and deductive reasoning.

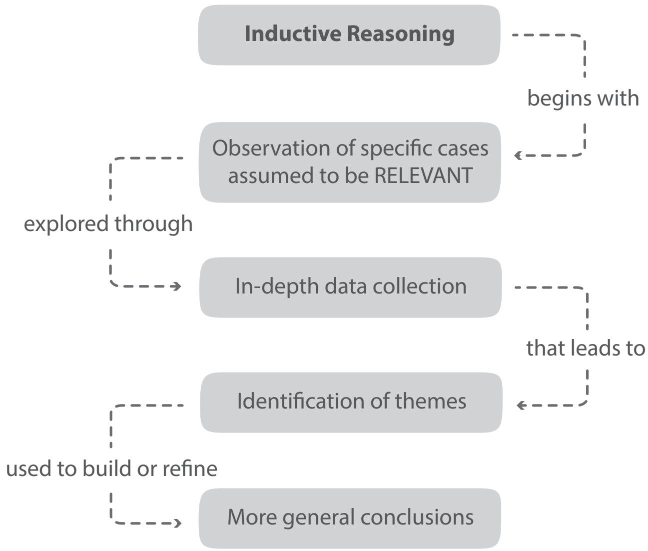


Figure 4.2 Inductive reasoning (Wheeldon and Ahlberg 2012).

Bryman (2012) posits that inductive reasoning is most useful when the exact concepts are not known and there is a lack of a formal body of theory from which to deduce a hypothesis. The most recognisable inductive method is grounded theory, where *'the researcher begins with an area of study and allows theory to emerge from the data'* (Strauss and Corbin 1998, p.12)—an approach that has been highly influential for the choice of methodological tools used in this study. The use of qualitative inquiry seemed both logical and necessary to offer insight and an enhanced understanding of 'reality'. This, however, did not prevent the use of some a priori constructs that were based upon social practice theory, which, as Eisenhardt (1989) points out, enhance the advantage of deductive approaches by building on existing knowledge without diminishing the flexibility that an inductive approach offers.

4.4. Social practice theory as a theoretical foundation of this study

Theories provide a rationale for the research being conducted and a framework within which social phenomena can be understood and research findings can be interpreted (Creswell 2015b). A theory (e.g. theory of adaptation, theory of change) might appear at the beginning of a study as an overall framework or inform different parts of the project (ibid). In their writings, Creswell and Plano Clark (2011) explain how theory can be woven into the literature review, and affect the wording of the research question, the sensitivity to the population during data collection, themes in the findings and the call for action at the end of the study.

This study looks at comfort practices and the effect of feedback in energy consumption in the workplace through the lens of *social practice theory*. Social practice theory provides a medium for understanding consumption as a part of daily practices, the elements involved in the formation of these practices and the processes that can contribute to change (Section 2.3.1). In particular, the use of practice theory in this study has the following implications:

a) It informs the research questions (see Table 1.1).
b) It sets out the analytical framework in such way as to consider comfort as a practice consisting of four interconnected elements: habits, technologies, knowledge and meanings (Gram-Hanssen 2010b). It considers that practices intersect with each other to form clusters of activities. Therefore, practices should be seen as dynamic and continuous processes rather than stable and fixed actions.
c) It reflects the choice of a mixed methodology with the use of qualitative (semi-structured interviews and observation) and quantitative (building and energy monitoring, comfort diaries), data collection methods.
d) It affects the way of analytical interpretation of findings (see matrix of emerging concepts in Table 4.5).

4.5. Case study approach

Research design is the logic that links the collected data in a study to the research questions. The case study as a strategy places the focus on the dynamics at play within a single setting, and involves numerous levels of analysis with the aim of generating a theory from the evidence gathered (Eisenhardt 1989). It is mainly associated with a small number of participants, a low degree of researcher control and high ecological validity (Plowright 2011)[3]. Yin (2009, p.18) defines case study research as *'an empirical inquiry about a contemporary phenomenon, set within its real world context—especially when the boundaries between the phenomenon and context are not clearly evident'*. As such, its suitability to examine and understand the formation and change of workplace practices related to comfort and consumption is apparent. This study employs *a case study* strategy to investigate a 'contemporary phenomenon' located within its real-world context of a higher education building where user practices are observed and conditions are monitored.

The same study may contain a single or multiple cases (Yin 2014). This study features a 'single-case' (embedded) design, which involves three units of analysis (office types A, B, C) and their sub-units (offices A-E) within the context of a single organisation (Department of Engineering) (Figure 4.3). The different units of analysis were chosen based on their user profiles and spatial characteristics and were considered typical within the case study. The case study offices are presented in detail in the next chapter (5).

The study is organised in two main stages: a) preparation, and b) fieldwork and data analysis. Figure 4.4 illustrates the adopted research design while Section 4.8. of this chapter provides a detailed account of each stage. A summary of the research design influenced by Eisenhardt's theory building

[3] *'Ecological validity concerns the degree of naturalness of the research location and situation without the researcher's intervention'* (Plowright 2011, p.30).

framework (Eisenhardt 1989, Eisenhardt and Graebner 2007) and Yin's (2014) multiple case study design foundation follows.

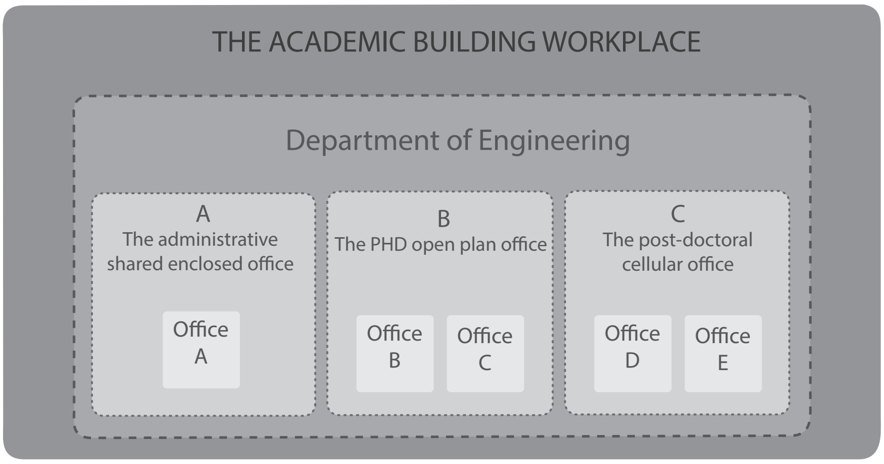


Figure 4.3 Single case study embedded design (Yin 2014).

During the preparation stage the research questions were defined and *a priori* constructs specified (Table 1.1). Then cases were selected in a way to provide examples of typical office typologies and a mixed data collection methodology was employed in a synergistic combination (Sections 4.8.1-4.8.3). In the second stage of this study, data collection began and overlapped with data analysis (Section 4.8.4). This flexibility allowed adjustments to the data collection methods (e.g. the addition of interview questions) and a better understanding of the application of social practice theory. Next, analysis of the data within and across cases allowed the generation of preliminary and comparative insights. As ideas emerged, research questions were revised and hypotheses were shaped through an iterative process by sharpening constructs and verifying that *'the emergent relationships fit with the evidence in each case'* ensuring validity (Eisenhardt 1989, p.542). At this stage, literature was revisited in search of similarities and contradictions to enhance the study's *'validity (…) and theoretical level of theory building from case study research'* (ibid, p.545). The study ended when theoretical saturation was reached, while taking into account pragmatic considerations of time and financial limitations.

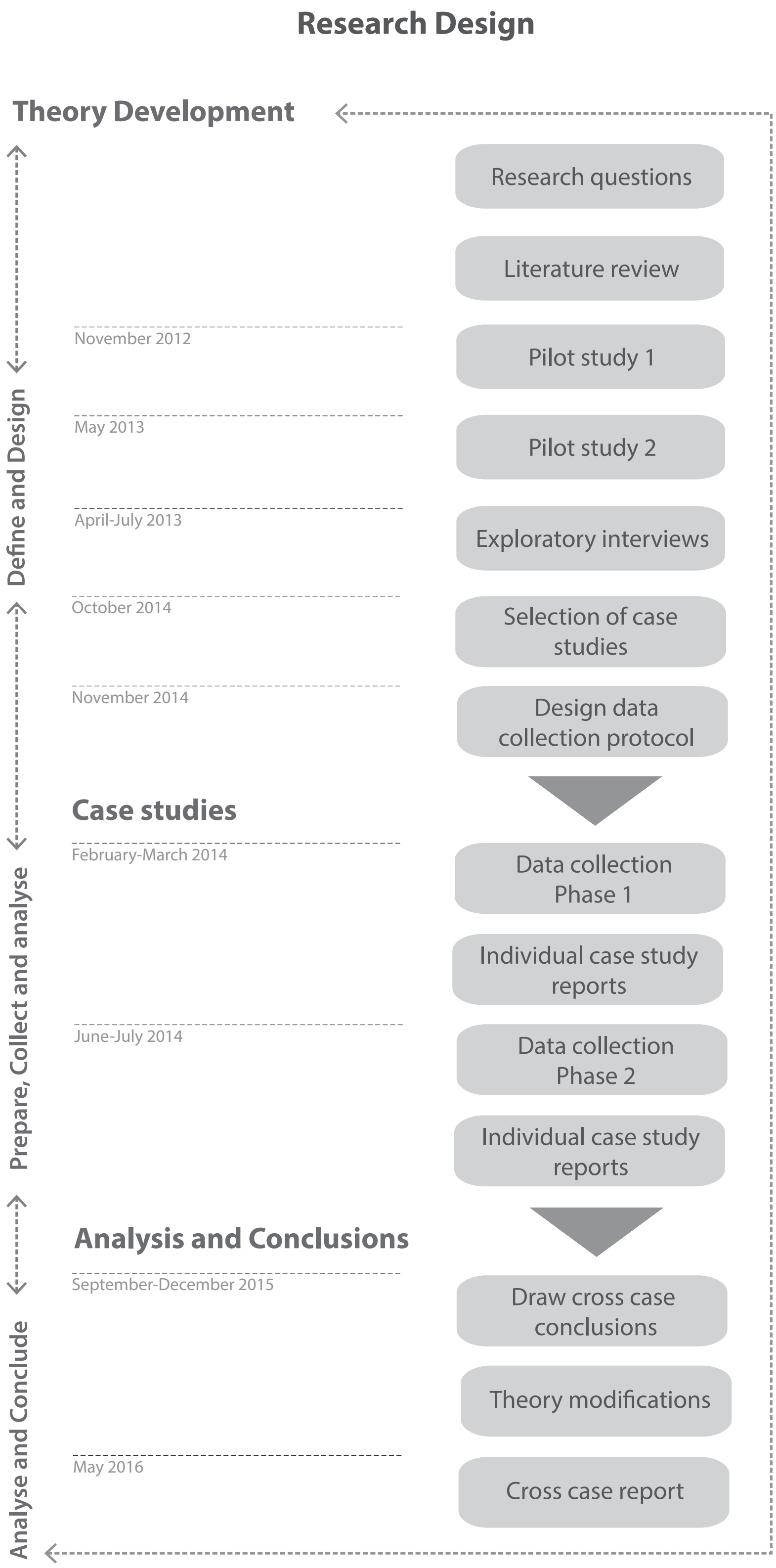


Figure 4.4 Summary of the adopted research design in this thesis, which provides a framework for the collection, analysis, interpretation and reporting of data, with the specific time-line of the study.

4.6. Mixed research methodology: a combination of the qualitative and quantitative

Methodology is a way of thinking about and studying social reality (Strauss and Corbin 1998). Mixed methodology has more recently received recognition as *'the third methodological movement'* (Creswell and Plano Clark 2007, p.13) gaining popularity in health and social science research (Tashakkori and Teddlie 2003). It rejects the traditional dichotomy between qualitative and quantitative methods, which advocated that different approaches of conceptualising and undertaking research cannot be used together through their synergistic combination (Plowright 2011). According to Creswell (2015a, p.59), in mixed research methodology *'the investigator collects, analyses, and interprets both quantitative and qualitative data, integrates or combines the two approaches in various ways, and frames the study within a specific type of design or procedure'*. However, while crossing borders can add to the effectiveness of research, it also requires caution when borrowing concepts from other disciplines (Hesse-Biber and Johnson 2015).

Miles and Huberman (1994, p.2) posit that qualitative data are *'a source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts'*. One of their major assets is that they focus on *'naturally occurring, ordinary events in natural settings'* in order to provide a good understanding of what *'real life'* is (ibid, p.10). Qualitative research refers to experiences, behaviours, social norms and interactions, and while some of the data may be quantitative (e.g. background information about people studied, census, etc.), the bulk of analysis remains interpretative (Strauss and Corbin 1998). In contrast, quantitative evidence answers the 'what' questions, and is useful in mixed methodologies to *'indicate relationships which may not be salient to the researcher'* (Eisenhardt 1989, p.538). It can also provide a useful guide to the interpretation of the qualitative data, which sometimes can give rise to vivid, but misleading, impressions (ibid).

Table 4.1 Qualitative and quantitative data collection methods in relation to the case studies.

Research methodology	Data collection method	Pilot 1	Pilot 2	Case A	Case B	Case C	Case D	Case E
Qualitative	Semi-structured interviews		x	x	x	x	x	x
	Observation			x	x	x		
Quantitative	Thermal conditions monitoring (temperature, RH)			x	x	x	x	x
	Comfort diaries			x	x	x	x	x
	Electricity audits			x	x	x	x	
	Questionnaire surveys	x	x	x				

This study follows a *mixed methodology* approach. Qualitative data are derived from semi-structured interviews and participant observation. The interpretation of these data makes use of coding (for interviews) and diagramming (for participant observation). Quantitative data are derived from environmental conditions monitoring (temperature, RH), electricity audits, comfort diaries and questionnaire surveys. Table 4.1 gives an overview of which data collection methods took place in each of the case study offices during the pilot and main study. The sequence in which the different approaches took place and the constant feedback that they provided to each other was crucial for the study's reasoning (see Section 4.7).

4.6.1 Qualitative methods

Semi-structured interviews

Interviews are the most popular method employed in qualitative research (Bryman 2012) and according to Hitchings (2012) constitute an efficient means for investigating routine practices. In terms of the number of interviews considered necessary, Strauss and Corbin (1998, p.281) advise that *'at least ten interviews with detailed coding are needed for building a grounded theory',* while Saldaña (2016, p.55) points out that utilising interviews from *'fifteen participants can provide sufficient variability to construct the core theory, its dimensions and properties'*.

In this research, interviews were conducted with twenty-two participants (Table 1) over two rounds (see Section 4.8.4), with their format structured in categories that covered the five main themes: comfort, habits, technologies, knowledge and meanings. Each category consisted of a list of questions that served as an interview guide (see Appendix A1). Their semi-structured approach provided flexibility allowing space in the sequencing of the questions and the length and nature of the responses. The data from the interviews were recorded, transcribed verbatim, coded and analysed using NVivo software.

Observation

Observation is a method mainly used in qualitative studies, which aims to provide insights into what is happening in a specific setting through the eyes of the observer (Galvin 2014). It is a useful way to study non-verbal communication such as gestures, postures, or seating arrangements that are unconsciously followed by people (ibid). In this study observation took place in two cases:

a) Participant observation during office hours.
b) Observation of key events ('CO_2 reduction Grand Prix' competition launch, induction of the WFT tool in offices) (see Appendix D2).

Participant observation took place in offices A, B and C. During the visit an observation checklist and a floor plan (Appendix A2) were used as a way to record the different aspects of behaviour, the environmental conditions and the movements of the office users every half-hour. Each office was numbered and detailed sketches and notes were kept (Figure 4.5). The approach was close to that used in ethnographic studies and relevant literature was reviewed (Sommer and Sommer 2002). The observation visits offered insight into how the layout (spatial arrangement) and environmental conditions impacted the way in which people behaved, interacted with each other and the nature and content of their communication. It also helped verify participants' assertions that emerged through the interviews.

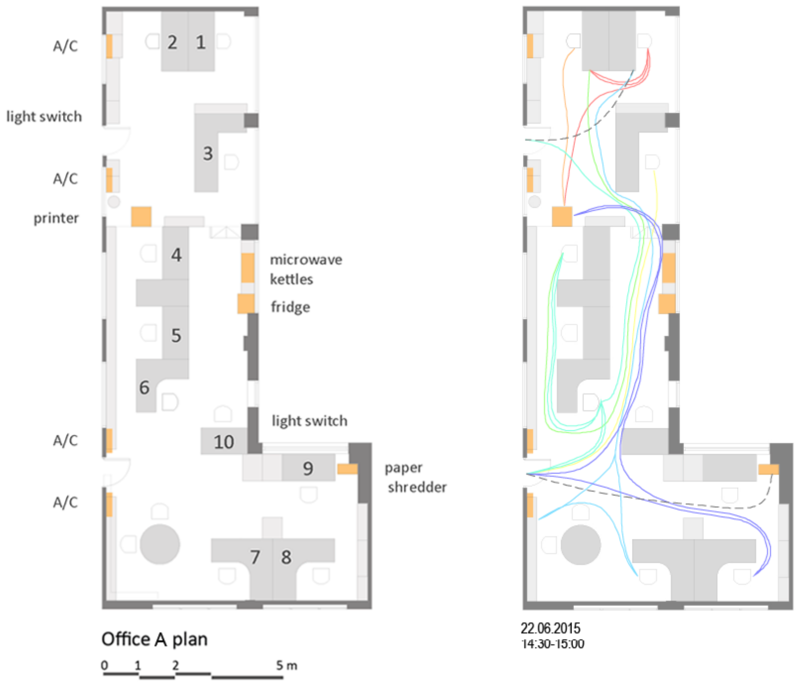


Figure 4.5 Office A plan and observation diagram.

4.6.2 Qualitative data analysis

After the collection of the qualitative data, the analysis process began. In qualitative research, data analysis can be seen as a way of 'conceptual ordering'—in other words organising data in discrete categories according to a selective set of properties and then using descriptions to elucidate these categories (Hammersley and Atkinson 1995, Silverman 2006). In this research, the conceptual ordering tool used was coding, one of the most popular data analysis methods of qualitative research.

Coding is based on themes that emerge from different types of actions that take place in the studied context. According to Saldaña (2016, p.3) a code is defined as *'a word or short phrase that symbolically assigns a summative, salient, essence capturing, and/or evocative attribute for a portion of language-based or visual data'*. Each code is effectively a category in which a piece of data is placed. In this thesis, codes refer to a way of organising and empowering the qualitative data consisting the 'critical link' between data collection and their explanation of meaning (Strauss and Corbin 1998).

Strauss and Corbin (1998, p.21) stress that to avoid scenarios in which the coding categories constitute just another classification scheme, a theory is needed that places the codes within a larger framework *'so that they begin to make sense'*. In this thesis, social practice theory provides the larger theoretical scheme that explains why certain codes (as opposed to others) evolved and their link to the research questions and wider phenomenon under investigation. Finally, coding is also aligned with the constructivist-interpretivist paradigm. Knowledge is first constructed by the participants as they describe their experiences and secondly by the researcher that tries to *'reconstruct'* and *'make sense'* of the data to explain the phenomenon under investigation based on the adopted theoretical framework (Charmaz 2001, p.117).

Coding process

Coding of the collected interview data was an iterative process, which was carried out using a combination of a deductive and inductive conceptual ordering approach. It consisted of three main cycles (a. preliminary, b. first, and c. second) and several reiterations and revisions until the codes were refined and the meanings became clear. Firstly, a set of preliminary deductive codes were produced based on the interview framework, thereby providing a general idea of participants' views; then the process was reversed and two cycles of inductive coding followed, allowing for concepts to emerge. A detailed account of the three coding cycles as they developed for the analysis of Chapter 6 is presented below as a reference to the coding process.

All the interview recordings were transcribed verbatim[4] in a Microsoft Word file and imported in NVivo 11, a computer aided qualitative data analysis software (CAQDAS) (Appendix A3, Figure A.1). Both Word and NVivo were used interchangeably as analytic tools and a way to organise and manage the data. While NVivo provided a great categorisation platform, its interface was found to be less user-friendly when lists of participants' quotes on specific topics had to be compared. In these cases, Microsoft Word was used to produce comparative lists of data (Appendix A3, Table A.1).

Preliminary (a priori) codes

Deductive coding was used as a preliminary approach to the qualitative data analysis. A two-level set of codes and sub-codes was developed to cohere with the semi-structured interviews questions, the literature review and the decision to adopt social practice theory as a theoretical framework. This practice helped tie the conceptual framework directly to the data and assisted with their further organisation during the analysis. The key elements of social practice theory (habits, technologies, knowledge, meanings) formed the first-level codes while the main interview categories constituted the second level sub-codes. The a priori codes used to analyse the main dataset are presented in Table 4.2.

This approach was useful for garnering a preliminary understanding of the data, a general idea of the research questions in context and the strengths and weaknesses of certain concepts. Although it was useful to organise the data in this way, it also seemed to be closer to a classification scheme, making

[4] Express Scribe software was used to assist the transcription of the audio recordings by offering speed control.

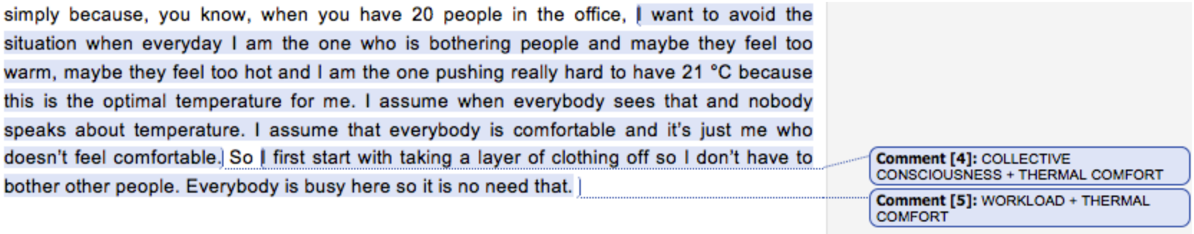
it difficult for emerging themes to stand out. Therefore, a second stage followed, where inductive codes were assigned.

Table 4.2 A priori codes and sub-codes. (deductive)

Codes	Sub-codes
Demographics	- Background info
	- Work-related info
Comfort	- Thermal comfort
	- Seasonal variation of comfort
	- Length of opinions about comfort
	- Colleagues opinion on office conditions
	- Thermal expectations
	- Adaptive actions when cold
	- Adaptive actions when warm
	- Ventilation
	- Lighting
Habits	- Embodied habits
	- Life routines
	- Past experiences
	- Home VS Work behaviour
Knowledge	- Energy awareness
	- Knowledge source
	- Opinion on energy saving and ability to do it
Technologies	- Understanding of heating/cooling system
	- Temperature settings
	- Hours of usage
	- Use of appliances
Meanings	- Opinion on energy saving in offices and ability to do it
	- Satisfaction and functional comfort
	- Energy consciousness
	- Territory, ownership and belonging
	- Green image
	- External influences to energy use
Change	- Aware of 'CO_2 reduction Grand-Prix'
	- Ability to change behaviour
	- Motivation for change
	- Feedback on RTDs

First cycle coding

In this phase, the two sets of interviews were re-coded. The transcripts were reviewed once more, summarising participants' views using 'descriptive codes' while keeping in mind the main research question related to Chapter 6 (Q1. Which elements form workplace thermal comfort practices?). Saldaña (2013, p.88) refers to descriptive coding as a process that *'summarises in a word or a short phrase the basic topic of a passage of qualitative data'*. At this stage, the codes were rather general, and sometimes contained more than one possible topic. An example is shown in Figure 4.6.


simply because, you know, when you have 20 people in the office, I want to avoid the situation when everyday I am the one who is bothering people and maybe they feel too warm, maybe they feel too hot and I am the one pushing really hard to have 21 °C because this is the optimal temperature for me. I assume when everybody sees that and nobody speaks about temperature. I assume that everybody is comfortable and it's just me who doesn't feel comfortable. So I first start with taking a layer of clothing off so I don't have to bother other people. Everybody is busy here so it is no need that.

Comment [4]: COLLECTIVE CONSCIOUSNESS + THERMAL COMFORT

Comment [5]: WORKLOAD + THERMAL COMFORT

Figure 4.6 1st cycle coding example.

The above excerpt refers to a participant views from office B on his daily comfort practices in the workplace. The student points out that he wants to avoid situations where others would feel uncomfortable due to his own thermal comfort preferences, so he prefers to adapt by adding or removing layers rather than change the temperature setting. This fact justifies the COLLECTIVE CONSCIOUSNESS and THERMAL COMFORT codes. The informant also claims that *'everybody is busy here'* so there is no time to discuss such issues. Therefore, the codes WORKLOAD and THERMAL COMFORT were used to refer to the fact that for him comfort comes secondary to work due to a tight daily schedule. At the end of this stage, a provisional list of codes was developed, which was classified, according to its relevance to the adopted theoretical framework. Examples of the topics categorised under the element of 'Meanings' are illustrated in Table 4.3.

Table 4.3 Example of broad categorisation of topics linked to the element of 'Meanings' in office B.

Meanings	
Common research acts as social glue	*'I guess the fact that we all pretty much belong in the same research field and help each other when we have problems in our research, that acts like a social glue. On top of that, we do some micro-mechanics socials and, therefore, if you have very good time with a person from your office and you become friends you won't go and do something that would annoy them such as set the temperature super low during summertime.'* (Alexia_B_1)
Being energy conscious is ideologically bound with Cambridge students	*'For certain type of people and especially the kind of people we have here, there are two things about them. First of all they are fairly technical and they generally understand the concept of energy and all the stuff, and second of all the people—the typical Cambridge people—have strong opinion about things and they really try hard to follow what they think. Let's say it that way. Most of the society is probably too lazy or too comfortable with whatever they have, and Cambridge people, some of them at least, if they think that being energy conscious is the right way to go they will actually turn off the light and try to convince other people about it. They have [sic] very strong people about their ideology and we have people like these here.'* (Peter_B_2)
Collective consciousness acting as a moderator for comfort practices	*'I would kind of accept that. Why would I accept it? Because if someone had already adjust the temperature it would be very rude to adjust it immediately after, and basically saying I am not satisfied with this temperature.'* (Ben_B_2)

By looking at these broad categories it became easier to identify similarities and differences between the views of participants on the topics they discussed that would lead to emerging themes linked to the research questions. It came across that most topics were linked to four main themes and the most tangible thing would be to focus on these:

a) Workplace routines and user profiles.
b) The configuration of the existing heating and cooling system and the relevant maintenance structure.

c) The relation between social dynamics and indoor climate practices.
d) The meaning of being energy-conscious in the workplace.

Second cycle coding

The main goal of a second coding cycle is to *'develop a sense of categorical, thematic, conceptual, and/or theoretical organisation from your array of first cycle codes'* (Saldaña 2016, p.234). The coded data were reorganised by putting all informants' quotes under the four key themes in order to produce a more select list of broader categories.

An example of an emerging sub-theme in office B concerning 'The relation of social dynamics and regulation of indoor climate practices' was that of 'Collective consciousness acting as a moderator for comfort practices'. There were fourteen cases were the students commented on the influence of their peers and the impact of the shared office environment on their comfort and indoor climate regulation practices. Table 4.4 presents three of these cases.

After the participants' quotes were organised under the emerging topics and subtopics for each case study office, the codes were updated multiple times in order for the sub-topics to be operational. *'Some codes do not work; others decay. No field material fits them, or the way they slice up the phenomenon is not the way the phenomenon appears empirically. This issue calls for doing away with the code or changing its level'* (Miles and Huberman 1994, p.61). Table 4.5 presents the final sub-topics that emerged after the second cycle of analysis; they have been used as the sub-sections of Chapter 6.

Table 4.4 Second cycle coding example in office B.

Collective consciousness, a moderator for comfort
'I guess the fact that we all pretty much belong in the same research field and help each other when we have problems in our research, that acts like a social glue. On top of that we do some micro-mechanics socials and, therefore, if you have very good time with a person from your office and you become friends you won't go and do something that would annoy them such as set the temperature super low during summertime.' (Alexia_B_1)
'Well, it's as I 've said. Because, in our place, even if you want comfort for yourself it means you are causing discomfort to somebody else because it's [the office] not optimally spaced. So, if I feel too warm, I just step outside and just get some fresh air and come back. If I feel too cold inside, then I wear a few layers of clothes.' (Ruchi_B_1)
'I want to avoid the situation when every day I am the one who is bothering people. And maybe they feel too warm, maybe they feel too hot, and I am the one pushing really hard to have 21°C because this is the optimal temperature for me. I assume when everybody sees that and nobody speaks about temperature, I assume that everybody is comfortable and it's just me who doesn't feel comfortable.' (Peter_B_1)

Table 4.5 Matrix with emerging themes of Chapter 6 after the full coding process.

	Know-how and embodied habits: workplace daily routines	**Technologies and infrastructure: a practice container**	**Knowledge: technical and environmental**	**Meanings: productivity and workplace dynamics**
A Administrative office	The 'busy' administrator	A/C system prefigures a 'default' mode and creates multiple heating zones	General knowledge but 'there is not much one can do'	Workplace dynamics and social considerations
	Background influences and traits from home	Set-up of office equipment favours a standby mode		Difference between practices at work and at home
		Difficulty to resolve problems with technologies		
B, C PhD office	A tight daily schedule	Heating system a cause of confusion and uncertainty	Advanced knowledge and opinionated	Collective consciousness, a moderator for comfort
				Being energy conscious carries 'ambiguous' connotations
	The 'green' PhD student	Slow maintenance makes passive users		To be a good researcher one needs to feel comfortable
		The use of equipment and research practices		
D, E Post-doctoral office	The '24-hour' researcher	Easy to share comfort issues	Aware and pragmatic	Productive and realistic
		Insufficient maintenance structure		

Check-coding

After the coding cycles were complete it was considered important to have the codes checked by another researcher who could give advice on their naming and definition. In order to examine the reliability and validity of the codes, a sample of the coded interviews was discussed with a second person, a post-doctoral researcher that had been an inter-rater before and was experienced in qualitative research analysis and coding. As part of the code-checking process, the research questions and framework were explained to the inter-rater and the provisional list of codes with their definitions was shared (Appendix A3, Table A.2). Two representative coded transcripts were reviewed and the inter-rater stated agreement or disagreement by adding new, removing or rephrasing the existing codes.

The rating agreements with the already assigned codes were calculated using the reliability check formula suggested by Miles and Huberman (1994, p.63) (Figure 4.7):

$$\text{reliability} = \frac{\text{number of agreements}}{\text{total number of agreements} + \text{disagreements}}$$

Figure 4.7 Reliability check formula (Miles and Huberman 1994, p.63).

The expected inter-coder reliability should be close to 80% and 90%. If less, some of the code definitions need to be expanded or amended. When the second coder finished with the coding of the transcripts, any disagreements were discussed until inter-coder agreement was estimated at 83%, which was considered a sign of valid codification process. An example of a disagreement raised through this process follows.

- Disagreement on code assignation

This type of disagreement involves differences in the codes assigned to the same piece of text but with consensus regarding the naming of the codes. It may occur in cases when the two raters used a different perspective during their interpretation of the data or when the code definitions are ambiguous. This example is taken from an interview with a PhD student in office B. The code PROFESSIONAL EXPERIENCE referred to the influence of the participant's professional background into his views on energy saving in the workplace. The first extract (Figure 4.8) shows the coding as was assigned by myself before the check-coding process while the second extract (Figure 4.9) indicates how the inter-rater coded the same piece of text. Apart from the PROFESSIONAL EXPERIENCE code, the codes ENERGY CONSCIOUS and PRAGMATIC, which describe the student's views and actions on workplace energy consumption, were suggested as relevant.

what I am trying to say is that you know, I did actually a couple of projects in my life in the energy sector, in the industry, and I saw that the environmental impact that these people have is thousand million times larger than I would have by turning on or turning off the A/C or lights. So, it's simply I don't feel that strongly about impacting the environment by turning on the A/C or turning it off. I think it's great to give an example, of course we are from Cambridge and we are supposed to be the people who give the example and I think that's

Comment [38]: KNO/PROFESSIONAL EXPERIENCE

Figure 4.8 1st rater code assignation.

what I am trying to say is that you know, I did actually a couple of projects in my life in the energy sector, in the industry, and I saw that the environmental impact that these people have is thousand million times larger than I would have by turning on or turning off the A/C or lights. So, it's simply I don't feel that strongly about impacting the environment by turning on the A/C or turning it off. I think it's great to give an example, of course we are from Cambridge and we are supposed to be the people who give the example and I think that's

Comment [43]: PROFESSIONAL EXPERIENCE+ENERGY CONSCIOUS+PRAGMATIC

Figure 4.9 2nd rater code assignation.

Since there was a disagreement in the coding of the above text, there was the need to revisit and refine the codes before reaching an agreement. To resolve this disagreement, my decision was to include the codes ENERGY CONSCIOUS and PRAGMATIC while retaining the PROFESSIONAL EXPERIENCE code since they both aligned with my research question which had to do with the influence of background knowledge and meanings associated with energy saving in the workplace. The second rater also agreed on this change.

4.6.3 Quantitative methods

Electricity consumption audits

Building monitoring provides a measure of energy performance and therefore constitutes a proxy for user practices (Foulds *et al.* 2013). It also helps to identify the electricity base load[5] of a space and therefore indicate any potential towards change. When it comes to qualitative research, it helps to clarify the context through insights derived from its total consumption or that of a specific technology. Energy consumption figures for the case study offices were retrieved from the online Workplace Footprint Tracker tool (see Section 5.2.4) and analysed on three levels:

- Monthly electricity consumption (KWh/m) for the period from September 2014 to July 2015 (academic year).
- Daily electricity consumption (KWh/d) for the period from October 2014 to July 2015.
- Daily electricity consumption (KWh/d) snapshot from April 2015 to July 2015 where the average weekly and weekend consumption are indicated.

Monitoring of thermal conditions and comfort studies

If we want to know how people feel in a particular situation there is no better way to find out than to go and ask them, Humphreys (1994) suggests. Comfort studies were based on field surveys of thermal comfort where measurements of the thermal environment (temperature, humidity) were combined with the simultaneous thermal responses of individuals captured in a series of comfort diaries. The purpose here was to capture variations in comfort levels during different seasons and between different participants and behaviours that may deviate from the norm.

Participants filled out a thermal comfort diary three times a day for a five-day period during the two monitoring periods (February-March 2014 and June-July 2014). The diaries were completed three times during the day: between 9:00 and 12:00, 12:00 and 14:00, and 14:00 and 18:00. Their design was based on the standardised Thermal Comfort Studies diaries (Nicol *et al.* 2012) and tailored to the needs of this study. Each one consisted of three sections, accounting for thermal sensation, preference and acceptability (Appendix A4).

Thermal responses were gathered through comfort votes based on the ASHRAE scale ranging from -3 (cold) to 3 (hot) with 0 being neutral (Table 4.6) indicating how users feel with the actual thermal conditions. Thermal preference votes ranged from -2 (Much cooler) to +2 (Much warmer) while the third question on the acceptability of thermal conditions was considered with a positive (Acceptable) or negative (Not acceptable) vote.

Thermal conditions monitoring included thirty-minute interval measurements of temperature and relative humidity with the use of self-contained 'Tinytag Ultra' data loggers (Appendix A5, Figures A4-

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[5] The minimum level of demand on an electrical grid over 24 hours.

A5). The loggers were small self-contained devices with an internal memory that can log and store data. They were calibrated and programmed before their installation in the offices to avoid any fault during the monitoring period. The loggers were placed in the offices twice for a period of a month, overlapping with the comfort diaries week and interview appointments.

Table 4.6 Descriptors for the ASHRAE and Bedford scales.

ASHRAE descriptor	Numerical equivalent	Bedford descriptor
Hot	3	Much too hot
Warm	2	Too hot
Slightly warm	1	Comfortably warm
Neutral	0	Comfortable
Slightly cool	-1	Comfortably cool
Cool	-2	Too cool
Cold	-3	Much too cool

In total, seven data loggers were placed inside the case study offices (Appendix A5, Figures A.2-A.3). The indoor loggers were attached to a wall away from sources of heat, cold or direct sunlight. In offices A and B, where the size and layout of the office could create temperature differences across the room, two data loggers were placed in opposite sides of the room. The external temperature and humidity data were obtained from a weather station placed on the top of the Engineering department shared online by the Digital Technology Group (DTG)[6].

4.6.4 Quantitative data analysis

The temperature and relative humidity monitoring data were plotted on two scale line graphs. Individual participant responses from the comfort diaries were matched with the actual room temperatures from the environmental monitoring and plotted in box-and-whisker graphs. The graphs indicated the first quartile, average and third quartile values with the 'whiskers' denoting the minimum and maximum temperature range.

4.7. Pilot studies

A pre-pilot study at Hokkaido University (HU) (JP) (Dantsiou 2013, Sonetti et al. 2014) and pilot survey at the Gurdon Institute at the University of Cambridge (UK) (Dantsiou et al. 2013) (Appendix B2) took place in November 2012 and May 2013. The two studies were exploratory in nature and aimed to identify factors that influence workplace comfort and energy use while exploring the

[6] The Digital Technology Group (DTG) is a research group within the Computer Laboratory of the Engineering Department at the University of Cambridge (https://www.cl.cam.ac.uk/research/dtg/www/).

effectiveness of behavioural[7] change tools (university-wide environmental campaigns and online consumption tracker).

The two studies were considered useful for offering practical and methodological insights:

a) They improved the understanding of the structure and implementation of carbon reduction strategies in universities and their effect on the behaviour of individuals (Sonetti *et al.* 2014), and
b) They provided a testing ground for planning, conducting and analysing semi-structured interviews and questionnaire surveys in a department where a behavioural change scheme took place, similar to the one implemented in the main case study *(Dantsiou et al. 2013)*.

4.7.1 Polar Research Institute, Hokkaido University (Japan)

The pilot study in Hokkaido University took place between 25.10.2012 and 21.11.2012 during a one-month research visit in Sapporo, Japan. It was part of the UNI-metrics research project[8], an EU-funded collaboration platform looking at sustainable development activities on university campuses. The aim of the pilot study was to:

- Review the carbon reduction strategies and sustainability campaigns of Hokkaido University.
- Investigate workplace comfort, energy use behaviour and sustainability perceptions of the campus users.

A series of semi-structured interviews were conducted with faculty members and staff from the Environmental Office of the University in relation to sustainability projects and practices in the campus. They were followed by a questionnaire survey aiming to gather information on comfort and energy use practices of the users in the Polar Research Institute (see Appendix B1, Figure B.5). The Institute (Table 4.7) was one of the three faculties that took part in the University's Office for a Sustainable Campus (OSC) energy reduction campaigns in February 2011, July 2011 and February 2012 with an effect of 14% annual CO_2 reductions (Nakamura and Morimoto 2011). A total of 149 questionnaires were distributed within both institutes' buildings occupied by academic researchers and PhD students along with administrative staff (Figure 4.10). The survey response rate was 68% and it was analysed using bar-graphs and pie charts to identify percentages and main trends.

[7] In both pilot studies the term 'behaviour' is used instead of 'practices' since the decision to adopt a social practice theory approach was taken after they were conducted.

[8] UNI-metrics stands for Value Metrics and Policies for a Sustainable University Campus. It was a research project financed by the European Commission under the 7th European Community Framework Programme within the Marie Curie Actions IRSES-International Research Staff Exchange Scheme (Grant agreement number PIRSES-GA-2010-269161) and coordinated by the Politecnico di Torino, Italy (project website: http://www.uni-metrics.polito.it).

Table 4.7 Polar Institute and Annex A buildings characteristics.

	Polar Research Institute	Annex A
Construction date	1968 (renovated in 2007)	2000
Building type	3 storey building	3 storey building
Number of occupants	126	47
Use	Research offices and labs, administration offices, amphitheatre	Research offices and labs, administration offices
Size	Total floor area: 3,948 m^2	Total floor area: 2,442 m^2
Heating type	Air-conditioning, manually set	Air-conditioning, manually set
Cooling type	Air-conditioning, manually set	Air-conditioning, manually set
Ventilation	Mechanical ventilation	Mechanical ventilation
Photo		

The survey indicated that, in the context of Hokkaido University:

- The major determinant towards behavioural change was the compromise of research activity (38%).
- Self-motivation was the main driver towards a pro-environmental behaviour (33%) in the workplace while other motivators were previous environmental campaigns in the campus (16%) and social pressure after the nuclear accident in Fukushima (10.5%).
- A low participation rate in campus carbon reduction activities was related to the lack of adequate information (38%), time constraints (15%) and other unstated reasons (37%).
- The participation interest in future campus sustainability initiatives was linked to the communication tools and information provided.

The pilot study in Hokkaido University developed an initial understanding on the determinants of pro-environmental behaviour and the effects of a behavioural change campaign at a university building level. It identified the saliency of personal norms, the short-term effects of sustainability campaigns and the difficulty of users understanding what ‘energy saving’ was related to in their workplace. It also pointed out the future potential of behavioural initiatives if the right information and communication strategies are implemented. Finally, the high response rate indicated the importance of a collaborative relationship with the University’s sustainability office (see also Appendix B1 for further information on the pilot study).

Figure 4.10 Offices in the Polar Research Institute.

4.7.2 Gurdon Institute, University of Cambridge (UK)

Under the auspices of the ECRP project (Section 5.2.3) (Appendix B2, Table B.1), the Gurdon Institute was the first pilot site to implement a behavioural change programme along with a series of technical interventions. Gurdon is a research institute that was established to bring different life science disciplines together. It is predominantly constituted of laboratories, a few offices and special equipment rooms and serves 250-300 building users—mainly academic staff and PhD students with a smaller number of administrative and technical staff (Table 4.8). The behavioural change programme was intended to increase the energy awareness of the building users and encourage individuals to change their energy use behaviour. It took place from March 2012 until September 2012 and was comprised of a series of behavioural change actions. These combined a Workplace Footprint Tracker (WFT), an energy reduction competition between different labs, an iPad near the building entrance to display the league table, an energy representative to inform and motivate energy reduction activities within each lab, information posters, e-mail prompts and related social activities.

The WFT is an online-tool where real-time metering of different work-zones (research laboratories and equipment rooms), indoor climate (heating, cooling and ventilation), and services (computer servers, compressed air and vacuum plant) is displayed (Appendix B2, Figure B.10). Different data display options include daily, weekly, monthly and annual consumption in carbon emissions (kg CO_2), cost (£) and kilowatt-hours (KWh). Researchers and staff members had full access to the on-line information tool through their computers where they could see their lab performance in a comparative league table (Figure 4.11).

Table 4.8 Gurdon Institute building characteristics.

	Gurdon Institute
Construction date	2005
Building type	3 storey building
Number of occupants	250-300 (academic staff, PhD students, administrative and technical staff)
Use	Laboratories, special equipment rooms, offices
Size	Total floor area: 7,000 m^2
Heating type	Air-conditioning, centrally controlled
Cooling type	Air-conditioning, centrally controlled
Ventilation	Mechanical ventilation
Photo	

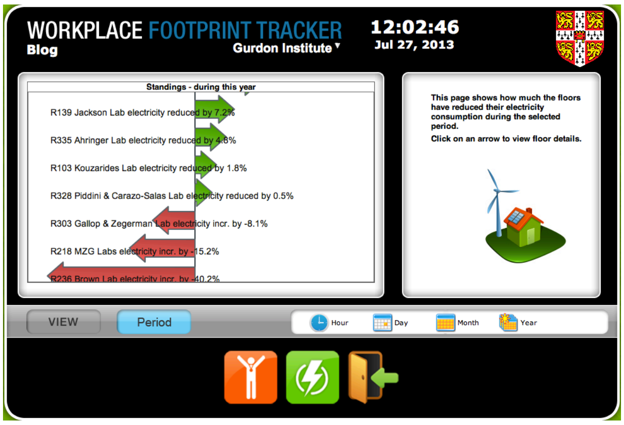

Figure 4.11 The league table of the Workplace Footprint tracker tool.

The second pilot study was informed by the findings from the Hokkaido University study and further literature review. The aims of the study were to investigate:

- Energy use behaviour and expectations about others' behaviour; cooperation towards the achievement of a common goal and barriers towards environmental behaviour.
- The effectiveness of the behavioural change programme.
- The level of environmental awareness in the workplace.
- The relation between energy use at home and in the workplace.

The survey took place in the beginning of May 2013 and was preceded by a building walkthrough to review the type, occupancy levels and size of different labs (Figure group 4.12, Figure 4.13). An on-line questionnaire survey was undertaken using the 'survey-monkey' free online survey tool. The survey was met with a 39% (105/234) response rate, which was considered satisfactory for on-line surveys. 72 responses came from labs, 14 from the FM, administration, media and computing departments while 19 did not specify.

The responses highlighted the following points:

- Energy use feedback needs to be easily accessible to the building users, unobtrusive to research activities and non-time consuming.
- The WFT was met with interest from those that could use it but almost half of the respondents were not aware or had never used it seven months after the end of the behavioural change programme.
- The effectiveness of group activities based on mutual concern and willingness to cooperate towards achieving of a common goal, such as energy savings.

Figure group 4.12 The laboratories in Gurdon Institute.

Figure 4.13 The equipment room in Gurdon Institute.

The Gurdon Institute pilot study raised important questions such as ‘why a sizeable group of fairly energy conscious individuals that discuss energy related issues at home don’t think that informational tools and economic incentives are enough to change their energy use behaviour at work’ and ‘what is the right informational structure to trigger action’. It also highlighted the potential of social dynamics to effect behaviour within the workplace and their capacity to drive change when combined with the right information. Finally, it informed the research questions by demonstrating that feedback systems need to consider energy use as a social construct, verifying the usefulness of adopting a socio-technical theoretical framework.

4.8. Case study selection and data collection protocol

4.8.1 Case study selection criteria

After the analysis of the pilot studies and relevant literature review, a set of selection criteria (Table 4.9) were drafted to ensure that the case study would provide a suitable context for the research questions to be answered.

Table 4.9 Case study selection criteria.

Case study selection criteria	
Accessibility	Cambridge University Campus, UK
Office typology	Representative types (open plan, cellular, labs)
Representative sample of participants	Mixed gender, age, education, job description, office use patterns
Energy saving potential	High energy use, behavioural change interventions and efficiency strategies
Practical requirements	Consent forms, Ethical approval

4.8.2 Set of meetings and preliminary interviews

Identifying appropriate case study offices and people to participate in this study was a multi-level process. First, a set of exploratory meetings with the University's Living Laboratory for Sustainability[9] coordinator, the University's Estate Office Energy Manager and the Manager of the Energy and Carbon Reduction Project took place between February and March 2013 (Table 4.10). The officials were interviewed on the existing university schemes and future plans aiming to behavioural change and awareness-raising within the campus.

These preliminary meetings led to a second meeting round with facility managers of buildings within the university that had already or were aiming to implement a behavioural change programme as part of the ECRP. A meeting was arranged with the facilities manager of the Gurdon Institute, where a behavioural change programme with the use of the online Workplace Footprint Tracker Tool had already taken place. This led to gaining permission to conduct the second pilot study (Section 4.7.2). Another meeting was set with the Safety Officer of the Engineering Department and the Managing Director of Building Sustainability Ltd., who were planning the implementation of a behavioural change

[9] The 'Living Lab' is a part of the Environment and Energy Section within the Estate Management of the University of Cambridge. It provides opportunities for Cambridge students to carry out research and projects across the University to improve its sustainability.

programme at the Engineering Department. The programme involved the installation of twenty Real Time Displays (RTDs) in different types of sub-metered spaces (offices, research laboratories, workshops, etc.) and the set-up of an awareness raising competition (‘CO_2 reduction Grand Prix’). An agreement was reached for this study to be conducted in parallel with the behavioural change programme.

A series of more detailed meetings and building walkthroughs with the Engineering Department’s Safety Officer along with relevant literature review (Bartley 2013, Coe and Slack 2013, ECRP 2013) followed to clarify the ECRP project details and make adjustments linked to this study. This process resulted in gaining access to the case study offices along with permission to recruit participants.

Table 4.10 Semi-formal communication during the first year.

Name	Affiliation	Organisation	Communication method
Claire Hopkins	Living Laboratory for Sustainability Coordinator	University of Cambridge, UK	Meetings and e-mail communication February-May 2013
Paul Hasley	Energy Manager	University of Cambridge, UK	E-mail and telephone communication March 2013
Kathy Hilton	Facilities Manager Gurdon Institute	University of Cambridge, UK	Meetings and e-mail communication April-May 2013
Robert Needle	Manager of the Energy and Carbon Reduction Project	University of Cambridge, UK	Meeting, April 2013
George Bartley	Managing Director, Building Sustainability Ltd	University of Cambridge, UK	Meeting, May 2013
Ian Slack	Safety Officer, Department of Engineering	University of Cambridge, UK	Meeting, May 2013

4.8.3 Ethical Approval

An Ethical Approval to conduct the research activities was granted by the Ethics Committee of the School of Humanities and Social Sciences (Appendix C1). To gain approval, a detailed research proposal, interview schedules and questionnaires, a participant information letter (Appendix C2), a participant consent form (Appendix C3) and a signed letter from the Head of the Architecture Department regarding the conduct of this research were submitted.

4.8.4 Data collection and analysis

Recruitment

After a series of walkthroughs in different offices with the building’s Safety Officer and discussions about the suitable case study offices, the five offices used in this study were selected. A short presentation of the research project and the participation commitment was arranged in each office in collaboration with each group administrator. The interested users filled out their personal information in a participation form and were provided with a detailed information sheet and a consent form to sign

(Appendices C2 and C3). After the forms were collected, the first round of data collection was planned.

Data Collection

The main study started along with the behavioural change programme, which was launched in July 2013 with the competition between the offices starting a week after. The competition ran for a six-month period and was initially planned to coincide with the installation of the screens (Figure 4.14). However, due to delays with ordering the screens and the Raspberry Pi's and a series of technical issues related to the installation and connectivity of the smart meters, the RTDs only came in approximately a year after the end of the online campaign. Planned observation took place on key events (e.g. the introduction of 'CO_2 reduction Grand Prix' competition in the department; presentation of the Footprint Tracker web tool during the University's Switch-off week; introduction of the web-tool in Office A) (Appendix D2) and more informal discussions were made with the participants (e.g. discussions during on-site visits; e-mails with relevant material) and the staff responsible for the behavioural change programme.

Figure 4.14 The 'CO_2 reduction Grand Prix' competition phases.

Table 4.11 Behavioural change programme and data collection timeline.

Event	Date
'CO_2 reduction Grand Prix' competition launch	June 2013
Installation of RTDs (order, installation, commissioning and configuration of electricity meters, screens and Raspberry Pi's)	September 2013 (intended) April 2014 – May 2014 (Offices B, C, D) October 2014 (Office A)
Run competition with monthly communications and prizes	July 2013 – December 2013
Winning teams announced	December 2013
Data collection – Round 1	February 2014 – March 2014
RTD in use in offices B, C, D	May 2014
RTD in use in office A	October 2014
Data collection – Round 2	June 2014 – July 2014
Introduction of the Workplace Footprint Tracker tool in office A	4th November 2014
Introduction of the Workplace Footprint Tracker tool in offices B, C and D	11th November 2014

The offices were monitored and the twenty-two participants interviewed and asked to fill out a comfort diary in two rounds:

- Round 1. February–March 2014

The first round aimed to reveal perceptions and prevailing conditions in the offices prior to the installation of the RTDs. It also provided an indication of winter comfort patterns and heating regimes. The interviews lasted on average 38 minutes in length (19-60 min range).

- Round 2. July 2014

The second round was conducted a few weeks after the installation of the RTDs. It focused further on the most important findings that came across during the first round, grasped the first impressions from the screens and captured thermal conditions and preferences during the cooling season. An average second interview was approximately 26 minutes (11-43 minutes range).

The detailed phases of the behavioural change programme and this study are presented in Table 4.11.

Writing up individual case study reports

After each data collection round, a report based on the semi-structured interview findings and the thermal conditions and comfort diaries was produced for each office. This helped identify some themes and update some the interview questions for the second round.

Undertaking cross-case analysis

After the data collection and analysis finished the findings from each office were cross-related so that commonalities and differences could stand out.

4.9. Limitations

The choice of methodology within a research project is often a point of major criticism given that any methodology has certain strengths and limitations. Often quantitative research is accused of ignoring the *'sensitive'* aspects which respond to the *'subtle nuances of, and cues to, meanings in data'* (Brager and de Dear 1998, p.35) while qualitative research is criticised for lacking 'reliability' because its findings are based only on a single or a few cases at the expense of representative sampling and their interpretation is subject to the researcher's preconceived notions (Strauss and Corbin 1998). In this study, the use of a mixed methodology, which drives the data collection and analysis, aims to maintain the balance between these two methods. Qualitative interviews capture the meanings latent within data while qualitative comfort field studies and building monitoring verify their reliability. To ensure trustworthiness, triangulation[10] of the results from the interviews with the monitored data takes

[10] Combining the analysis with findings from different data sources is useful as a means for demonstrating trustworthiness in the analysis.

place and confirmation bias in the coding process is avoided through check-coding (see Section 4.6.2).

Case study research has also been often criticised by the research community for its inability to construct theory and ensure validity and reliability (Kvale 1994, Silverman 2006). Despite its apparent applicability in looking at real-world situations and addressing contemporary phenomena, the limited sample size and context-dependent approach inherent to case study research raise a series of questions. Flyvbjerg (2006) has tried to address these issues through a detailed discussion of five common misunderstandings about case-study research (Table 4.12).

Table 4.12 Five misunderstandings about case study research (Flyvbjerg 2006).

Misunderstanding 1	General, context-independent theory is more valuable than practical, context-dependent knowledge.
Misunderstanding 2	Difficulty to generalise from an individual case to a wider scale and therefore contribute to the scientific development.
Misunderstanding 3	Useful as an exploratory tool for generating hypothesis but unsuitable in testing and building theories.
Misunderstanding 4	Bias towards verification of findings due to researcher's preconceived notions.
Misunderstanding 5	Difficulty to summarise and develop general theories based on specific case studies.

This study responds to Flyvbjerg's stated misunderstandings through its design and mitigation actions. Regarding the importance of practical, context-dependent knowledge it is acknowledged that this approach is directly linked to the study of human affairs. Thus, since this study is looking at workplace daily practices related to comfort and energy use, the case study method is highly relevant. The view that one cannot generalise from a case study is often strong within the research community. However, case studies can often *'be central to scientific development via generalisation as supplement or alternative to other methods'* (ibid, p.228) since the choice of method is dependent on the issue under investigation and its circumstances. The aim of this study is not to statistically generalise but to make analytical and theoretical generalisations instead using practice theory to understand 'how' and 'why' people shape their practices in the workplace. However, given the type of the problem if feedback does not work here, it does not work in all cases.

Another misconception is that a case study is better at generating a hypothesis through its exploratory nature rather than testing it. Therefore, it is considered weak in building theories and generalising. In this case, the strategic selection of the cases plays a major role in their validity and therefore *'generalisability capacity'* (p.229). In this study, three office types within the Engineering Department were considered to be critical cases with strategic importance to the research hypothesis. This assumption was based on the representativeness of their typology and user profile within the context of the university workplace (see Section 5), allowing a generalisation of the sort *'if it is not valid for this case, then it is not valid for any (or only a few) cases'* (p.230). The fourth misunderstanding stands on the grounds that case studies may lack objectivity due to the researcher's bias and own preconceptions. In this study, using a mixed methodology, results were triangulated while the iterative coding process imposed research questions and findings in constant revisions and check-coding verified the reliability and validity of the codes. Finally, the difficulty of summarising case study findings, given that they constitute narrative histories, has been met with the use of Gram-Hanssen's (2010b) analytical framework (see Section 2.3.2) to structure the narrative so that the process and outcomes read clearly. In specific, the emergence of themes based on the social practice theory elements, were useful in summarising the case studies (Table 4.5).

4.10. Chapter summary

This study adopts an interdisciplinary socio-technical perspective in order to explore comfort and energy consuming practices in the workplace. Its ontological view is linked to constructivism aligned with a pragmatic epistemology that aims to combine the reliability of empirical knowledge with the validity of social reality. Within this context social practice theory is employed as a theoretical framework to provide the analytical lens through which thermal comfort and work are understood as daily practices. Practice theory has been woven into the study to inform the research questions, data collection methods and analysis, while an inductive reasoning allows findings to emerge through observation of specific cases and identification of key themes. A case study research strategy helped investigate workplace practices within their real-world setting. Three office types were used as units of analysis based on their user profile and the spatial characteristics—considered typical within the case of the higher education building.

The socio-technical paradigm within which the study is located, as well as the use of practice theory favoured the use of a mixed methodology. Qualitative data (including semi-structured interviews and participant observation) captured rich descriptions and naturally occurring processes while quantitative data (such as indoor thermal conditions monitoring, electricity audits and comfort diaries) offered a more objective view and verified findings that are not otherwise salient. A meticulous coding process helped for emerging interview themes to stand out while line graphs and box-and-whisker plots illustrated energy, thermal monitoring and comfort conditions.

The research was structured in two main stages: a) a preparation stage, and b) a fieldwork and data analysis stage. In the first stage, two pilot studies took place looking at comfort and behavioural change in the workplace offering methodological and practical insights. After the case study offices were selected and participants recruited, the data collection took place over two rounds (February-March 2014 and July 2015).

5. The case study

5.1. Introduction

The central building of Cambridge University Engineering Department (CUED) on Trumpington Street was selected as a case study. It is one of the oldest and largest academic departments of the Cambridge University campus and the sixth most energy intensive (University of Cambridge 2010, p.13) with great saving potential. It was selected as a case study based on its high-energy use, and by extension, its scope to achieve energy savings, impact the user-related electricity consumption and raise awareness through a behavioural change programme with the use of Real Time Displays and a variety of office space configurations and occupant profiles (see Table 4.9). Within the CUED building, three office types were studied: a) the shared, enclosed administrative office, b) the PhD open-plan office, and c) the post-doctoral cellular office.

This chapter looks at the history of the building, the physical arrangement of the offices, their technological configuration and the characteristics of their users. Section 5.2 presents the academic department where the case study offices are located, the department's history and its energy consumption profile. It also outlines the behavioural change programme that took place, explaining its rationale and main components. In Section 5.3, the three case study offices are introduced and described in terms of their layout, heating and cooling system, occupant profiles and the location of RTDs. At the end of the section, the main characteristics of each office type are summarised based on both technical and social aspects—aligned with the main elements of social practices (routines, technologies, knowledge, meanings).

5.2. The Cambridge University Engineering Department

The University of Cambridge, is one of the oldest academic institutions in the world, founded in the city of Cambridge in 1209. It holds a collegiate structure and consists a confederation of thirty-one Colleges and over a hundred academic Departments counting 9,000 members of staff, 12,000 undergraduate and 5,500 post-graduate students (Facts and Figures, 2017). There is one new built campus site in north-west Cambridge while the rest of the university buildings are dispersed within and around the city (123,867 population, Census 2011). Due to its age, there is a wide chronological and typological diversity in the existing building stock which ranges from 13th century historic listed buildings to modern biomedical facilities.

Since its foundation in 1875, the Engineering Department has grown to become the largest department at the University, numbering approximately 200 academics and principal investigators, 300 contract research staff and research fellows, 900 graduate students, and 1200 undergraduates (Guilford 2016). The department moved into its current location in the 1920s and since then its growth has been consistent over the years.

5.2.1 Building performance

The Engineering Department central site is the result of several building phases, upgrades and extensions (Figures 5.1, 5.2). The oldest part is the Hopkinson laboratory of the Inglis building, built in 1924. Later the building expanded with further sections added, such as the lecture rooms 1 and 2 (1932), the workshops (1946) and the Inglis A building (1967) (Booth 2009b). The eastern spine of the Baker building was completed in 1952, followed by the centre, south and north wings that were built over the course of the next thirteen years (ibid). To provide the space and resources for its continuous growth, further refurbishments and in-fill building projects took place since then. The library was refurbished and doubled in size in 1997, a loft development was added to the Inglis building in 1998, and a fifth floor was added to the north end of the Baker building in 1999 (Newland 2001). There is still pressure for further expansion, and as a result, the new Dyson Centre for Engineering Design was built on the existing site in 2016 and some of the department's divisions have moved to the West Cambridge site, where a new Engineering campus is planned to be completed within the next decade (Guilford 2016).

Figure 5.1 The Cambridge University Engineering in Trumpington street site looking southeast from the Inglis A building. The Baker building is in the left background and the Inglis building is in the middle and foreground (Source: https://commons.wikimedia.org/ w/index.php?curid= 36562782).

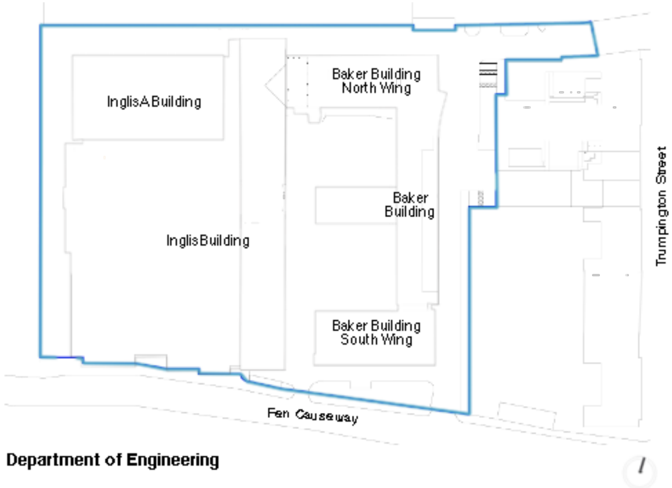

Figure 5.2 Cambridge University Engineering Department site and building plans.

The central site (floor area = 29,400 m^2) is currently the main teaching location and hosts approximately half of the research activities of the department. Its average occupancy rate per year is approximately 730 members according to the 2013 EDDA (Engineering Department Database for Administration)[11] (Table 5.1). The directory includes academic, administrative and maintenance staff; graduate students; visitors (other than very short-term); and embedded researchers. During the three academic terms (Michaelmas, Lent and Easter), the number of undergraduate students using the lecture theatres, teaching facilities and workshops can reach up to 1,200 students per day.

Table 5.1 Building occupancy rates for the years 2010-2013 (Source: EDDA).

Year	Occupancy rate
2010	567
2011	598
2012	627
2013	730

5.2.2 Energy use at CUED

The CUED is one of the major energy consumers within the University with an average electricity consumption of 300,000 kWh every month, equivalent to approximately 165,000 kg of CO_2 (Figure 5.3) (Appendix D, Table D.1). The age of the building, the different construction phases and the existing heating system are some of the reasons for energy inefficiency, while the impact of user behaviour both in offices and workshops has been found to add to the consumption levels of the building. An analysis of the department's electricity consumption during a plug load measurement study indicated that 26% of its baseline consumption in 2011 was due to desktop equipment being left

[11] http://itservices.eng.cam.ac.uk/services/edda/

on standby overnight and during weekends, communal printers not being switched off and A/C units being left on unnecessarily (UROP 2011).

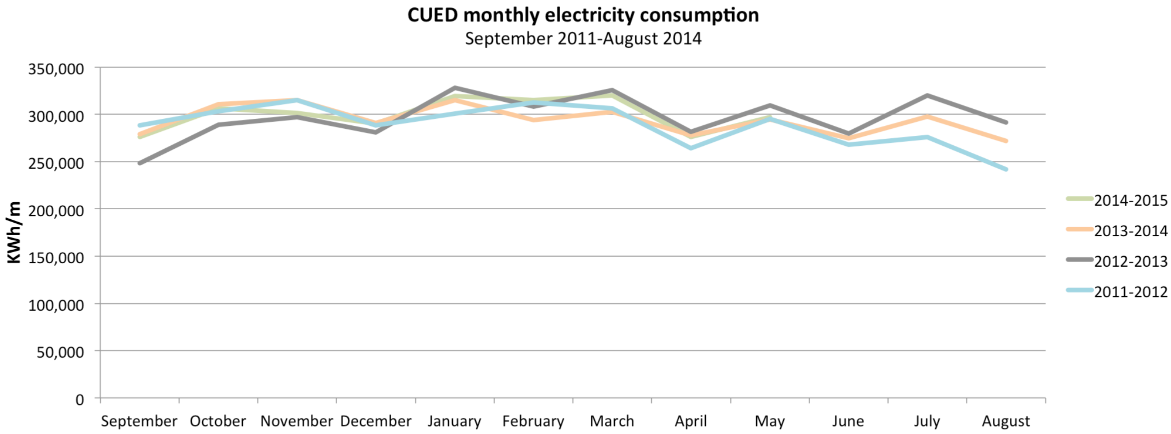

Figure 5.3 Monthly electricity consumption (KWh) of the Engineering Department building for the years 2011-2015.

Booth (2009a) assessed the heat loss and energy consumption of the main site building with the use of IES-VE modelling and pointed out that the building's inefficiency is largely due to issues related to the building fabric and the existing heating system. Many of the external building walls are made of brick and have no cavity or insulation, while most windows are single-glazed. At the same time the existing Low Temperature Hot Water heating system and its current set up results in an increased energy demand. Booth (2009b, p.10) explains that *'it involves a number of "heating zones" around the building, which are each independently controlled, but are all supplied with heat from the same centralised boiler. Each zone is controlled separately, but all the spaces within each zone are heated at the same time, with a solitary sensor in one space giving the signal as to whether the heat is supplied to the whole zone or not at all'*. Thus, despite their different occupancy patters, offices, workshops and lecture rooms that are located within the same zone are often under-heated or over-heated during evenings, weekends or afternoons, given that there is no independent control.

In order to achieve a reduction on its current consumption levels CUED became a pilot case in the University's ECRP project (Sections 5.2.3, 5.2.4) and implemented a series of technical and behavioural interventions. During 2012 the department managed to reduce its baseload consumption by 18% with approximately half of this resulting directly from the ECRP measures (ECRP 2012) (Appendix D, Table D.2).

5.2.3 Behavioural change initiatives at the University of Cambridge

Decarbonisation agendas resulted in the adoption of a series of efficiency measures in universities targeting both the building stock and the campus users. The Higher Education Funding Council for England (HEFCE), in an effort to comply with the UK's Climate Change Act, has set a reduction target of 43% by 2020 and 83% by 2050 (relative to the 2005 baseline) for all universities and colleges and released a relevant strategy report (HEFCE 2010). Among the wide range of areas where carbon reduction can occur, the report points out the potential of behavioural change as an efficiency measure. In response to HEFCE's carbon reduction guidelines, the University of Cambridge approved a Carbon Management Plan, which set out a central strategy on how this target should be achieved (University of Cambridge 2010).

Among its key components, the Energy and Carbon Reduction Project (ECRP) was established in 2011 *'to explore how and to what extent the University can achieve reductions in its energy-related carbon emissions without adversely impacting on research activity'* and achieve its environmental sustainability vision (ECRP 2013, p.7). The project began by piloting energy and carbon related measures—including increasing awareness on energy use—across five buildings: The Engineering Department, the University Library, the Department of Plant Sciences, the Gurdon Institute and the Department of Chemistry. The pilot buildings were among the most energy intensive within the University Estate and accommodated a variety of research facilities, therefore lessons learnt could be rolled throughout the Estate generally. As a part of the ECRP project, a real-time web-based energy dashboard was piloted in Gurdon Institute (see Section 4.7.2), the Department of Engineering (see Section 5.2.4) and the University Library to increase awareness of energy and carbon usage.

In order to promote user engagement at a campus level, the Environment and Energy section (responsible for the environmental policies throughout the University), established a series of initiatives under the umbrella of 'Cambridge Green Challenge' (Table 5.2). These consisted of awareness raising and behavioural change schemes addressing staff and students from departments and colleges. Among them, the Living laboratory scheme also offered the opportunity to engage further with sustainability within the university at a research level through projects and case studies.

Table 5.2 Cambridge Green Challenge engagement and behavioural change initiatives (ECRP 2013)

Green Impact[12]	Environmental accreditation scheme that encourages departments and colleges (staff and students) to reduce their environmental impact.
Environment and energy coordinators[13]	Network of student and staff volunteers who act as champions on environmental issues in their department and encourage their colleagues to make small changes to everyday work practices. They act as a point of contact between the Environment and Energy Section, department staff, students and senior management.
Living laboratory[14]	A scheme to provide opportunities for Cambridge students to improve environmental sustainability on the University estate through projects, internships and research.
Student switch off[15]	Energy-saving competition between Colleges.

5.2.4 The behavioural change programme at CUED

As a part of the ECRP project, a behavioural change programme was launched in the CUED to promote energy awareness and lead to energy savings. The programme was designed by the same

[12] http://www.environment.admin.cam.ac.uk/green-impact
[13] http://www.environment.admin.cam.ac.uk/EECs
[14] http://www.environment.admin.cam.ac.uk/green-impact
[15] http://studentswitchoff.org/unis/cambridge/

environmental consultancy that had set out the Gurdon Institute's Behavioural change project with the support of the department's Safety Officer. It involved the installation of twenty Real Time Displays (RTDs) in different types of sub-metered spaces (offices, research laboratories, workshops, etc.) and the set-up of a competition called the 'CO_2 reduction Grand Prix', where the selected work areas would race among each other to achieve the most energy savings. It assumed that individuals are willing to more effectively perform activities related to energy consumption in their workplace if the right incentives are created. This approach also resonated with Cialdini's (2003) theory of 'normative messaging', where people tend to save energy when they are told how they are doing compared to others, which can be more effective than financial savings or the abstract idea of saving the environment.

The 'Grand Prix' competition was communicated through e-mail, the launch event, the department's intranet page and monthly e-bulletins. A grand prize, along with monthly prizes, was available for the best performing team. The RTD was a 15-inch monitor mounted on the wall. It displayed information on each office's current energy use compared to an intended reduction target (Figure 5.4) and the ranking of the office in the competition's league table (Figure 5.5). This was done using a customised version of the Workplace Footprint Tracker (WFT), an energy management and visualisation dashboard. The behavioural change programme was launched in July 2014 with the competition starting a week after. A detailed account of the programme's phases in relation to this study is presented in Table 4.11.

Figure 5.4 The screen in office A featuring the actual and target consumption graph.

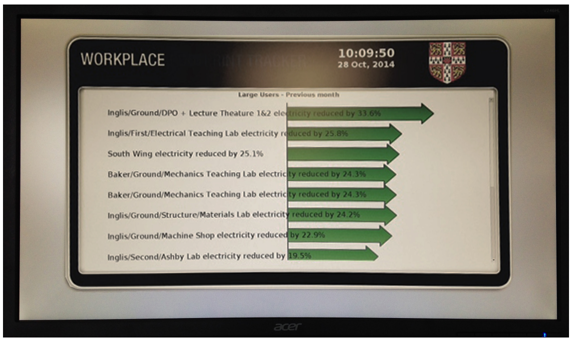

Figure 5.5 The screen in office A featuring the League Table.

5.3. Case study offices and their users

Higher education buildings constitute a special category of public buildings that accommodate a variety of uses and occupant profiles. Seminar rooms, auditoriums, laboratories, offices and common spaces are occupied daily by many transient and permanent users. While the provision of administrative, student and academic workplaces vary between different universities, there are some commonly recognisable elements. Harrison and Hutton (2014, p.158) provide a practical description of the workplaces contained in a higher education building:

> *'Academic departments often consist of rows of offices, teaching rooms and other support spaces arranged on either side of a central corridor or surrounding a central core. Social or interaction space for staff is often limited to a small tea point or kitchen area and many academics or administrative groups choose to have their own unofficial coffee and tea facilities within their own space, despite the consequent health and safety issues. The size of offices provided is generally based on an assessment of the work undertaken by the occupants and the rank or position of the person within the office hierarchy (Fink 2005). Large academic spaces for deans and professors may contain a meeting table or a soft seating area as well as the standard desk, filing cabinets and bookshelves. More junior staff members may have small individual offices or may share two-or three-person offices. Postgraduate research students may be allocated a desk in a shared research centre or in a postgraduate area within the department.'*

The above description largely reflects the setting within the main building of the CUED. Within the Engineering Department, three different office types accommodating different user profiles were selected:

a) The administrative shared, enclosed office (x1),
b) The PhD open-plan office (x2), and
c) The post-doctoral cellular office (x2).

Each office type has a different occupancy schedule, user profile, space typology and energy demand profile (Table 5.3). All these aspects were important for understanding their users' practices and the impact that Real Time Displays had on them. The following sub-sections give an account of the main characteristics of each office type.

Table 5.3 Summary characteristics of case study offices.

Office	**A**	**B**	**C**	**D**	**E**
Typology	Shared enclosed	Open plan	Open plan	Cellular office	Cellular Office
Heating and Cooling system	A/C	Central Heating/ A/C	Central Heating/ A/C	Central Heating	Central Heating/ A/C
Size (m^2)	64	101	88	23	7
Space per person (m^2/p)	12	4	4	5.8	2.3
Number of users	8	26	24	4	3

Number of participants	5	6	4	4	2
User profile	Administrative staff	PhD students	PhD students	Post-doctoral researchers	Post-doctoral researchers

5.3.1 The administrative shared enclosed office (A)

The administrative office A is located in the mezzanine floor of the CUED (Figure 5.6). It is inhabited by eight office users, six of whom—of different ages (from 27 up to 57) and gender (three female and three male)—took part in the study (Table 5.4). The length of their employment varied from eight months for the most recently employed, to nineteen years for the senior members.

The office was relocated to its current space in 2011, and previously was housed in an office at the basement of the building. Since the current room was not initially designed to be an office, it is not connected to the central heating system and has a relatively low ceiling height (≈2.5 m). The office is heated through four A/C units and occupied by eight users. Each unit is meant to cover the needs of two desks. The office operates daily, weekends excepted, during normal working hours (9am-5pm). It is open to public until 1pm and is regularly visited by other staff members during the day regarding collaborative work tasks.

Figure 5.6 Office A layout and its location within the Engineering Department.

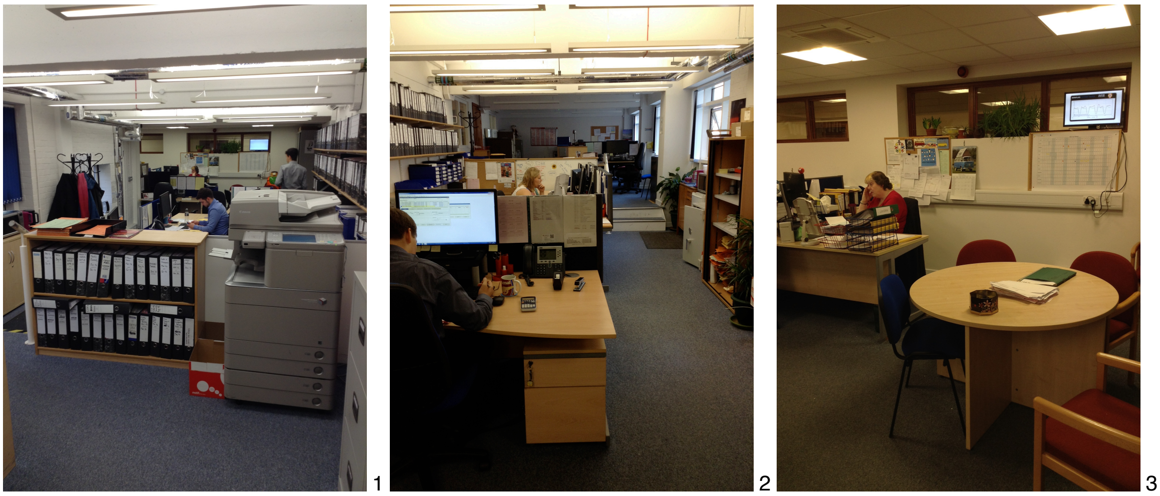

Figure group 5.7 Office A internal views (1,2,3).

The office desks are arranged in such a way that people working on the same projects would be sit close to each other to facilitate communication between them (Figure group 5.7) (See also Appendix D, Figure group D.5). Daily practices that take place are typing on desktop computers, cataloguing documents in relevant folders on the wall-mounted bookshelves, printing, photocopying, talking on the phone, visiting other offices and having one-to-one or group work-related discussions. There are eight desktop computers and telephones, a communal photocopier/printer and a paper shredder. A small kitchenette by the corridor allows for the storage and preparation of meals, coffee and tea. In addition, the office is equipped with a small fridge, two kettles and a microwave. The RTD was positioned in the far end of the room next to the meeting table rather than on the wall above the kitchenette (as initially planned), owing to the easier internet access (Figure 5.6).

Table 5.4 Office A participant demographics.

Case	Participant	Gender	Age	Job description	Education	Income	Ethnicity

Office A	1_Diana	F	27	Administrative staff	GCSE	£20,000 - £29,999	White (British)
	2_Luke	M	19	Administrative staff	A Levels	£10,000 - to£19,999	White (British)
	3_Laura	F	57	Administrative staff	A Levels	£30,000 - £39,999	White (British)
	4_Daniel	M	33	Administrative staff	A Levels	£20,000 - £29,999	White (British)
	5_Oliver	M	21	Administrative staff	A Levels	£10,000 - £19,999	White (British)
	6_Hannah	F	45	Administrative staff	A Levels	£20,000 - £29,999	White (British)

5.3.2 The PhD open-plan office (B and C)

Office B

Case study office B is a computer-based research laboratory for PhD students working on Micro-mechanics and Bioengineering-related research. It holds desk spaces for twenty-five people arranged in an open-plan layout (Figure 5.8, Figure group 5.9) (Appendix D, Figure group D.6). Six students were recruited: three female and three male of similar age (25 to 26 years old) who have been working in the office between two and three years (Table 5.5). They all had an advanced knowledge of energy systems and environmental issues due to their education background and expertise.

The office is accessible around the clock during the whole week. There are two types of researchers occupying the office: those who work at their desk full-time doing computer simulations and those who divide their working day between their labs (where they run experiments) and the office (where they process the data). As a consequence, different people work in the office at different times depending on the nature of their research. Alexia (B_1), a PhD student, explains that her daily schedule is *'pretty randomised'* and adds that *'in a week I spend two full days on my desk and three or four days popping in and out because I am usually here over the weekends as well'*. On a daily basis, in the early morning normally five or six people are in the office, while in the afternoon the number rises to ten or fifteen. On average, people would use the office approximately nine hours in a weekday and six hours during the weekend. The maximum tenure period in the office is four years, equivalent to the length of a PhD degree.

A combination of a central heating system and two user-operated A/C units are used for heating purposes while the A/C operates during summer as well for comfort cooling. Central heating is on during certain hours of the day and centrally controlled while during the evenings, overnight and weekends it is off, with the A/C used instead. A series of windows on both sides of the room serve for natural ventilation all year round.

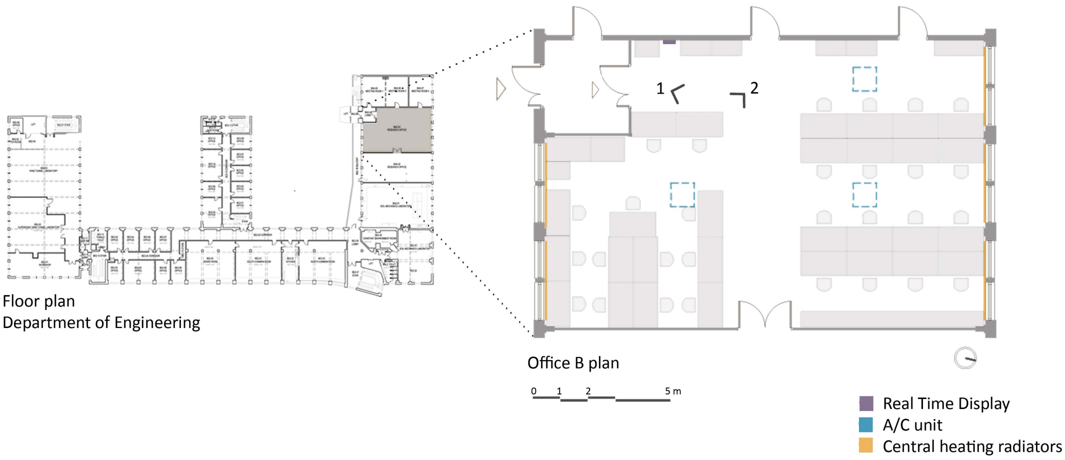

Figure 5.8 Office B layout and its location within the Engineering Department.

Figure group 5.9 Office B internal views (1,2).

The office was recently renovated (September 2013) and all the desks replaced with new ones, at which point equipment cables were covered and additional sockets were installed. The layout has been optimised so that offices face each other—rather than the wall—and four new desks were added. Each researcher is allocated a desk space, equipped with a desktop computer and has access to a common printer. Electricity consumption in the office is related to the use of the A/C, lighting patterns and the desktop computers. There is also a common printer in the room and the few small appliances—an electric coffee maker and a kettle. The Real Time Display was placed next to the office entrance (Figure 5.8).

Table 5.5 Office B participant demographics.

Case	Participant	Gender	Age	Job description	Education	Income	Ethnicity
Office B	1_Alexia	F	25	PhD Candidate	MSc	£10,000 - £19,999	White (Greek)
	2_Silvia	F	25	PhD Candidate	MSc	£10,000 -	White

					£19,999	(Canadian)
3_Ruchi	F	25	PhD Candidate	MSc	£10,000 - £19,999	Asian (Indian)
4_Peter	M	26	PhD Candidate	MSc	£10,000 - £19,999	White (Polish)
5_Wilhelm	M	25	PhD Candidate	MSc	£10,000 - £19,999	White (German)
6_Ben	M	25	PhD Candidate	MSc	£10,000 - £19,999	Chinese (HK)

Office C

Office C is another computer-based research office occupied by PhD students in the field of Signal Processing. It shares the same research culture and occupancy schedule with office B. Of its twenty-four users, four (all males) participated in this study (Table 5.6).

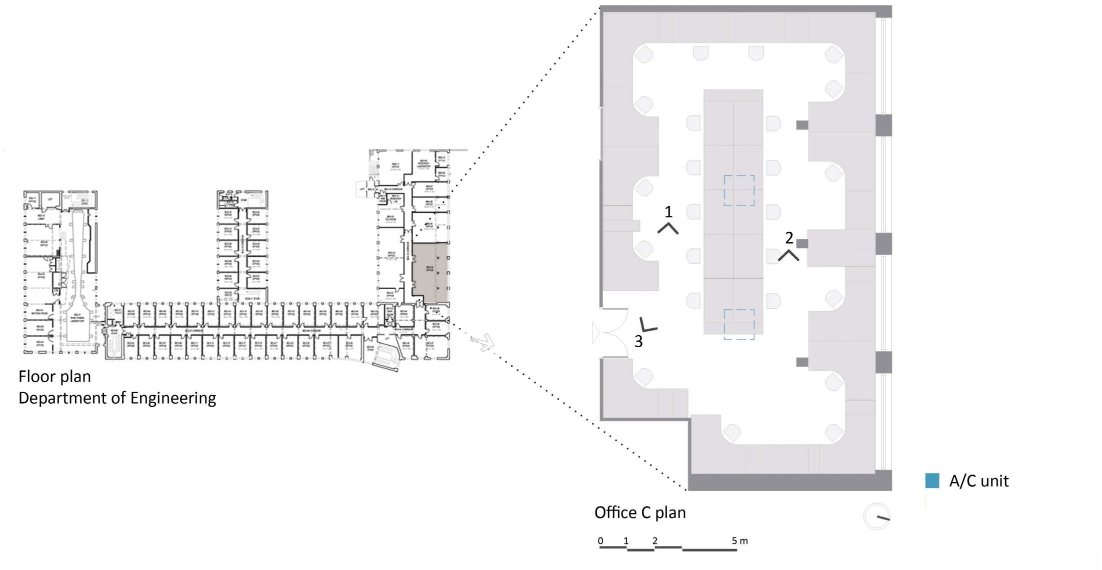

Figure 5.10 Office C floor plan and its location within the Engineering.

The office is equipped with fourteen desks for permanent users and ten 'hot-desks' for transient users (Figure 5.10, Figure group 5.11) (Appendix D, Figure group D.7). Its main difference with office B is the slightly larger desk space allocated to each user to accommodate two computer monitors and, sometimes, more than one central units due to increased computational research needs. Although the office does not have a stable occupancy rate, on most days four to ten people are present.

The office was renovated a year before the interviews took place and all the furnishing is new. Two ceiling cassette air-conditioners provide heating and cooling and windows are used for natural ventilation. All lights are operated by movement censors. A common room, located at the end of the office corridor, serves as an informal meeting and discussion space, and this is where the RTD was placed.

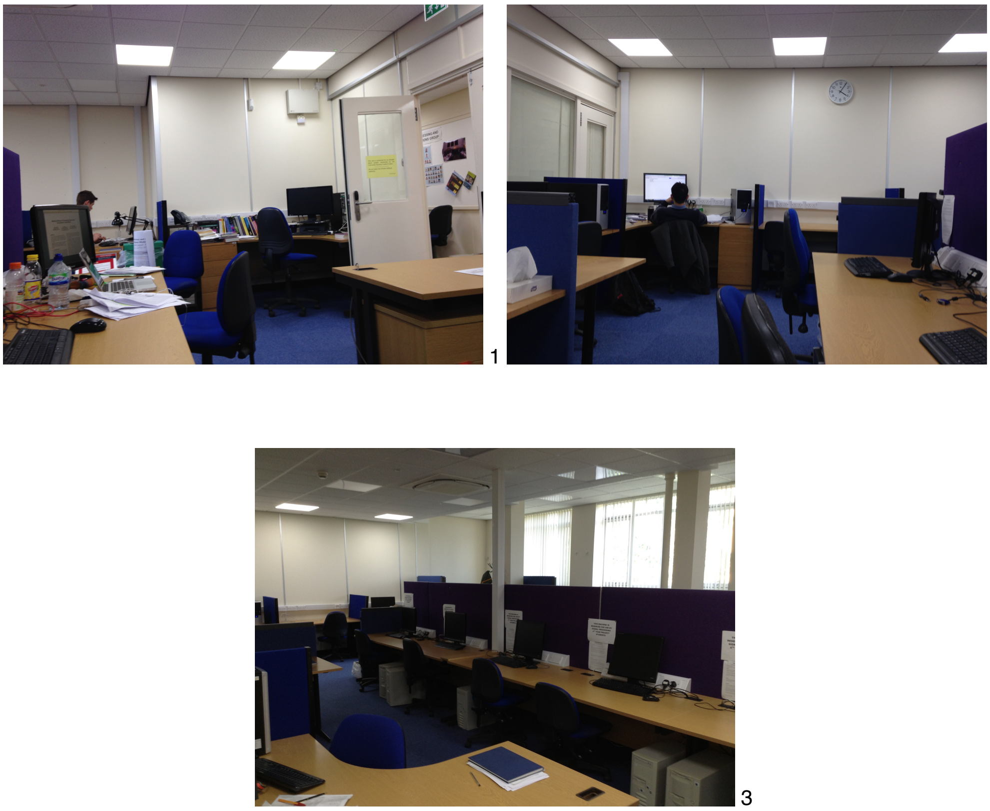

Figure group 5.11 Office C internal views (1, 2, 3).

Table 5.6 Office C participant demographics.

Case	Participant	Gender	Age	Job description	Education	Income	Ethnicity
	1_Matt	M	28	PhD Candidate	MSc	£10,000 - £19,999	White (British)
Office C	2_Alan	M	28	PhD Candidate	MSc	£10,000 - £19,999	White (British)
	3_Steven	M	24	PhD Candidate	MSc	£10,000 - £19,999	White (British)
	4_George	M	27	PhD Candidate	MSc	£10,000 - £19,999	White (Italian)

5.3.3 The post-doctoral cellular office (D and E)

Office D

The post-doctoral office D is a private research and study space and sometimes a space for small group meetings (Figure 5.12, Figure 5.13) (Appendix D, Figure group D.8). The office is occupied by four male researchers, all of whom participated in this study (Table 5.7). They have been using the office from five months (in the case of the most recently employed researcher) to four years (in the case of the most senior one) at the time when the interviews took place. The office is occupied daily between 8am and 8pm for nine to twelve hours. During weekends, the users prefer to access their computers remotely from home. They would also travel for conferences and other research purposes, causing them to be out of the office for extended periods.

Radiators connected to the central heating system and located below the window heat the office. The users open the windows for natural ventilation and, in the summer, a fan is used for cooling purposes. Each desk is equipped with a desktop computer and there is a printer and a scanner, which are shared. As the office belongs to the same research group as office C, they use the same common room where the RTD is placed.

Figure 5.12 Office D floor plan and its location within the Engineering Department.

Figure 5.13 Office D internal view.

Table 5.7 Office D participant demographics.

Case	Participant	Gender	Age	Job description	Education	Income	Ethnicity
Office D	1_Robert	M	33	Research Associate	PhD	£30,000 - £39,999	White (British)
	2_Sina	M	31	Research Associate	PhD	£30,000 - £39,999	Asian (Persian)
	3_Henrik	M	40	Research Associate	PhD	£30,000 - £39,999	White (German)
	4_John	M	32	Research Associate	PhD	£30,000 - £39,999	White (British)

Office E

Office E is a small (7m^2) post-doctoral research office used by three male researchers, two of whom participated in this study (Figure 5.14, Figure group 5.15, Table 5.8). The office is occupied daily between 9am and 8pm, with occupancy varying plus or minus two hours on either end.

The use of powerful desktop computers is essential for the research undertaken here and it is an established office policy that all computers remain constantly on and are shared by the whole group. Within the office, each user has his own computer and has access to a communal printer placed in the corridor. The room space is centrally heated and equipped with an A/C unit. Office E did not have access to an RTD and was used as a control group.

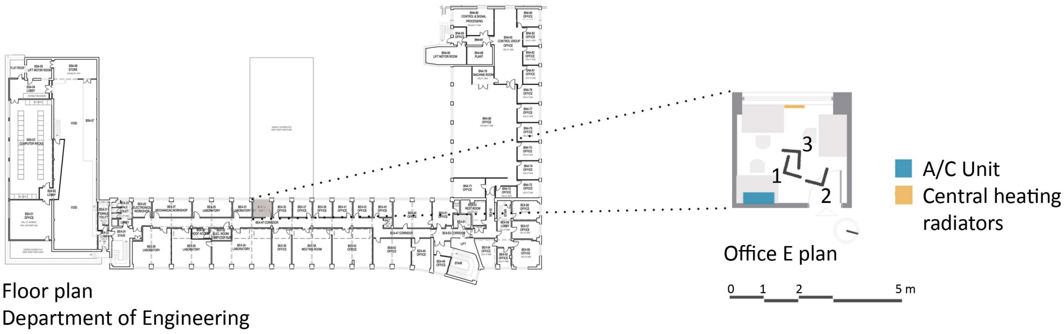

Figure 5.14 Office E floor plan and its location within the Engineering Department.

Figure group 5.15 Office E internal views.

Table 5.8 Office E participant demographics.

Case	Participant	Gender	Age	Job description	Education	Income	Ethnicity
Office E	1_Zack	M	31	Research Associate	PhD	£30,000 to £39,999	White (American)
	2_Jacob	M	30	Research Associate	PhD	£30,000 to £39,999	White (Danish)

5.3.4 Case study offices in relation to practice elements

Table 5.9 outlines the characteristics of the case study offices in relation to the main elements of the social practice theory as adopted by Gram-Hanssen (2010b) and referred to in Section 2.3.2. It consists of a comparative and informational review based on onsite observation and interview data and acts as a useful basis for the following analysis chapters.

Table 5.9 Characteristics of case study offices in relation to practice elements.

	Office A **Administrative shared, enclosed office**	**Offices B and C** **PhD open-plan office**	**Offices D and E** **Post-doctoral cellular office**
Routines	- Standard working hours (9am to 5pm) 5 days a week - Daily use of office equipment - Administrative tasks	- Variable working schedule - The office is often used during weekends - Both research and laboratory tasks	- Extended standard working hours (8 to 10 hours a day) - Remote access to computers over the weekend - Research tasks
Technologies/ Material	- Open plan layout (8 users) - Offices equipped with desktop computers - A/C's provide heating and cooling - Naturally ventilated	- Open plan layout (24-26 users) - Powerful desktop computers - Both radiators (central heating) and A/C - Naturally ventilated	- Cellular plan (3-4 users) - Powerful desktop computers shared in a common network - Radiators (central heating) and A/C (Office E only) - Naturally ventilated
Knowledge	- Above average level of education (A levels)	- Higher level of education (MSc Degree) - Advanced knowledge on energy systems and environmental issues due to education and expertise	- Higher level of education (PhD Degree) - Advanced knowledge on energy systems and environmental issues due to education and expertise
Meanings	- Permanent users - Standardised working schedule - Hierarchical positions	- Transient users (maximum 4 years of stay) - Equal roles - Sharing student culture	- Transient users (approximately three years of stay) - The office as a space for academic performance - 24-hour research culture

5.4. Chapter summary

This chapter introduced the Cambridge University Engineering Department as the case study academic building and presented the office typologies selected as units of analysis. As a part of the Energy and Carbon Reduction Project, a behavioural change programme was implemented in the CUED and RTDs were placed in offices and workshops. This study ran in parallel to the programme, five offices of three office types were selected for monitoring—the shared, enclosed administrative office (A); the PhD open-plan office (B and C), and the post-doctoral cellular office (D and E)—and participants were recruited among their occupants. A detailed review of these offices' space and user characteristics was carried out as preparatory stage for understanding how the purpose, design and technologies accommodated in an office can affect its users' practices.

6. Thermal characteristics and comfort preferences of users

6.1. Introduction

This chapter examines the thermal characteristics of the case study offices and identifies the comfort preferences of their users by bringing together the results of the indoor thermal conditions monitoring and comfort diaries. Here, the aim is to investigate indoor temperature and humidity conditions in each office and map the comfort temperature for the users. The chapter is divided into two main sections. The first (Section 6.2) presents the weekly and monthly temperature and relative humidity monitoring results of the five offices in winter and summer season. The second section (6.3) gives an account of the comfort diary results, which recorded the sensation, preference and acceptability of users in relation to the actual office conditions. The concluding section (6.4) summarises the discussion and findings from the two previous sections.

The methodology for this chapter is described in detail in Chapter 4 (see Section 4.6.3). Two monitoring and comfort studies took place in the five case study offices during two different periods; the 'winter season' (February 2014) and the 'summer season' (June 2014). During these months, the selected offices, which represent three typical office typologies, were monitored using Tiny-Tag data loggers at 30-minute intervals. In addition, the twenty-two participants completed a total of 167 thermal comfort diaries three times a day over the period of a week in both February and June (Appendix A4). The diaries were based on the adaptive comfort model, thus borrowing elements from field studies. They were analysed by plotting the variables against each other as described by Nicol and Humphreys (2002).

6.2. Thermal performance

6.2.1 Climatic conditions

Figure 6.1 illustrates the average monthly temperature and humidity values for February and June 2014 when the comfort surveys were carried out. During the winter monitoring period, the outdoor temperature fluctuated between 0.8°C and 13.6°C with an average of 6.6°C recorded. There was daily rainfall and the average humidity level was 79%, indicating cold and humid conditions. The summer period was warmer, with an average temperature of 15.9°C and a daily range between 6.8°C and 26.5°C, whilst humidity levels averaged 71%.

The average weekly climatic conditions are presented in Figure 6.2. During the winter week that the comfort diaries were completed (3-9/02/2014) weather conditions were consistent with only small variations. The temperature was cold, ranging between 2.8°C and 9.2°C, and averaging 6.3°C. There was daily rainfall, resulting in an average humidity level of 79.1%. The summer study week in June (23-29/06/14) did not present extreme variations either, although the swing between the minimum and maximum values was wider. The average weekly temperature was 17.1°C, reaching a peak of 25.5°C towards the beginning of the week. A minimum of 12.5°C was logged in the last day. Humidity levels were reasonably high, with an average of 79% indicating that it was a rainy week with high outdoor humidity levels.

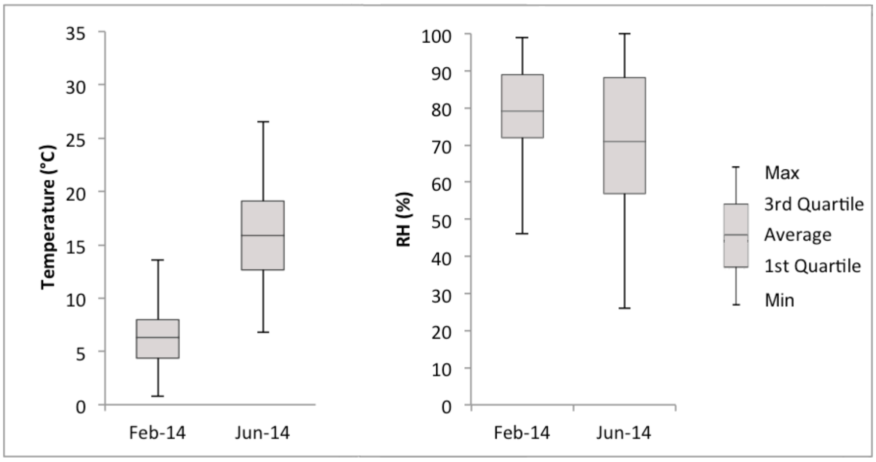

Figure 6.1 Average monthly temperature and relative humidity values for the two monitoring periods (February and June 2014)(Source: DTG Weather station).

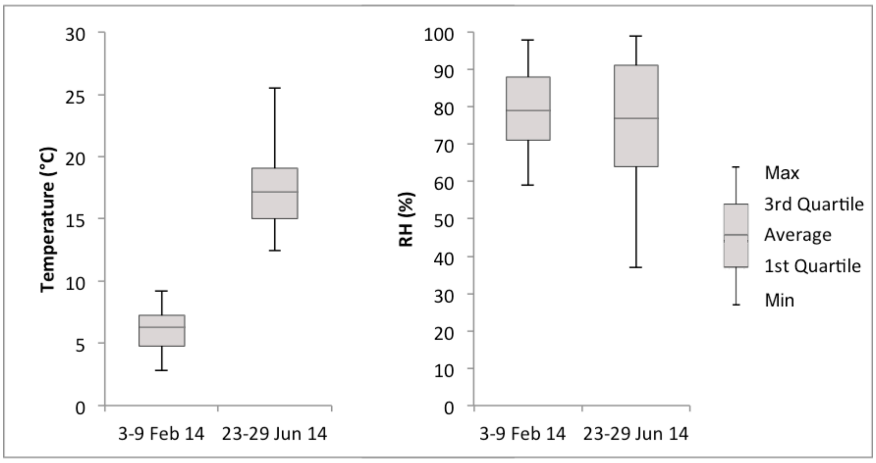

Figure 6.2 Average weekly temperature and relative humidity values for the two monitoring periods (3-9 February and 23-29 June 2014)(Source: DTG Weather station).

The climatic conditions during the two study periods are considered representative of typical conditions for this time of the year although there were slight temperature variations when compared with average past weather data (Figure 6.3). During February, the temperature range was towards the highest values for that month, with a difference of approximately 1°C and the average daily maximum standing at 7.7°C. In June, the average temperature was representative of the summer period (16°C), although there were some peaks during the days of the study; a maximum of 25.5°C was recorded.

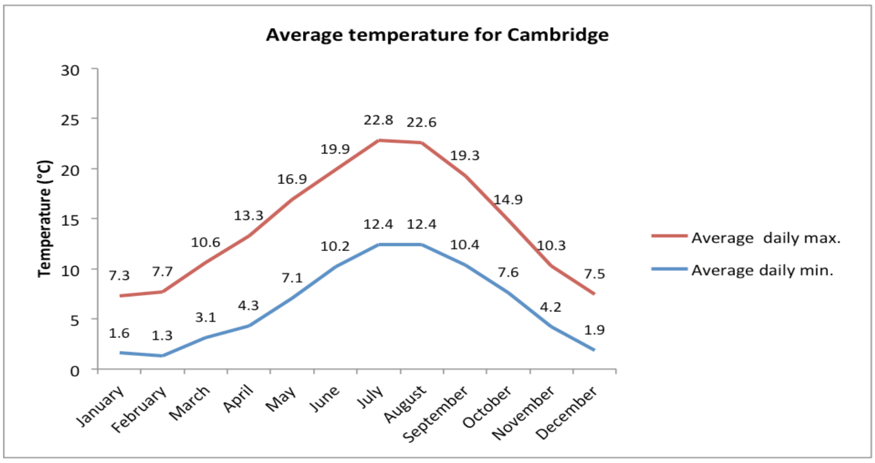

Figure 6.3 Annual temperature graph for Cambridge indicating the average temperature conditions during the monitoring and comfort study periods (Source: http://www.metoffice.gov.uk/ public/ weather/ climate/ u1214b469).

6.2.2 Winter season

6.2.2.1 Monthly temperature and humidity trends

The temperature and relative humidity monitoring results of the case study offices for February 2014 (the 'winter season' study) are presented in two box-and whisker plots (Figures 6.4 and 6.5). The outdoor values retrieved from the DTG weather station are also included in the graphs (Out MET) to provide a weather reference. They were preferred to the Tiny-Tag logger recordings located outdoors as they were considered more accurate since they were drawn from the specialised weather instruments.

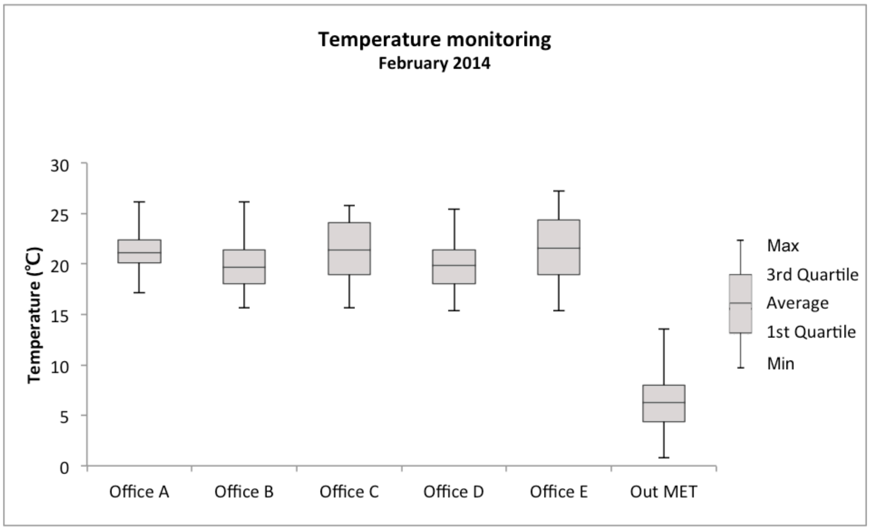

Figure 6.4 Box-and-whisker plot of the winter monthly (February 2014) temperature monitoring values of the case study offices.

The monthly temperature results for the five offices during February were relatively uniform, although some individual trends can be spotted (Figure 6.4). The average values are remarkably similar for all the case study offices and range between 19.7°C and 21.6°C, which is considered normal for educational workplaces according to CIBSE[16] (2006) standards. The highest values for maximum and minimum temperatures (27.2°C and 15.4°C) were recorded in the post-doctoral offices D and E respectively (see Figure 6.4).

A trend that stands out is that the administrative office (A) presented a more stable temperature profile compared to the other offices, with its inter-quartile range being 2.3°C for the whole month. This meant that more than 50% of the recorded temperatures were between 20.1°C and 22.4°C. Offices B and D followed, with a slightly higher range of 3.4°C. The PhD office (C) and post-doctoral office (E) meanwhile presented the highest inter-quartile range of 5.5°C, indicating a wider temperature variation (between 18.9°C and 24.4°C).

Relative humidity results during February had average values between 35.8% and 41.4% (Figure 6.5). There was a slight variation between the different offices but the general trend was that humidity levels were below 42%. Similarly to the temperature profiles, the administrative office (A) had the smallest inter-quartile swing between 33.6% and 37.3%, indicating a consistently dry environment. The post-doctoral office (E) and the PhD office (C) had the largest relative humidity fluctuations while post-doctoral office (D) and the PhD office (B) presented a more consistent relative humidity range.

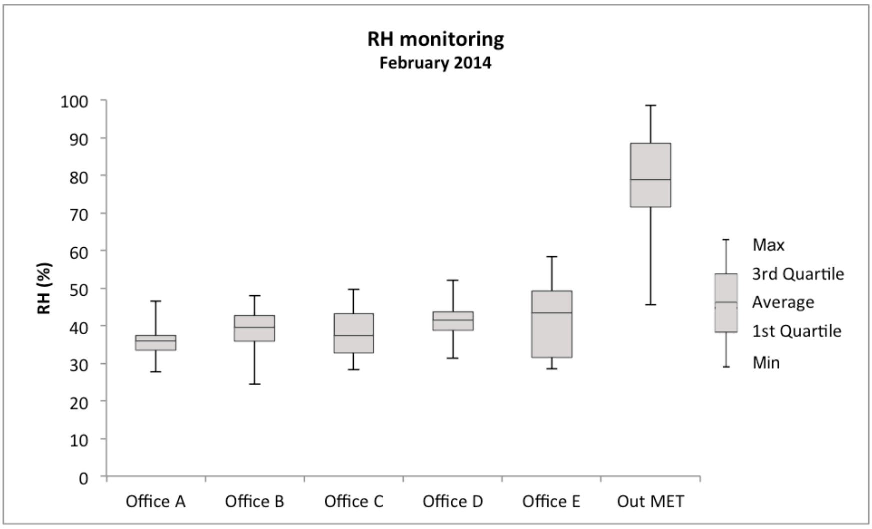

Figure 6.5 Box-and-whisker plot of the winter monthly (February 2014) relative humidity monitoring values of the case study offices.

6.2.2.2 Weekly patterns

The following section gives an indication of the temperature and relative humidity levels in the case study offices during the period of a week in February and June 2014 respecticely, coinciding with the days the comfort diaries were filled. The seven-day period was considered indicative of both the typical diurnal and working week thermal condition patterns of the case study offices.

[16] Chartered Institution of Building Services Engineers.

The administrative shared enclosed office

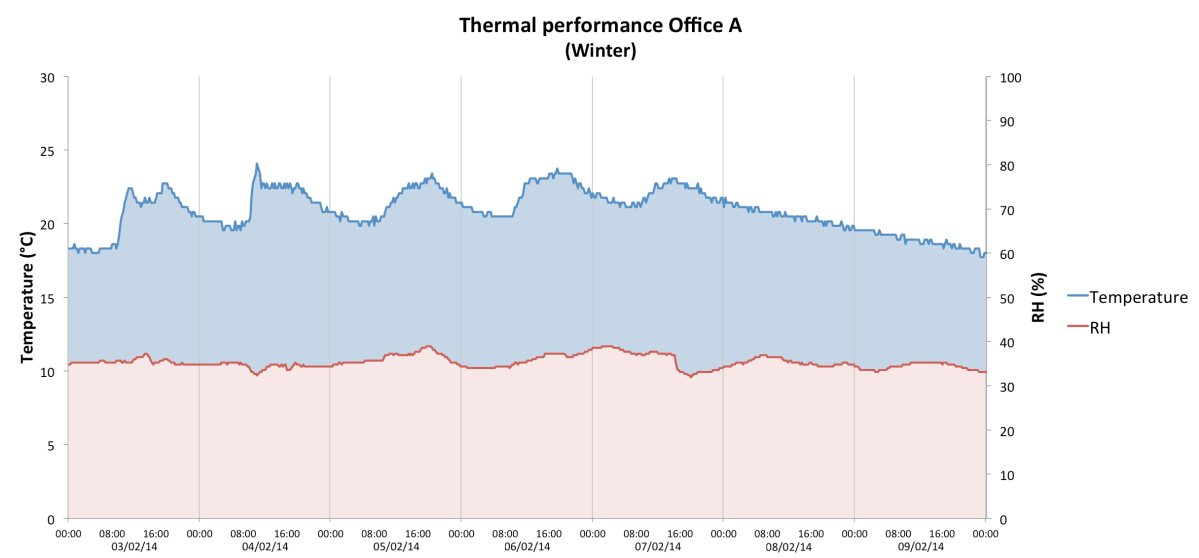

Figure 6.6 Graph of environmental conditions monitoring (Temp, RH) in office A over the period of a week during winter (03-09 February 2014).

Figure 6.6 illustrates the daily temperature and humidity pattern for the administrative office over the seven-day winter study period. The weekly temperature fluctuates between 19°C and 23°C with an average of 21.4°C, thus recording a comfortable office environment. A few sharp early morning peaks are noticed in the beginning of the week indicating the use of A/C to heat the room while the office temperature gradually drops off over the weekend. Humidity is found to be consistently low, with an average of 35% recorded for the whole week.

The PhD open plan workplace

The thermal conditions of the two PhD student open-plan offices are presented in Figures 6.7 and 6.8. Both offices performed similarly in terms of temperature and humidity. The temperature pattern had a steady fluctuation during weekdays and became more uniform during weekends when the offices were in less use. The minimum recorded value of 15.7°C was spotted at the beginning of the week, following an unheated weekend. This value gradually rose to accommodate an inter-quartile swing between 17.4°C and 21°C and an average of 18.3°C. Relative humidity values appeared to be consistent throughout with a negligible swing and an average value of 44%, indicating a normal but potentially dry environment.

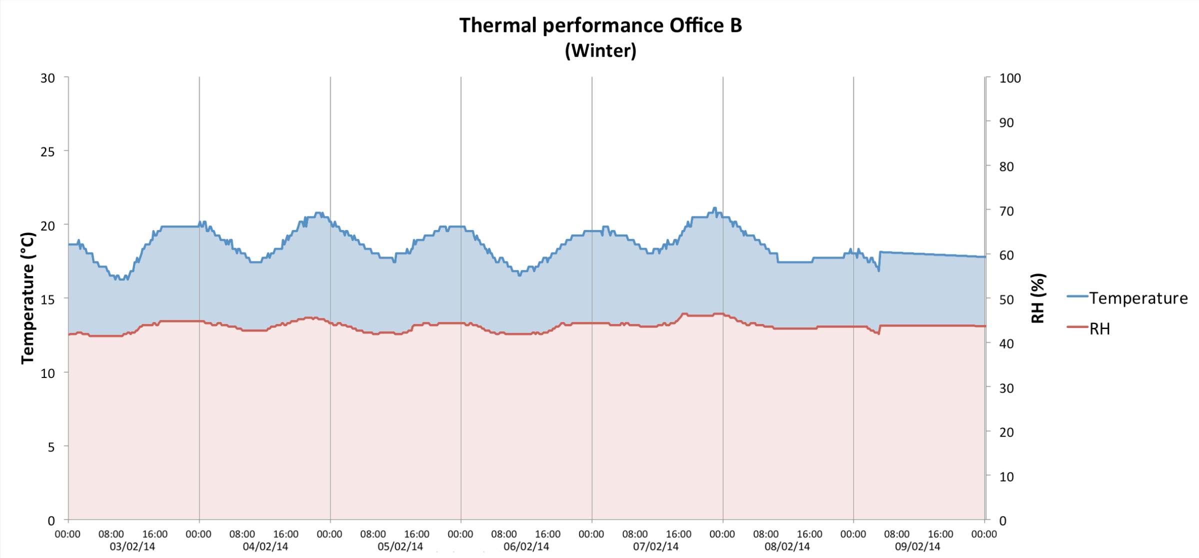

Figure 6.7 Graph of environmental conditions monitoring (Temp, RH) in office B over the period of a week during winter (03-09 February 2014).

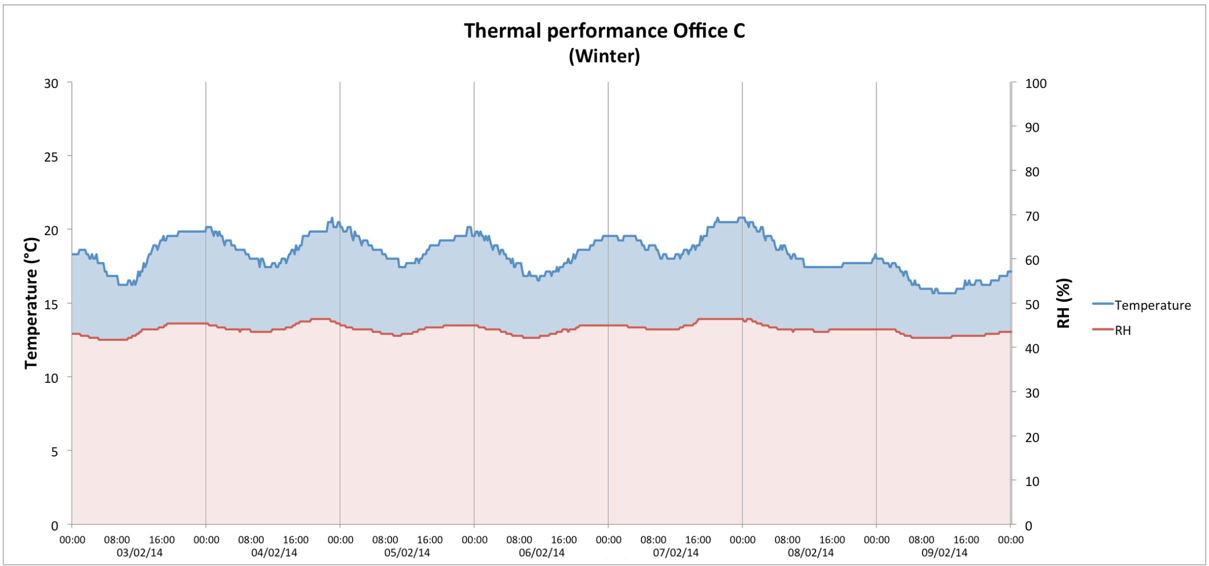

Figure 6.8 Graph of environmental conditions monitoring (Temp, RH) in Office C over the period of a week during winter (03-09 February 2014).

The post-doctoral research cellular office

The two offices presented an identical temperature and relative humidity weekly profile (Figures 6.9 and 6.10). The indoor temperature inter-quartile swing was between 17.5°C and 20.8°C, starting low in the early morning hours, only to gradually build up and reach its peak around midnight, before falling again during the course of the night. During weekends, the temperature remained stable at around 17.5°C, which denotes the lack of heating and low room occupancy. The average room humidity was 42.9% for office D and 44.6% for office E, suggesting a stable but slightly low value in both student offices.

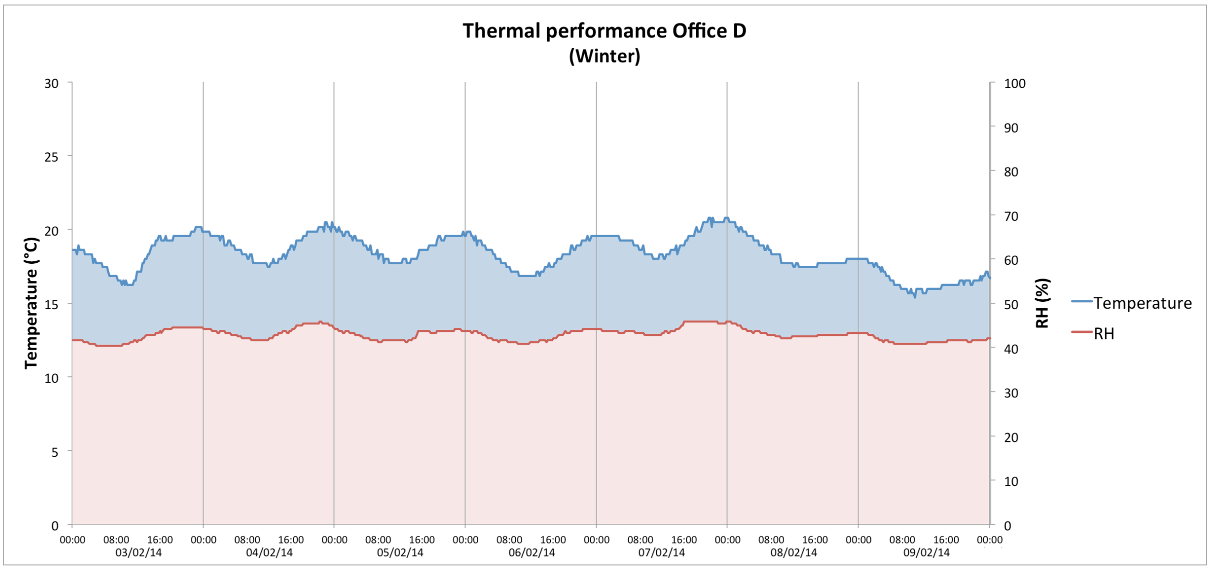

Figure 6.9 Graph of environmental conditions monitoring (Temp, RH) in office D over the period of a week during winter (03-09 February 2014).

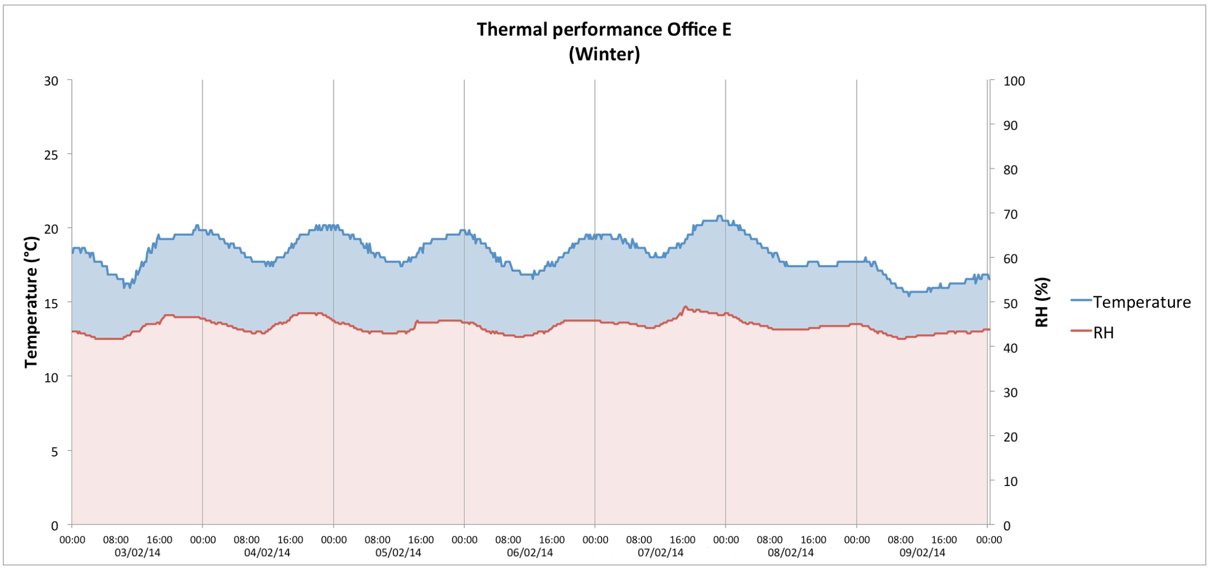

Figure 6.10 Graph of environmental conditions monitoring (Temp, RH) in office E over the period of a week during winter (03-09 February 2014).

6.2.2.3 Cross-case results

Figure 6.11 overlays the weekly winter temperature profiles of the five case study offices in one graph. A general trend becomes apparent according to which the diurnal temperature patterns of offices B, C, D and E are similar, as indicated by a homogeneous band of profiles, while office A presents a differentiated result with an approximately 2.5°C warmer profile. Looking more closely at this difference, we can see that the average temperature swing of the PhD and post-doctoral offices is between 17.2°C and 19.2°C, while in the administrative office it moves two degrees higher, between 20°C and 22°C. This difference can be explained by the differentiated heating system, which allows greater control over temperature settings by the users. With respect to the outdoor conditions, both trends seem to act independently of external temperature swings.

During the winter, relative humidity levels appeared to be relatively low for all five offices (Figure 6.12). The PhD and post-doctoral offices (B, C, D, E) shared identical patterns, while a lower and slightly differentiated pattern was recorded at the administrative office (A). This lower recording mirrored the daily temperature. The average RH value for the first office group was 44%, contrasting with the value recorded for the administrative office, namely 35%.

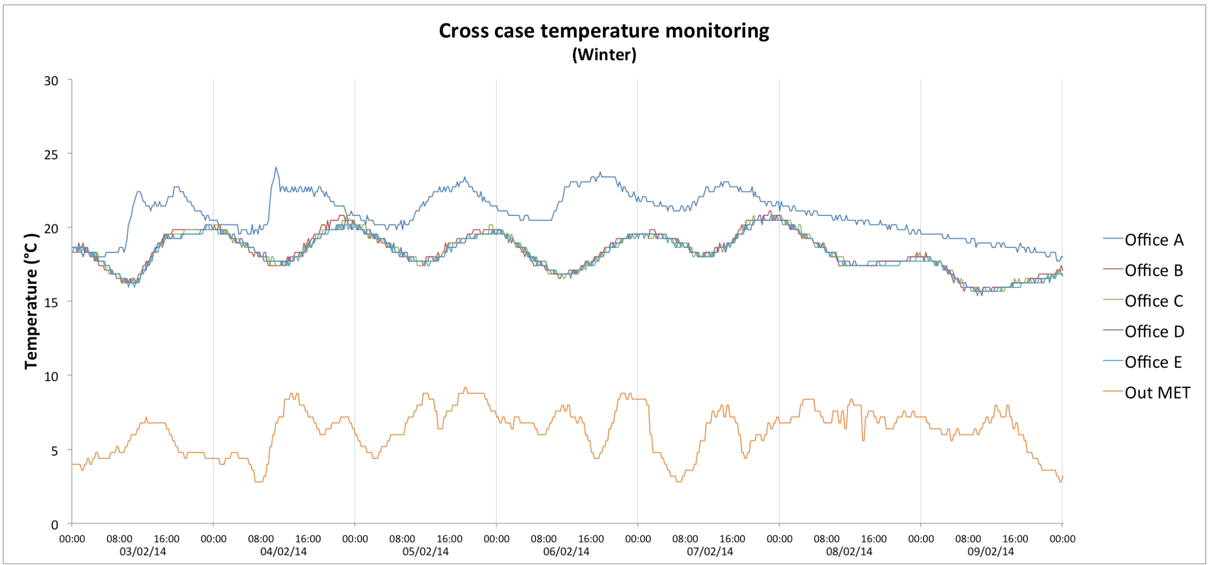

Figure 6.11 Cross case temperature monitoring graph over the period of a week during winter (03-09 February 2014).

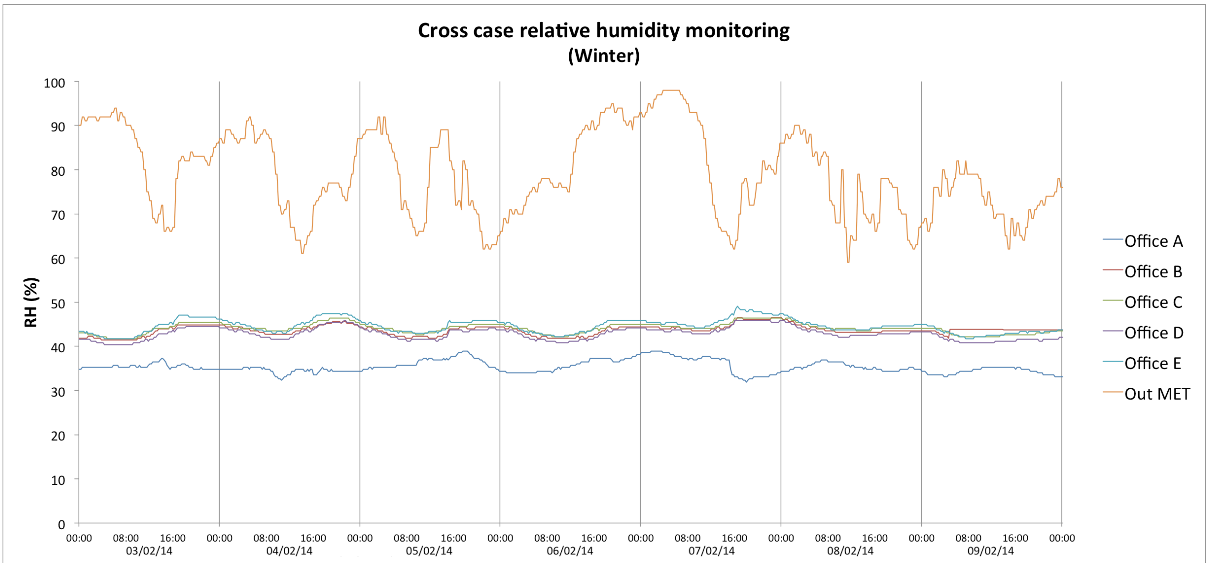

Figure 6.12 Cross case relative humidity monitoring graph over the period of a week during winter (03-09 February 2014).

6.2.3 Summer season

6.2.3.1 Monthly temperature and humidity trends

Unlike the homogeneous winter temperature patterns, the five offices in summer presented variable profiles (Figure 6.13). The average indoor temperature range was between 22.6°C and 25.1°C with the outdoor temperature being 15.9°C, indicating slightly warmer indoor conditions than one would expect. Office A, had an average of 24 °C and a stable indoor environment similar to offices C and D. The PhD office B seemed to present lower and more uniform temperatures, with an average of 22.6°C and an inter-quartile difference of only 1°C. Contrastingly, the post-doctoral office E had consistently higher temperatures, with an average of 25°C and reaching a maximum of 29.1°C. This possibly results from its smaller size and western orientation.

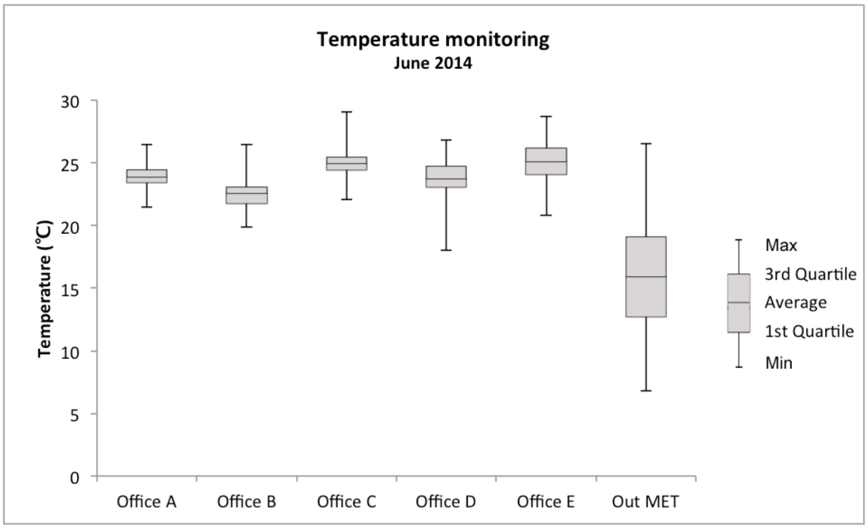

Figure 6.13 Box-and-whisker plot of the summer period temperature monitoring of the case study offices.

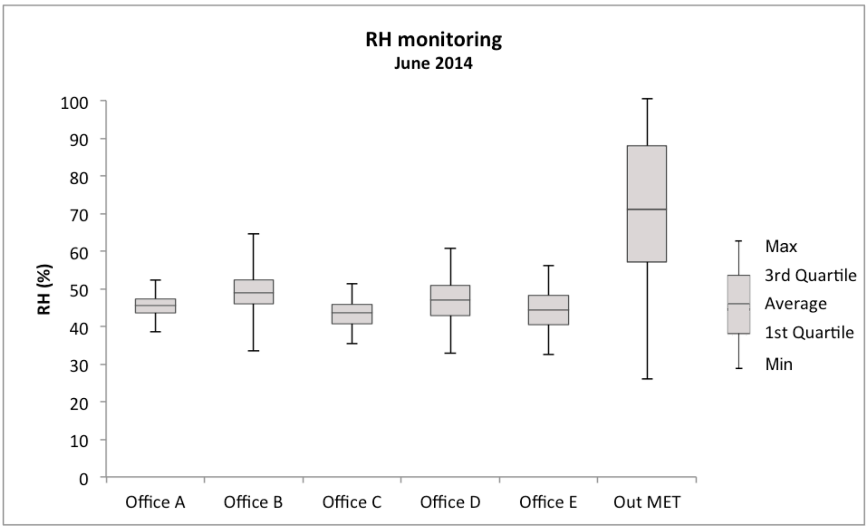

Figure 6.14 Box-and-whisker plot of the summer period relative humidity monitoring of the case study offices.

Relative humidity average values ranged between 43.5% and 49%. As witnessed in the temperature results, the administrative office A had the most stable humidity levels, with an average of 45.6%. The PhD student offices B and C presented a small difference between their average values—49% and 44% respectively—and office B had a slightly wider swing. Finally, the post-doctoral offices performed in a similar way, with average values between 45 and 47%.

6.2.3.2 Weekly patterns

The administrative shared enclosed office

During the summer study week, the thermal performance of the administrative office was stable and marginally warmer (Figure 6.15). The average temperature was 24.3°C, with a narrow swing between 23.7°C and 25.1°C during the working days, which dissipated during the weekend. The humidity conditions followed a similarly stable pattern, with an average value of 44.8%. Small peaks and drops could meanwhile be identified. These were possibly due to the opening and closing of windows.

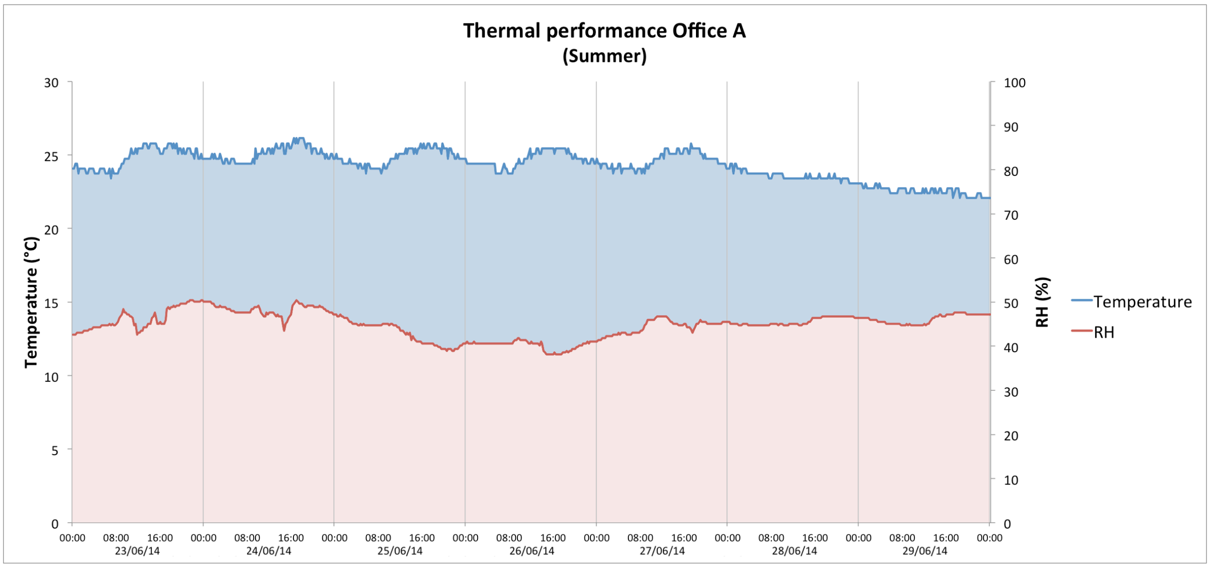

Figure 6.15 Graph of environmental conditions monitoring (Temp, RH) in office A over the period of a week during summer (23-29 June 2014).

The PhD open plan workplace

The PhD office B presented a more irregular temperature and relative humidity pattern (Figure 6.16) if compared to the administrative one and its winter profile (Figure 6.7). During the working week, the temperature fluctuated between 19.8°C and 26.1°C, with an average of 23.1°C. It appeared to be higher in the afternoons, which related both to outdoor conditions (Figure 6.20) and higher occupancy levels. Similarly, the humidity profile turned out to be also irregular compared to the stable winter one, possibly due to opening and closing of windows. Its average value of 48.9% is the highest of all offices.

The second PhD office (C) was found to have a more stable temperature and humidity profile (Figure 6.17). During the whole week, the temperature swing was of only 2°C, but the conditions were slightly warmer with an average temperature of 24.6°C. Average humidity was 44.9%, with a narrow interquartile swing between 42.2% and 47.8%.

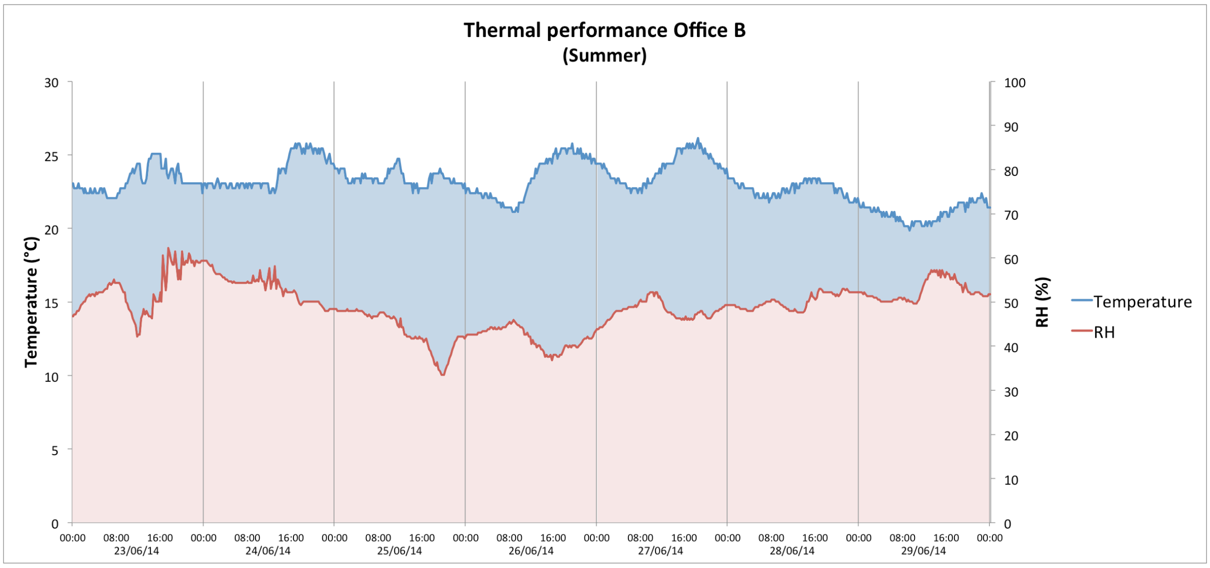

Figure 6.16 Graph of environmental conditions monitoring (Temp, RH) in office B over the period of a week during summer (23-29 June 2014).

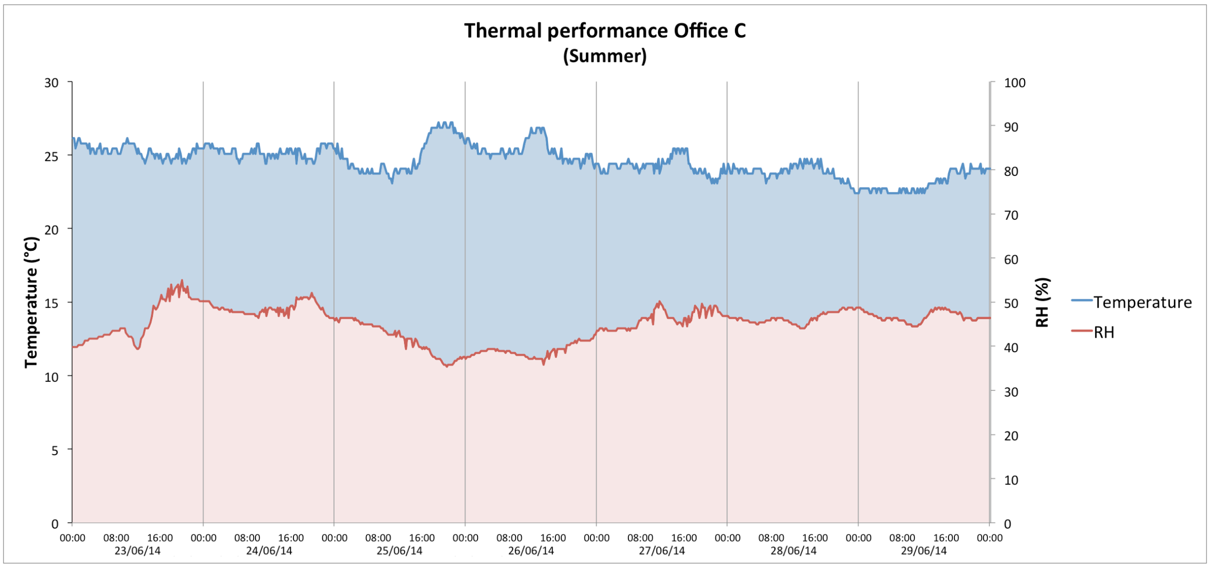

Figure 6.17 Graph of environmental conditions monitoring (Temp, RH) in office C over the period of a week during summer (23-29 June 2014).

The post-doctoral research cellular office

The two post-doctoral offices in a typical summer week presented almost identical temperature and humidity ranges (Figures 6.18 and 6.19). The temperature average was 23.9°C (office D) and 24.4°C (office E) while the respective RH values were 47.6% and 46.8%. Thermal conditions were stable. There was one noticeable trend in office D whereby a regular morning temperature drop could be seen during the working week, probably because of windows being open at that time of the day.

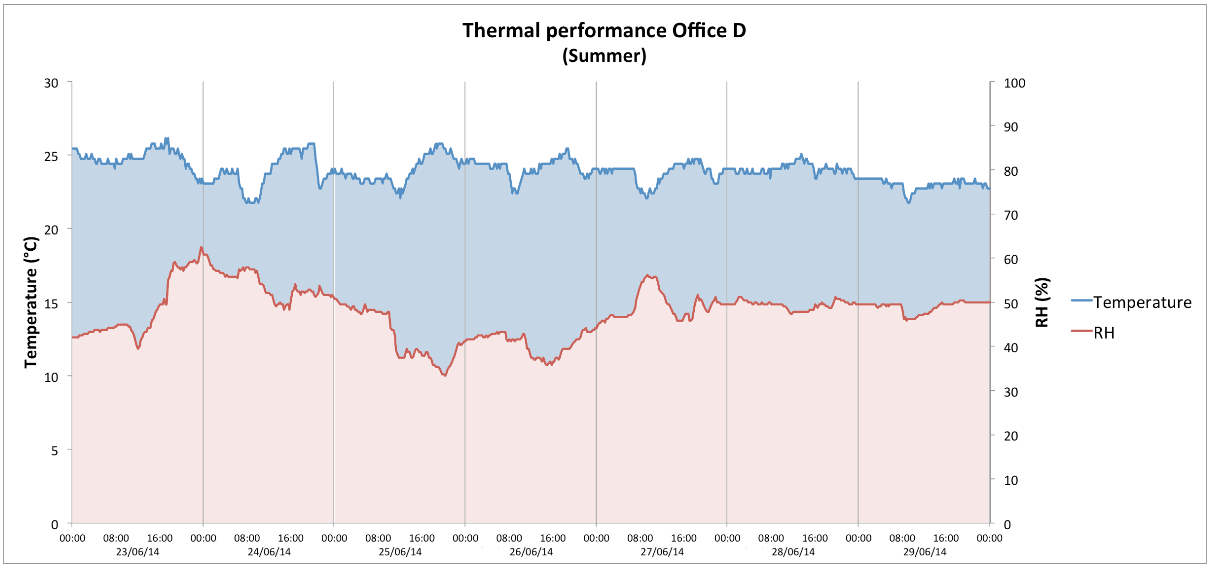

Figure 6.18 Graph of environmental conditions monitoring (Temp, RH) in office D over the period of a week during summer (23-29 June 2014).

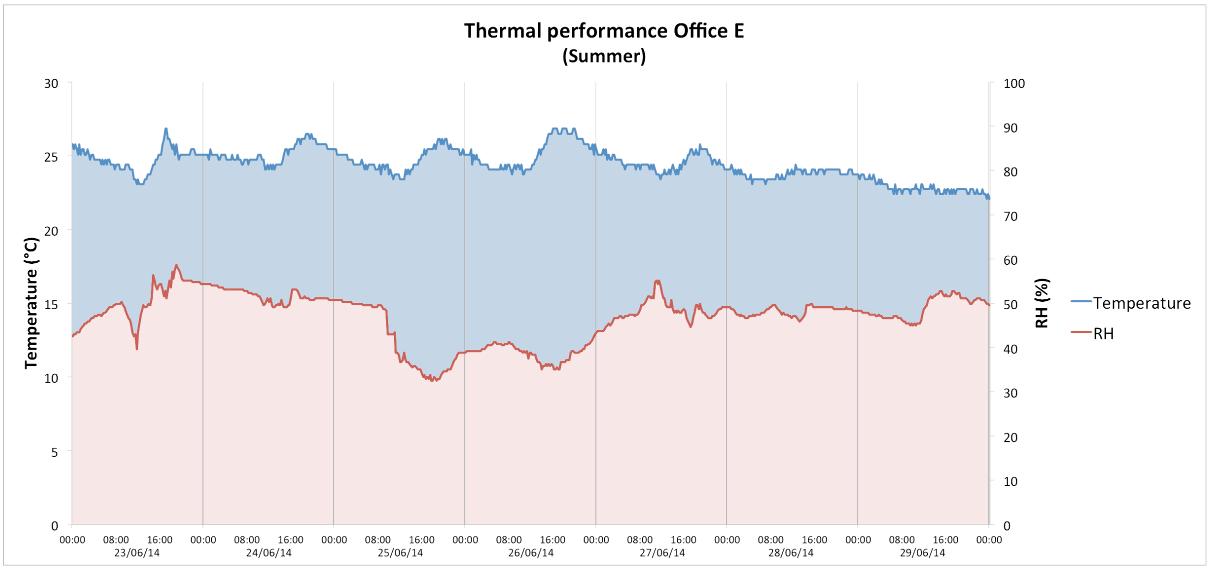

Figure 6.19 Graph of environmental conditions monitoring (Temp, RH) in office E over the period of a week during summer (23-29 June 2014).

6.2.3.3 Cross-case results

Looking across the summer weekly profiles, a general trend with a slight variation between the different offices stands out. There is a uniform indoor temperature peak in the afternoon following the rise of the outdoor temperature that gradually drops off during the evening before starting to rise again the next morning in accordance with the outdoor temperature pattern but with the obvious effects of a time-lag. Any trend associated with the office typology could not be identified.

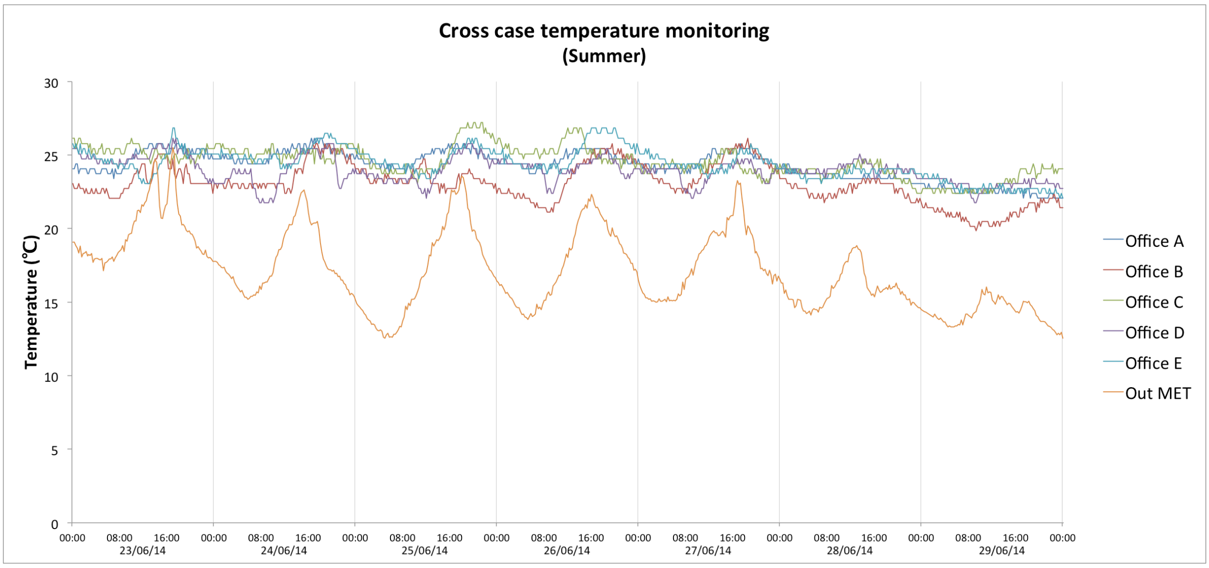

Figure 6.20 Cross case temperature monitoring graph over the period of a week during summer (23-29 June 2014).

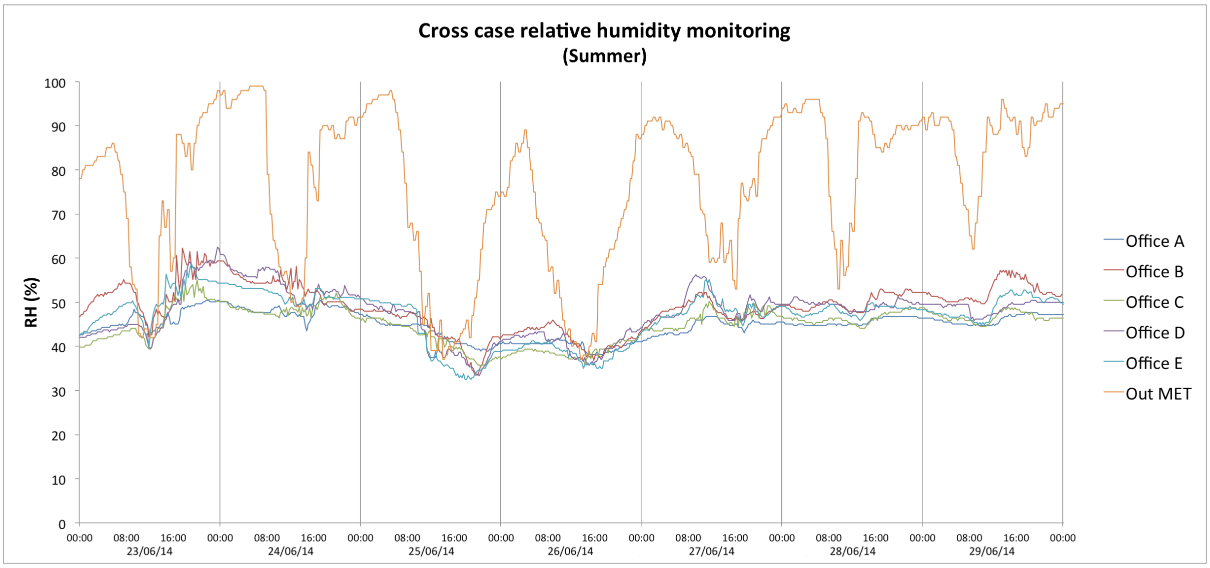

Figure 6.21 Cross case relative humidity monitoring graph over the period of a week during summer (23-29 June 2014).

In Figure 6.21, cross case relative humidity levels follow a uniform pattern but with a wider range compared to the winter results (Figure 6.12) of approximately 10%. A correlation between outdoor and indoor humidity variations is also visible, with drops in indoor humidity mainly during the afternoon hours when the outdoor humidity drops to its lower levels.

6.2.4 Discussion

The monitoring results indicated uniform and dry conditions for all five offices in both seasonal studies during a typical working week. During winter, the average indoor temperature fluctuated between 19.7°C and 21.6°C while humidity ranged between 35.8% and 41.4%. A noticeable trend was the consistently warmer and drier conditions in the administrative office compared to the more homogeneous profiles of the PhD and post-doctoral offices. In summer, the five offices presented less homogeneous but stable temperature and humidity profiles. There was meanwhile an evident correlation between indoor and outdoor conditions, especially in terms of humidity. This was probably due to the opening of windows, given that all offices are naturally ventilated. The average temperature ranged between 22.6°C and 25°C, slightly above the CIBSE (2006) office standards. Relative humidity ranged between 43.5% and 49%, which is on the lower side of the recommended spectrum of 40-70%. The post-doctoral office E appeared to have the warmest temperature profile, with a daily summer average of 25 °C.

Closer examination of the divergence and convergence between office thermal conditions, whilst considering the literature on comfort (Section 2.4) identifies three factors affecting the results: firstly, the heating and cooling infrastructure; secondly, the typology and building physical characteristics, and thirdly, the social dynamics and considerations of their users. The differentiated and rather unconventional heating and cooling system for a typical workplace of the administrative office (A) (this consists of six air-conditioning units) compared to the rest of the offices (B, C, D, E), is a significant factor in the creation of a drier indoor environment. In addition, its low ceiling height and a layout placing most desks opposite rather than by windows, seems to prevent most of the users from opening them on a regular basis (Figure group 5.7). In the case of office E and the high summer temperatures documented, its smaller size, western orientation and the reluctance of its users to turn on the A/C are possible reasons (Figure group 5.15). Finally, social considerations within the shared office of an academic institution could also affect ventilation practices and therefore indoor thermal conditions.

Similar factors could explain the uniformity in the thermal conditions of the PhD and post-doctoral offices during winter and summer. Firstly, the common heating schedule and infrastructure, which is a combination of central heating with air-conditioning and secondly, their layout and the effects of time-lag due to the building's physical characteristics. The thermal storage capacity of the concrete and brick walls affects the diurnal temperature pattern, which seems to reach its peak during afternoon and gradually drop during the evening. Finally, the comparable occupancy patterns and social considerations of PhD students and post-doctoral researchers may have informed their use of the heating and cooling system.

6.3. Thermal sensation, preference and acceptability of the users

Thermal comfort preferences are closely related to decisions regarding the approach towards heating and cooling a space (Nicol and Humphreys 2002). In this section, the results of the winter and summer comfort field studies are presented. The aim is to understand how comfortable people feel with the thermal conditions in their office (sensation), if they would like to change these conditions (preference) and whether they consider them acceptable or not (acceptability). In total, 80 and 97 diaries were completed during the winter and summer periods respectively (Table 6.1). The participation rate was consistent for the five consequent days of the study only in the administrative office with some PhD and post-doctoral participants completing the remaining diaries the week after. This can be explained by the nature of academic work in that it keeps people away from their office desks for certain hours during the day or for whole days due to lab experiments or travel commitments. The following sub-sections present the findings for the case study offices and the cross-office results. Graphs and tables on thermal comfort votes for office A are discussed in detail. Graphs relating to the other offices are located in Appendix E to avoid repetition, given that significant differences were not identified.

Box plots are used to illustrate the relationship between the sensation and preference votes with regard to operative office temperatures. The lines in the boxes represent the average temperature values; coloured boxes cover the 50% of the values; whiskers show the range of values. Outliers are shown as small circles within the graph.

Table 6.1 Comfort diary participation summary.

	Winter			**Summer**		
	Number of participants	Diaries completed	Number of entries	Number of participants	Diaries completed	Number of entries
Office A	5	26	77	5	23	65
Office B	4	20	59	6	30	90
Office C	2	9	27	3	15	39
Office D	3	15	40	4	20	55
Office E	2	10	26	2	9	23
Total	16	80	229	20	97	272

6.3.1 The administrative shared enclosed office (A)

Winter study

In the administrative office, during the winter study there were 75 thermal sensation responses. 26 of these were on the cool side (-2 to -1), 34 were neutral (0) and 16 were on the warm side (+1 to +2), while no -3 or +3 votes were cast. The data of Table 6.2 and Figure 6.22 reveal two main trends. Firstly, a wider distribution in the temperature range for ‘Cool and ‘Slightly cool’ votes located between 19°C and 24°C and a narrower temperature range for feeling ‘Slightly warm’ and ‘Warm’ between 21°C and 23°C; secondly, a very similar temperature average of approximately 22.2°C for the entire range of votes.

Despite the variation noticed in the comfort votes, when participants stated their thermal preference, the majority of responses implied that they would not favour any change (Figure 6.23, Table 6.3). In 70% of cases, participants preferred temperatures between 20°C and 24°C; the remaining 20% stated a preference for warmer conditions and 10% suggested a preference for colder office conditions. Finally, all participants stated conditions were acceptable.

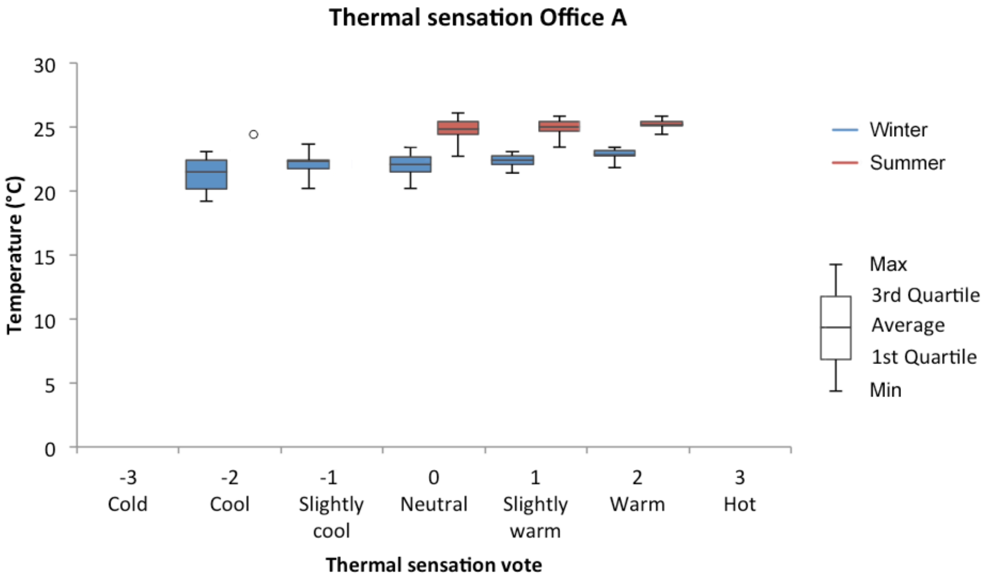

Figure 6.22 Box-and-whisker plot of winter and summer thermal sensation against temperature for office A.

Table 6.2 Summary of winter and summer thermal sensation votes and temperature for office A.

				Winter			
	-3 Cold	**-2** Cool	**-1** Slightly cool	**0** Neutral	**1** Slightly warm	**2** Warm	**3** Hot
Number of votes	0	5	20	35	13	3	0
Average temperature (°C)	-	21.5	22.3	22.1	22.4	22.8	-
Minimum temperature (°C)	-	19.2	20.2	20.2	21.4	21.8	-
Maximum temperature (°C)	-	23.1	23.7	23.4	23.1	23.4	-
Standard deviation	-	1.7	0.9	0.9	0.5	0.7	-
				Summer			
Number of votes	0	1	0	45	13	7	0
Average temperature (°C)	-	24.4	-	24.8	25	25.2	-
Minimum temperature (°C)	-	24.4	-	22.7	23.4	24.4	-
Maximum temperature (°C)	-	24.4	-	26.1	25.8	25.8	-
Standard deviation	-	-	-	0.8	0.6		-

Summer study

In summer, office users found the office conditions comfortable (neutral) at an average of 25°C (45 cases), though a few 'Slightly warm' and 'Warm' votes were also casted (20 cases) (Figure 6.22, Table 6.2). As with the winter results, the average temperature for the different sensation votes was similar, indicating a variety of comfort perceptions for the same temperature. The preference rate towards 'no change' was 74% for a range between 23°C and 26°C, while the votes for the other preferred conditions did not suggest a significant temperature difference. The participants found conditions acceptable: only four 'not acceptable' instances were recorded when the temperature reached a peak of 25.5°C and 26°C in the morning and afternoon on two consecutive days.

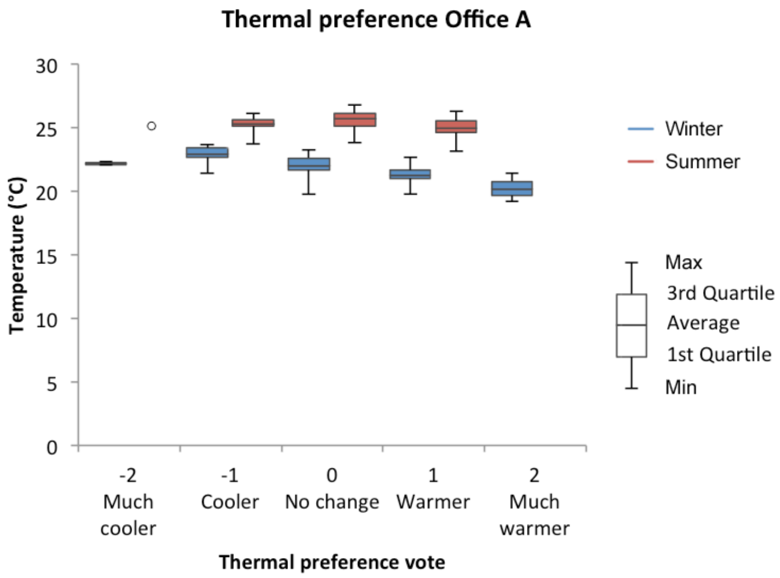

Figure 6.23 Box-and-whisker plot of winter and summer thermal preference against temperature for office A.

Table 6.3 Summary of winter and summer thermal preference votes and temperature for office A.

			Winter		
	-2 Much cooler	**-1** Cooler	**0** No change	**1** Warmer	**2** Much warmer
Number of votes	2	5	54	13	3
Average temperature (°C)	22.2	22.9	22.4	21.7	20.3
Minimum temperature (°C)	22.1	21.4	20.2	20.2	19.2
Maximum temperature (°C)	22.4	23.7	23.7	23.1	21.4
Standard deviation	0.2	0.9	1	0.9	1.1
			Summer		
Number of votes	1	10	49	6	0
Average temperature (°C)	25.1	24.5	24.9	24.5	-
Minimum temperature (°C)	25.1	23.4	23.1	22.7	-
Maximum temperature (°C)	25.1	25.8	26.1	25.8	-
Standard deviation	-	0.6	0.7	1.1	-

6.3.2 The PhD open plan office (B, C)

Office B

Winter study

Winter thermal sensation votes in the PhD office B ranged from -1 to 2 with most of them being ‘neutral’ (28/59) and ‘slightly warm’ (17/59) and very few instances indicating feeling ‘slightly cool’ (5/59) (Appendix E, Figure E.1, Table E.1). Average values were between 21.3°C and 22.3°C and stayed within a temperature range of 17.7°C and 26.1°C. Subsequently, there were 32 ‘no change’ preference votes and 22 votes stating a preference for the space to be cooler (Figure E.2, Table E.2). In terms of acceptability, 91.5% of the votes indicated a general approval of the existing conditions, with the few cases of discontent resulting from temperatures ranging between 22.5°C and 24.5°C.

Summer study

In summer, there was no clear trend between sensation and temperature. However, the votes showed slightly warm and warm conditions (Figure E.1, Table E.1). From a total of 90 votes, nearly half of all participants indicated a neutral sensation (43), whilst with most of the remaining votes related to being on the warm side (41), in response to a temperature range of between 21.8°C and 25.8°C and an average of 23.9°C. Consequently, preference votes claimed a desire for a 'cooler' or 'much cooler' environment, even if a linearity between temperature and preference is not visible (Figure E.2, Table E.2). The few non-acceptable votes (11%) were for temperatures between 22.7°C and 25.8°C and were mainly recorded during afternoon and early evening hours.

Office C

Winter study

In the second PhD office (C), participants found conditions mainly neutral but there were also a few comfort votes suggesting slightly cool and slightly warm conditions in response to an average of 24 °C (Figure E.3, Table E.3). In terms of preference, the votes indicated that users did not wish any change in temperatures between 21.8°C to 25.1°C (Figure E.4, Table E.4) and in almost all cases conditions were considered acceptable.

Summer study

In summer, conditions were predominantly considered comfortable (29/39) in response to an average of 25°C (Figure E.3, Table E.3). There were only three votes reporting slightly cool conditions and seven, slightly warm. Thirty-two votes suggested no need for change, whilst five and two participants stated a preference for cooler and for warmer conditions respectively. In all instances, the thermal conditions were considered acceptable.

6.3.3 The post-doctoral research office (D, E)

Office D

Winter study

In the research office D, thermal conditions were considered neutral for the majority of the cases at an average of 21.4°C, with very few votes on either side of the thermal sensation scale (Figure E.5, Table E.5). Conditions were considered acceptable (38/40) and there was no intention for a change (Figure E.6, Table E.6).

Summer study

In summer, a positive linear trend between sensation and temperature can be noticed which shows that as temperature rises, people in the office tend to feel warmer (Figure E.5, Table E.5). Again, most of the votes sit in the middle of the scale, indicating that the office users feel comfortable for a range of temperatures between 22°C and 25.8°C. Preference votes indicate resilience towards the existing thermal conditions and acceptability is almost unanimous.

Office E

Winter study

The winter results of office E show that participants had either a neutral and slightly hot feeling in response to the existing conditions (Figure E.7, Table E.7). From the 26 votes cast over the winter study period, 11 were neutral, 8 on the slightly warm and 7 on the warm side of the scale. The average temperature was 21.8°C for the neutral votes and 25°C for the two warmer scale points. As a response, preference votes reported 11 'no change' and 15 votes preferring cooler conditions (Figure E.8, Table E.8). In contrast to the previous offices, acceptability was only 65%, indicating a stronger relation between preferred and acceptable conditions.

Summer study

In summer, the thermal environment was considered comfortable (Figure E.7, Table E.7). All but three votes were on the middle of the sensation scale for a range of temperatures within 23.1°C and 26.9°C and an average of 24.6°C. Thermal preferences indicated that conditions could be slightly cooler in only three of the cases where temperature reached 24°C, while all other cases were considered acceptable.

6.3.4 Cross case results

The cross case graph of the winter thermal sensation votes did not reveal any general typological trends. During the winter study (Figure 6.24), the administrative office (A), the PhD office (B) and the post-doctoral office (D) indicated similar average comfort temperatures between 21.4°C and 22.1°C, while the student office (C) and post-doctoral office (E) presented a higher average of 24°C. Office B was found to have the largest range of temperatures in all votes verifying the existence of different reactions to the same temperature. In summer, there is an apparent uniformity amongst all five cases in terms of thermal sensation (Appendix E, Figure E.9). However, there is an absence of a linear correlation between temperature and comfort, which one would expect. There is also an unexpected ordering of sensation votes for similar temperatures, highlighting the variability of comfort profiles within the same office.

Cross case thermal preference results followed a similar pattern with comfort votes indicating that people feel comfortable in a wide range of temperatures spanning between 20°C and 25°C (Figure E.10). Offices D and E slightly differed from the other three in having a higher temperature threshold in terms of acceptance of the existing conditions, while office B following the winter comfort trend presented the widest temperature range for each vote. In summer, there seemed to be a tolerance for higher temperatures and 'no change' votes for all offices were recorded for temperatures ranging between 21.8°C and 26.9°C (Figure E.11).

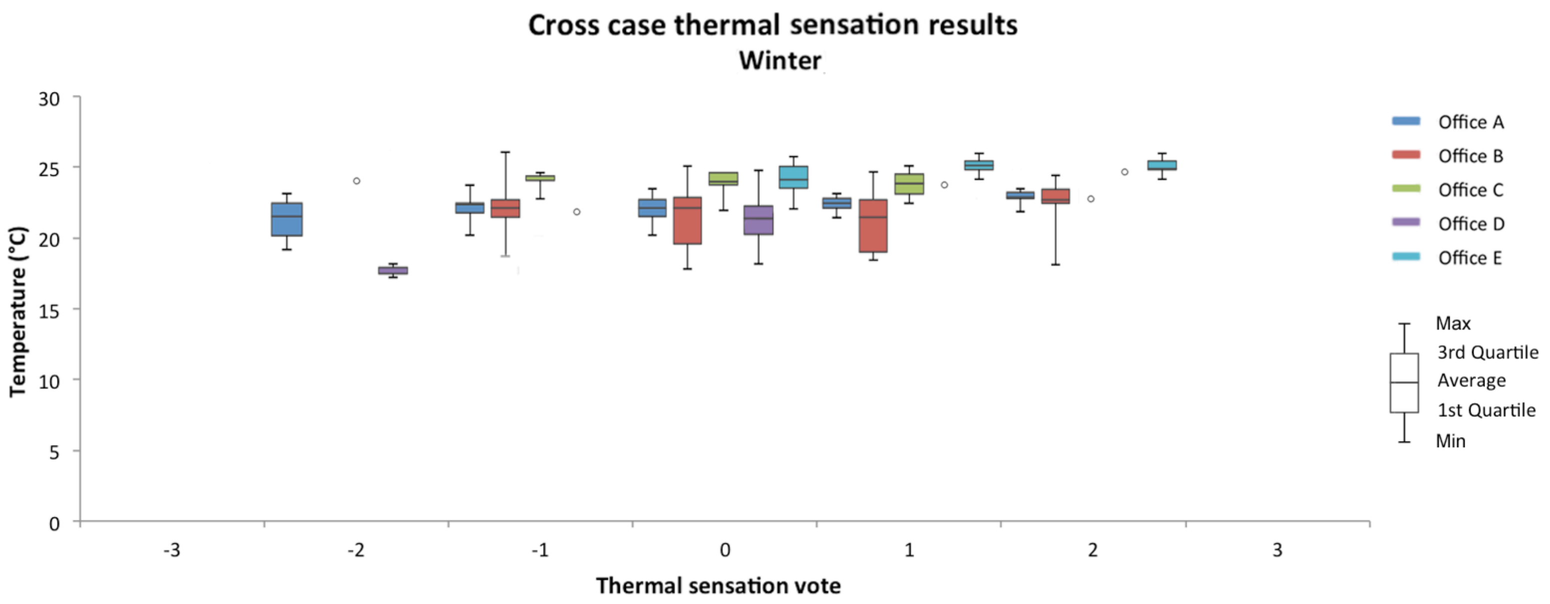

Figure 6.24 Cross case thermal sensation box-and-whisker plot graph during a week in winter.

6.4. Discussion

The diversity of thermal sensation votes for similar temperature conditions emerges as an apparent trend when looking at the results from the comfort diaries. There is no linear correlation between temperature and sensation and it is common for different comfort votes to be cast for similar temperatures and not increase in accordance with the scale points, as one would expect. The scatterplot in Figure 6.25 gives an example of this diversity in office A during winter.

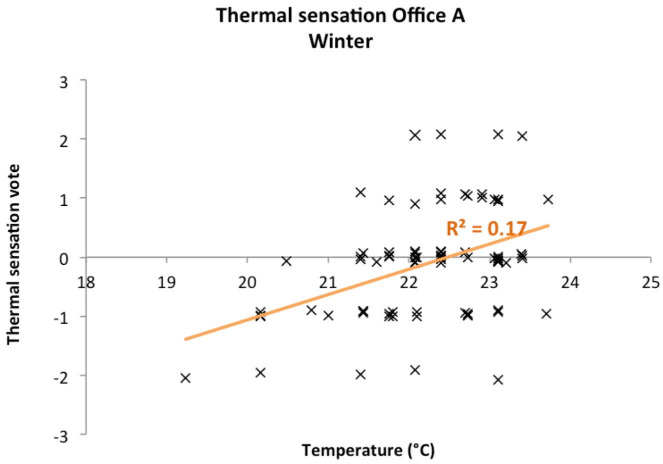

Figure 6.25 Scatterplot indicting the relationship between sensation votes and temperature during winter in office A.

Another noticeable trend is that comfort is achieved in much wider temperatures than the acceptable temperature and humidity standards indicated by CIBSE (2006) and ASHRAE (2013) comfort standards confirming the notion of the adaptive approach, as has been also demonstrated in previous studies (Raja *et al.* 2001, Wagner *et al.* 2007). Namely, in winter comfort, neutral temperatures would range between 17.7°C and 25.8°C and in summer between 21.8°C and 26.9°C compared to the 21-23°C winter and 22-24°C summer range suggested by CIBSE (2006). The cross case graphs (Figures 6.24, E.9, E.10) show that there is no significant variation in this range between the case study offices, which would suggest a certain typological trend. However, it is evident that the average and absolute comfort temperature range for the different offices is similar in summer and slightly differentiated in winter, which mirrors the thermal conditions recorded within the offices.

Finally, an interesting trend revealed by the comfort diaries is that, while the office users might not feel comfortable, they would often find the conditions acceptable and tolerate feeling a bit cold or warm instead of hoping for change to take place. Considering all the questionnaire responses, in 59% of the cases users stated that they felt comfortable with their office conditions and in 65% of cases, users reported they preferred no change. Finally, in 93% of the cases users found the conditions acceptable. This means, however, that in 41% of the cases in which the conditions were not found to be comfortable, there was no willingness towards change and users were eager to accept them. This disparity between comfort and acceptability suggests that while comfort perception is a more personal matter, preference and acceptability are related to wider social and contextual considerations, which, in this case, are set by the workplace environment.

6.5. Summary

Thermal comfort practices are closely related to decisions regarding the use of heating and cooling of a space and thus influence its energy consumption. The aim of this chapter was to capture the objective and subjective comfort aspects of the office environment through the monitoring of its thermal conditions and the account of its users' comfort perception.

The monitoring results indicated uniform and slightly dry conditions in all offices, which were close but not always within acceptable industry standards. It was seen that the temperatures and relative humidity levels would be more homogeneous in winter than in summer and the administrative office would have a slightly differentiated profile compared to the other offices. This heterogeneity between office thermal conditions was mainly related to differences in technological and physical building components. Other parameters such as the office layout and the social considerations of the users might have also influenced the results, although they would need to be verified with qualitative evidence. Comfort diaries indicated a diversity of comfort preferences and a temperature comfort range between 17.7°C and 25.8°C in winter and 21.8°C and 26.9°C in summer. Finally, although in 41% of cases users were dissatisfied with the conditions, in 93% of cases they considered them acceptable.

To follow this examination of the actual thermal conditions and the users' perceptions through monitoring and comfort diaries, the next chapter investigates workplace comfort in a more exploratory way. Through the use of semi-structured interviews it looks to unearth those material and social elements responsible for shaping comfort practices in the workplace.

7. Framing workplace practices

7.1. Introduction

Chapter 6 presented the thermal conditions and comfort preferences in the three case study offices. It confirmed the assumptions of the adaptive approach towards comfort. This indicated a wide range of temperatures are considered comfortable by the users but also revealed an inconsistency between comfort and acceptability. This chapter explores workplace practices relating to indoor climate regulation, identifies the main influences that shape them and explores how different energy consuming practices might interact and affect one another. It presents the findings gathered from the first and second round of semi-structured interviews and office observation.

The chapter is divided into four sections in line with Gram-Hanssen's (2010b) analytical framework (Section 2.3.2) which suggests practices consist of the following elements: know-how and embodied habits; technologies and infrastructure; institutionalised knowledge; and meanings (or engagements). Participants from the case study offices—the administrative shared office (A), the PhD open-plan (B and C) and the post-doctoral cellular offices (D and E)—were asked to reflect on their everyday practices in relation to indoor climate regulation, the use of lighting, computers and electrical appliances. The nature of their work and daily duties, the effect of the office materiality and infrastructure, the influence of their colleagues and family, the meaning of being energy conscious in the workplace and the way they perform similar practices in their home environment formed the basis for the interview questions (Appendix A1).

7.2. Know-how and embodied habits: workplace and daily routines

Embodied habits or otherwise unconscious ways of performing certain actions have a significant influence on daily practices. All the participants are aware of the indoor climate regulation practice and have their own embodied habits related to the use of A/C, radiator valves and windows. They also carry out other daily practices that consume energy in the office, such as the use of lighting, computers and appliances. In the case study offices, the impact of daily working schedules and differing research activities on workplace routines that were accommodated by the users was further discussed.

7.2.1 Administrative office

In the administrative office, five out of the six interviewees claimed to have similar comfort practices at home and work, which they linked to their family background and upbringing. However, although these habits often meant achieving comfort in lower temperatures, the daily workload did not allow time to consider regulating the temperature in the office even when the conditions became slightly uncomfortable. Similarly, turning off lights and appliances was often considered a waste of time. A 'passive' user profile that preferred the default A/C settings and limited interaction with lights and office equipment prevailed.

The 'busy' administrator

Trying to address the daily workload in an administrative office is not always a straightforward task. As was evident during observation and interviews, it consists of a set of different activities such as responding to e-mails, photocopying and classifying documents, discussing project details and visiting other offices within the building. All these actions take time and require responsibility and commitment; therefore, as was commented upon by all participants, thinking of regulating the temperature settings in the office was not a priority. The busy daily schedule at work seemed to make people more adaptable to the existing indoor conditions and as Diana explained:

> *'I think the workload of some people, you know, they don't bother, it's too much. You take some time out if you think "Oh, I've got to go and turn that off". Again, it's just taking the time out to do it, which given the amount of workload, you just haven't got the time to stop. I think that's the main reason.'*
>
> (Diana_A_2)

Similarly, regarding the use of lights and office equipment, she commented that people leave their computers and the lights on during their break unconsciously. '*Energy saving is something that there is no time to think about'* Diana (A_2) remarked and under the time-pressure people will adjust and perform their tasks in an uncomplicated and quick way. Laura (A_1) agreed, pointing out that *'it is easier just to leave it [your computer] on for the hour you are leaving the office'* because *'it takes a long time to load it back up, to get all your webpages open'*. Therefore, turning computers and lighting off were actions that users would not consider because they would equate them with time wasting, which would affect their productivity.

Background influences and traits from home

Interviewees acknowledged a close relation between home and office comfort patterns. Three out of six traced the gradual build-up of their routines back to the prevailing thermal conditions and habits in their home. For example, Luke explained how *'it has always been a force of habit rather than an influence'* and suggested that his upbringing in an energy conscious household has shaped his behaviour ever since.

'We were not poor but we were not a particularly rich family so we were always trying to save on energy, save money basically, so we were conscious. I suppose its been a habit of mine ever since.'

(Luke_A_1)

Laura (A_1) explained how she considered the office as her *'territory'*. She stated, *'at home if I am cold, I would go and get under the cardigan or get a fleece and put it on, so that's what I would do here (…) I feel my office as if it is my territory, I don't think I behave any differently towards the heat or the light'.* She also commented on her upbringing and how the absence of central heating in her house when she was a child made her more mindful and tolerant in colder indoor temperatures and remembered that *'getting up in the morning and getting dressed was absolutely freezing'*. Diana associated her unconventional heating habits with a health condition that has been on-going since she was a child. She mentioned how she was found to suffer from low blood pressure and osteopenia, a condition that makes her more sensitive to cold than others.

'I think it probably has to do with my background. I tend to always feel the cold a lot more. (…) At home I would tend to turn the thermostat up and when my husband comes he would say, "It's warm in here" and would turn it down.'

(Diana_A_1)

Having worked in the office for almost ten years she is the only one that has a portable heater next to her desk in order to bring the temperature up. She said, '*I do occasionally have a fan heater that I would literally put on just for 30 seconds just to take what I feel like* "*the little chill" off me*'. However, she admitted that she doesn't feel very comfortable about it and would always turn the heater off if there is a complaint from one of her colleagues.

In terms of using electrical appliances, transferring habits from the home to work was immediate for Oliver, who explained how he would always leave his desktop on standby and other appliances plugged in with the sockets turned on because of the power of habit.

'I 've never actually turned a computer fully off, neither at home nor at work. Or even at College when we used computers there. (…) It's partial habit partial laziness I would say from my part. I'd rather say more habit than laziness.'

(Oliver_A_1)

7.2.2 PhD office

The heating and cooling preferences of the PhD students were directly related to their daily working patterns and athletic activities. Long and irregular hours in the office and the focus on research tasks often meant that regulating the indoor temperature or making sure that computers and lights were turned off was not a priority. In addition, being committed to regular sport activities often resulted in an increased need for ventilation and cooling. Outside the office, all students felt that their practices were quite efficient as a result of their 'low carbon lifestyle', since they were living in a College and used a bicycle for their daily transport needs—as is most common amongst students at the University of Cambridge.

A tight daily schedule

In the PhD offices, research practices were prioritised over indoor climate regulation. Similarly, to office A, a common point that came across when the participants were asked about their heating and cooling habits was that the daily workload does not leave much time for deliberately thinking about regulating the thermal environment. Alexia (B_1), a second-year PhD student working in the open-plan PhD office B, explained how her schedule is designed in a way that she is available ten hours daily, but would pop in and out the office very often. For her, work alternates between her office desk, the lab where her experiments take place, the department's library and meeting rooms where she meets her supervisor and colleagues. She said, *'there are days I am there 10 hours in a row if you take out lunch and coffee breaks and some other days, I pop in and out and don't sit in [sic] my computer for more than half an hour'.* She pointed out that the workload of a research student could often be so heavy that *'people might skip lunch or dinner and even have to come to the office really early in the morning or late at night'*.

With regards to the indoor thermal conditions, Alexia (A_2) explained that the heating and cooling regime often follows the irregular working patterns of the students. She used the term 'work comfort' and added that '*if someone had an awful lot of work to deliver, the last thing they care about is their thermal comfort'.* She then pinpointed that in winter the A/C might be left on for hours without people noticing due to their intense focus on their tasks, while in summer it is left on to cool them down, often to help them stay alert after mealtimes and thus increase their productivity. For example, she said:

> *'One day I stepped in the room and I just couldn't breathe. There were only [a] few people in the room and I said, "Haven't you realised?". But they were doing simulations so they were calm and focused in their work, so they hadn't noticed any difference. But those in the lab that do lab work as well, and just run from one building to the other, those have a better understanding because they can compare temperatures of different places.'*
>
> (Alexia_B_1)

Peter (B_1) agreed that trying to establish an optimum environment in the office is a distraction that students could not afford since it might impact their research. He said *'generally people are too concentrated in their work, they feel like they don't want to be distracted. It's a secondary issue, they don't want to go down that road.'* Similarly, in the PhD office C, Zack explained that he takes a notice of the thermal conditions around him only when he is on a break after long working hours.

> *'I just ignore everything and enter the zone of the researcher, of problem solving. (…) In the evening, sort of late evening, maybe I 'll get a bit cold. But that's usually only when I am getting bored and start to actually notice what is happening because I am tired of work.'*
>
> (Zack_C_1)

The 'green' PhD student

In the PhD workplace, it seemed that it is not only the daily workload but also the student lifestyle that defines indoor climate practices. Students seemed to be energy conscious both because of their level of education and engineering background, but also because being a student in Cambridge prescribes a 'green' style of living.

When workplace practices in general were discussed, Peter commented on the fact that the university and collegiate system in Cambridge make daily practices both at home and at work more efficient. For example, most of the PhD students live and eat in a College, use mainly bicycles and public transport for the daily commute and share an office with other colleagues. As he puts it:

> *'I don't have a car; I live in one room; I don't have a house; I share the office with twenty people. It's extremely green, I don't even cook. Most of the time I eat in Colleges (…), I don't have a heater or something.'*
>
> (Peter_B_1)

Another example relating to the same issue comes from Alexia (B_1) who added that financial incentive is of no importance to her since being energy conscious and acting as such in the office *'happens automatically'*. She said, *'it doesn't matter if I am paying or if the department is paying. It is the same thing. If I can wear one more jacket and switch off the heating, or if I can just open the window and switch off the cooling, I would do it.'*

A component of the student lifestyle that influenced the levels of indoor thermal comfort was the fact that a third of the students in case B were engaged into a sporting activity, such as rowing and running. As a result, many of them felt comfortable in a cooler environment due to their increased metabolic rate and adjusted their comfort practices accordingly. Alexia (B_1) recalled how '*in the morning when you see people coming from rowing, (…) for the first half an hour they are frozen trying to get back to normal temperature and then you see them losing layers'.* According to Silvia (B_1), these would normally be the people more actively engaged in the control of the indoor temperature, but would also be willing to adapt to existing indoor conditions if necessary.

7.2.3 Post-doctoral office

Being a post-doctoral researcher in the Department of Engineering meant spending nine to twelve hours a day in the office and sometimes working during weekends. Work in the post-doctoral offices was prioritised over more considerate use of heating and cooling or thoughts on energy saving. Since the main research activity involved tasks on large databases and computer simulations, computers were seen as valuable resources, therefore their constant use was deemed necessary.

The '24-hour' researcher

The researchers interviewed were on two-year contracts during which time they aimed to produce academic journal publications, secure funding for future projects and disseminate research findings at international conferences. Their weekly schedule was tight and they worked approximately ten hours a day. Three out of six mentioned that they might also come to the office during the weekend and they often connected their computers to the office network remotely from home.

In terms of regulating the indoor temperature, in the smaller cellular office (E) the three users seemed to prefer using the windows and opening the door rather than turning on the A/C. According to Jacob (E_2) '*it just feels like a waste of energy, it's not that warm. If it's like 35°C we 'd probably turn on the A/C but if it's around 30°C that's within the range where you shouldn't use the A/C. Everybody agrees'.*

The issue of working practices prioritised over heating regulation was also a point of discussion. For the post-doctoral researchers in office D, the daily workload would be too demanding to start thinking about the office temperature and the easiest awayway to deal with it would be to just open a window since the office is usually too warm. Henrik (D_1) commented that there are '*sometimes in the afternoon when it becomes warmer that it would be time to turn the heating system down a bit'* but since there is no actual control over the radiator and he is too busy with his daily work tasks he would compromise and just try *'not to think about it'.*

The work on human learning includes computational modeling and experimental approaches using robotic and virtual reality interfaces, therefore computers are the main working tool for the researchers. All computers were shared between the research laboratory and always left on for people to use from other offices or remotely from home. They were considered a work resource therefore it didn't make sense for them to be off or on standby mode at any time since it would have a direct impact on researchers' productivity. Echoing the views of the PhD students, Zack explained:

> *'The thing is that they are not necessarily all being used at the same time but it's unclear when someone would like to log in and run something. And then, if I am*

not in my office, I can't turn my machine on to let someone run something on that, so, —it definitely sounds wasteful—but trying to be more conscious about that would directly impact people getting the work done.'

(Zack_F_1)

7.3. Technologies and infrastructure: a practice container

Existing technological infrastructure, devices, and physical objects, can be strong components that hold practices together. The office layout, the existing heating and cooling system, the office electrical equipment (desktop computers and printers) were the material components related to workplace practices. Participants were asked to comment on the use of these components in their office and how they might affect their daily comfort and other energy consuming work practices. The existing maintenance structure was also discussed, as it seemed to be a significant factor in the formation of workplace practices.

7.3.1 Administrative office

The lack of information on how to use more complex A/C settings and the set-up of the office equipment in networks resulted in users leaving them on their default settings. Their difficulty to communicate related problems to the maintenance team exacerbated this situation.

A/C system prefigures a 'default' mode and creates multiple heating zones

In office A, there were four A/C units covering the heating and cooling needs of eight people. Each unit was meant to cover the needs of two offices and had a remote control placed on the wall (see Figure 5.7).

When asked whether they understood how to use the A/C system, the users commented on the lack of control and full understanding of its settings as well as the absence of informational support when they moved in. They were only aware of basic features such as how to turn the system on and off and set the temperature but were unable to set a timer or change the mode from winter to summer. For example, Daniel wondered whether the A/C near him had a thermostat break or it was broken since it run constantly at a certain temperature and did not switch off when the desired temperature was reached. He thought that it might need fixing, but never actually tried to report the issue:

'It does [react] but then it doesn't…well, that's the thing. I don't know whether there is a thermostat break because it seems to stay on constantly. It doesn't shut off so maybe that needs looking at in some respects.'

(Daniel_A_1)

Diana did also not feel comfortable with the A/C technology. She said it was not easy to understand and she was not aware of how to change the mode from winter to summer given that no one had explained to them how to use the A/C properly:

> *'These A/C units are a bit hard to figure out I think. Sometimes when I get in first thing in the morning at eight I put them on and then it just seems it never warms up. I think they have a summer or winter setting but we've never been shown how to use them correctly.'*
>
> (Diana_A_1)

Laura responded in a similar way. Even though she was senior office member, she was not aware of an instruction or user manual that would help them use the system efficiently. As a result, the A/Cs were constantly set on a certain temperature limiting any control option.

> *'Ever since we moved into here we have got no instruction manual [sic] for those control panels so we tend to leave them in their original setting (…). Other than that, we have never been able to work how to set the timers on them.'*
>
> (Laura_A_1)

Finally, the suitability of an A/C system was also questioned based on the unlimited control individuals had on them and the creation of multiple heating zones in the office. Hannah (A_2) stated that four independently controlled A/C units in a space that was not originally designed to be an office might impede efficient functioning. She commented that *'there is [sic] all these different units on the wall, and people can put them on, turn them off as they want and you might have somewhere 28°C somewhere 21°C so you have a big range of temperatures across one office'.*

Set-up of office equipment favours a standby mode

In terms of the use of office equipment, another aspect that seemed to affect office practices was the set-up of devices such as the scanner, printer and desktop computers in ways that would favour a standby mode and therefore affect electricity consumption accordingly. Having the office appliances plugged into networks was also found to affect the users' ability to turn them off.

Luke (A_1) mentioned that the scanner would automatically go on standby mode without giving any visual signal. This resulted on it being regularly forgotten on and thus would not be turned off. He said *'occasionally people use it and then leave it on over the day and then forget it, it goes on standby but you can't really see it is on, it's probably on now. It can stay on for ages. It depends on who is using it to be honest'*. In relation to the same issue, Diana (A_2) commented on her inability to turn off her computer at the socket due to the position of her desk, meaning she is unable to reach it.

DD

'How easy is it to turn-off or put office appliances on standby?'

Diana

'With my computer, I usually shut it down but don't turn it off from the plug because I can't actually get to the plug. So, it's more on standby.'

Another example of the difficulty to turn off appliances was related to the photocopier/printer. Laura shared her experience:

> *'A year and a half ago the Head of Department gave a talk about turning computers and appliances off when you go home, etc. The same evening, when we left, we all turned the computers off at the socket, turned the printer off and off we went. When we came back in following day, we turned them back on but none of us could print and we couldn't get hold of the computer officer till nearly ten in the morning'.*
>
> (Laura_A_2)

She explained that when the computer officer came along, he noticed that the printer had been deliberately turned off and not because of a power cut. Laura responded that they followed the prompt from the Department's Head to be more energy conscious in the office and had turned it off. The problem was resolved but she stressed that although *'it took them only ten minutes [to fix] (…) we never turned it off again'*.

Apart from the impact of the above-mentioned experience on the office's energy consumption, another indirect consequence could be deduced, namely that office users lost trust in their organisation and its ability to support the change in attitudes it calls for. After the failure of the expert staff to provide a solution that would allow the photocopier to be properly turned off, there was seen to be little point in trying to save energy through more efficient use of appliances.

Difficulty to resolve problems with technologies

Another issue linked to the technological element in the office was the apparent difficulty to communicate equipment failure to the maintenance officer and receive a prompt reaction. The lack of prompt maintenance mechanisms in conjunction with previous comments on the appliances being set-up in complicated networks were considered important in encouraging a 'passive' attitude towards the regulation of the office thermal conditions.

For example, Laura, Hannah and Daniel highlighted the on-going problem with the ceiling A/C vent whose air supply was often contaminated with car fumes, and which resulted in an uncomfortable smell filling the office. They all commented on their inability of reaching the maintenance department so that it could be fixed. The situation was left unattended for so long that Daniel seriously wondered why the Safety Officer would not take any action.

'We 've told our Health and Safety Officer but he sort of said he needs to come in here when it is happening. But, of course, it just happens, and by the time you get it and move around the corner it's gone. I don't know why he can't get our word for it. He thinks we are lying obviously.'

(Daniel_A_1)

7.3.2 PhD office

In the PhD offices, the participants felt that the configuration of the central heating system and the set-up of the A/C units within the office was problematic (see Figure 5.8). The generic heating zones of the building, the lack of user control over central heating radiators, the inability of the existing temperature sensors to adjust it according to external temperature fluctuations and the lack of prompt maintenance response mechanisms made users passive towards the regulation of the indoor temperature and sceptical regarding the department's energy efficiency intentions.

Heating systems as a cause of confusion and uncertainty

When the participants were asked about their understanding of the heating system, there seemed to be some confusion as to the set up and the daily heating schedule given that the central heating and A/Cs tended to be on at the same time in both PhD offices. The central heating operates daily but the users do not have control over it, therefore the A/Cs and the opening of windows were a means of regulating the temperature in the offices.

In office B, the heating system configuration became a topic of *'big discussions'* between the office users, given that it seemed to waste energy. Silvia (B_2) explained how her expectations were higher when she first started her PhD in terms of the provision of heating and cooling and admitted that she was *'shocked'* when she realised that the central heating was set independently of external temperature fluctuations. She stated a preference for having a system that combines individual control along with automation elements; *'it certainly has to be better than what it is right now',* she remarked. In a similar vein, Alexia (B_2) mentioned how *'weird'* it felt when the heating was on during a warm period in late May and the students had to turn the A/C on in order to cool the office down. The students found it difficult to rationalise the situation and were critical of the department and its maintenance team for failing to anticipate such situations.

'We don't tend to discuss about this now [sic] but we were having major fights, not bad fights but big discussions when both of the [central] heating and the A/C were on. That is kind of the department's fault because (…) it was very warm outside. But it was on and we had opened most of the windows but then there is noise coming in as well and some of us were allergic, so they tend to close the windows and put the cooling on as well. It wasn't making any sense.'

(Alexia_B_2)

Another issue that was brought up during the interviews was the position of the ceiling A/C's in office B (see Figure 5.8). It was deemed to be problematic because the areas right under the units made the space uncomfortably cold for an individual to work. Ruchi (B_2) claimed that even when she walked nearby she could feel *'there is a very cold blast of air'*. She added that this is something that happened after the renovation took place and the main problem now is the lack of control since *'you cannot really have the choice of temperature when sitting under that'.* As a consequence, the hot or cold air is not evenly distributed around the office creating different heating zones. As she puts it:

> *'The A/C in our room is in a very wrong position because where it is right now, it ends up making four spots where you get very, very cold (…). So, people who are sitting right under it do not want that amount of A/C [air blowing] so they tend to decrease it and that makes the other corner warm. So, there is not distributed cooling or heating. If one of the (room) corners is fine, it evidently means that somebody in the centre or some other part of the room is actually suffering.'*

(Ruchi_B_1)

Slow maintenance makes passive users

The slow reaction of the department's maintenance staff was criticised by most of the interviewees (6/10) in the PhD offices and there was uncertainty as to who students were supposed to contact when a technical problem occurred. In office B, Ben (B_2) expressed his frustration with the difficulty of resolving a heating issue when it remained on during warm days in spring. He said that *'the person in charge was on holiday and so we were complaining to the department but nobody was changing anything and then they were waiting for the person to come back 'til the end of May to get it turned off!'*. Peter, who had a more proactive approach in the office with regard to such matters, said that he had *'e-mailed the office administrator several times'* but there was no prompt reaction. He commented that the lack of clear feedback structures and the delays in systems' maintenance made most of the people in the office passive and indifferent to dealing with such issues. In his words:

> *'To be frank, (…) the people who would complain about it they prefer to switch it off than actually go and sort it out.'*

(Peter_B_2)

In a similar vein, in PhD office C, George (C_2) agreed that students had no confidence in the proposed solutions so they would not react to problems unless the situation became uncomfortable. For example, he explained that there is no way to control the heating in their office apart from opening the windows since the radiator valve is broken. However, no one would complain about it and a passive attitude would prevail because they felt that the maintenance team would not resolve the issue.

> DD
> *'Is there someone in the office that has a strong opinion about how to use the heating? In a way that would generate discussions?'*
> George
> *'No, I don't think so. We are quite passive, waiting for things to become really uncomfortable to react. (…) One thing is just that maybe we don't have much trust in the solutions that they would propose to us. And for the valve for example, the solution was just closing it completely, so if we did that in winter, we wouldn't have heating in the room.'*

The use of equipment and research practices

Another workplace practice that was associated with energy consumption was the use of computers. The students thought that this was the second main source of consumption after the use of the A/C, but also a necessary tool for their work. They also pointed out that linking computers to networks did not favour their efficient use.

In office B, Silvia acknowledged this and claimed, *'it will probably help if we could turn off our computers completely at the end of the day but I know that for some people who are doing modelling they have to have their jobs running'*. She wondered whether a possible solution would be buying new, quicker and more efficient ones. On the other hand, Peter was sceptical about the effectiveness of *'bigger and stronger machines'* since he would *'frankly still do the same'* as this is his way of working; it is a habit he is not willing to change. He explained that turning his computer off every time he leaves the office would take approximately twenty minutes because of all the applications that are on; a similar length of time would be required to restart it on his return. For this reason, he would *'simply put it on sleep or just turn off the monitor'*.

In office C, George (C_1) described how computers are set-up in a common network so other students can use the ones that are free at the time they need them '*without being physically there at all'* and have the ability to do multiple jobs simultaneously. However, this means that computers always remain on and available for use as *'turning your computer off might affect someone else's work'*. As he said:

> *'Once I turned the computer off and restarted it and then I received an angry e-mail of someone saying, "You should warn me before restarting your computer because I was working on it!". Every computer stays on during the nights and also on holidays.'*
>
> (George_C_1)

7.3.3 Post-doctoral office

The layout and size of the post-doctoral offices seemed to have an effect on heating and cooling practices since they facilitated more intimate communication and coordination between users. Office D was 23m^2 and was shared between four researchers while office E was only 6m^2 and shared among three (Section 5.3.3).

Easy to share comfort issues

In both offices, it seemed that the users had better coordination and shared understanding regarding the indoor thermal environment and its regulation. The smaller office size along with the small number of people sharing the office allowed the creation of a more intimate social environment and a feeling of territory. The office users seemed to share common views on the indoor conditions more readily and without concerns about affecting others or being rude. As Oliver noted:

> *'This apathetic stance [regarding the indoor thermal conditions] is probably more common [in a bigger office] because it's less your territory; you are more in a shared space. This is a small office, it's just the four of us, so I feel it's much easier to bring that up, to talk about it.'*
>
> (Oliver_D_2)

Similarly, in office E, Zack (E_2) felt that it was easy to regulate the thermal environment in the office as they all *'have the same comfort zone'*. For his part, Jacob (E_2) explained how they had discussions in the office regarding the use of the A/C and *'even though it was warm nobody wanted it on'*. Everybody agreed that *'if the temperature is like 35°C we 'd probably turn it on but if it's around 30°C it's not necessary'*.

Insufficient maintenance structure

As with the administrative and PhD offices, the post-doctoral researchers were also sceptical as to the effectiveness of the maintenance team within the department and the lack of a contact person. In office D, Robert (D_2) commented that there is no one to defer to when the heating is on while not necessary and the temperature in the room gets uncomfortable. In particular, he said:

> *'You 've got to put yourself on the mind-set of someone sitting in the office. They look over through their data. It's too hot, so, do I know who to e-mail to have my radiator switched off? No. [I] Search on the department's website "heating person" ... nothing. I could go and sort of wander up and down the office corridor and ask who got admin control of my heater, or I open the window. At that point it is clear, right?'*
>
> (Robert_D_2)

7.4. Knowledge: technical and environmental

Knowledge refers to 'rules' related to the way of doing things. Knowledge in relation to indoor climate and comfort can be established through different venues such as educational institutions, media, campaigns and governmental organisations (Gram-Hanssen 2010a). In this case, the research questions focused on the users' technical knowledge on how to use and regulate the heating system, as well as on the relationship between heating, energy consumption and environmental problems. Given that the level of understanding of the energy efficiency concept can affect practices, participants were also asked the source of this knowledge.

7.4.1 Administrative office

The participants in the administrative office acquired general knowledge on the relationship between energy consumption and environmental issues from media and information given by utility companies. They felt that the main problems related to energy consumption were related to energy supply and the technological infrastructure, rather than energy demand.

General knowledge but 'there is not much one can do'

Most of the interviewees were aware of the interrelationship between energy consumption and environmental problems but had limited knowledge regarding what they could do about it and the impact they have as individuals. For example, Diana (A_1) said she was '*aware of the problem but not of the way to fix it*' while Oliver (A_1) also indicated that he knew *'they all relate to each other but not about how and which way they affect each other'.* Thus, their workplace practices did not seem to be directly shaped by environmental considerations.

Burning fossil fuels to produce electricity and the inefficiency of technological means were revealed during the discussion as the main reasons for environmental problems. Daniel (A_1) stated that '*we all know we [have] got to save energy as much as we can but the problem is with technology these days and the energy side of things*'. Laura was a bit more sceptical and seemed uncertain as to the level of responsibility between energy industry and individuals on environmental problems. She acknowledged that modern living standards can lead to a *'glutinous'* lifestyle but remarked that energy industry was a key factor to consider. In her words:

> *'I fully understand that we need to do something about the way that we actually manufacture energy. (…) I am not absolutely convinced that the heat that goes out of doors is causing as much damage, as some people would have us believe.'*
>
> (Laura_A_1)

Although there was sufficient general knowledge on environmental issues in the office, there seemed to be no connection between this and the impact that they as individuals could have on the energy consumption of the building by altering their comfort or other energy consuming practices.

7.4.2 PhD office

In offices B and C, participants had advanced technical knowledge and strong personal opinions on energy issues. Their previous studies in engineering had given them a good understanding of energy systems, which, in most cases, was supported by work experience in the energy industry through internships and short-term placements. This in combination with a 'green' university culture (see Section 7.2.2) made them feel they were able to do more for the environment and have an impact if armed with the right technological configurations and incentives to do so.

Advanced knowledge and opinionated users

Alexia (B_1) considers herself environmental friendly and knowledgeable. Accordingly, she recycles and tries to save energy in any possible way. She therefore commented that *'more energy consumption is one step towards the global warming effect and I know that these two are linked and I know that I am responsible and although my act is a very small portion is still a portion so my act of switching off a light or turning down the heat is a small fraction of what is really affecting but it's still a fraction'*. In terms of the source of her knowledge, she relayed that this was garnered from non-governmental organisations, and relevant publications, news outlets and her scientific background, saying that *'it's not difficult to put all these puzzle pieces together and have a better understanding'.*

Silvia (B_1) was also deeply concerned with the environment and with leading a green lifestyle. She acknowledged the fact that there are many different views on how to solve environmental problems and remarked that *'the big problems are really personal transportation and the way which we generate electricity'*. She was unsure of the ultimate outcome of turning down the heat in the office but she would favour such an action since it would be a small step towards change. As she put it:

> *'I think that if you don't turn on the heat at all, that's great, you are doing a little something for the environment, but you are not going to stop climate change by not turning up heat.'*
>
> (Silvia_B_1)

For Peter, energy related practices at work such as turning down the heat and turning off lights had negligible impact compared to that of the energy sector. As he said:

'Sometimes some people feel like if they turn off the light they will save the world, I am not feeling that way. (…) I did actually a couple of projects in the energy sector, in the industry, and I saw that the environmental impact that these people have is thousand million times larger than what I would have by turning on or turning off the A/C or lights. So, it's simply that I don't feel that strongly about impacting the environment by turning on the A/C or turning it off.'

(Peter_B_1)

From a similar perspective, George in case D remarked upon the effect of individuals on energy consumption as being *'a bit like democracy'* where *'a single vote will not change anything but nevertheless a large number of people can make a difference'*. For him, the way indoor comfort is achieved in the workplace comes through collective efforts, thus making an interesting point regarding the social aspect of practices and how to address change.

7.4.3 Post-doctoral office

The post-doctoral researchers were knowledgeable and pragmatic with regard to the impact of workplace practices on the energy consumption of the building. They were aware of the energy mechanisms but not of the specific issues that a building might have in terms of energy consumption.

Aware and pragmatic

The post-doctoral researchers were modest about their level of knowledge and felt that they had *'a reasonable understanding of the environmental circumstances of energy use'* (James_D_2). Their age and experience of research made them less enthusiastic compared to the PhD students when commenting on energy efficiency in the workplace.

In office D, Oliver mentioned *'you think about things such as energy policy and I feel like I am somewhat informed about this to a normal extent'.* In the same office, Robert claimed that, despite being aware of the energy mechanisms, he could not translate them to tally with the energy consumption needs of the department building.

'I know how energy works, I know what the units are, and I know that if you increase entropy then you take energy to do so. But I don't know what the issues in the department are regarding heating and lighting.'

(Robert_D_2)

7.5. Meanings: productivity and workplace dynamics

There are meanings, concepts, emotions and beliefs associated with the performance of certain practices that can affect how people act (Gram-Hanssen 2010a). Practice theory posits that people become motivated to act as they do because they want to be seen in a certain way e.g. to be environmentally aware, hardworking or role models. Warde (2005, p.137) suggests that practices generate *'motivations'* and *'wants'* and *'the conventions and standards of the practice steer behaviour'*.

In relation to the indoor climate in the workplace, motivation can come from different venues such as the importance of being energy conscious and having a low environmental impact, saving money or being a part of an environmentally aware research group. Hence, thermal comfort and other workplace practices could be a result of social, environmental, financial, technical or other meanings attached to their performance and can explain why people engage in these activities.

During the first interview round, participants were asked to self-assess their lifestyle on a scale from one to five based on how green they thought it is. They were also asked to comment on the importance of being energy-conscious in their workplace. In addition, there were discussions about individuals' attachment to their office—related to territory, ownership and belonging—, the impact of their research identity and the influence of colleagues' behaviour on their own practices.

7.5.1 Administrative office

In the administrative office, social dynamics and a sense of hierarchy heavily influenced the shaping of indoor heat regulation practices. Maintaining a balanced work environment was very important for the participants and many of them would adopt a passive approach to achieve that.

Workplace dynamics and social considerations

Among the eight office users, two seemed to be more active over the regulation of heating, lighting and ventilation in the office, while the rest were more accommodating of indoor conditions. The more active users—Laura, the office manager and Hannah, the accounts clerk—were female, middle-aged and senior members in the office.

For Laura, comfort conditions and energy consumption in the office were important matters and she felt in charge of any relevant issues that may arise. Her responses during the interviews were lengthier and more detailed compared to the other participants and she mentioned that she is the one who gets in touch with the Safety Officer regarding maintenance issues. During the observation, she cared more than others as to whether lights were on and windows open. She turned the lights off during the lunch break and, as the last person leaving the office in the afternoon, made sure the A/C and all lights were turned off. Hannah explained that, among the three people sharing her side of the office, she is usually the one who regulates the A/C and discusses the conditions in the room. She said, *'it will be one of the two of us that switches the heater on and the third one would sit there and suffer until one of the others switches it on'* (Hannah_A_2) referring to her more inactive colleague.

The rest seemed to follow a more adaptive approach. Their view was that trying to set the optimal temperature in an office might be *'intruding'* or a *'cause for arguments'*. Diana noted that most of the times she accepted the existing conditions as she knew that she is normally the person who feels colder than the rest and conceded that *'everybody else can't be wrong'*.

> *'I am aware that I feel the cold more than other people so I show more understanding (…), I wouldn't expect the rest of them to suffer with the heat'*
>
> (Diana_A_1)

Similarly, Oliver (A_2) acknowledged his social considerations saying that he would *'happily sit with the A/C or the heater on'* because he likes the situation in the office to be *'smooth'* and does not cause any arguments by changing the existing conditions.

> DD
> *'Could you say that there are social reasons? Would you minimize your comfort because of your colleagues?'*
> Oliver
> *'Yes, I won't really say anything just to put them at ease and not cause an argument or discussion.'*

Difference between practices at work and at home

Even though in the administrative office participants could use the heating system and equipment more efficiently, there was no motive to do so. In addition to the daily workload and social considerations, this can be also explained by the lack of direct financial impact in contrast to similar practices in a home setting. The idea of energy saving for the office users was mainly associated with economic benefits deriving from reduced bills as well as fuel costs linked to domestic and transport practices rather than office use. Thus, there was a bigger incentive to 'construct' efficient practices and be energy aware at home rather than at work.

Oliver (A_2) indicated a lack of motivation saying that *'it's not something that clearly crosses my mind'.* For Daniel (A_1), the office and home were two different cases. He noticed that he would *'just treat it (the office) as a workplace really which is for normal people'* and rather *'construct savings'* in his house. He believed that the effect of *'paying the bills'* in informing daily home based practices was a significant incentive and therefore the home is prioritised over the workplace where energy saving matters are concerned. Diana (A_2), who shared the same office, agreed that, at home, energy saving has financial benefits and that, for her, not wasting energy in the office is considered a *'time-consuming'* activity outside the remit of the workplace.

7.5.2 PhD office

The social setting within the office, the environmental ideology of Cambridge students and the importance of being productive were key factors shaping workplace practices in the PhD open plan office.

Collective consciousness, a moderator for comfort

Maintaining a balanced social atmosphere within the shared office was a major consideration of the PhD students and arguing over the temperature in the room seemed rather trivial for them. There was a variation of thermal preferences among the office users; *'the people who think it's too cold and the people who think it's too warm'*. This brought about *'negotiations'* over whether to open the windows or change the A/C setting in the office, Peter (B_1) noted. Similarly, in office C, Steven (C_1) said that people were willing to compromise their comfort for others—given that this would not lead to any extremes—in order to work in what they called *'a nice relaxed environment with little conflict'*.

It also came across that comfort expectations in the workplace were highly influenced by social dynamics. The concept of the office users as *'members of a team'*, as indicated by Alexia (B_1), seemed to act as a moderator for comfort issues and *'social glue'* when discussions on office conditions took place. Common research interests and informal social events between the users also created a sense of community amongst the users and rendered them adaptive to the indoor thermal conditions out of respect for their colleagues. Alexia additionally explained how they *'have coordinated and set the heating system in a way that we all feel comfortable'* to avoid conflicts in the office and maintain a balanced work environment. She said:

> *'I just don't touch it [the heating system] because you know; I don't want to inconvenience everybody else. And if they are happy with it the way it is then, you know, I can always just work in my room or go somewhere else or put an extra layer.'*
>
> (Alexia_B_1)

In office D, George found the temperature during summer slightly high, but did not think it was a major issue. He also commented on the influence of others on the regulation of the indoor temperature, stressing that *'the limitation is not really the office but the presence of other people. So if I am alone I can open the windows if not, I have to respect the others'.* (George_D_2)

Being energy conscious carries 'ambiguous' connotations

As argued in Section 7.4.2, the engineering background of the PhD students meant an elevated understanding of energy concepts and associated environmental implications and, in turn, indicated they could be more critical of energy efficiency issues. This, in combination with a 'green' university culture, made the students feel differentiated from the rest of society. They thought that they ought to do more for the environment if appropriate meaning was to be associated with their action. In office B, Peter described this situation:

> *'Most of the society is probably too lazy or too comfortable with whatever they have, and Cambridge people, if they think that being energy conscious is the right way to go they will actually turn off the light and try to convince other people about it. They are very strong about their ideology and we have people like these here [in our office].'*
>
> (Peter_B_2)

Although the existence of this environmental ideology came across when interviewing two of the participants, namely Alexia and Silvia, being labelled as 'green' and an 'energy saver' did not seem to be considered a positive attribute by others. It was even thought to have *'a lot of negative connotations'* (Steven_C_2). In office C, when discussing energy saving, Steven (C_2) said, by being an environmentalist '*my social outlook is such that people are absolutely theatrical and even joke about it'.* Being actively energy conscious and trying to influence other people could be *'annoying and a little bit counterproductive'* he added. He also mentioned that, even if he agreed with the concept of saving energy in offices, it irks him when *'people tell others to turn things off or save electricity'*. He concluded that, for him, financial rewards or the idea of saving the planet are not important and common sense is all that is required for someone to feel motivated:

> *'In terms of motivation I think it's just being sensible, as I am not paying to what I use directly, I think my common sense is all I need to motivate me'.*
>
> (Steven_C_2)

George (C_2), another PhD student, agreed that having a green lifestyle and trying to change other peoples' practices can sometimes be irritating and socially isolating. He gave an example by explaining a case in his College common room where the coffee machines used paper cups instead of reusable porcelain ones. When he pointed this out at his friends, he realised that they were not keen to change their habits and commented that *'it feels almost strange to tell them if you use the paper cup then you are throwing it away, if you use the porcelain cup it will be washed and used again, because it's just their habit'.*

To be a good researcher one needs to feel comfortable

Research practices were prioritised over considerations of both indoor climate regulation and the department was seen as responsible in maintaining a comfortable environment. The view that being *'in an office doing research, which is good for the society'* (Ben_B_2) should not be burdened by additional concerns over energy consumption was common between the research students. It was suggested that one compensates for the other and it is important for the office to maintain a comfortable indoor environment in order for its users to be productive. If there was a need to put more effort into changing existing indoor thermal conditions '*it has to also take into account student comfort because this is a working place and you have to be comfortable so that you can be productive'* said Ben (B_2).

Wilhelm put it in another way, suggesting regulating the heating and cooling system in order to save energy is the department's rather than the researcher's responsibility in that the former might reap direct financial benefits, whilst the latter are there to study and do their job. He claimed:

> *'The people who are in charge of paying the bill in the end, they will be very interested in saving energy. The people who are affected by this have other things they should be worried about. I don't know what the other people are saying, but I could imagine if you are working here as a PhD student or Post-doc, you just don't worry whether the radiators are running or not and if it's too hot you open the window.'*
>
> (Wilhelm_B_2)

Alan (C_2) also shared the opinion that the facilities manager rather than the researcher is the one who should care about the provision of comfort adequacy and quality. He added that *'you have got other things to worry about as opposed to heating and cooling the office, generally it is the concern of the people that manage the facility'*.

7.5.3 Post-doctoral office

In the case of the post-doctoral staff, comfort and workplace practices were not considered particularly wasteful since they felt that they are using existing resources in a reasonable way and as matches their job requirements.

Productive and realistic

The post-doctoral researchers were more neutral and pragmatic about the importance and the effects of being energy conscious in terms of comfort and energy consumption in the workplace. They felt that there was not much one could actually do, since the existing heating system and the type of research, which required the use of computers around the clock, did not leave much room for alternative practices.

Jacob in office E explained that, even if they tried to reduce the energy consumption in the office through keeping the temperature of the heating system low, the overall impact would be negligible. This was because the researchers are a part of an institution and the temperature in an office does not make a big difference in the overall consumption. He said, '*if you just look at the spending part, if I am keeping 2°C warmer in my office it's not going to make a big impact in the total cost of the heating and maybe in the total energy use'*. For him, it is important to be reasonable and pragmatic rather than be *'a super energy saving person'*. He explained that:

> *'It's just more to be aware of it (energy consumption) and not doing stupid things like keeping open window and the A/C running and using the A/C unless it's necessary. If it was 35°C I would probably open the A/C, I wouldn't sweat here because I want to save energy but it's more doing it at a reasonable level.'*
>
> (Jacob_E_2)

For Sina (D_2), being energy conscious in the workplace is not a priority. He remarked that the difference between the concept of energy consumption at home and at work affects how he approaches comfort conditions. In his words, *'if I use something at home I would think about how much or how long I would use it but that's not the same at work'.* For him, just like the users of the administrative office, the lack of financial incentive would justify a different mind-set. Henrik also noted that, if he feels comfortable, he would focus on his research tasks and that there was no need for him to think further about it:

> *'Because I usually focus either on my work or in discussion with colleagues and as long as I feel comfortable (…), as long as I don't feel any need to change something, I don't care too much.'*
>
> (Henrik_D_2)

He added that, although he would be very careful not to be wasteful and he was the only one in the office that turned down the valve of the radiator when he felt that it was getting too hot, being labelled by others as an energy saver held little value for him.

7.6. Summary

Based on extensive interviews carried out in two rounds, this chapter looked at the elements that framed workplace practices related to thermal comfort in three typical office types within an academic building. It also looked at the relation of these elements to other energy consuming practices such as the use of computers and office equipment. The key themes that emerged were:

a) Workplace routines and user profiles.

Three distinctive user profiles were identified among the participants based on routines that they developed as part of their working schedule and relevant administrative and research activities. These were: the 'busy' administrator, for whom the tight daily schedule and relevant tasks do not allow time to think about comfort and energy use in the workplace; the 'green' PhD student, for whom productivity is a priority with the result that research practices are of greater importance than efficient indoor climate practices and use equipment and whose 'low carbon' lifestyle due to being a student makes him already energy-conscious, and the '24-

hour' researcher, whose main focus is research, and who is professional and pragmatic about workplace practices as well as mindful of his impact on energy use.

b) The configuration of the existing heating and cooling system and the relevant maintenance structure.

Material elements such as the heating system configuration and its central management throughout the university's estate service, which meant office occupants had little control over the settings, were major determinants in the way thermal comfort was approached by the users. This, combined with the slow and inadequate maintenance structure within the department, were elements that supported a more apathetic approach towards the regulation of thermal conditions and made any correlation with associated energy consumption unfavourable even for an energy conscious office user.

c) The relation between social dynamics and indoor climate practices.

In the administrative office, social considerations had a significant impact on users' thermal comfort practices. Comfort expectations were compromised and adaptability seemed necessary in order not to cause any inconvenience among colleagues. Similarly, in the PhD workplace, collective consciousness was important in the formation of heating and cooling patterns. The students acknowledged differing comfort expectations within their group due to varying ethnic backgrounds, working patterns and fitness levels. Nevertheless, a balanced social working environment was prioritised over individual considerations. The same applied for the post-doctoral researchers, although it came across that they managed to coordinate their thermal preferences without the need for compromise, possibly because the smaller office size allowed better communication and interaction among them.

d) The meaning of being energy conscious in the workplace.

The association between achieving thermal comfort and the energy consumption this practice entails was non-existent in the case study offices. Workplace comfort was directly related with productivity and research excellence rather than with being energy conscious. The daily workload in the administrative office and the nature of research in the PhD and post-doctoral offices, which required 24-hour access and continual use of office facilities, meant that thinking of the optimum thermal conditions was a waste of time and could compromise the research quality, something that is to be avoided. For the administrative staff, it was also evident that considerations of energy consumption were more related to practices at home due to their direct financial impact, while the workplace was not considered the place to 'construct' energy savings. As a result, a 'passive' attitude towards the regulation of thermal conditions and a 'work comfort' approach was adopted.

This chapter de-constructed workplace practices and considered their social and material elements, thus providing a route to devising a strategy to encourage a change in practices.

Chapter 8 outlines how the users experienced a behavioural change intervention and the impact it had on their office practices.

8. Transforming practices: Real-time consumption feedback as an intervention

8.1. Introduction

The previous chapter discussed in detail the socio-material arrangements that lead to a ‘passive’ user profile with regard to thermal comfort practices in the workplace. Irrespective of the control level over the heating system, users would accept indoor conditions even when these were not considered comfortable. This stemmed from social concerns, their focus on work tasks, and a lack of time, as well as there being little incentive to interact with the heating system due to its inefficient configuration and inadequate maintenance.

This chapter discusses the findings from the second round of the semi-structured interviews that took place between the 2 and 7 July 2014, approximately six weeks after the installation of the RTDs. The focus is on the potential of energy use feedback in transforming practices. To this end, this chapter explores how the concept of energy saving is encountered in the workplace, the first impressions from real-time feedback and its impact on the electricity consumption of the case study offices in the short-term. This investigation informs the concluding reflections on the elements that constrained change and thus offer the basis for potential future action as first indicated by the participants.

Section 8.2 presents the electricity consumption data obtained from the smart meters connected to the RTDs before and after the project implementation. Section 8.3 examines how the office users reacted towards the concept of energy saving in the workplace, the constraints and prompting aspects. The next section (8.4) discusses the first impressions of the RTDs, with a special focus on the installation process, the induction process and the design of its interface. Finally, Section 8.5 focuses on learnings associated with the encountered socio-technical constraints and identifies energy saving opportunities.

8.2. Electricity audits at case study offices

Monitoring provides a measure of energy performance and therefore a proxy for building practices (Foulds *et al.* 2013). This section examines the daily and weekly consumption patterns of the case study offices in order to identify the actual impact of the RTD technology, with special focus on the consumption figures before and after installation. Among the case study offices, A and B had their own separate electricity meter, C was in the same metering arrangement with two offices of similar size and type, while offices D and E were not sub-metered. Monthly and daily electricity figures were retrieved from the electricity sub-meters by using the Workplace Footprint Tracker web-tool (Table 8.1). Electricity consumption data was analysed in three levels:

- Monthly electricity consumption (KWh/m) for the period from October 2014 to July 2015 (the academic year).
- Daily electricity consumption (KWh/d) for the period from June 2014 to July 2015 (after the installation of the RTDs).
- Daily electricity consumption (KWh/d) snapshot from April 2015 to July 2015.

Table 8.1 Monthly, weekday and weekend electricity consumption in offices A, B and C (October 2014-July 2015).

Office	Monthly (KWh/m) October 2014 - July 2015			Weekday (KWh/d) April - July 2015	Weekend (KWh/d) April - July 2015
	Min	**Max**	**Ave**	**Ave**	**Ave**
A	233 (Dec)	277 (Mar)	251	10.5	3.2
B	403 (Jan)	1460 (Oct)	930	35.9	21.4
C[17]	893 (May)	1872 (Jan)	1473	36.2	22.9

8.2.1 The administrative office (A)

Electricity consumption in office A remained stable throughout the academic year (October 2014 to July 2015), with an average consumption of 251 KWh/m. A small peak was identified between March and May 2015, possibly due to weather conditions, which required an increased use of the A/Cs. From Figure 8.1, it becomes clear that the installation of the RTD in October 2014 did not have any impact on daily consumption levels. Figures 8.2 and 8.3 indicate a stable weekly consumption pattern, with an average value of 10.5 KWh/d, which more than halves during the weekends reaching 3.2 KWh/d. According to the Safety Officer the energy consumption during weekends is due to standby power from appliances and equipment (e.g. computers, printer, fridge) that are either left on standby or switched off, whilst still using some power (Slack 4.08.2015) .

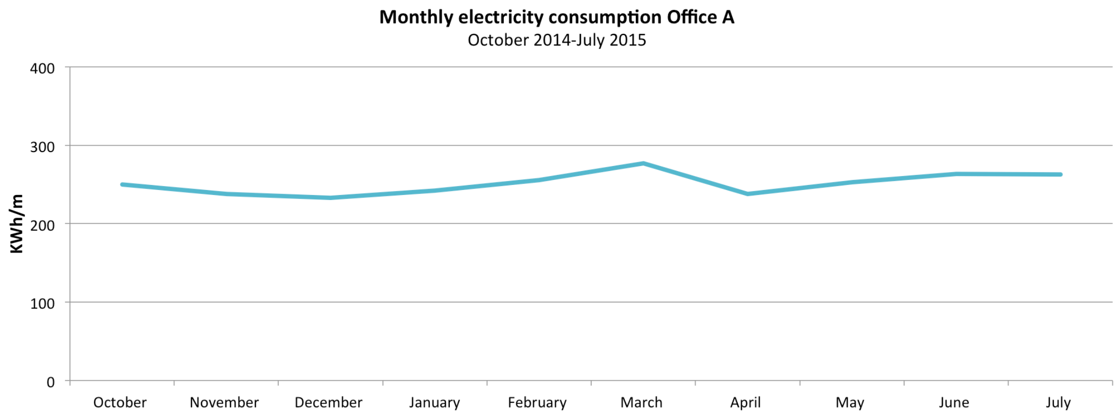

Figure 8.1 Graph of monthly electricity consumption (KWh/m) in Office A over the period of an academic year (October 2014-July 2015).

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[17] The amount is cumulative of office C and two similar size offices.

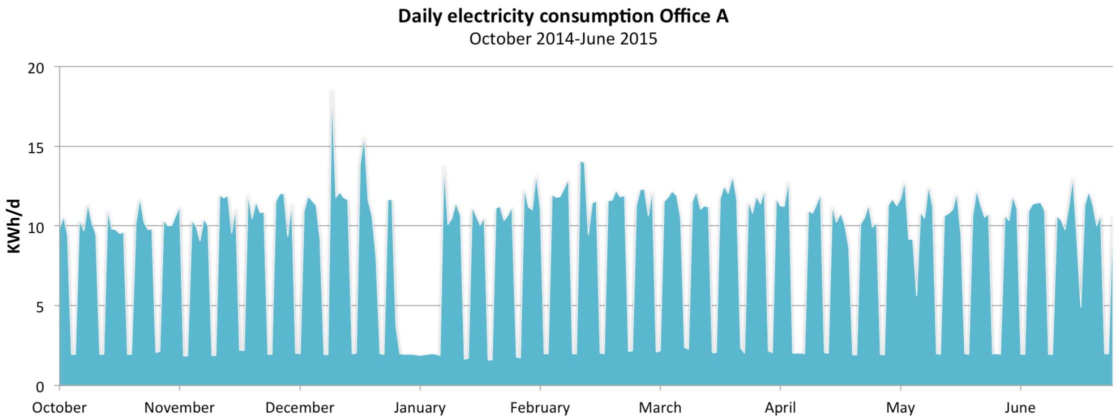


Figure 8.2 Graph of daily electricity consumption (KWh/d) in office A over the period of an academic year (October 2014-June 2015).

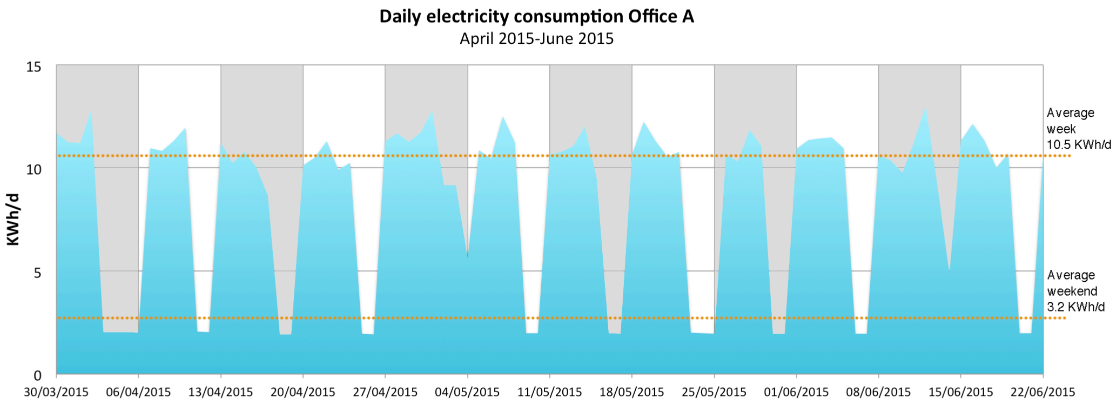


Figure 8.3 Graph of daily electricity consumption (KWh/d) in office A with average week and weekend consumption indications (April-July 2015).

8.2.2 The PhD office (B and C)

In the PhD office B, the monthly electricity consumption had an unstable pattern (compared to office A), mainly because of metering problems between the months of December and February, which resulted in faulty meter readings (Figures 8.4 and 8.5). A weekly and weekend pattern can still be identified in Figure 8.6, which illustrates a snapshot of the daily consumption in the period between spring and summer. Energy consumption during weekends drops to half of that of weekdays, indicating that activity is still taking place in the office, as verified in the participants' interviews (see Section 7.2.2). The office is usually used on Saturdays and sometimes Sundays while the computers remain on in order to run simulations. After the installation of the RTD in July 2015 a small drop in consumption is noticed which quickly rises indicating a minimal if any impact in users' energy consumption.

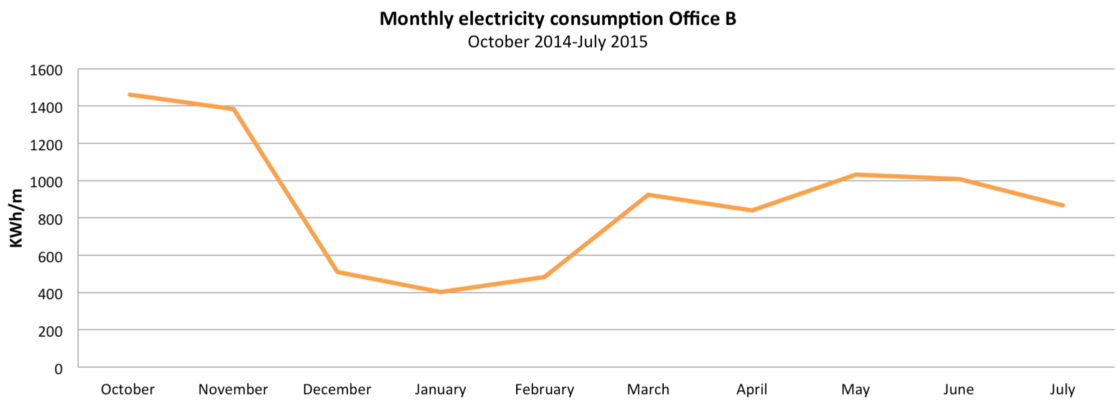


Figure 8.4 Graph of monthly electricity consumption (KWh/m) in office B over the period of an academic year (October 2014-July 2015).

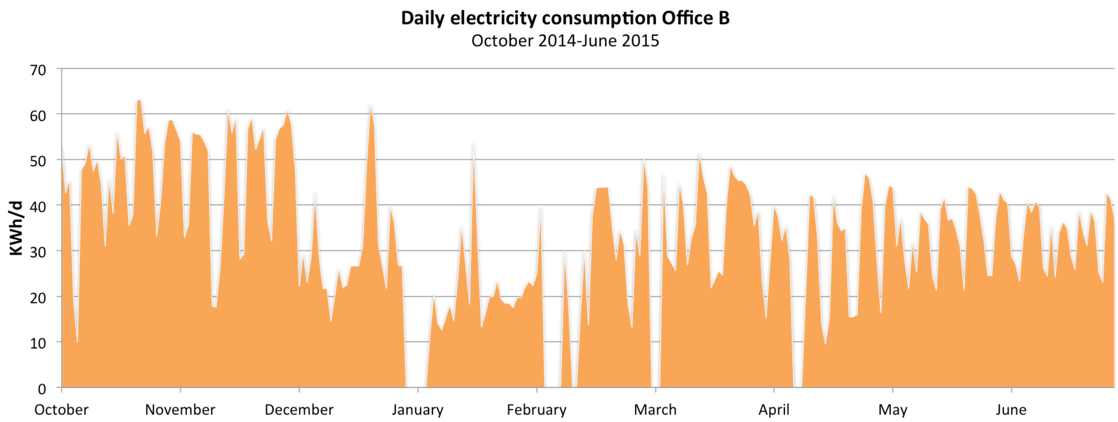


Figure 8.5 Graph of daily electricity consumption (KWh/d) in office B over the period of an academic year (October 2014-June 2015).

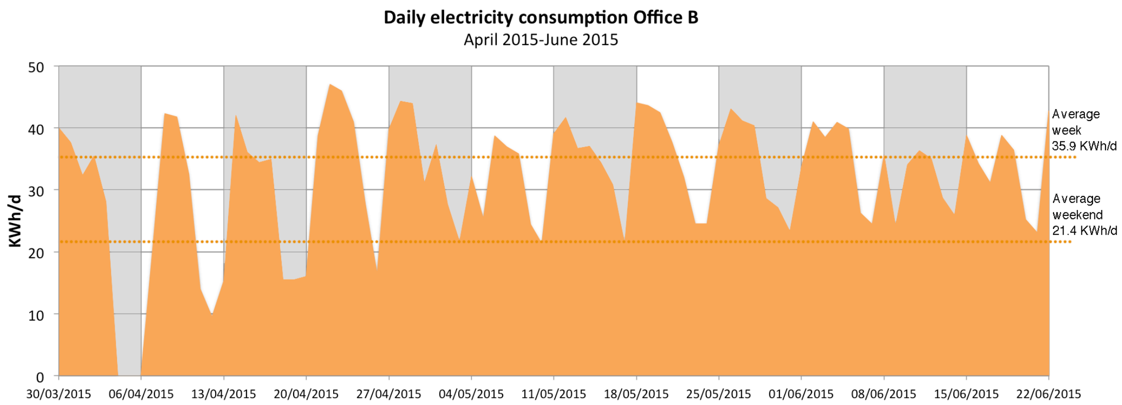


Figure 8.6 Graph of daily electricity consumption (KWh/d) in office B with average week and weekend consumption indications (April-July 2015).

Electricity consumption in office C was metered alongside the other two adjacent PhD offices of the same size and heating system configuration. It is not, therefore, representative of one office and easy to compare. The monthly consumption in Figure 8.7 indicated that October 2014 and January 2015 are the months with the highest consumption levels reaching 1804 KWh and 1872 KWh respectively, possibly related to higher occupancy levels at the beginning and end of academic terms. From March 2015 onwards, electricity consumption falls to 893 KWh (in May), possibly due to weather conditions and changes in the occupancy level of the offices, as the Safety Officer explained (Slack 4.08.2015). Weekly consumption patterns are easy to identify from the daily consumption graphs (Figures 8.8 and 8.9). On the weekends, consumption halves to that of weekdays, indicating less intensive but still on-going activity.

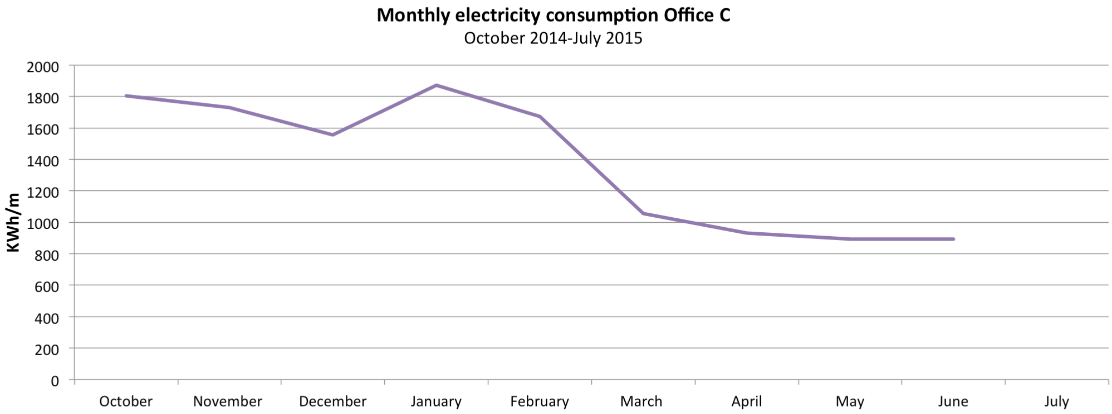


Figure 8.7 Graph of monthly electricity consumption (KWh/m) in office C over the period of an academic year (October 2014-July 2015).

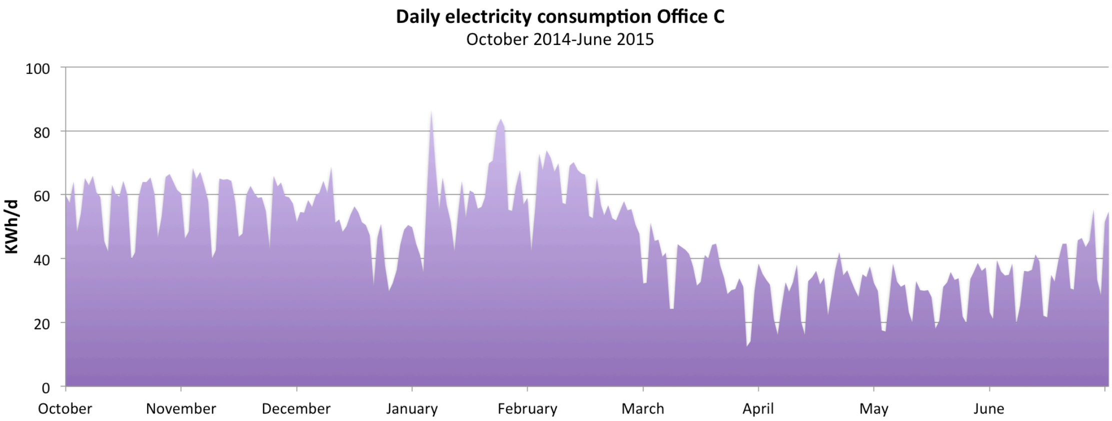


Figure 8.8 Graph of daily electricity consumption (KWh/d) in office C over the period of an academic year (October 2014-June 2015).

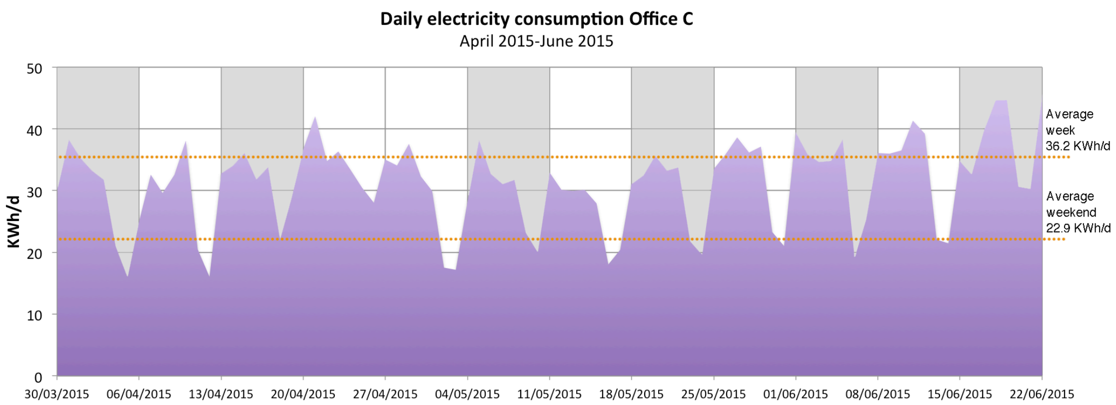


Figure 8.9 Graph of daily electricity consumption (KWh/d) in office C with average week and weekend consumption indications (April-July 2015).

Overall, the electricity data from the case study offices A, B and C verified that the installation of the RTDs did not affect electricity consumption in the short-term (Figure 8.10). Only office B evidenced a small drop in daily consumption the months after the installation of the RTD (June and July 2015), which quickly rose back to previous levels. All the offices except the administrative office (A) were occupied or used remotely during weekends, as indicated by their electricity consumption levels and verified during interviews. The administrative office (A) presented the most stable weekly consumption pattern due to its standardised working tasks and fixed daily schedule.

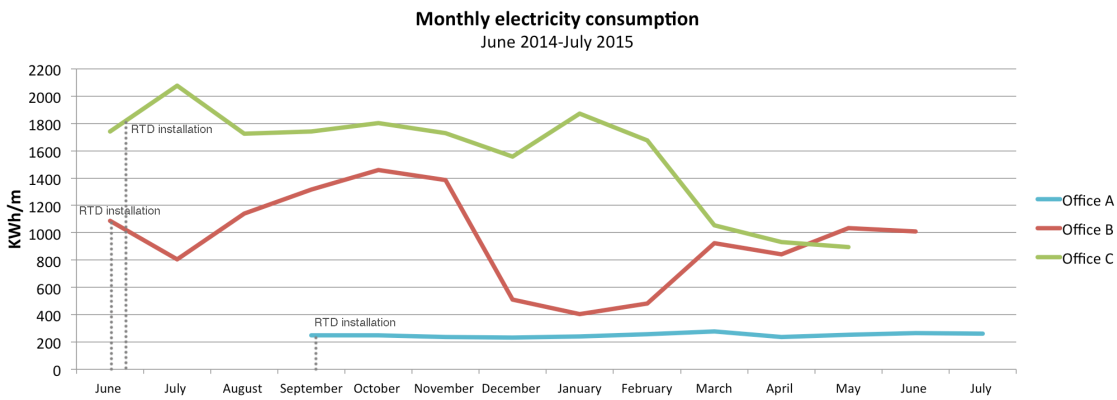


Figure 8.10 Graph of monthly electricity consumption (KWh/d) in offices A, B and C after the installation of the electricity sub-meters and RTDs (June 2014-July 2015).

8.3. Users' socio-technical constraints and opportunities to save energy

In the second interview round that took place after the installation of the RTDs in offices, the study participants were asked to comment on whether they agree or not with the concept of energy saving in the workplace (see Appendix A1 for the questions). Subsequent questions focused on whether users thought they had adequate knowledge to save energy in their office and what would motivate them to do so. The key themes that emerged, which also structure this section, were the need for more efficient technologies and infrastructure, 'true' information in order to understand how change can take place and suitable reward for the audience.

8.3.1 Inconspicuous consumption and the material element

The participants related energy saving actions in their office to the efficient use of the heating system (when control was allowed), the office equipment (computers and printers) and lighting. Thus, opportunities for change were directly linked in the users' minds with existing material infrastructure.

The post-doctoral office D was the only case that had central heating but no air-conditioning unit. When asked about their knowledge on saving energy in his office, Henrik (D_2) appeared sceptical, stating that the main question was not whether one is positive towards the concept of energy saving in offices but *'what can you really change'*. For him, energy use was related to basic heating and lighting standards, namely essential elements of an office that are not energy wasting and therefore cannot be subject to change:

> *'Of course you can switch the light on and off but I just switch it on when I really need it for my work. We have no A/C and of course the heating in the summer doesn't make sense so there are not really a lot of options, right? (…) At least during my work I don't really see that I waste energy.'*
>
> (Henrik_D_2)

In the same office, Robert (D_2) agreed that one possibility to save energy would be to switch off lights *'but these are relatively efficient lights and there is no great deal to what you can save'*. Given that they could not control the heating, he concluded that the only way to save energy would be to replace his computer with a more efficient one and *'devolve more (computer tasks) to the departmental infrastructure'*. This would, however, require more time and effort than a researcher can afford and is also not his responsibility. Moreover, Robert remarked that it needs to be *'for a reason'*, which was not currently clear to him.

Another material element that appeared to affect the users' mentality and predisposed their practices was the age of the department building and existing infrastructure (see Section 5.2.1). Users felt that saving energy was not in their hands as they were already as cautious as they could be. In office A, Laura (A_2) described that within her group they feel *'pretty aware of consumption'* and there is not *'much that we have got running that we could really not have'*. Since, in Diana's view *'in the office there is only so much that you can do (…), trying to keep it low'* adds unnecessary pressure. Laura additionally explained that *'it's very hard in a building of this age'* to achieve large energy savings due to the image it carries and gave the following example:

> *'It's like going into a hospital, isn't it? A really old hospital. It doesn't mean that the care is not right but the feeling of the people that are in there is probably not [the same as in a modern one]. You could have two people with the same problem and if one is in a modern airy building you would probably find that he*

gets better a week before the other (…). I don't know how you measure it but I think it [the building age] definitely affects people.'

(Laura_A_2)

Finally, in the PhD office B, Alexia (B_2) described how energy wasting that would take place in their office resulted from either necessary consumable used for lab experiments or *'normal behaviour'* because *'people feel that they are not in charge'*. These practices would be difficult to change while *'getting people to be cautious'* in their office should be avoided because that would compromise research. Furthermore, she commented that more efficient technologies such as light sensors or semi-automatic temperature controls seemed to be the only way to achieve savings.

In summary, participants felt that their daily practices were already energy efficient and there was no room for improvement because energy wasting mainly stemmed from existing technological configurations (see Section 7.3) and research consumables rather than their personal energy intensive habits. Therefore, changes that would affect the way of doing things would be difficult because they could compromise the execution of research. When a change in practices was discussed, efficient technologies such as having a semi-automatic heating and cooling system, efficient lighting and modern office equipment were considered as prerequisites.

8.3.2 Need for information on 'where' and 'how' to achieve energy savings

Among the surveyed participants more than half (n=10) were sceptical as to whether they had the right instructions to act accordingly if energy savings were to be made in their office. Linked to their cautiousness was the feeling that there was a lack of adequate information as to whether waste was actually an issue and how, if so, to accommodate more efficient workplace practices.

In office D, Sina (D_2) would welcome further input on the energy consumption of his office. He argued that *'knowing that I am using an excessive amount of something that I shouldn't use I think it's enough to motivate someone not to use it excessively'*. For others, however, it became apparent that this type of one-way information was insufficient. Apart from knowing that wasteful practices take place, one also needs to have clear goals and directions as to 'how' to change them. For example, Ruchi (B_2) declared she did not think *'the screen is helpful enough'* and that there needs to be *'more control on a group basis'* with specific information identifying precisely how far a certain goal has been surpassed. Sharing a similar view, Luke addressed the need for encouragement on a regular base and the setting of specific targets:

'I would like to see something publicised, someone sending e-mails out saying how, trying to encourage you to do it (…). I think you 'd need to have someone setting targets for you.'

(Luke_A_2)

George (C_2) agreed, saying that he would try to change if he was *'aware of actions that can improve the [efficiency] conditions'* given that in an office there is a lot of freedom as to what one can actually do but no directions and *'true'* information as to how one can do it. His views were also relevant to the recent experience with the RTDs and the type of information they aimed to convey. When asked about the type of instructions he would like to receive in order to take action, he noted:

'If there are goals or clear things to do or clear information especially on waste, if I realise that something is really producing waste and it's not too expensive for me to act then yes [I would engage] but otherwise, I would not feel motivated.'

(George_C_2)

Overall, it appeared that users would be eager to try if they felt the right informational support was provided. Clear instructions, certain goals and reliable information that would reflect the actual consumption of the office and set realistic strategies and objectives for action were the points highlighted.

8.3.3 Social and financial incentives for change

The sorts of incentives that would drive change and reward efforts were also discussed with participants. The monetary award associated with the 'CO_2 Reduction Grand Prix' was highly criticised by the PhD and post-doctoral researchers, while it was more in line with the expectations of administrative staff.

In office B, Ben (B_2) would like to *'see the bigger picture'* and how their efforts of saving energy in their office would *'benefit the whole university'*. Peter agreed and noted that *'we are doing this for the wrong reason',* remarking that *'the office alone is nothing in terms of energy consumption'*. In response to the financial award he commented:

'I can definitely do it for environmental reasons, I will not do it for the reason of whoever it will be in the division of the department winning a chunk of money because I am sitting in a too warm office or something. I don't feel very well about it.'

(Peter_B_1)

He also added that he is willing to be more pro-active and change existing habits if this would be an example for the rest of the university or even the country, thus feeding into social impact on the matter. This could come through a research project or pilot energy saving initiative that would extrapolate findings for public use. In his words:

> *'If we would be setting an example of some sort [then I would be eager to try]. I don't mean publicity, (…) but what I am trying to say is that if you have the feeling that what you can impact other people, then yes [you become motivated].'*
>
> (Peter_B_2)

Although the idea of setting an example to the wider academic and public community through participation in pilot studies was accepted as a motivator for change, only two out of the ten PhD students professed to be engaged in the University's raising awareness campaigns (Section 5.2.3, Table 5.2). Alexia (B_1) enthusiastically described the 'Switch-off' campaign and its activities that was being followed in her College and kept track of their updates on her Facebook account. For example, she said *'they have a movie screening and the people who go to the screening need to bring some items to recycle. It's not that bringing a can would make a difference; it's that if someone brings something that no one else has recycled before. It's really exciting!'*.

In the administrative office, the importance of a green company image whereby *'the staff is [sic] encouraged by the company to follow what it is trying to achieve'* constituted an important factor for change in Laura's view (A_2). For her, when people feel proud of working in an organisation, then they follow any recommendations. Since the university is a prestigious establishment, the combination of the right infrastructure with organisational green goals could thus positively impact staff's behaviour. On the other hand, Diana and Oliver argued that a financial reward would encourage greater consideration of energy saving. As Oliver (A_2) said:

> *'It would have to be a personal one [incentive] to get me paying attention to be honest. (…) It makes me sound a bit selfish but as it is not technically my money it is not something that would make me change'.*
>
> (Oliver_A_2)

Different types of users had different views on the type of incentive that would motivate them to save energy in the workplace. For most of the students and post-doctoral staff, collective actions with obvious public impact would be a strong driver. However, their participation in existing university schemes was found to be low, thus raising questions as to the way in which these policies are delivered. In contrast, a direct financial award seemed to be a legitimate reason for change for most (5/6) of the users in the administrative office. Thus, goals need to be carefully planned in order to be of interest for different audiences. This might possibly require the combination of different approaches (e.g. individualistic and socio-technical).

8.4. Users' experience with feedback through Real Time Displays

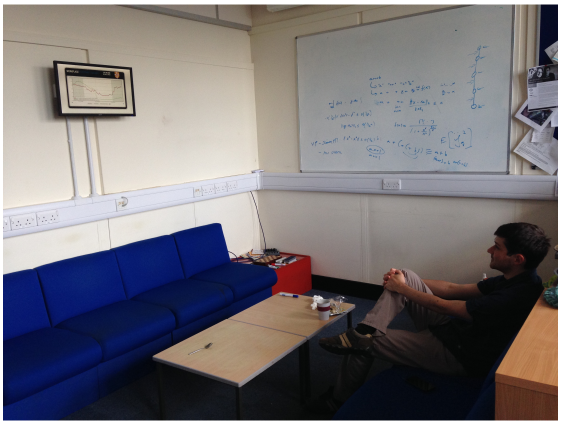
This section discusses the first impressions from the RTD installation process. Overall, direct electricity consumption feedback through RTDs (Section 5.2.4) was not found to be useful. Only four participants were positive about its benefit and prospects, four were neutral, while the remaining ten gave negative feedback. In three offices (B, C and D) the screens were turned off by the users approximately four weeks after their installation because the projected information was considered irrelevant and the screens themselves energy consuming. The fourth (in office A) remained on for a few weeks longer but was also eventually turned off. The delays in the installation process, the lack of proper induction and the difficulty in understanding the type of projected information were the main issues that were relayed in interviews.

It is worthy of mention that the RTDs were computer screens and not interactive intelligent systems. The information projected was not accessible in other ways such as online, unless specially requested. Furthermore, there was a lack of associated incentives in the form of a reward scheme, as a result of delays in the installation process. Nor was there a change agent, such as a dedicated facilities manager that would provide relevant information and feedback. Thus, the RTDs took the form of a passive one-way information provider as opposed to the multiple functions behaviour change interventions can accommodate (see Table 3.2).

8.4.1 Installation delays and technical problems

The RTD installation process was not straightforward and was subject to significant delays. This was the result of several administrative and technical challenges. According to the initial project plan the installation and configuration of the screens and relevant equipment (electricity meters, raspberry Pi's, internet and electricity sockets) was planned to take place before the end of September 2013 to coincide with the 'Grand Prix' competition that started in July and ended in December 2013 (see Section 4.8.4, Figure 4.14). The competition and the RTDs were the key elements of the behavioural change project and were complemented by additional project information communicated through the launch event (Appendix D2, Figures D.1-D.3), informational monthly e-mails (for six months, until the end of the competition) and access to the information projected by the screens through the department's intranet page. However, due to the lack of clear project roles and efficient coordination, departmental staff redundancies and equipment failure, the installation of the RTDs was completed approximately one year later (Table 4.11) (Office A had its screen installed and configured in October 2014—a year and a month later the initially planned date in September 2013—while offices B, C and D had their screen in place in May of the same year (Figure group 8.11)).

1



2

Figure group 8.11Real Time Display located in office A (1) and in the common room of offices C and D (2).

Delays and technical problems during the installation process caused both anticipation and a feeling of disappointment, especially in the administrative office where the installation process took half a year to complete (May 2014-October 2014). When Hannah (A_2) was asked about her thoughts on the potential of such a scheme, she relayed that she was not sure since the office was *'still waiting for this meter'* to be sorted, while Diana described her experience of the installation as filled with disappointment:

> *'They came to install it and then they said something about the meter not working and then Terry [the electrician] came back in over the weekend because he had to turn all our power off. I think he's been back about three times since then. Apparently, it's the only meter now that doesn't work.'*
>
> (Diana_A_2)

Delays in the installation of the screen and, in turn, feedback provision meant that the initiative did not coincide with the 'CO_2 Reduction Grand Prix' competition, as hoped for in the original project plan. This resulted in a gap in users' understanding of the competition's and RTD aim. Not only they came to be considered as two separate entities but also five of the interviewees were completely unaware that the competition ever took place. When asked about it, John (D_2) explained that although he was aware of the scheme he never actively engaged:

> *'We had the energy competition a few months ago; I don't know why or how this was set up. There was some sort of competition between different areas of the building to reduce energy consumption by so much in so much time. (…) That had the fault that no-one actually told us the results.'*
>
> (John_D_2)

Similarly, Luke (A_1) said that he had heard of the competition but *'can't tell what it is about'* because he never read the e-mail as he was just saving them *'in a folder somewhere and never got back to it'*.

Delays were also caused by the general mistrust in maintenance structures and lack of control over the existing heating system (as also pointed out in Section 7.3). In the PhD office B, the installation coincided with a heating problem that students had repeatedly reported but was never addressed because of the remote management of the heating system by the University's Estate service. Ben (B_2) described the situation *'funny',* while Peter (B_2) added that, because of this, the RTD became subject to *'sarcastic comments'*. *'People are just so frustrated with this'* Ruchi (B_2) complained, explaining that the central heating was turned on during May and June while there was a warm outdoor temperature, which made the office uncomfortably warm. The group felt unable to change the situation because when trying to communicate the problem to the maintenance staff they were given *'huge explanations about how it is not in their control, how we have to talk to somebody else and it is so much upsetting that we don't care about energy conservation anymore'*. When the screens arrived, the general feeling within the office was already ominous:

> *'It's like a slap on the face to have those issues [maintenance difficulties]. And you are forced to be working in such non-energy efficient manners and then somebody is trying to tell you "This is how you have to be energy efficient".'*
>
> (Ruchi_B_2)

Finally, she noted that *'if it can work it's good but it's clearly not applicable here'* indicating her scepticism regarding the project's suitability for the existing context.

8.4.2 Lack of proper induction

A significant constraint in the project's effective implementation was that the participants felt it was not officially introduced to them. These generated questions, uncertainty and a feeling that they were undervalued. Two inductions led by the building's Safety Officer took place in November 2014, one for office A (see Appendix D2, Figures D.3-D.4) and another one for offices B, C and D (Appendix D2, Figure D.5) as part of the University's 'switch-off week' green campaign. While in the case of the administrative office it was received with interest, in the case of the PhD and post-doctoral researchers, the induction was poorly attended (only three of the project participants came along).

Robert described that for the post-doctoral researchers *'the actual implementation was so bad that it just annoyed people a lot more than it ever informed'*. In specific he said:

> *'There is no explanation; we don't know what it means; the figures are presented without any context; and generally, we don't know what we are supposed to try*

and get out of it. (…) There is no sign that says who to talk to [in order to ask for more information]. It's a contextless display of things, which offends us.'

(Robert_C_2)

After *'long spirited'* discussions and a few days of observation, the screen placed in the common room of their office group was turned off. The PhD students had a similar experience, as Ben noted:

'It [the RTD] was only installed without mentioning anything and there was no one to tell us what it is for. (…) We had to find out on our own and all we see is a graph of energy usage which is very similar to (…) this smart meter [you have in normal households] which basically tells you the same thing, this one is just a prettier version.'

(Ben_B_2)

Ruchi (B_2) from the same office said that *'they just came, installed it and left'* without giving any further explanation. She felt that there was little reason to have the screen in their office, given that they can have access the information in the canteen's display. She could not see *'why they have an extra one'* in the office.

8.4.3 Design considerations and constraints

The design of the screen interface and the projected graphs were at the centre of harsh criticism between the office users in the PhD and post-doctoral offices. Table 8.2 sets out an account of the RTD design constrains as experienced by the users in the interviews. The type of information and the way they were projected, the reference points, the non-interactive control features and the naming of the different office groups were identified as the most common issues.

Table 8.2 Design constraints of the RTD interface as indicated by the users.

RTD interface design and implementation constraints
Confusing naming
Confusing arrows in graphs
Lack of reference point in graphs
Slow slide transition
Non-immediate results
Non-interactive control features in screen
Missing project URL
Non-downloadable data
Wasted pixel space

The arrows used on the league table to indicate energy savings for each user group were found particularly confusing. The table was designed to show the user groups in descending order according to their cumulative savings. A reduction in electricity consumption would be illustrated with a green arrow pointing right, whilst an increase would be indicated with a red arrow pointing left (Figure 8.12). Alexia (B_2) in office B, said this was the first thing that she noticed and that she *'got confused'* because for her *'to the right it was higher consumption and to the left lower consumption of energy'* while she would expect this to be the opposite way round. Similarly, Robert (D_2) explained that *'arrows and minus signs have no correlation'* and they *'don't understand what the direction means because they show exactly the same thing'*. In addition, the existence of controls that were not interactive, such as the arrows in the consumption graph (Figure 8.13), and the inability to scroll down the league table were widely criticised. As Robert (D_2) noted, *'either have the controls and have them interactive or don't have the controls, otherwise it's just inconsistent'*.

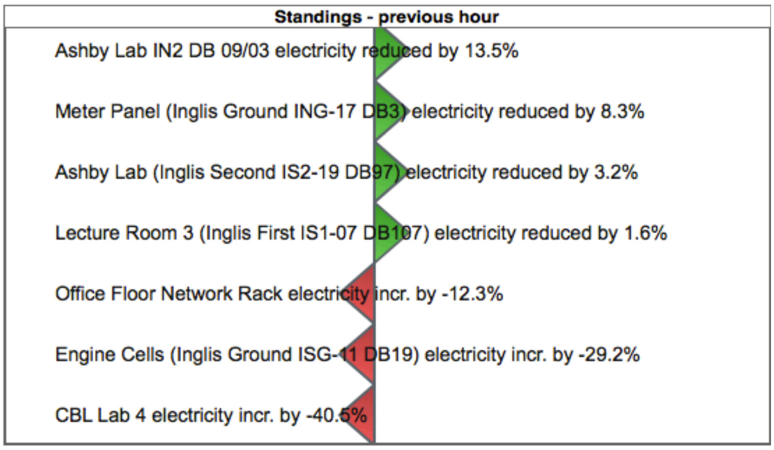


Figure 8.12 The workplace footprint tracker league table.

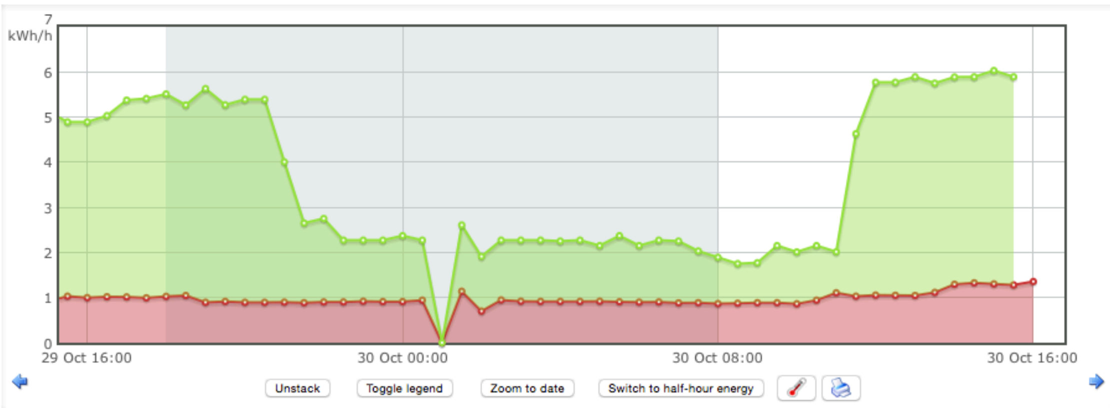


Figure 8.13 Graph of half-hourly electricity consumption (KWh) in office B (30th October 2015).

The granularity of the projected data and the lack of a clear reference point were also highlighted. Among the post-doctoral researchers, John (D_2) stressed how important details were missing, such as the goal of the scheme, the clear naming of the participating groups and a reference point. He added that no one was sure *'what that [the league table] was, what section of the building [it was referring to], or where it is measuring the energy from'*. Ben (B_2) found that this was *'a major problem'*, explaining that *'even though you give me the* *reference point of what we want it to achieve, I don't see the significance of that and I don't see the energy saving from my own office, how that can contribute to a bigger picture'*.

8.4.4 One size-fits-all approach

The above concerns regarding the induction and design elements of the RTD made the users feel undervalued as knowledgeable actors and gave them the impression that a generic and 'one size fits all' approach was implemented. The participants also highlighted the spatial and equipment differences between the office groups participating in the competition. In addition, as most of them were engineers with expertise on signal data processing they became very critical of the scheme's design aspects. They also mentioned that an opportunity of co-design, dialogue and feedback with the environmental consultants that had set up the project would have been useful.

The applicability of the scheme with its current design features at the case study offices level was strongly criticised. In office B, Wilhelm (B_2) pointed out that having worked as a consultant before, it became instantly apparent that the project was designed by external consultants and did not take the office setting into account. He felt that the way information was provided was not relevant to the office users but *'might be useful for the department'* and that the data was more relevant for the building maintenance team who have actual control over the heating and cooling system. Similarly, for Henrik (D_2), the screen was more suitable *'for places where you have more choices to save energy, like for instance in a workshop where you have lots of machines or some laboratories'.* Finally, Sina (D_2) added that the competitive character of the scheme requires *'all the rooms having the same [physical and infrastructural] conditions'* if comparisons are to be made, which is not the case in the department and current office selection.

Alexia (B), Steven (D) and Robert (D) commented that the project did not consider the users' engineering background and interests. For example, Alexia (B_2) highlighted that *'engineers understand trends. I don't know (…) where you are planning to use it outside of this department but in this department, they want to get the trends'* while Steven (D_2) stated that *'as engineers who work with graphs all the time, the presentation of it is what annoys us and we tend to be more critical to the way the information is presented rather than what it shows us necessarily'*. In addition, Robert (D_2) stressed the inability to get access to the raw data, resolve any queries or feedback any comments back to the design team. He explained that their engineering background makes them more critical to such schemes and important elements were missing such as *'a URL to download the raw data everyday or "energy.eng.cam" to exist (…); links, Frequently Asked Questions, and everything you could care about'*. So, in fact, *'the design managed to tick all the wrong boxes, which is why it (the screen) is off most of the time'*.

8.5. Discussion

Analysis of the participants' views after the installation of the RTDs revealed the shortcomings of a project designed to address behaviour from a solely individualistic perspective. The design of the scheme, which was based on Cialdini's (2003) theory of 'normative messaging', presumed users are driven by motivations and desires and are capable of making energy saving choices on the basis of information and economic incentives which placed the responsibility for change on them. However, as Shove (2010, p.1281) contends, such an approach is limited and disregards the effect of *'other (socio-technical) actors that configure the fabric and the texture of daily life'*. A series of socio-technical constraints that emerged corroborated her view.

One of the constraints was the fact that energy saving does not have a part in workplace practices which are systematically structured around productivity and social dynamics. As Luke (A_2) commented *'saving energy in the office is not necessary and we don't need it that much'*, a point, which was also stressed when the focus was specifically on comfort practices (see Section 7.5). This raised questions as to how to cultivate such a meaning in a non-domestic context. Nevertheless, the type of feedback displayed by the RTDs was useful for the Safety Officer, as was acknowledged by him and pointed out also by some of the users. For him, access to the data was possible directly through his personal computer and, as he was aware of the sub-metering details and specific features of each space, the use of the WFT provided useful insights on energy use and possible ways of saving energy.

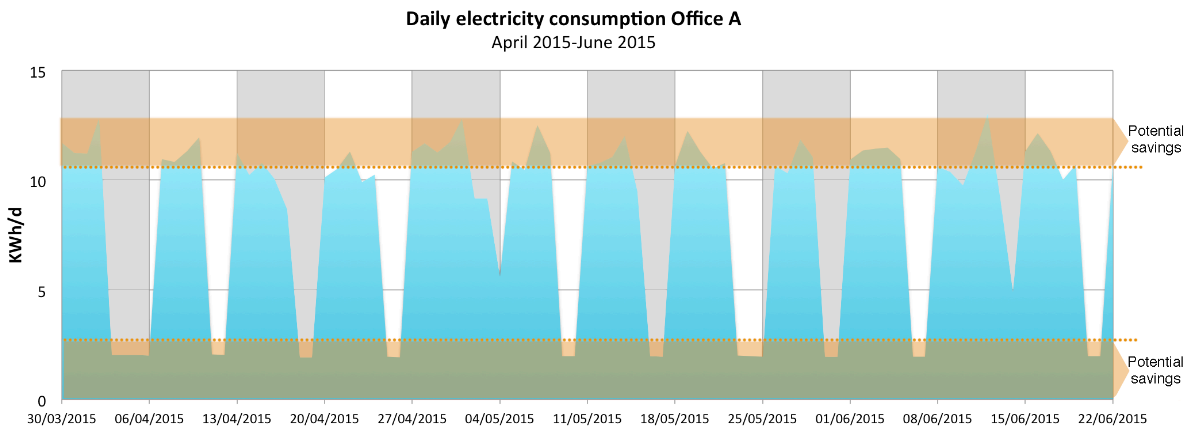


Figure 8.14 Graph of daily electricity consumption (KWh/d) in Office A with potential saving areas (April - July 2015).

Finally, even though behavioural change did not take place through feedback provision, the electricity data indicated opportunities for energy savings in all offices and underlined the benefits of integrating electricity monitoring with qualitative data when researching practices and '*when considering the everyday implications of technological changes'* (Foulds *et al.* 2013, p.622). Figure 8.14 illustrates the location of these savings in the area above the weekly average usage and below the weekend baseline for office A, similar to the other cases. Discussions with the building's Safety Officer associated them with the use of A/C's and lighting during the week and appliances that remain on standby during weekends (Slack 4.08.2015). Therefore, these elements constitute key areas for improvement.

8.6. Chapter summary

This chapter explored the potential of real-time consumption feedback through RTDs to transform workplace practices to achieve a more energy efficient office environment. It looked at how the concept of energy saving was experienced in the office and reasons that the screens failed to meet their purpose as indicated by the users.

Energy audits (Section 8.2) revealed that there was no change in daily office consumption after the installation of the RTDs and indicated a saving potential linked to standby and peak electricity consumption (Figure 8.14). Section 8.3 underlined that consumption in the office was mostly 'invisible' to its users whilst they were engaged in their research and daily work tasks. Users felt that the way to save energy in the workplace was the use of efficient technology. They were, however, open to 'true' and 'clear' information on the energy impact of their practices. Furthermore, it was found that different users—the administrative staff on the one hand and the students and researchers on the other—had different views on the type of 'reward' that would incentivise them to change. For the first group, a personalised financial award would be considered as a reason to change, while for the latter, social impact and access to the data was more valued. Possibly a combination of different approaches in one scheme could be a way to achieve a greater impact. Finally, Section 8.4 explained why direct feedback through RTDs, as designed and implemented, was met with scepticism and was considered unsuitable for the academic office context. Significant delays in the installation process, lack of support/feedback structures and poor interface design were identified as main barriers. In addition, past experiences with slow maintenance and lack of complete control over the heating system predisposed the users against their ability for change. Although feedback did not work for the office users it proved to be a useful tool at the level of facilities management.

9. Conclusions

9.1. Introduction

This thesis explored workplace practices relating to comfort and energy use in the workplace where real-time consumption feedback through displays was implemented as an intervention. It explored social and material elements that inform thermal comfort practices in the workplace, their interconnection with other energy consuming practices and the extent to which feedback through RTDs could act as a mechanism for change. Social practice theory provided the theoretical framework to situate the research within a socio-technical paradigm. This also informed the conceptualisation of practices, their interaction with other practices and their ability to change.

Previous socio-technical research on comfort and energy use has mainly focused on domestic settings (Wilhite *et al.* 1996, Strengers 2008, Gram-Hanssen 2010a). Meanwhile, research conducted on offices has taken place in the context of commercial buildings (Cole *et al.* 2008, Hargreaves 2011) rather than other types of premise such as university buildings. When looking at the impact of feedback as an energy efficiency intervention, practice theory literature follows a similar domestic orientation (Hargreaves *et al.* 2010, Strengers 2011), while studies focusing on a university context largely adopt individualistic approaches (Carrico and Riemer 2011, Matthies *et al.* 2011, Dixon *et al.* 2015). Furthermore, although real-time feedback is a potentially promising intervention, its impact in universities has been found to be ephemeral (Murtagh *et al.* 2013) and the meaning it carries for the range of associated stakeholders, unclear. This study addresses a gap in energy and buildings' research on the study of comfort and energy use in the workplace under the effect of real-time consumption feedback in a higher education building through socio-technical practice theory lenses. Hence, it consists a *sui generis*[18] contribution to empirical studies of social practices and energy use feedback in higher education buildings.

Selecting a higher education building as a research setting has important implications for the applicability of findings. Although a direct resemblance with other tertiary sector buildings is not suggested, academic buildings bear many similarities to commercial offices, private research organisations and colleges and therefore findings could have a wider application. These similarities can be traced in relation to aspects such as social hierarchies, productivity considerations and the meaning of energy saving in the workplace. However, in the case of modern new buildings with efficient facilities and building envelope, such alliances between

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[18] Original.

material and social elements might change as the already efficient building predisposes practices in a more sustainable way (Palm and Darby 2014).

This study followed a case study research approach, where three typical office typologies within an academic building setting were examined: the shared, enclosed administrative office; the open-plan PhD office, and the post-doctoral cellular office. A mixed methodology was applied. Quantitative evidence through environmental conditions monitoring and comfort diaries mapped the thermal conditions in the offices, participants' comfort preferences and acceptability. An initial understanding of the offices' thermal characteristics and users' comfort preferences was developed and showed the influence of social and contextual factors in users' comfort practices. These preliminary findings were further investigated with the use of qualitative enquiry and participants' observation. Gram-Hanssen's (2010b) framework for empirical research on daily practices based on know-how and embodied habits, technologies, knowledge and meanings was adopted. Two series of semi-structured interviews took place during the winter and summer seasons (February and July 2014) to capture seasonal comfort profiles and reactions before and after the installation of the RTD intervention. Findings from the interviews were then correlated with electricity audits to give an objective account as to whether practices changed over time and the potential sources of savings. Each of the aforementioned components—research aims, questions, conceptual framework, methodology and validity—were linked to form an integrated whole through an interactive mixed method design (Figure 9.1) (adapted from: Maxwell and Loomis 2003). The research components were interconnected and influenced each other, thus empowering and validating their role rather than being a part of a linear sequence within the research process.

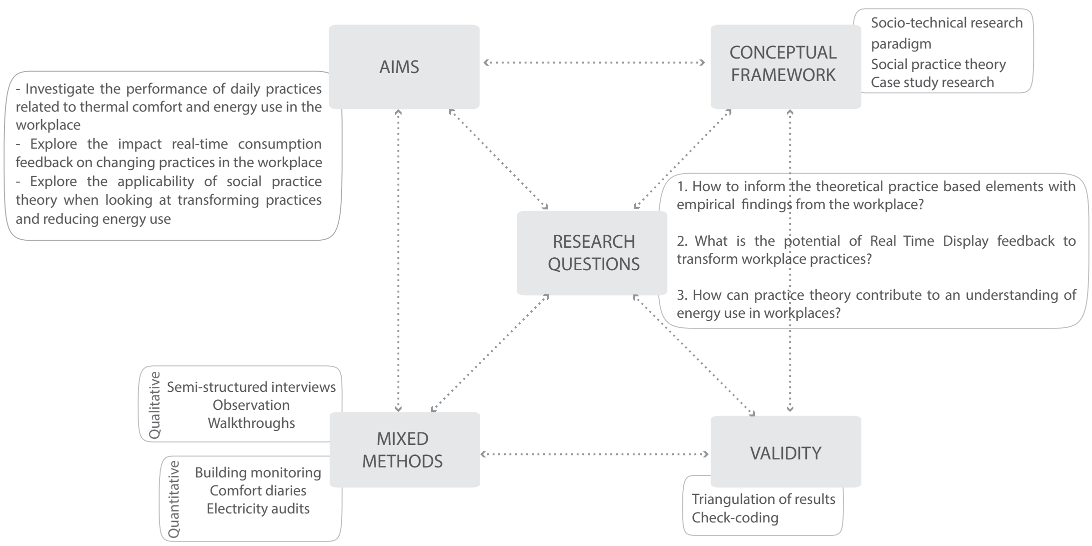

Figure 9.1 Interactive mixed-method research design.

9.2. Key findings

9.2.1 Research question 1

- How to inform the theoretical practice based elements with empirical findings from the workplace?

The first step in understanding thermal comfort practices in the workplace was to select three typical office types and investigate their thermal characteristics. 'Objective' evidence through the use of thermal conditions monitoring were cross-related with 'subjective' data from comfort diaries which captured users' thermal sensation and preference.

The results from the comfort diaries suggested that within the same office a diversity of comfort profiles exist. These profiles neither followed a proportional trend with office temperatures nor were limited to the industry comfort standards. They confirmed the adaptive notion of comfort and aligned with existing empirical studies, thus indicating that the range of comfort conditions in offices is often much wider than recommended national standards (Raja *et al.* 2001, Wagner *et al.* 2007, Nicol *et al.* 2012). In the case study offices, the winter comfort (neutral) temperature as documented by the users was between 17.7°C and 25.8°C while in summer it was found to fluctuate between 21.8°C and 26.9°C, a much wider and higher range compared to the 21-23°C winter and 22-24°C summer range recommended by CIBSE (2006). In addition, the comfort diaries gave revealing results regarding the acceptability of these conditions: while 41% of the comfort votes identified conditions were considered uncomfortable at certain times during the day, 91% of the votes indicated people would accept them rather than effect a change. This disparity between comfort and acceptability and the lack of incentive towards change suggested that while the perception of comfort is a more personal matter, preference and acceptability are related to wider social and contextual considerations, which in this case are established by the workplace setting.

In the next stage, two series of semi-structured interviews and participants' observation were carried out to explore social and material elements relating to thermal comfort during the winter and summer seasons. Know-how and embodied habits, technologies and infrastructure, knowledge and meanings were further investigated adopting a social practice theory analytic framework (see Section 2.3.2). It was found that the key elements shaping workplace practices were related to: a) workplace routines and user profiles; b) the configuration of the existing heating and cooling system and the relevant maintenance structure; c) the relation between social dynamics and indoor climate practices, and finally, d) the meaning of being energy-conscious in the workplace.

Considering workplace routines and the user profiles of the case study offices, the 'busy' administrator with the tight daily schedule would adjust comfort practices as a result of time scarcity. By adopting a 'passive' stance and letting more active colleagues regulate indoor temperature or by just leaving the A/C on its default setting, unnecessary timewasting would be avoided. Similarly, for the PhD students, the irregular and often heavy workload meant that regulating indoor temperature could be a 'distraction' and users would see their comfort sitting in a wider temperature range than that considered comfortable. As it was pointed out, *'there is another matter of comfort in the offices which is the "work comfort", so if someone had an awful lot of work to deliver the last thing they care about is their thermal comfort'* (Alexia_B_2). Likewise, post-doctoral researchers prioritised research tasks and would not concern themselves with temperature levels unless there was an extreme case of discomfort.

The configuration of the existing heating system was an element that often caused uncertainty amongst users in terms of their ability to regulate indoor conditions effectively. On the one hand, the lack of division of the central heating system into multiple space zones controlled by a building-based BMS system in favour of a centrally operated system controlled by Estate Management meant that sometimes the heating was on when it was not necessary. On the other hand, both in the administrative and PhD offices, the A/C system was found difficult to set-up in a setting other than the default mode that would allow a timer or temperature control. *'Ever since we moved into the office we have got no instruction manual for those control panels so we tend to leave it how it has been originally set (…). Other than that, we have never been able to work how to set the timers on them'* said Laura (A_1) in the administrative office. In addition, their location within the office created indoor temperature variations that would be a cause of discomfort. As Ruchi (B_2) pointed out, *'I am not directly under the A/C vent but when I walk in form outside I can feel how much the temperature changes from the office entrance to my desk. (…) I guess I am lucky to be in a good spot'*. Finally, slow maintenance structures, which caused distrust of proposed solutions only reinforced existing passive comfort attitudes.

An association between energy consumption and comfort in the workplace was found to be non-existent. Firstly, social considerations and the need for a balanced and sociable working environment limited the users' interactions with thermostats. In all offices, users compromised their comfort out of respect for their colleagues and to avoid distractions that could affect the group dynamics and obstruct the working process. Diana (A_1) in the administrative office explained that most of the times she would accept the existing conditions as she assumed that *'everybody else can't be wrong',* while Alexia (B_1) in the PhD office described that to avoid having conflicts in the office *'we have coordinated as a team and set the heating system in a way that we all feel comfortable'*. The case was different in the smaller post-doctoral office as users found it easier to coordinate and talk about it. Secondly, meanings associated with thermal comfort were directly related to productivity and research excellence rather than energy use and saving. '*If you think that you are in an office doing research, which is good for society, I should not worry about me wasting energy because I am entitled of that energy [sic]'* Ben (B_1) remarked.

Furthermore, there was a strong difference in approach to comfort at home and at work, which predisposed users' practices. Users were found to have a good understanding of environmental and technical issues, which made them also more aware in relation to the perceived low level of impact their daily routines had on the total energy consumption of the Engineering Department. While at home, there were more opportunities to regulate temperature and 'construct' savings. At work, the lack of time and incentives, as well as social considerations, would encourage a more apathetic stance contradicting Røpke's (2009, p.2496) suggestion that consumption that occurs in the workplace is largely intertwined with consumption at home. According to Henrik (D_1) *'at home I would turn it (the heating) down and at the same time save energy and it would be more comfortable as well',* but in the office, there is no such incentive and lots of work to do.

The findings corroborated the notion of comfort as a *'socio-material configuration'* that needs to *'include an understanding of different social, cultural and material structures'* (Gram-Hanssen 2010a, p.176). The importance of being productive and excelling in research, the existing heating system configurations and social considerations in the case study offices resulted in the adoption of a 'work comfort' approach different to that adopted at home. The profile of an 'apathetic' user would prevail, namely a user who would not interact very much with the heating and cooling system and prefer to use the 'default' mode if full control was allowed.

Findings challenged previous research undertaken by Karjalainen (2009), Wagner *et al.* (2007) and Raja *et al.* (2004) who associated comfort at work only with the perceived level of control over the heating system. In this study, social considerations that practices bring about—as with Hargreaves's (2011, p.93) point on *'the close relationship between practices and the power and social relations they support',* Cole et al.'s (2008) discussion of comfort as a collective experience and Chappells and Shove's (2005, p.34) consideration of comfort as a *'socio-cultural achievement'*—seemed to be strong components informing and largely differentiating them from practices at home. In addition, the configuration of unsustainable technologies due to the age of the building and the nature of research activity, resonated with Palm and Darby's (2014, p.89) note on the *'limited room for manoeuvre in very highly technical buildings, once the design decisions have been made'*.

9.2.2 Research question 2

- *What is the potential of Real Time Displays to transform workplace practices?*

The ability of direct feedback through RTDs to challenge energy consuming practices was non-existent in the case study offices in the short term, as indicated by the energy audits and interviews. The users' impressions a few weeks after the screens were turned on revealed how a series of technical installation problems, the lack of proper induction, the unfriendly interface of the RTDs and disjuncture between workplace practices and energy saving constrained their take-up and led to the decision of the screens actually being turned off by users themselves in all offices up until the end of this research.

Energy saving was a meaning not directly embedded in energy consuming practices in the workplace as opposed to practices at home and—similarly to the use of heating and A/C—using the computer, electric office equipment and lighting was directly associated with the ability to be productive in research or administrative tasks. Saving energy was seen as time-wasting and came into conflict with the existing way of doing things in line with Palm and Darby's (2014, p.89) case that *'the significance of the "core business" of the labs can overwhelm energy considerations'*. A similar argument is leveraged by Røpke (2009, p.2496), suggesting that environmental considerations are usually missing from practices since their impact *'is not embedded as an aspect of their meanings'.* Of further relevance is Røpke and Godskesen's (2007) identification of the relationship between time scarcity and high material intensity.

Consequently, the question of 'what can you actually change' to save energy prevailed. Users felt that their daily practices were already energy efficient and any waste was related to the unsustainable configuration of the existing heating system, lack of prompt maintenance or the use of unrecyclable consumables in the lab. It was suggested that emphasis should be placed on the efficiency of technologies and the promotion of a green organisational identity, rather than changing users' behaviour. As Ruchi (B_2) explained, *'you are forced to be working in such non-energy efficient ways and then somebody tries to tell you "this is how you have to be energy efficient". (…) It's clearly not applicable here'*.

It appeared however that users would be eager to try and change if the right informational support and incentive was provided. In all offices participants stressed the need for further information regarding their actual energy consumption and welcomed more specific suggestions on ways they could be more energy efficient. As George (C_2) said, he would like to be *'aware of actions that can improve the (office efficiency) conditions'* and *'true'* information as to how to do it. Furthermore, different users were found to hold different views on the type of incentives—economic or social—that could leverage change in the academic building context. While the administrative staff favoured a financial incentive such as the economic rewards of the 'CO_2 Reduction Grand Prix' programme, PhD students were supportive of a social incentive that would have a public impact on a campus or even policy level. By contrast, the post-doctoral researchers wanted to have access to the projected data and use them for research purposes. This builds upon findings by Carrico and Riemer (2011, p.11) which state that *'efforts to support behaviour change through social support, behavioural reinforcement or peer influence have the capacity to deliver meaningful levels of behaviour change even when economic incentives are not present'*. It also highlights that behavioural change projects such as the 'CO_2 Reduction Grand Prix' might benefit from a design that incorporates socio-technical rather than only individualistic views and which, in turn, means goals can address different audiences and possibly combine both individualistic and socially oriented types of incentives.

The installation process of the RTDs, with its delays and interface limitations, coupled with the lack of an induction for users, only confirmed participants' previous concerns as to the inadequacy of existing operational and maintenance structures. A series of technical issues resulted in a delay of approximately a year, resulting in a failure to meet the project's initial goal to run alongside the 'CO_2 Reduction Grand Prix' competition and, ultimately, a complete disassociation of the two project elements. The lack of an official induction and several design faults also resulted in users losing their interest in the scheme early on and the screens being turned off as they were deemed not to fit their purpose.

The failure of the scheme to specifically effect a behavioural change among the administrative and academic staff does not amount to overall failure. It was, for example, considered relevant to interests and needs of the buildings' Safety Officer, something also suggested by users themselves. The Safety Officer, who had direct access to the WFT data from his computer and was also involved in the design of the scheme, acknowledged that it was a useful tool to monitor consumption of different offices, assist the design of, and estimate the impact energy saving interventions had in the buildings' energy use. Since energy saving was a meaning attached to his job description, the positive uptake and effect of real-time feedback was clearer to him than the other building users. For the latter, energy saving came as a consequence of their actions, rather than being an inherent characteristic of their workplace practices. Feedback as an intervention was not, therefore, enough to trigger change.

9.2.3 Research question 3

- How can practice theory contribute to an understanding of energy use in workplaces?

This thesis used social practice theory as a means to conceptualise comfort and energy consumption in the workplace. In the context of the case study offices, it was particularly useful in identifying the social and material elements related to energy consuming practices, as well as their interrelation and alliances with other practices. It thus provided a basis to assess and plan energy saving interventions. This resonates with Shove and Walker (2010, p.475) whose study suggests that a practice approach of planning interventions is ought to *'first understand how consumers, users and practitioners are, in any event, actively involved in making and reproducing the systems and arrangements in question,* (…), *instead of figuring out how to involve more different stakeholders in an externalised process of design'*.

Although there are evident opportunities to conserve energy in the workplace, previous studies have identified barriers such as the lack of direct financial incentive, the absence of information on the energy impact of individuals' actions and the lack of incentive due to shared use of appliances (Carrico and Riemer 2011). Furthermore, while the use of energy use feedback in universities has been found to cause a reduction in overall energy consumption (see Table 3.2), this is not always sustained in the long term (ibid, Murtagh *et al.* 2013). In this study, by (de)constructing comfort and examining other energy consuming practices in the context of the academic workplace, it was possible to move beyond consumption figures and understand 'why' it is so difficult to save energy. In sum, this study brought additional focus on meanings and level of control over technologies. It became evident that energy use in the workplace had a completely different meaning to parallel attitudes at home since energy was considered an essential working resource. Energy saving was thus a missing element from users' engagement in daily office practices such as regulating the indoor environment, printing and using the computer. As Daniel (A_1) pointed out, *'my home is different to my workplace as it is for normal people. I would rather construct more in my house than I would in my workplace'*. This shared perception impeded attempts to effect change, since such efforts were considered unnecessary. Therefore, to achieve change a new meaning should be attached to existing practices to revert existing notions.

In addition, practice theory provided a basis for understanding why a behavioural change intervention with the use of RTD feedback did not have the intended uptake by the users. In the first instance, it revealed the influence of social dynamics, the impact of existing technological configurations and maintenance structures, and the prevalence of productivity over energy saving as key elements shaping practices in the workplace. In relation to the competition and economic reward linked to the RTD intervention it was evident that the different users—administrative staff, PhD students and post-doctoral researchers—had contrasting views on what would motivate them to change. While a direct financial benefit was considered important for some, a wider social impact and the ability to access and use the raw data for research purposes was meaningful for others. In this case, social practice theory was useful in understanding why participation in certain practices might vary and provided useful insights as to how to design interventions, which might address such inequalities (see Section 9.4). As Blue *et al.* (2016, p.45) suggest, *'behavioural change'* interventions should allow the promotion of *'new meanings, provision of relevant infrastructure and assistance or prevention of the development and diffusion of specific competences and skills'*.

Finally, the combination of a qualitative enquiry with electricity audits and indoor conditions monitoring within a practice framework gave useful directions as to where and how potential savings could be achieved. Empirical studies of practices tend to be based on qualitative methodologies and historical narratives (Halkier and Jensen 2011, Strengers 2011, Kuijer 2014, Behar 2015) although the potential of integrating quantitative methods such as building monitoring (French 2011, Foulds *et al.* 2013) and end-use metering of electricity (Gram-Hanssen 2014a, Palm and Darby 2014) or water consumption (Browne *et al.* 2014) has been acknowledged. This study tried to overcome methodological boundaries by using a mixed methodological approach. Systematic descriptive coding was used to discern emerging themes and patterns that a questionnaire survey could not reach, while indoor thermal condition monitoring and energy audits indicated the actual impact of practices and how they changed over time within the study context. As such, it was possible to identify directions for potential savings as in the case of standby electricity use (Section 8.2.3). In addition, the use of a case study approach featuring three office types—the administrative, the PhD and post-doctoral office—representative of the users and typologies within an academic building, allowed an in-depth understanding of a practice-as-performance (Shove *et al.* 2012), which in turn, gave insight into the inequalities within a practice where some practitioners engage and others defect.

9.3. New contribution to the field

This thesis has sought to contribute an original piece of research through its practice theory orientation and interactive mixed method research design (Figure 9.1), thus moving beyond techno-economic studies and individualistic methodologies.

The adopted research design highlighted the potential of a case study investigation and mixed methodology where the complexity of interactions between occupants, feedback and building systems is at stake. The choice of Yin's (2009) case study embedded design and its application in three different office typologies within an academic department was combined with a set of qualitative interviews and building monitoring. By comparing different office typologies and narratives of different users, this study shed light on the commonalities and inequalities between performed practices within the same building context and underlined the difference between practices at home and in the workplace. The case of 'work comfort' as opposed to that at home, and the significance of productivity and group dynamics in a higher education building, was communicated by all users. The incentive to save energy in the workplace differed, however, between the administrative staff, PhD students and post-doctoral researchers. Findings pointed out the need to capture the diversity of performances of practices across populations, thus building upon single case study research in the workplace as undertaken by Hargreaves (2011) and Palm and Darby (2014), as well as to consider the incorporation of quantitative methodologies in the research of practices as underlined by Gram-Hanssen (2014a), Browne *et al.* (2014) and Foulds *et al.* (2013).

On a practical level, this study challenged the ability of the current 'blanket' university policies formulated to raise energy awareness, to connect with various users on the academic campus. The design of the 'CO_2 Reduction Grand Prix' and RTD initiative, which was based on a conventional one-size-fits-all approach, did not allow for a holistic consideration of users' behaviour and thus did not cause any change, with screens being turned off by the users a few weeks after their installation. The study findings also indicated how different user profiles favoured different types of incentives—financial award for the administrative staff, social impact for the PhD students and research material for the post-doctoral researchers—and carried different views of the meaning of energy saving in the workplace—part of the job description for the Safety Officer, but an obstruction for the researchers and staff. Findings suggest the need for a more nuanced and user-centred approach in the design and implementation of such interventions in order to overcome existing barriers (see Chapter 8) and enhance their uptake and impact.

9.4. Implications for stakeholders

Despite its limitations (see Section 9.5), this study provides a series of socio-technical insights with regard to how to understand energy consumption in the workplace from an end-user perspective and assess the impact of direct feedback as an intervention for change. In this section, implications of this study for the involved stakeholders—the University's Environment and Energy team, the behavioural change consultants, the facilities management team and the office users—are discussed.

9.4.1 University Environment and Energy team

- This study exposed the scepticism of users of a higher education building towards energy saving in the workplace, which came across as a barrier for change. Future energy awareness initiatives could benefit from schemes that would nurture the idea of energy saving in the workplace as a practice that is both possible and meaningful and does not obstruct research or daily office duties. With regard to what would incentivise users of an academic building to change the study identified three factors: financial benefits related to a monetary award; the wider social impact, and the promotion of research. It was also found that the provision of energy efficient infrastructure and proper allocation of responsibilities regarding the maintenance and operation of the building is equally important and complements users' education, training and incentivisation. The above findings suggest that energy awareness initiatives on a university campus level should follow a more user-oriented approach, taking into account the needs and expectations of different user groups (see also Section 9.3).
- This study was the result of a collaborative effort between the University's Environment and Energy team and a doctoral researcher through the 'Living Laboratory' scheme (see Table 5.2). The promotion of research activities and small-scale survey investigations within the academic community similar to the current study would be helpful to tailor green initiatives in response to empirical evidence, a condition considered necessary to improve the relevance of future interventions.

9.4.2 Environmental and behavioural change consultants

- This case study investigation revealed that the intention of the 'CO_2 reduction Grand Prix' and RTDs was not successfully communicated to its target audience. The way the WFT tool was applied, its interface design and the type of projected information were more relevant and useful to the building's facilities management team than the office users. Such findings highlight that further consideration of the socio-technical context of the intervention might be warranted. The behaviour or technology at stake (e.g. assessment of the heating load at a building level, assessment of heating and appliances usage at an office level) and the target audience (e.g. academic staff, FM, students, administrative staff) could be better linked to the interface design (feedback reported by participants is detailed in section 8.4.3 and outlined in Table 8.2). In particular, the location of the RTD within the office (e.g. entrance, tea room, corridor), the type and frequency of projected information (e.g. graphs, messages and tips, images, league table) and the way they are communicated (e.g. online desktop computer, RTD, designated energy champion) could be points of further consideration for the next stage of the behavioural change scheme.

- The usefulness of a participatory approach involving the building users and stakeholders during the project's design phase is another issue to consider. In this study, the RTDs targeted users of a higher education building consisting of PhD and post-doctoral engineering researchers as well as administrative staff. All users had a good understanding of trends and graphs due to their job duties and educational background while users from the first two groups had further expertise in communication technologies and signal processing. In all cases, participants felt excluded from the design of an intervention in which they could potentially have useful insights. This resulted in criticism of the interface design and the purpose of the WFT. Such criticism was nevertheless tempered by a series of suggestions. As Rich (D_2) explained, *'what you 've got to understand is that this is a pool full of data scientists. We want data and we want context. And also it is full of software engineers and to a certain extent we are User Interface designers as well so we also want it well implemented'.* Hence, further consideration could be given to the involvement of the target audience from the conception phase of the intervention in order to gain useful insights, generate trust and create anticipation towards the forthcoming project.

9.4.3 Energy and facilities managers

- The study indicated that the role of the facilities manager (Safety Officer) was vital in the design and support of the behavioural change scheme, since he had extensive knowledge of the building context such as existing systems and user groups. He also acted as the link between the users, the environmental consultants, the departments' management and the University's Energy and Environment section. This role was obstructed by a lack of knowledge of how to use specialised features of the WFT and time limitations that restricted the ability to deal with the project's shortcomings, leading to significant delays. Meanwhile, a lack of leadership regarding the active support of the behavioural change scheme was prevalent. By informing the profile of the facilities manager and clarifying tasks in order to effectively support the implementation of sustainability measures, the efficiency of such initiatives could be optimised. Facility managers could take the role of *'middle actors'* in line with Parag and Janda's (2010, p.40) espousal of their importance to influence other agents *'upstream, downstream and sideways'* and thus initiate, enable and promote infrastructural changes, technology adoption and energy efficiency.

9.4.4 Office users

- The office users were in some cases unsure how to operate the A/C and the office appliances in a more efficient way (see Section 7.3.1). Issues such as the difficulty of setting the A/C timer or deciding how feasible it might be to switch off the printer were relayed. The development of better communication structures between office users and the FM team could be mutually beneficial in terms of the efficient use of office equipment. In addition, a closer relationship between the two groups in conjunction with the help of energy monitoring could help identify the sources of energy wasting, such as the case of the stand-by consumption in office A (Section 8.5).

9.5. Limitations of the study

The scope of this study has certain limitations. Due to its small sample size and case study approach any generalisations of the research findings should be avoided (see Section 4.9 for limitations of case study). Through its case study approach, it rather attempts to provide a clear understanding of 'how' and 'why' certain material, contextual and social elements shape practices and obstruct or drive change in the workplace in the context of a higher education building.

A limitation related to the data collection is that interviews, participant observation and comfort diaries took place over a limited time, although a concern of this study was to track change. A longer observation period was initially planned but was not possible for the following reasons: delays in the installation process that took a year longer than projected in the initial project plan; and the almost immediate reaction of the users, which was to turn off the screens a few weeks after their installation. Another limitation was that historical energy data of the previous years was not available, thus preventing a historical comparison and calculation of a baseline. It is possible that systematic changes in energy consumption were not detected within such a limited measurement window. Future research should consider collecting electricity data before and after the intervention to allow for a more precise measurement of its effect on energy use and potentially expose behavioural variance over time.

In addition, the new electricity sub-meters were installed based on already existing and rather out-dated distribution boards, which, in some cases, meant that it was not always possible to meter individual offices but rather a group of them instead. Such a configuration obstructed the granularity of data and the possibility of making precise cross-office comparisons. Furthermore, the sub-meters would often break down and the lack of prompt maintenance resulted in gaps within the data sample (see Figure 8.8). Mitigation of these risks involved the close monitoring of the database and reporting any shortcomings to the facilities manager and the careful selection of data in order to avoid, where possible, any faulty electricity measurements.

As is the case of any theoretical approach, the use of social practice theory has both strengths and limitations. Although it overcomes the boundaries of the individualistic paradigm by capturing the contingent elements of peoples' activities in certain situations it is often criticised on the basis that it becomes difficult to propose simple intervention guidelines due to its socio-technical nature. As Cohn (2014) remarks, in practice theory trying to define the boundaries of a practice or the extent to which some practices differ to others is a matter of analytic judgement with debatable causal explanation. This study aligns with Blue *et al.'s* (2016, p.46) pragmatic approach which states that *'whilst some established forms of intervention are compatible with a practice orientation others are not'* therefore practice-oriented studies should allow some flexibility and be *'actively involved in continuously monitoring and adopting to changes in the arrangements of social practices that make up everyday life'*.

9.6. Future work directions

In light of this study's findings and the potential for energy savings thin the workplace holds, there is fertile ground for future research. A consideration of areas for further investigation is described below.

9.6.1 Socio-technical methodologies

The relevance of social practice theory in understanding how user practices relate to resource consumption and highlight transformation paths as discussed in the findings of *research question 3* (Section 9.2.3) points towards the need to advance socio-technical methodologies in energy and buildings research. In particular, the establishment of a mixed methodological approach incorporating qualitative findings from interviews and observation with quantitative data gathered from energy audits (electricity, gas, water), environmental monitoring (temperature, RH) and occupants' surveys could have a substantial potential. Given the dominance of qualitative approaches, there is a call in existing literature for an approach whereby the benefits and cautions of mixed methodology are further investigated (Foulds *et al.* 2013, Browne *et al.* 2014, Gram-Hanssen 2014a). As such, Browne *et al.* (2014, p.27) note that the use of mixed and quantitative methodologies could help *'translating practice-based research into policy; developing indicators to track patterns of practices as they change* *over time; and the exploration of methodologies that reflect the bundling and coordination of practices (…) inside and outside the home'.* Foulds *et al.* (2013, p.634) similarly suggest that *'the understanding of everyday life can be enhanced through approaches utilising building monitoring, or indeed any other methodological innovation'* while it is *'through illustrating such innovations that understanding [of energy consumption in buildings] can be developed and applications across contexts recognised'*.

9.6.2 The role of different stakeholders in the formation of practices

In this study, the main unit of analysis has been the practices of the office users and, in particular, research and administrative staff. A higher education building nevertheless consists a multi-purposed setting and is, therefore, occupied by a variety of users. Within such settings, there are often complex interplays that need to be aligned, necessitating cooperation and agreement. The interaction between different stakeholders (e.g. occupants, facilities managers, research coordinators, senior management) and their impact on energy use could be further investigated in order to understand how the intersecting practices of these agents impact energy savings. As Cole (2011, p.431), suggests, *'a* missing *catalyst is the social and organizational interplay amongst and between different stakeholders. In particular, there is a need to orchestrate the complex array of stakeholders and to understand each other's particular motivations and drivers'.*

9.6.3 Energy consuming practices at the (future) workplace

Although some research has been undertaken in workplace settings, it mainly focuses on commercial buildings. This leaves much uncertainty about energy consumption on the end-user side in other types of workplaces such as those in higher education buildings, research institutes and new types of hybrid offices (e.g. co-working hubs). The current study focused on the notion of 'work comfort'. In relation to this notion, it underlined that the significance of productivity and a balanced social environment between colleagues would undermine any considerations of comfort and energy use. Further research on the relationship between wellbeing, productivity and energy use in the workplace is recommended. In particular, elements such as routines related to workplace practices (e.g. the impact of net-culture and flexible work schedule), meanings (e.g. the shift from hierarchical and organisational structures to co-creation, openness and sharing), knowledge on how to maintain an efficient workplace (e.g. the effect of feedback), and new technological configurations (e.g. use of efficient devices such as laptops and iPads instead of desktop computers) offer new research directions.

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APPENDIX A. Data analysis

A1. Semi-structured interviews

SEMI-STRUCTURED INTERVIEWS

Round 1, February/March 2014

Date:

Participant:

INTRODUCTION

(Allow 3-5 minutes for this section)

- Introductions and brief chat. Reassurance that there are no wrong answers and how much they know about certain issues raised is not important.
- Confirm information about the background of the office space user e.g. how long they have been working in the office, what they do, with how many people they share their office.
- Reiteration that the interview will be audio recorded, a walkthrough will be conducted and photos may be taken. Permission for this should be sought.
- Explanation of the confidentiality statement.

DEMOGRAPHICS

Q1. Background information

1. What is your age?
2. What is your job description?
3. How long have you worked here?
4. How much do you use the office?
    a. Every day for a number of hours
    b. Every day but only very briefly
    c. On average, less than once a day – why?
5. Which of these is the highest qualification that you have?
If a qualification is not specified, choose the nearest equivalent.
    a. GCSE
    b. A levels / AS levels, or Higher School Certificate
    c. First degree (e.g. BA, BSc)
    d. Higher degree (e.g. MA, PhD, PGCE, post-graduate certificate/diploma)
    e. Other
6. How would you describe your ethnic background?
    a. White (British, Irish, or any other White background)
    b. Mixed (White and Black Caribbean, White and Asian, or any other Mixed background)
    c. Asian or Asian British (Indian, Pakistani, Bangladeshi, or any other Asian background)
    d. Black or Black British (Caribbean, African, or any other Black background)
    e. Chinese or other ethnic group
7. Could you tell me which of these bands your income fits into?
    a. £0 to £9,999
    b. £10,000 to £19,999
    c. £20,000 to £29,999

d. £30,000 or above

COMFORT AND CONTROL - WINTER

Q2. Thermal comfort

1. How thermally comfortable is your office? Is the temperature too high or low?
2. Is there high or low humidity inside?
3. Do you usually achieve comfort or minimise discomfort?

Q3. Seasonal variation of comfort

1. Are you more comfortable in summer or in winter? Why?

Q4. Length that opinions on comfort have been held

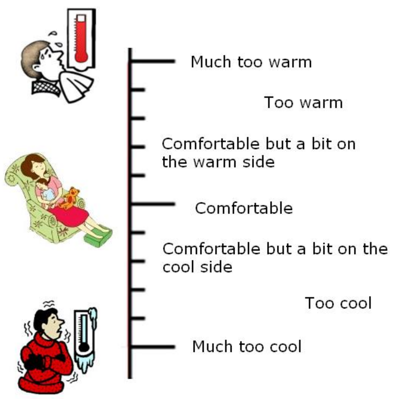
1. Are these opinions new or have always been held?

Q5. Colleagues' opinion on office conditions

1. What are the opinions of your colleagues regarding the office conditions?
2. Who has the control, who is more keen setting the temperature?

Q6. Thermal expectations

1. Please could you indicate on this scale how the office feels normally?
2. How warm or cool do you like your office to be?
3. Do you expect it to be comfortable all the time?



Q7. Adaptive actions when cold

1. If too cool/much too cool: What do you do to warm up?
    a. Behavioural: Do you move location? Add more clothing layers?
    b. Technological: Do you use fan or AC? Explore use of fans, opening windows and portable air conditioning.
    c. Psychological: Do you expect it to be warm in winter? Or you put up with the cold? Is this example a unique or typical response? Seasonal adaptation?

Q8. Adaptive actions when warm

1. If too warm/much too warm: What do you do to cool down?

Q9. Ventilation

1. How often do you ventilate your office and for how long? Do you open the windows or have mechanical ventilation?
    a. When during day?
    b. Using what?

c. Any problems?
d. Air quality
e. Ease of use

Q10. Lighting

1. Do you get enough light through the windows during the day?
2. When do you turn on the lights during the day?
3. How effective is the artificial lighting in the office?

TECHNOLOGIES

Q11. Understanding of the use of the heating system

1. How well do you understand the use of your heating system? Could you explain to me how it works?
    a. What temperature do you set it on and for how many hours per day? Do you run it constantly or on intervals?
    b. Ease of use (How easy is to set the temperature setting?)
    c. Responsiveness (How quickly does the heating system respond?)
    d. Quality of heat
    e. Why do you use it this way?
2. Have you had any problems with it so far? If yes:
    a. What was the problem?
    b. How did you/do you deal with the problem?
    c. Do you feel you can resolve/control the problem?

Q12. Temperature setting and hours of usage

1. Have you tried to set the temperature yourself?
2. What temperature do you set it on?

Q13. Understanding of the use of appliances

1. Is there any appliance used in the office that you are not sure how it works?
2. How easy is to turn-off or put office appliances on standby?

KNOW HOW AND EMBODIED HABITS

Q14. Embodied habits, life routines and experiences

1. Are there any life experiences or habits that formed your thermal comfort levels or ways using appliances/heating/electronic devices in your office? (e.g. childhood experiences of how parents practiced indoor climate regulation, past office experiences, experiences with valves and meters)
2. Are there any health issues that imply a certain use of appliances/ heating/ cooling in your office?

Q15. Relation of work/home heating and comfort patterns

1. Do your comfort levels at work relate to the ones you have at home?
2. Are the temperatures the same?

KNOWLEDGE

Q16. Relationship between energy consumption, heating and environmental problems

1. What is your level of knowledge concerning the relation between energy consumption, heating and environmental problems?

Q17. Knowledge source

1. Where did you acquire this knowledge from and how this influenced your behaviour?
2. Are you receiving any training, advice, information on energy use issues in your office or elsewhere (e.g. local community, participation in environmental groups, etc.)?

Q18. Opinion on saving energy in offices and ability to do it

1. How much do you agree with the idea of saving energy in your office concerning heating and electricity consumption?
2. Do you feel you have the knowledge and skills to reduce energy use in your office?
3. Are there any particular activities you do to save energy in the workplace?
4. Is there someone in the office that influences your practices?

Q19. Aware of 'CO_2 reduction Grand Prix' competition

1. Are you aware of the CO_2 Grand Prix that takes place between different office groups in the CUED?

ENGAGEMENT/ MEANINGS

Q20. Satisfaction and functional comfort

1. How satisfied are you with your work area?
    a. Environmental conditions
    b. Furniture layout (workstations, offices and shared amenities)
    c. Social environment (interaction with colleagues, team work)

Q21. Territory, ownership and belonging

1. What are your feelings on your work environment in terms of territory, ownership?

Q22. Views about being green.

1. What are your views in general about being green and saving energy in the workplace?
2. How green do you think your general lifestyle is, on a scale of 1 to 5, 1 being not at all and 5 being very?

Q23. External influences to energy use issues

1. To what extend do other people influence you in your close environment (friends, family) on energy use issues? Is there any person in particular that motivates you to do so in your office?
2. What or who would motivate you to save energy at your workplace?
3. Are you a member of an environmental group, university society or organization (e.g. Greenpeace, WWF, etc.)?

NOTES

SEMI-STRUCTURED INTERVIEWS

Round 2, July 2014

Date:

Participant:

INTRODUCTION

(Allow 3-5 minutes for this section)

- Introductions and brief chat. Reassurance that there are no wrong answers and how much they know about certain issues raised is not important.
- Confirm information about the background of the office space user e.g. how long they have been working in the office, what they do, with how many people they share their office.
- Reiteration that the interview will be audio recorded, a walkthrough will be conducted and photos may be taken. Permission for this should be sought.

COMFORT AND CONTROL - SUMMER

Q2. Thermal comfort

1. How thermally comfortable is your office? Is the temperature too high or low?
2. Is there high or low humidity inside?
3. Do you usually achieve comfort or minimise discomfort?

Q3. Seasonal variation of comfort

1. Are you more comfortable in summer or in winter? Why?

Q4. Length that opinions on comfort have been held

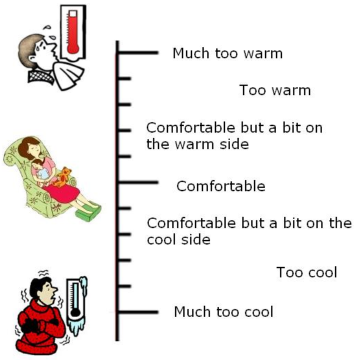
1. Are these opinions new or have always been held?

Q5. Colleagues' opinion on office conditions

1. What are the opinions of your colleagues regarding the office conditions?
2. Who has the control, who is more keen setting the temperature?

Q6. Thermal expectations

1. Please could you indicate on this scale how the office feels normally?
2. How warm or cool do you like your office to be?
3. Do you expect it to be comfortable all the time?



Q7. Adaptive actions when cold

1. If too cool/much too cool: What do you do to warm up?

Q8. Adaptive actions when warm

1. If too warm/much too warm: What do you do to cool down?

Q9. Ventilation

1. How often do you ventilate your office and for how long? Do you open the windows or have mechanical ventilation?
    a. When during day?
    b. Using what?
    c. Any problems?
    d. Air quality
    e. Ease of use

Q10. Lighting

1. Do you get enough light through the windows during the day?
2. When do you turn on the lights during the day?
3. How effective is the artificial lighting in the office?

TECHNOLOGIES

Q11. Understanding of the use of the cooling system

1. How well do you understand the use of your cooling system? Could you explain to me how it works?
    a. What temperature do you set it on and for how many hours per day? Do you run it constantly or on intervals?
    b. Ease of use (How easy is to set the temperature setting?)
    c. Responsiveness (How quickly does the heating system respond?)
    d. Quality of heat
    e. Why do you use it this way?

2. Have you had any problems with it so far? If yes:
    a. What was the problem?
    b. How did you/do you deal with the problem?
    c. Do you feel you can resolve/control the problem?

Q12. Temperature setting and hours of usage

1. Have you tried to set the temperature yourself?
2. What temperature do you set it on?

Q13 Real time displays

1. When was the RTD placed in your office?
2. What kind of information does it show? Do you find it useful in helping you understand energy consumption in your office?
3. Does the RTD affect your energy saving practices?
4. Has anyone explained you how to use it? Are you encouraged?
5. Do you have any suggestions on how it could be better used in the future?
6. What are the opinions of your colleagues?
7.

KNOW HOW AND EMBODIED HABITS

Q14. Embodied habits, life routines and experiences

1. Can you describe some routinised actions that have to do with energy use (appliances, lighting, heating system) in your office?

Q15. Relation of work/home heating and comfort patterns

1. Do your comfort levels at work relate to the ones you have at home?
2. Are the temperatures the same?

KNOWLEDGE

Q17. Knowledge source

1. How well informed you think you are on energy use issues?

Q18. Opinion on saving energy in offices and ability to do it

1. How much do you agree with the idea of saving energy in your office concerning heating and electricity consumption?
2. Do you feel you have the knowledge and skills to reduce energy use in your office?
3. Are there any particular activities you do to save energy in the workplace?
4. Is there someone in the office that influences your practices?

ENGAGEMENT/ MEANINGS

Q20. Importance of being energy-conscious

1. Is it important for you to be seen as an energy conscious person? Why?

Q22. Views about being green.

1. Is there a green identity in the department and if yes what is it related to?

NOTES

A2. Participant observation

PARTICIPANT OBSERVATION SHEET

Date/Time: 15.06.15 | 14.20-17.20
Office: A

Number of staff: 10 (total), 8 (present during observation)

1. What are people doing? (Sitting, walking, etc.)
2. How do they communicate to one another or avoid it?
   a. What distance do they keep between one another?
   b. What is the topic of discussion? (work, daily life, use of appliances)
3. How is electricity consumption linked to their activities?
   a. How often do they interact with the heating system? (Times that the A/C gets on/off.)
   b. How decisions on temperature settings, opening/closing windows are announced and taken?
   c. On-site temperature measurements.
   d. What are they wearing and are there any adoptive comfort actions they perform?
4. How does the setting encourage/hinder communications?

Seating Plan

1. Laura, Finance Office supervisor
2. Diana, Accounts payable (looks over students' maintenance, vehicles, researchers' time sheets, oversees accounts)
3. Luke, Accounts receivable (joined March 2014)
4. Stewart, Accounts Payable (joined November 2014)
5. George, Accounts Payable (September 2014)
6. Dora, Accounts Payable (January 2014)
7. Hannah, Research grant administrator in collaboration with PIs
8. Oliver, Research grant administrator in collaboration with PIs
9. Daniel, Research grant administrator in collaboration with PIs
10. Empty
11. Sharon, (joined today)

14.20 Conditions: A/C's off, windows closed, noise coming from ceiling fan above Hanna's desk (7) and from outdoor (cleaning of courtyard tiles)

- People are sitting on desks working on their computers, occasionally they stand to place documents in cabinets or shelves, use the printer/photocopier or talk to their colleagues.
- All computers and lights are on. A/c is off.
- Semi-formal attire. Men are wearing shirts with sleeves up, one wears a tie. Women with light shirts, one without sleeves (6) and two with t-shirts. There is a cardigan or jacket in their seat.
- All office users have mugs and/or water bottles on their desk which they refill often with coffee, tea or water.

14.45

- Printing is a key activity taking place in the office. The printer is activated with card use so it can be controlled. When waiting for documents to be printed people chat to each other.
- Hannah starts a discussion on the new plants placed in the department's entrance and other people engage. Some laugh others remain focused on what they are doing
- The atmoshphere is quite hot and after some time in the office started feeling sleepy and almost getting a headache. People (3,2,6) have a break drinking tea or having a fruit.

15.00 Diana (2) gathers 5 people around her desk to discuss a work issue (10 min).

Laura informs her colleagues that she will open the window. She mentions that they are closed because of the noise coming in.

Quite informal atmosphere and chats. Most of the staff is quite young.

Dorra (6) comments on the new IKEA trees.
George and Stewart have an informal chat on drinking, lack of a separation board supports interaction.

15.30 The noise from the ceiling fan has been there since people moved in the office. The FM seems not to know where it comes from so it is always there. It is quite annoying but can also become a habit.

The Finance Office Manager who is in another office enters to bring cake and everyone has a slice. This seems to be something that happens quite often. Sociable and happy work environment.

16.00 The atmosphere in the office becomes quieter, people are doing desk-based job mainly. Three windows open.
People start leaving the office (6,7).
Informal chats.

By 17.13 all but Laura and Sharon have left the office.

A3. Coding

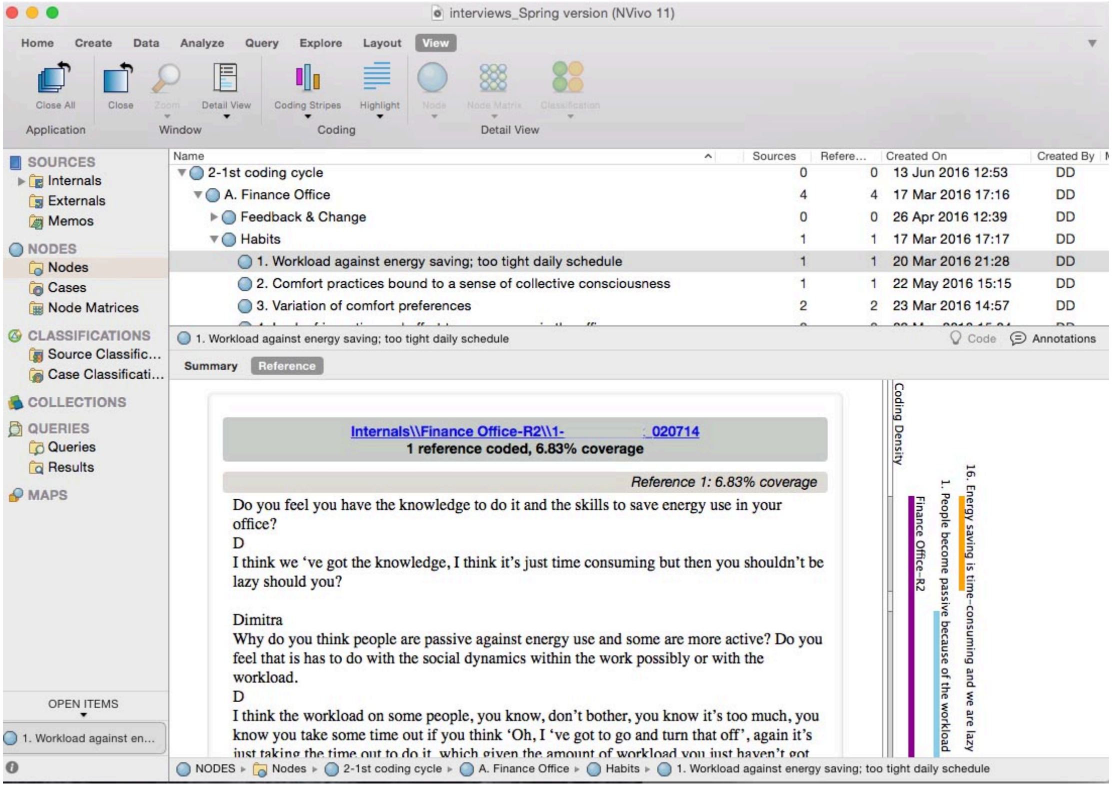


Figure A.1Example of NVivo coding.

Table A.1 Crude categories of informants' views (Excerpt from Case study A).

- People become passive because of the workload	*'I think the workload on some people, you know, don't bother, you know it's too much, you know you take some time out if you think "Oh, I 've got to go and turn that off". Again, it's just taking the time out to do it, which given the amount of workload you just haven't got the time to stop them, I think that's the main [reason].'* (Diana_A_2)
- Comfort practices bound to a sense of collective consciousness	*'I am aware that I feel the cold more than other people so I show more understanding. (…) I wouldn't expect the rest of them to suffer with the heat.'* (Diana_A_1)
- Use of extra appliances to warm up	*'I do occasionally have a fan heater that I would literally put on just for 30 seconds just to take—what I feel like—the little chill off me.'* (Diana_A_1)
- Energy conscious but lack of motivation to construct in the workplace	'(*Ehm) I don't know. I just treat it as a workplace really. So, my home is different to my workplace which is for normal people, but I 'd rather construct more in my house than I would in my workplace, but if I learn things at work I could put into practice at my home.'* (Daniel_A_1)
- Energy conscious at home, not much to do in the office	'*At home we are really looking at saving the energy and I think the same should be in the office. I personally wouldn't think we use awfully lot in here.'* (Diana_A_1)
- Financial incentive drives energy saving at home	*'I see the only time we have a conversation me and my wife is when the bills arrive really. That's the only time we short of say "we must cut down on the heating" or "this needs looking at."* (Daniel_A_1)
- Influence of social dynamics, 'happy to go with the flow'	*'Probably Helen [is the one who controls the A/C]. It's normally Helen that's [active with setting the temperature], I wont speak up really. I am happy to go with the flow.'* (Daniel_A_1)
- Building design and age affect consumption practices	*'I do think the environment around you [is motivating]. If you are working to a building where there is lighting tubes [sic] then you are going to feel a different person, aren't you?, to if you are working in a 1930s building. So, that I think personally for me affects me and I think it must affect everyone. (…) It's like going into a hospital, isn't it? A really old hospital. It doesn't mean that the care is not right but the feeling of the people that are in there is probably not [the same as in a modern one]. You could have two people with the same problem and if one is in a modern airy building you would probably find that he gets better a week before the other (…). I don't know how you measure it but I think it [building age] definitely affects people.'* (Laura_A_2)
- Energy saving is time consuming and we are lazy	*"I think we've got the knowledge. I think it's just time consuming but then you shouldn't be lazy, should you?'* (Diana_A_2)
- Lack of financial incentive in the office makes you less energy conscious	'Y*es, I think if he was told he was paying electricity bill obviously he'd be a bit more conscious of how much he is using, but I think in the office he just sort of think 'Oh, it's there.'* (Diana_A_2)
- Apathetic on comfort issues because doesn't like to intrude on anyone	'Perhaps, it's just not want to intrude on anyone to be honest.' (Luke_A_2)

Table A.2 Provisional list of codes and definitions.

ROUTINES (RTN)	
WORKLOAD	The daily amount of work to be done as recounted by the users.
VARIABLE SCHEDULE	Daily work duties outside a standardised time-frame.
RESEARCH	The type of academic research that often requires energy intensive equipment (e.g. lab experiments) and processes (e.g. advanced computation and simulations).
USE OF EQUIPMENT	Use of existing infrastructure (HVAC) and appliances (photocopiers and desktop computers).
USE OF HEATING	Use of the heating system.
STANDBY USE	Leaving appliances on standby mode.
BACKGROUND (INFLUENCE)	Family background and/or country of origin influences.
SPORTSPERSON	Person active in sports.
(ACHIEVING THERMAL) COMFORT	The condition of mind that expresses satisfaction with the (thermal) environment.
LAZINESS	Being lazy and not willing to put any effort.
TECHNOLOGIES (TEC)	
CONTROL	The ability to control the settings of the HVAC or technological equipment.
FEEDBACK	The feedback structure within the organisation addressing issues related to technologies.
UNDERSTANDING	Knowledge about how technologies operate.
DESIGN	The design of the office building.
MAINTENANCE	Maintenance of the building systems.
CONFIGURATION	The particular arrangement of technologies or equipment that make a system operational (e.g. computer/printer networks).
KNOWLEDGE (KNO)	
PROFESSIONAL EXPERIENCE	Professional experience in the energy sector or related industries.
EDUCATION	The level of knowledge received through formal education.
INSTRUCTIONS	Information and guidance provided on the proper use of the workplace systems and equipment.
INFORMATIONAL CAMPAIGNS	Energy industry campaigns such as the roll out of smart meters and information provided with energy bills.
MEANINGS (MEA)	
COLLECTIVE CONSCIOUSNESS	Being a part of a team and act according to commonly shared attitudes.
ENERGY CONSCIOUS	Being aware of the effects of energy use in the environment and follow an energy conscious lifestyle.
GREEN ORGANISATIONAL IDENTITY	The way an organisation presents itself through an environmentally oriented strategic approach (e.g. efficient building infrastructure, support of green employee behaviour, informational campaigns, etc.)
ENVIRONMENTALISM	Being interested in or study the environment and try to protect it from being damaged by human activities.
CAMBRIDGE STATUS	Being a researcher, student or employee at the University of Cambridge.
STUDENT LIEFESTYLE	Live in College accommodation, use a bicycle or public transport for daily commute and carry a low budget lifestyle.
ROLE MODEL	Being someone who others admire and whose behaviour they would like to copy.
TIME-CONSUMING	A task, which takes a lot of time to do.
FINANCIAL INCENTIVE	Being encouraged to act in a certain way in order to save or earn money.
PRAGMATIC	Thinking in a sensible way that suits the conditions that really exist, rather than obeying fixed theories, ideas, or rules.
HOME/ WORKPLACE NOTION	Beliefs and ideas related to home/ workplace.
ACTIVE/ PASSIVE (USER)	Actively engaged/ not engaged at all in matters related to energy use in the office.

A4. Comfort diary

THERMAL COMFORT DIARY

Date:

Name:

Office:

Each diary is for one day. Fill the diary three times a day between 09:00-12:00, 12:00-14:00 and 14:00-18:00. Please note the actual time you fill the diary in the first column.

1. Temperature	**How do you feel at this moment?** Tick relevant box (✓) (1.Much too cool, 2.Too cool, 3.Comfortably cool, 4. Comfortable neither warm nor cool, 5. Comfortably warm, 6. Too warm, 7. Much too warm)	**You would prefer it to be:** Tick relevant box (✓) (1.Much cooler, 2.A bit cooler, 3.No change, 4. A bit warmer, 5. Much warmer,
09:00-12:00 Actual time:	Much too cool [1] [2] [3] [4] [5] [6] [7] Much too warm	Much cooler [1] [2] [3] [4] [5] Much warmer
12:00-14:00 Actual time:	Much too cool [1] [2] [3] [4] [5] [6] [7] Much too warm	Much cooler [1] [2] [3] [4] [5] Much warmer
14:00-18:00 Actual time:	Much too cool [1] [2] [3] [4] [5] [6] [7] Much too warm	Much cooler [1] [2] [3] [4] [5] Much warmer

2. Overall Comfort	**How would you rate your overall comfort at this moment?** (considering temperature, air quality, humidity, lighting and noise) Tick relevant box (✓) (1.Unsatisfactory, 2.Barely satisfactory, 3.Fairly satisfactory , 4. To a great degree satisfactory 5. Satisfactory)
09:00 -12:00	Unsatisfactory [1] [2] [3] [4] [5] Satisfactory
12:00-14:00	Unsatisfactory [1] [2] [3] [4] [5] Satisfactory
14:00-18:00	Unsatisfactory [1] [2] [3] [4] [5] Satisfactory

3. Activity level	**What have you been doing in the last hour?** Tick relevant box (✓)				
	Sitting - passive	Sitting - active	Standing - Relaxed	Walking - Indoors	Walking - Outdoors
09:00 -12:00					
12:00-14:00					
14:00-18:00					

4. Clothing	**How many layers of clothing on your upper body?** (Number of layers and comments if any e.g. vest, shirt, cardigan)
09:00 -12:00	
12:00-14:00	
14:00-18:00	

5. Conditions	**Tick all that apply at the moment (✓)**						
	General heating on	A/C on	Extra heating on	Lights on	Fan on	Window open	Door open
09:00 -12:00							
12:00-14:00							
14:00-18:00							

A5. Data logger position

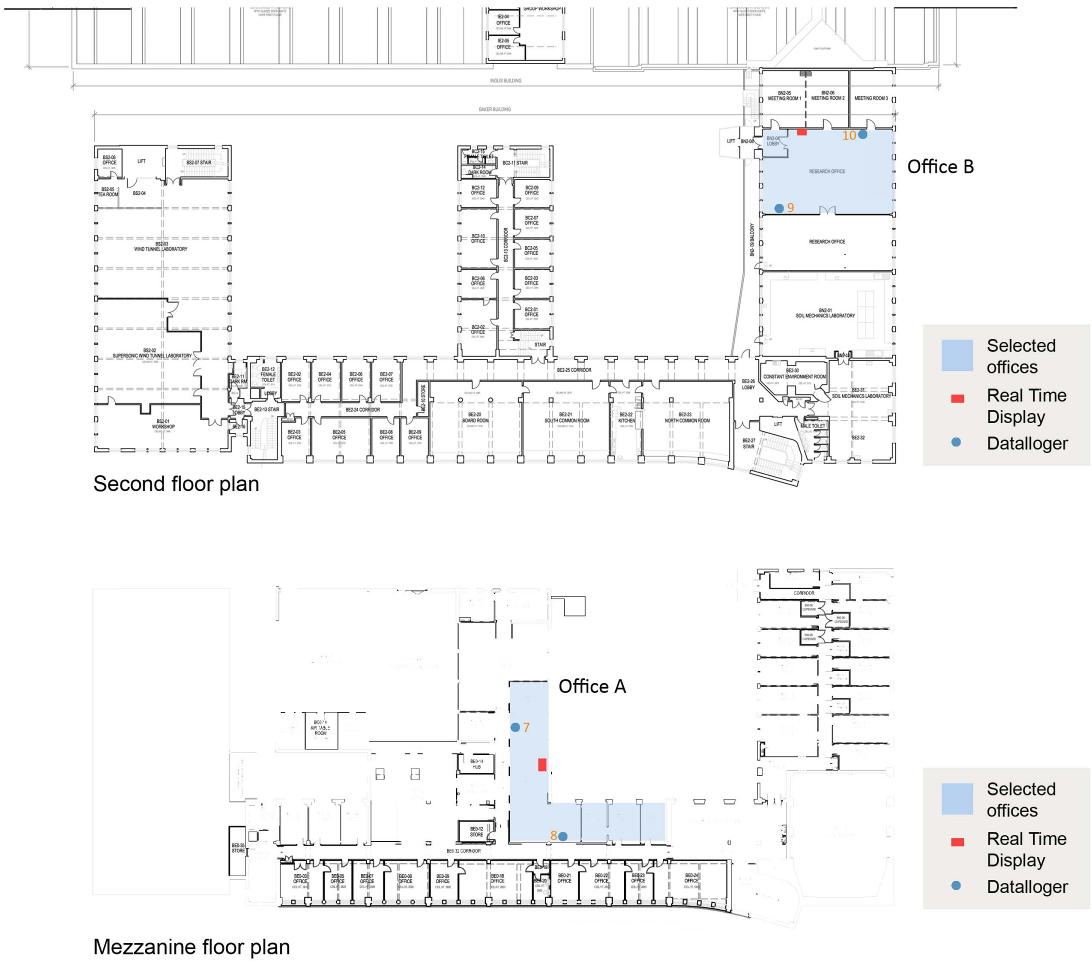


Figure A.2 Data logger position in mezzanine and second floor (Offices A and B).

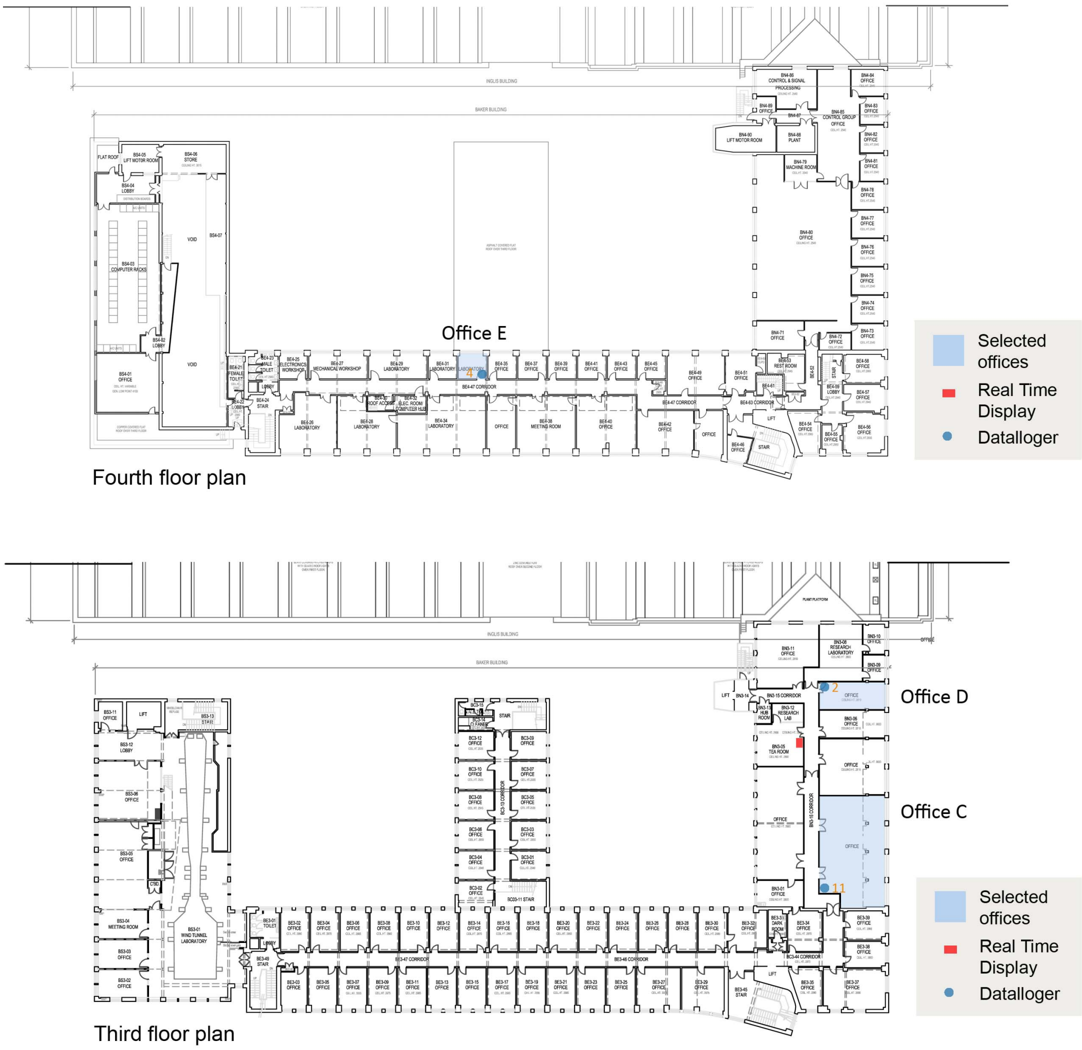


Figure A.3 Data logger position in third and fourth floor (Offices C, D and E).

Figure A.4 Tinytag Ultra2 internal temperature and humidity data logger.

Figure A.5 Tinytag Plus2 external temperature data logger.

APPENDIX B. Pilot studies

B1. Polar Research Institute, Hokkaido University (Japan)

Background

Hokkaido University was founded in 1876 and is located at city centre of Sapporo (1.9 million population, 2011 census) on the northern Japanese island of Hokkaido. It comprises of 31 schools (12 Undergraduate and 19 Graduate) and counts over 18,000 students. The campus covers an area of 1,776,249 m^2 with a floor area of 739,368 m^2 (Figures B.1, B.2). The Polar Research Institute is the 17^{th} largest institute in the campus out of 46 and has the 11^{th} place in the primary energy consumption table ranking.

Figure B.1 Aerial photo of Hokkaido University Campus with the Polar Research Institute and its building Annex (Source: Nakamura & Morimoto, 2011).

Figure B.2 Modern and historic building structures in Hokkaido University campus.

Data collection

In order to understand the energy use behaviour and sustainability perceptions of the campus users, a questionnaire survey took place in the Institute of Low Temperature Science (Figures B.3, B.4). The research centre, located in the south part of the campus had a research focus in the field of natural sciences in cold environments and was accommodated in four interconnected buildings. Each building consisted of of labs, offices, meeting and lecture rooms.

The questionnaire was organised in four sections (Figure B.5). The first section gathered demographic information. In the second section, a set of questions prompted the building users to commend on the environmental conditions and comfort levels in their workplace. Following that, there was a section related with their energy use practices in their office. Finally, it focused on their experience with sustainability campaigns in a university campus level.

Demographic information was collected through relevant choice options. For the second and third section, a 7-point rating scale was used providing additional space for comments. For the rest questionnaire a 'yes/maybe/no' response format was adopted with space for individuals' comments. The attitudinal assessments took the form of a statement where individuals indicated whether they agree or disagree.

Before the survey, the study aims and the questionnaire structure were presented to the Institute's head in order to attain official permission to conduct the survey. A day before the questionnaire distribution, building users were informed on the study and the exact time of the survey through an e-mail. The survey took place on the 14.11.2012 in two of the Institute's buildings; the main building and the new annex A, addressing a total of 173 users. Students and staff that were present on the distribution day (103) were asked to fill and return the questionnaire the same day on a designated location at the entrance of the building.

Figure B.3 Questionnaire distribution.

Figure B.4 Interior images of research offices.

HOKKAIDO UNIVERSITY *Office for a Sustainable Campus*

UNI-METRICS

Energy use behavior questionnaire survey

Date:14.11.2012

The aim of the survey is to understand the energy performance of your building and the effectiveness of the sustainability campaign in order to improve energy consumption in the future. The survey team will treat the information confidentially and the survey reports will use summaries of the information gathered.

If you have any queries please contact: Dr. Maki KOMATSU, coordinator1@osc.hokudai.ac.jp

Background

Note: We ask about sex and age because they are both relevant to people's needs in buildings.
Please tick ✓ the relevant boxes

1. What is your age?	Under 20 1☐ 2☐ 20-29 30-39 3☐ 4☐ 40-49 50-59 5☐ 6☐ 60 or more
2. …and your sex?	Male 1☐ 2☐Female
3. What is the type of your working area	1☐ Office 2☐ Lab 3☐ Other, please explain ________________________
4. …and your job description?	1☐ Student 2☐ Research/teaching staff 3☐ Administrative staff 4☐ Other, please explain ___________________________
5. How many people share your office work area?	Only you 1☐ 2☐ 2 3-4 3☐ 4☐ 5- 8 More than 8 5☐
6. How long have you worked in this building?	Less than a year 1☐ 2☐ A year or more
7. How long have you worked in your present office space?	Less than a year 1☐ 2☐ A year or more
8. Which day do you usually use the room and for how many hours in a normal working week?	Please fill the relevant boxes ■ Example: ☑ Monday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 M☐ Monday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 T☐ Tuesday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 W☐ Wednesday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 T☐ Thursday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 F☐ Friday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 S☐ Saturday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 S☐ Sunday 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
9. How many hours do you spend working with a computer screen?	Hours per day____
The building overall	Please tick your rating on each scale ✓
10. Are you satisfied with the building design overall?	Unsatisfactory 1 2 3 4 5 6 7 Satisfactory
Your work area	Please tick your rating on each scale ✓
11. Especially for the work that you carry out how well do the facilities in your office meet your needs?	Unsatisfactory 1 2 3 4 5 6 7 Satisfactory Please give examples for things that obstruct your work …and things that usually work well

12. What is the equipment working when you are on holidays?	1☐ PC 2☐ Printer 3☐ Fax 4☐ Pot 5☐ Other,_________ 6☐ __________ ☐ _________ ☐ ____________		
Heating			
13. Which hours is your heating on during a typical working day?	Please fill the relevant boxes ■ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24		
14. At what temperature (^{o}C) do you set your thermostat? Please tick ✓	1☐18 2☐19 3☐20 4☐21 5☐22 6☐23 7☐24 8☐25 9☐26 10☐ If other, please explain____________________		
15. Do you turn off the heating when you leave the room? Please tick ✓	1☐ Yes 2☐ Leave in automatic mode 3☐ No		
16. Do you use extra heating equipment? Please tick ✓	1☐ Yes 2☐No If yes, please specify: Type of equipment: 1☐ Fan heater 2☐ Radiative heater 3☐ Radiator 4☐Floor mat 5☐Other _____________________________ Hours of use Please fill the relevant boxes ■ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24		
Lighting	Please tick your rating on each scale ✓		
17. How would you describe the quality of lighting in your work area?	Overall	Unsatisfactory 1 2 3 4 5 6 7	Satisfactory
	Natural lighting	Unsatisfactory 1 2 3 4 5 6 7	Satisfactory
	Artificial lighting	Unsatisfactory 1 2 3 4 5 6 7	Satisfactory
18. Do you turn off the lights during lunchtime? Please tick ✓	1☐ Yes…all 2☐Some of them 3☐ No		
19. Do you turn off the lights on a sunny day when you feel it is bright enough? Please tick ✓	1☐ Yes…all 2☐Some of them 3☐ No		
Comfort	Please tick your rating on each scale ✓		
20. How would you describe the typical environmental conditions of your office during WINTER?	Temperature	Uncomfortable 1 2 3 4 5 6 7	Comfortable
		Too hot 1 2 3 4 5 6 7	Too cold
		Stable 1 2 3 4 5 6 7	Variable
	Air Quality	Still 1 2 3 4 5 6 7	Draughty
		Dry 1 2 3 4 5 6 7	Humid
		Fresh 1 2 3 4 5 6 7	Stuffy
	Overall conditions	Unsatisfactory 1 2 3 4 5 6 7	Satisfactory
	Clothing level	1☐ High 2☐ Middle 3☐ Low	
	Comments about comfort in winter		
21. How would you describe the typical environmental conditions of your office during SUMMER?	Temperature	Uncomfortable 1 2 3 4 5 6 7	Comfortable
		Too hot 1 2 3 4 5 6 7	Too cold
		Stable 1 2 3 4 5 6 7	Variable
	Air Quality	Still 1 2 3 4 5 6 7	Draughty
		Dry 1 2 3 4 5 6 7	Humid
		Fresh 1 2 3 4 5 6 7	Stuffy
	Overall conditions	Unsatisfactory 1 2 3 4 5 6 7	Satisfactory
	Clothing	1☐ High 2☐ Middle 3☐ Low	

	level
	Comments about comfort in summer
Personal control	Please tick your rating on each scale ✓
22. Please note the level of control you have over the following aspects of your working environment.	Heating — No control 1 2 3 4 5 6 7 Full control Cooling — No control 1 2 3 4 5 6 7 Full control Ventilation — No control 1 2 3 4 5 6 7 Full control Lighting — No control 1 2 3 4 5 6 7 Full control
Energy saving	
23. Do you take any measures for energy saving? Please tick ✓	1☐ Yes 2☐ No If yes are they any of these? 1☐ Raise the refrigerator temperature 2☐ Turn off the draft chambers when not in use 3☐ Set PC in sleep mode 4☐ Turn off lights when leaving the desk and pull down the blinds 5☐ Other If other please explain… What was the reason for you to change your energy use behavior? 1☐ Office for a Sustainable Campus energy reduction campaigns in February 2011, July 2011, February 2012 2☐ Ongoing Office for a Sustainable Campus energy reduction campaign since February 2012 3☐ Personal reasons 4☐ Government policies 5☐ Social pressure after Fukushima earthquake 6☐ Other If other please explain…
24. Are you actively involved in any energy reduction program/activity in the campus? Please tick ✓	1☐ Yes… please name the activity____________________________ 2☐ No If no, what prevented you to participate? 1☐ Time constrains 2☐ Lack of adequate information 3☐ Other If other please explain…
25. Would you be interested to participate in an energy reduction program in the future?	1☐ Yes 2☐ Maybe 3☐ No
26. Do you think that energy saving in the campus is more important than activity enhancement?	1☐ Yes 2☐ Maybe 3☐ No
Comments	
Please write any positive or negative comments you may have on all the previous issues raised.	
Thank you for your time.	Please leave the questionnaire in the box next to the entrance no later than Friday (6.11.12) 5 p.m..

Figure B.5 Hokkaido University questionnaire survey.

Main findings

Demographics

The survey participants were male dominated (66%), with the majority of them being students between 20-29 years old (38%) working in shared offices (76%) (Figure B.6). Three quarters of the participants (74%) stated that they had been working in the building for more than a year, indicating a possible awareness of the energy reduction campaigns that took place during the past year.

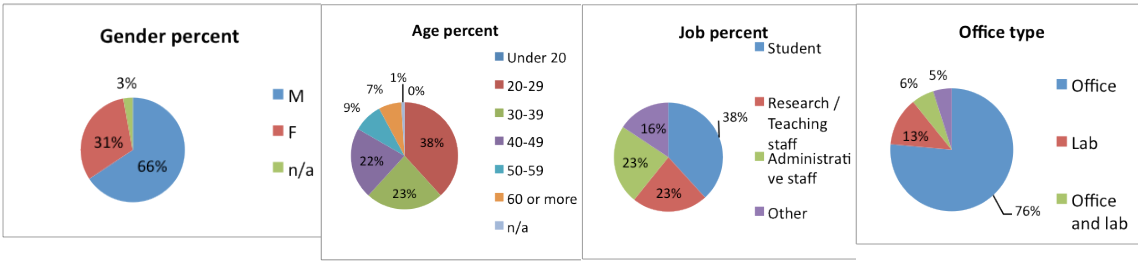


Figure B.6 Demographics.

Pro-environmental behaviour and the effect of personal and social norms

With regard to their attitude towards energy saving in the campus, a third of the participants (33%) stated personal reasons while the past and on-going OSC campaigns followed (16% each) (Figure B.7). Social pressure after the Fukushima accident and Japanese Government policies were also considered but to a lower extent (11% and 5% respectively). When the campus users were asked whether they prioritize energy saving over activity enhancement a noticeable 42% answered 'maybe' while an equivalent amount of respondents (38%) responded negatively.

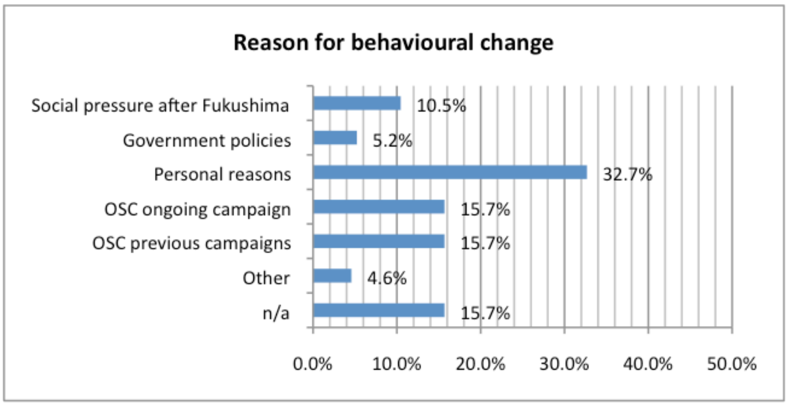


Figure B.7 Reason for behavioural change.

Campus sustainability campaigns

A low participation rate in campus carbon reduction activities (78%) was stated (Figure B.8). The main reasons were the lack of adequate information (38%), time constraints (15%) or other unstated reasons (37%) indicating the weakness of the OSC activities to reach and engage a large number of campus users. A difficulty in the understanding of the term 'energy reduction activity' was pointed out by some of the respondents along with the need of appointing faculty 'green' representatives.

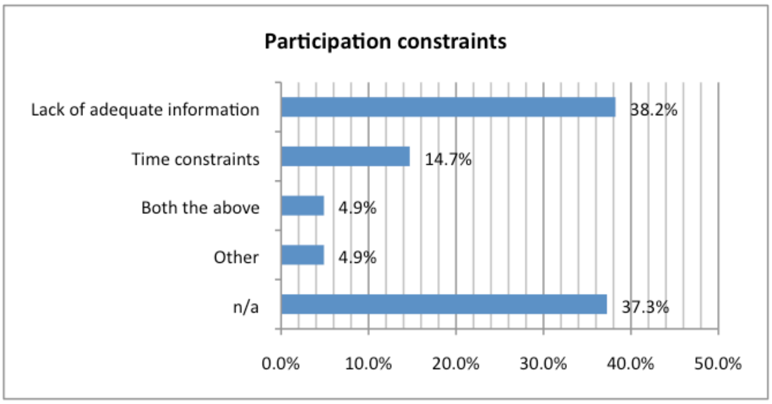


Figure B.8 Participation constraints.

Interest in future participation

The participants' interest in future carbon reduction activities was moderate (38%) (Figure B.9). However, a considerable number of users gave a 'maybe' as an answer (38%) indicating a possibility of shifting this opinion towards a positive response.

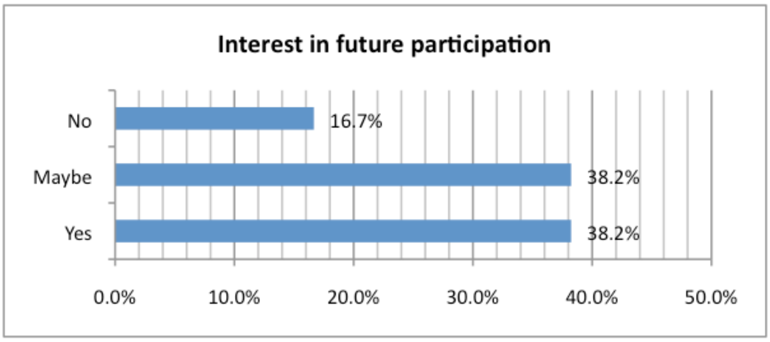


Figure B.9 Interest in future participation.

B2. Gurdon Institute, University of Cambridge (UK)

Table B.1 Type of ECRP activities and related savings in Gurdon Institute.

Type of initiative	Actions	Percentage saving (April 2009-December 2012)
Behavioural change programme	- Workplace Footprint Tracker (WFT) online tool - I-pad display with access to the WFT - Energy reduction competition between labs (£1000 reward) and league table - 'Energy representative' in each lab - Information posters, stickers, cards - 3-day awareness campaign - E-mail prompts - Energy use related social activities	19% (Reduced to 14% by the end of the 2012)
Technical interventions	- Feasibility report into the efficiencies of the ventilation systems to reduce energy costs while maintaining safe and comfortable research strategies - Lighting trials: 1. Installation of wireless PIR / sensors of equipment room 323 linked to the light switch 2. Retrofitting of occupancy sensors, T5 tubes and daylight harvesting controls in two labs	60% (Did not result in the expected reduction)

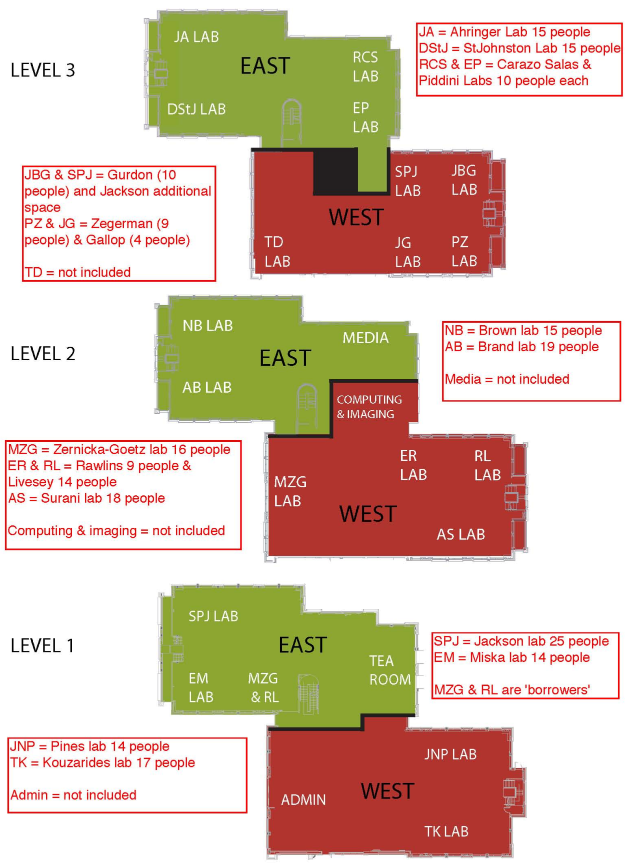


Figure B.10 Gurdon sub-metered areas and lab sizes.

Data collection

The questionnaire survey was categorised in four sub-sections presented in detail in Table B.2. Initially, a set of questions was asked regarding basic demographics. In the second section, the questionnaire prompted building users to comment on their energy use behaviour based on how often they conducted different actions with regard to *'expectations about others'* behaviour. The same section looked at the strength of social and personal norms and barriers preventing behavioural change. Then, building users were asked to comment on their energy awareness and self-assess their energy consciousness. Section three, focused on the evaluation of the effectiveness of informational tools at a building and university level. The degree of difficulty in carrying out different actions related to the WFT was also examined. Finally, the fourth section focused on participants' energy use behaviour in their home environment.

Table B.2 Gurdon Institute questionnaire survey structure.

Questionnaire section	Interest field	Question
1. Demographics (Q1-Q3)	Background information	Name of lab and job description, age, length of occupancy
2. Environmental behaviour and expectations about others' behavior (Q4-Q7)	Environmental behaviour and expectations about others on certain actions	Switch off appliances completely, rather than put on stand-by, Switch off lights when leaving a room, Use the recycling bins, Check labs performance on the WFT, Discuss with colleagues about energy use in your workspace, Cooperate with colleagues about energy use in your workspace (Never/ Always 4-point scale or applicable)
	Barriers to environmental behaviour and importance of personal and social norms	To what extent do the following prevent you from changing your energy use behaviour at your workspace? Compromise of research activity/ Lack of relevant information/ Lack of energy use feedback/ Lack of economic (or other incentive)/ Time constraints/ Social pressure/ Unwillingness of colleagues to change their attitude (Not at all/ To a great extent 4-point scale or non applicable)
	Environmental citizenship	Are you a member in any environmental group or organisation (e.g. Greenpeace, WWF, etc.)? (Y/N/ non-applicable) Are you actively involved in any energy reduction program/activity at the University or your College? (Y/N/non-applicable)
	Self-assessment of energy awareness	Strongly energy conscious/Fairly energy conscious/ Not really energy conscious
3. Effectiveness of energy use feedback tools (Q8-Q9)	Effectiveness of informational tools	Switch-off week/ Workplace Footprint Tracker/ I-pad near the entrance with information on whole building performance and individual labs/ Energy competition with league table between labs/ Presence of energy representatives in each lab (Not at all/To a great extent 4-point scale or non applicable)
	Assessment of the Workspace	What is the degree of difficulty to carry

	Footprint Tracker	out the following actions related to the Workspace Footprint Tracker? Check online your lab's energy use through your personal computer/ Navigate through its web-interface/ Understand the energy units/ Change your energy behaviour based on the provided information/ Ask for explanatory information from the members of staff (Very difficult/Very Easy 4-point scale or non applicable)
4. Energy use at home (Q10)	Energy use at home	Do you check your energy meter regularly? (Never/Always 4-point scale or non relevant) Do you monitor your fuel consumption? (Never/Always 4-point scale or non relevant)

Main findings

The survey was met with a 39% (105/234) response rate, which is considered satisfactory for an on-line survey. Seventy-two responses came from labs, fourteen from the FM/Administration/Media/Computing departments and nineteen did not specify.

Demographics

- Nearly half of the respondents (43%) were young researchers (between 25-34 years old) working in one of the labs for a period of more than a year, thus familiar with their workspace environment (Figure B.11).
- Wide variations between inter-lab participation rates were noticed ranging from 5.5% to 57%. This was possibly due to additional prompts received in some of the labs from the lab representatives and facilities manager or their awareness and active participation in the past behavioural change campaign.

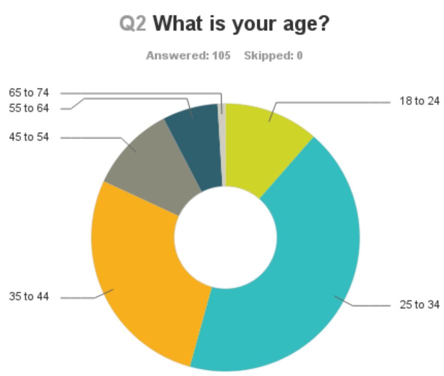


Figure B.11 Background information: Age band (Q2).

Environmental behaviour and expectations about others behaviour

- Overall, building users were energy aware and the majority focused on switching off lights and equipment in order to achieve energy savings at eh workplace. The use of the WFT proved to be a less popular activity with users claiming that either they had '*never*' (37%) or only '*sometimes*' (43%) checked their lab's performance online.
- Discussions about energy use in the workplace were frequent among the respondents (68%). Half (51%) were found to actively cooperate with colleagues to reduce energy use in their lab indicating a common concern regarding the Institute's energy use.
- In most cases, peoples' expectations of their colleagues' environmental behaviour were lower than in reality. For instance, 79% of the participants claimed to '*fairly often*' or '*always*' switch off equipment after use but only half (51%) expected '*a large part*' or '*everybody*' else to do so. However, in the case of the WFT and willingness to cooperate with colleagues to reduce energy usage, expectations of others' were higher that users' actual actions.

Barriers to Environmental behaviour

- Among the seven possible barriers to behavioural change indicated in the survey, research activity was regarded as the most significant one by 38% of the building respondents (Figure B.12). Time constraints and lack of relevant information followed (31% and 20% respectively), while the lack of energy use feedback was conbsidered as a barrier only by a minority (13%).
- One of the respondents interestingly commented on *'the lack of sufficient effect [of their action] on global climate change'* underlining the need to provide building users with further information on 'why' they are expected to change their behaviour.

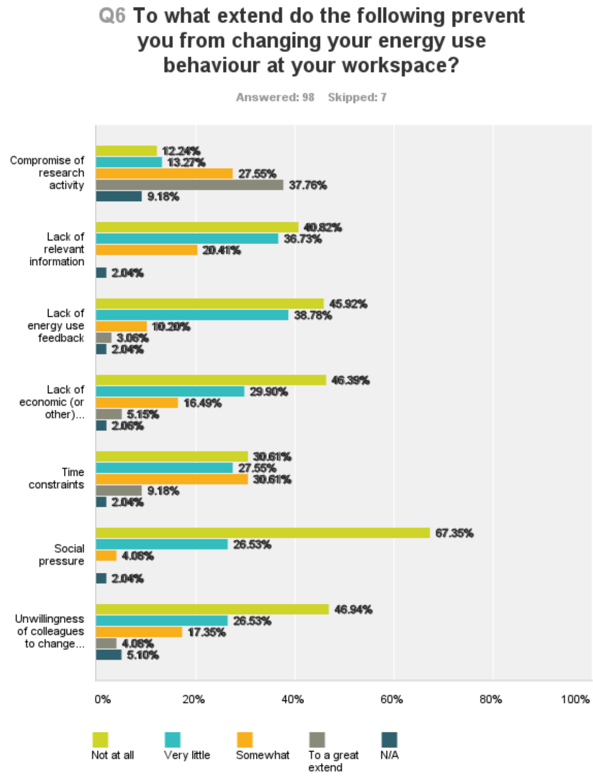


Figure B.12 Barriers to environmental behaviour and importance of personal and social norms (Q6).

Environmental citizenship and self-assessment of energy awareness

- Although respondents assessed themselves as ‘*fairly’* (72%) and *‘strongly energy conscious*’ (25%) suggesting the existence of environmental knowledge, their participation in University or College activities and other environmental groups was noticeably low (17% and 8% respectively).

Effectiveness of energy use feedback tools

- Visual prompts through informational cards, posters and labels were considered to be among the most effective behavioural change strategies (21% ‘*to a great extent*’) while the competition league table and its access through the iPad display and the WFT were disregarded (64% and 57% ‘*very little*’ or ‘*not at* all’) (Figuregroup B.13).

- The existence of an energy representative was not appreciated by more than half of the participants (54% ‘*very little*’ or ‘*not at all*’) pointing out that their selection and training process possibly needs to be revisited.

Figure B.13 Informational posters and iPad near the entrance featuring the WFT league table.

Assessment of the Workspace Footprint Tracker

- Half of the respondents (≈50%) were not aware of how to access to or use the WFT. This fact suggests the difficulty of relevant information to reach the building users, given that three quarters of the respondents have been in the building for a year or more, and therefore were present when the behavioural change programme took place (Figure B.14).
- The ones familiar with the tool had a positive view finding it easy to use (≈38%), understand (≈37%) and navigate (≈34%).

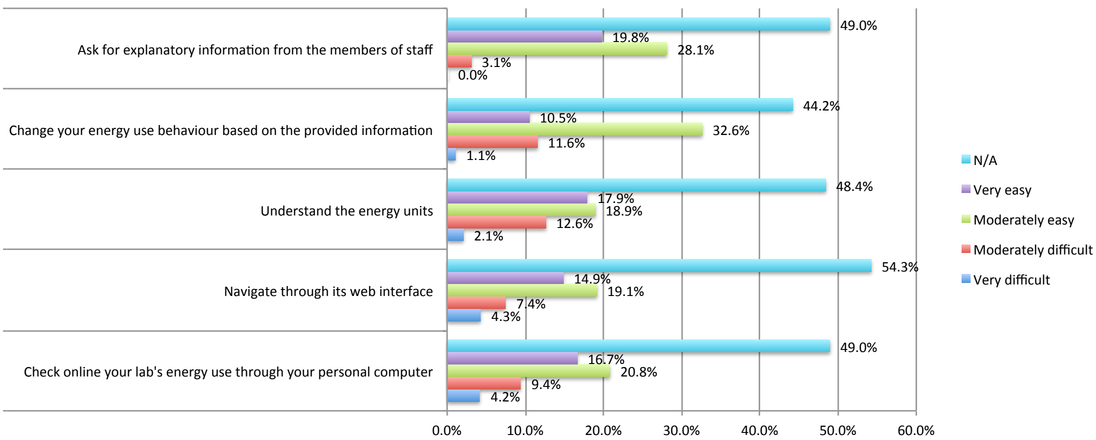


Figure B.14 Assessment of the Workspace Footprint Tracker tool (Q10).

Energy use at home

- Answers on energy use behaviour at home revealed a moderate environmental and energy use level of awareness for the majority of the respondents (55%). People were more eager to discuss energy related issues with members of their household (29% '*very often*') than with colleagues (17% '*fairly often*') and noted that they checked their electricity or gas meter readings fairly often (20%).

APPENDIX C. Fieldwork administration

UNIVERSITY OF CAMBRIDGE
School of the Humanities and Social Sciences

Ms Tamara Hug
Ethics Committee Secretary

Dimitra Dantsiou
Department of Architecture
Faculty of Architecture and History of Art
Christ's College
St Andrews St
Cambridge CB2 3BU

14 January 2014

Dear Dimitra

Ethical approval: Determining the relationship between energy use behaviour and feedback: The case of behavioural change strategies in a UK university carbon reduction scheme

The Ethics Committee for the School of the Humanities and Social Sciences has considered the documentation you provided, which followed the procedures concerning ethical approval of research.

I am able to inform you that approval, with respect to ethical considerations, has now been given to your project. Please note that this clearance is based on the documentation you have submitted. You must resubmit your application to the Ethics Committee should you subsequently make any substantive changes relating to matters reviewed by the Committee.

With best wishes

Tamara Hug
Ethics Committee Secretary

cc Dr Minna Sunnika-Blank

17 Mill Lane
Cambridge CB2 1RX

Tel: +44 (0) 1223 766238
Fax: +44 (0) 1223 760433
Email: cshssethics@admin.cam.ac.uk
www.cshss.cam.ac.uk

Figure C.1 Ethical approval letter.

INFORMATION TO PARTICIPANTS

Project title: *Determining the relationship between energy use behaviour and feedback: The case of behavioural change strategies in a UK university carbon reduction scheme*

Dear building user,

You are being invited to take part in a research study. Before you decide whether or not to accept this invitation, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information. If you have any queries or something is not clear to you do not hesitate get in touch using the provided contact details.

What is the purpose of the study?
This research aims to investigate the interactive relationship between the building user and the technological aspects of the building looking at how embodied habits, knowledge, motivation and technological configurations constitute consumption practices and provide the opportunity for change. The research will focus on three basic objectives:

- To increase the understanding of how daily consumption practices and comfort levels are formulated in a workspace environment.
- To capture the extent that innovative technologies such as Real Time Displays (RTDs) and retrofitting interventions in heating and ventilation influence users' electricity consumption practices.
- To identify the relationship between the perception of indoor comfort and electricity consumption.

Why have I been invited to participate?
You have been invited as your office group is being sub-metered for its electricity consumption and there is a plan for a Real Time Display providing feedback on the consumption of your group to be placed in your workplace area. Thirteen people from four different office groups (four from each group) will be invited to participate in a questionnaire survey, provide information on their comfort levels and are going to be further interviewed.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. In this case, you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?
If you decide to take part:

- The temperature and humidity of your office will be monitored using a small datalogger device (Figure 1).
- You will be asked to fill in a questionnaire, *three* times over *a period of one year*, to map the change in your behaviour and comfort levels during different seasons.
- You will also be engaged in completing *logging sheets, in order to see how you use* the heating system and appliances, and how comfortable you are. This will be about *three times a day* for one week in every season during the period of the study.
- You will be interviewed three times (interview not lasting more than half hour). The interviews will include questions about your energy use habits, knowledge, social influences and technological configurations in your office.

Figure 1 A Hobo datalogger device.

What is the time commitment for taking part in the study?
Your participation will include the completion of a questionnaire (10 minutes) three times a year and also thermal comfort and activity diaries (5 minutes each day for one week) and semi-structured interviews (30 minutes) three times a year.

What are the possible benefits of taking part?
By participating in this research you will enhance your understanding on how different factors shape energy use behaviour in offices and enhance the success of this research. As a 'thank you' at the end of the study participants will enter a draw for two £20 book vouchers.

Will what I say in this study be kept confidential?
All information collected about the individual will be kept strictly confidential. Your personal data will never be revealed in the study, keeping your privacy and anonymity ensured in the storage and publication of the research material.

What should I do if I want to take part?
Please fill in the consent form (attached), and e-mail it back to dd356@cam.ac.uk.

What will happen to the results of the research study?
The results of the research will be used as empirical evidence for the needs of a PhD research project. A report will be also fed back to the Environmental Office of the University of Cambridge to improve energy reduction policies and behavioural change activities in university buildings. If you wish you can obtain a report at the end of the study with the main outcomes of the study by informing the PhD researcher.

Who is funding the research?
This research is funded by EPSRC (Engineering and Physical Sciences Research Council) and supported by the Living Laboratory for Sustainability Scheme of the University of Cambridge.

Who has reviewed the study?
The School of the Humanities and Social Sciences Research Ethics Committee has approved the above research.

Contact for Further Information
Dimitra Dantsiou, PhD Candidate
Department of Architecture,
1-5 Scroope Terrace, Cambridge, CB2 1PX
E-mail: dd356@cam.ac.uk

Figure C.2 Participant information sheet.

UNIVERSITY OF CAMBRIDGE

CONSENT FORM

Project title: *Determining the relationship between energy use behaviour and feedback: The case of behavioural change strategies in a UK university carbon reduction scheme.*

Name, position and contact address of Researcher:
Dimitra Dantsiou, PhD Candidate
Department of Architecture,
1-5 Scroope Terrace, Cambridge, CB2 1PX
E-mail: dd356@cam.ac.uk

		Please initial box
1.	I confirm that I have read and understood the information sheet for the above study and have had the opportunity to ask questions.	☐
2.	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.	☐
3.	I agree to take part in the above study.	☐

Please tick box

		Yes	No
4.	I agree to the interview being audio recorded.	☐	☐
5.	I agree to the interview being video recorded.	☐	☐
6.	I agree to the use of anonymised *quotes in publications.*	☐	☐

Name of Participant	Date	Signature
Dimitra Dantsiou		
Name of Researcher	Date	Signature

FigureC.3 Participant consent form.

APPENDIX D. Case study offices

The information included in this Appendix is complementary to Chapter 5: The case study.

D1. Energy use at CUED

Table D.1 Monthly electricity consumption (KWh) of the Engineering Department based on energy statements.

	2012-2013	2013-2014	2014-2015
September	-	277,834	274,771
October	277,700	309,296	304,730
November	295,283	313,251	300,079
December	279,303	289,541	288,835
January	326,789	313,412	318,347
February	307,025	292,297	313,887
March	324,055	300,971	318,290
April	279,956	276,702	275,042
May	307,614	293,089	294,961
June	278,294	273,590	283,038
July	318,429	295,904	291,535
August	289,812	270,536	-
Total	**328,4259**	**350,6423**	**326,3514**

Table D.2 Key ECRP measures taken in the Department of Engineering (Source: ECRP 2012).

Project	CO_2 abated per annum (tonnes)	Cost (£)	Annual Saving (£)	Payback (years)	Scalability
Installation of Evaporative Cooling to Baker Building Server Room	256	181k	40k	5	Larger server rooms
User Engagement (UROP Surveys) & IT Network Power Management	50	0	9k	0	Whole Estate
LED Lighting (External Floods)	11	17k	2k	9	Whole Estate
Energy Roof (70.4 kWh array on roof of Inglis Building)	30	19k	19k	15	Whole Estate
Cooling for process loads	81	14k	14k	13	Department s with demand for cooling loads
Cooling for office areas	30	TBD	TBD	TBD	Whole Estate

D2. ‘CO_2 reduction Grand Prix’ key events

Figure group D.1 An RTD along with relevant information placed at the entrance of the Engineering Department during the launch event.

Figure group D.2 User commenting on league table during the ‘CO_2 reduction Grand Prix’ launch event.

Figure group D.3 Tracker induction in office A (4th November 2014).

Figure group D.4 Tracker induction (offices B, C, D, E) with poor attendance (11th November 2014).

D3. Case study offices

Figure group D.5 The administrative office (A).

Figure group D.6 The PhD office (B).

Figure group D.7 The PhD office (C).

Figure group D.8 The post-doctoral office (D).

APPENDIX E. Supporting material for Chapter 6

The information included in this Appendix is complementary to Chapter 6: Thermal characteristics and comfort preferences of users.

E1. The PhD open plan office (B,C)

Office B

Thermal sensation

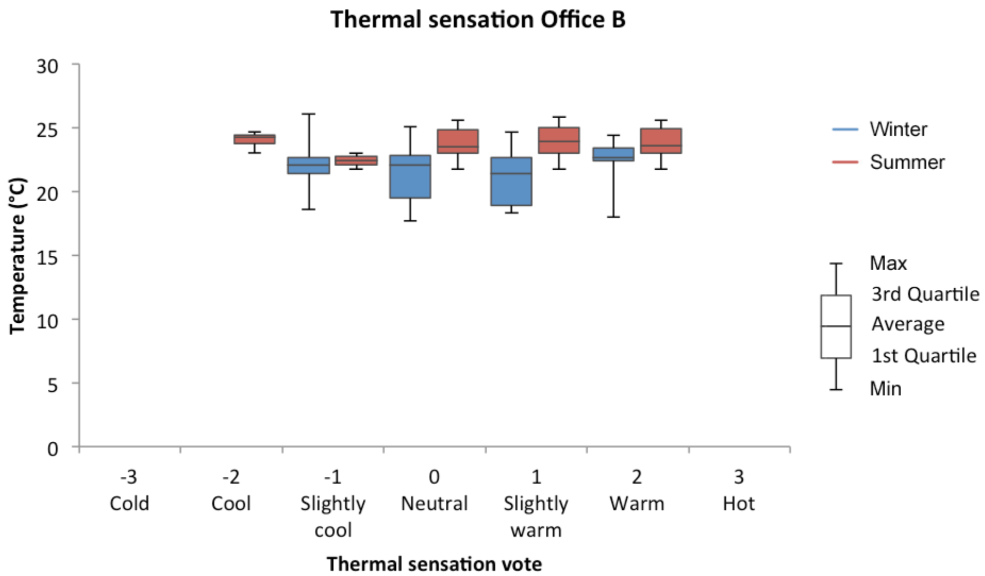


Figure E.1 Box-and-whisker plot of winter and summer thermal sensation against temperature for office B.

Table E.1 Summary of winter and summer thermal comfort and sensation votes for office B.

				Winter			
	-3 Cold	**-2** Cool	**-1** Slightly cool	**0** Neutral	**1** Slightly warm	**2** Warm	**3** Hot
Number of votes	0	0	5	28	17	9	0
Average temperature (°C)	-	-	22.2	21.4	21.3	22.3	-
Minimum temperature (°C)	-	-	18.6	17.7	18.3	18	-
Maximum temperature (°C)	-	-	26.1	25.1	26.1	24.4	-
Standard deviation	-	-	2.7	2.1	2.2	1.9	-
				Summer			
Number of votes	0	4	2	43	28	13	0
Average temperature (°C)	-	24.3	22.4	23.6	24	23.7	-
Minimum temperature (°C)	-	23.1	21.8	21.8	21.8	21.8	-
Maximum temperature (°C)	-	25.8	23.1	25.8	25.8	25.8	-
Standard deviation	-	1.1	0.9	1.1	1.1	1.2	-

Thermal preference

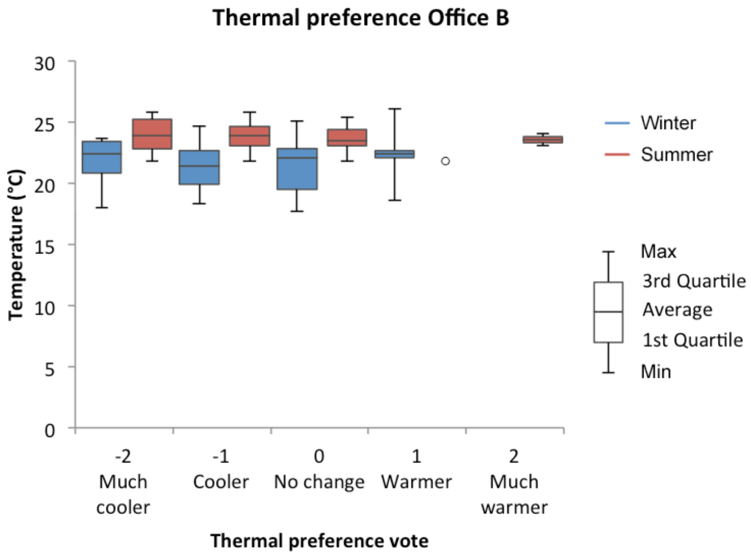


Figure E.2 Box-and-whisker plot of winter and summer thermal preference against temperature for office B.

Table E.2 Summary of winter and summer thermal preference votes and temperature for office B.

			Winter		
	-2 Much cooler	**-1** Cooler	**0** No change	**1** Warmer	**2** Much warmer
Number of votes	5	17	32	5	0
Average temperature (°C)	21.7	21.5	21.5	22.4	-
Minimum temperature (°C)	18.0	18.3	17.7	18.6	-
Maximum temperature (°C)	23.7	24.7	25.1	26.1	-
Standard deviation	2.3	2.2	2	2.7	-
			Summer		
Number of votes	14	38	35	1	2
Average temperature (°C)	23.9	23.8	23.5	21.8	23.6
Minimum temperature (°C)	21.8	21.8	21.8	21.8	23.1
Maximum temperature (°C)	25.8	25.8	25.4	21.8	24.1
Standard deviation	1.3	1.1	1.1	-	0.7

Office C

Thermal sensation

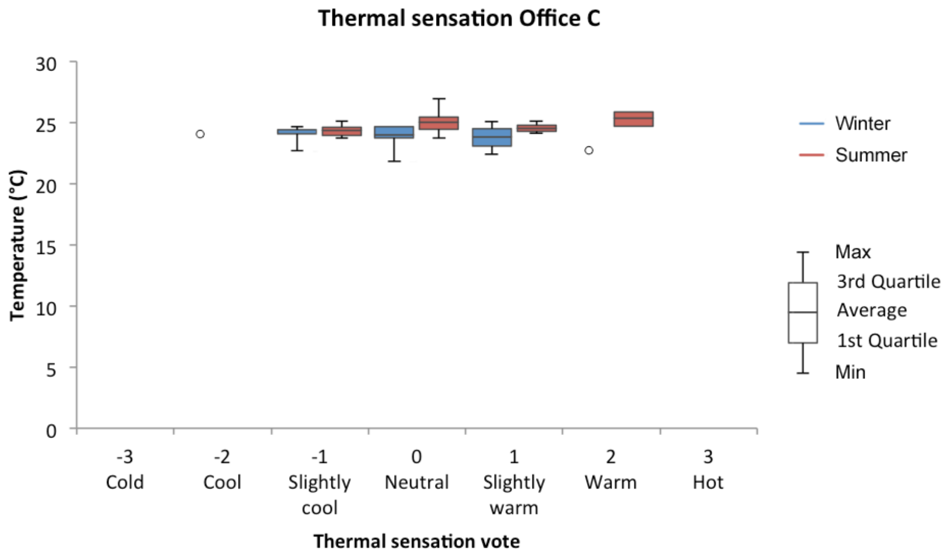


Figure E.3 Box-and-whisker plot of winter and summer thermal sensation against temperature for office C.

Table E.3 Summary of winter and summer thermal comfort and sensation votes for office C.

				Winter			
	-3 Cold	**-2** Cool	**-1** Slightly cool	**0** Neutral	**1** Slightly warm	**2** Warm	**3** Hot
Number of votes	0	1	8	12	5	1	0
Average temperature (°C)	-	24.1	24.1	24	23.8	22.7	0
Minimum temperature (°C)	-	24.1	22.7	21.8	22.4	22.7	0
Maximum temperature (°C)	-	24.1	24.7	24.7	25.1	22.7	0
Standard deviation	-	-	0.6	1.1	1.1	-	-
				Summer			
Number of votes	0	0	3	29	3	4	0
Average temperature (°C)	-	-	24.3	25	24.5	25.3	-
Minimum temperature (°C)	-	-	23.7	23.7	24.1	24.7	-
Maximum temperature (°C)	-	-	25.1	26.9	25.1	25.8	-
Standard deviation	-	-	0.7	0.8	0.5	0.6	-

Thermal preference

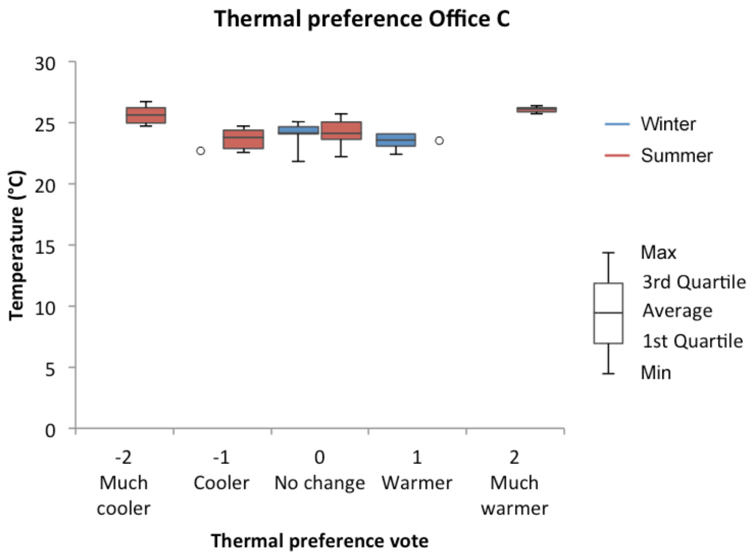


Figure E.4 Box-and-whisker plot of winter and summer thermal preference against temperature for office C.

Table E.4 Summary of winter and summer thermal preference votes and temperature for office C.

			Winter		
	-2 Much cooler	**-1** Cooler	**0** No change	**1** Warmer	**2** Much warmer
Number of votes	-	1	20	6	0
Average temperature (°C)	-	22.7	24.2	23.6	-
Minimum temperature (°C)	-	22.7	21.8	22.4	-
Maximum temperature (°C)	-	22.7	25.1	24.1	-
Standard deviation	-	-	0.9	0.8	-
			Summer		
Number of votes	2	3	32	2	0
Average temperature (°C)	25.3	25.2	24.9	24.4	-
Minimum temperature (°C)	24.7	24.7	23.7	23.7	-
Maximum temperature (°C)	25.8	25.8	26.9	25.1	-
Standard deviation	-	0.6	0.8	1.0	-

E2. The post-doctoral research office (D, E)

Office D

Thermal sensation

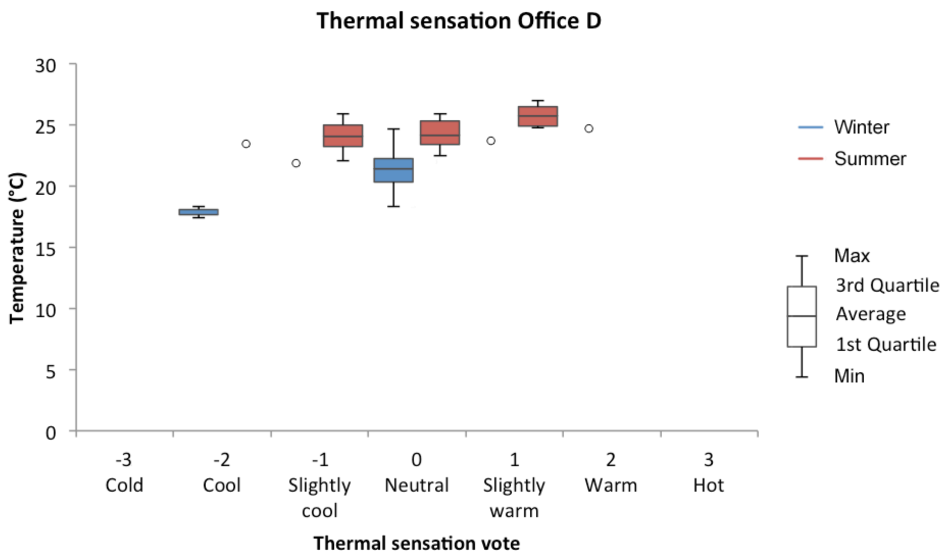


Figure E.5 Box-and-whisker plot of winter and summer thermal sensation against temperature for office D.

Table E.5 Summary of winter and summer thermal comfort and sensation votes for office D.

				Winter			
	-3 Cold	**-2** Cool	**-1** Slightly cool	**0** Neutral	**1** Slightly warm	**2** Warm	**3** Hot
Number of votes	0	2	1	35	1	1	0
Average temperature (°C)	-	17.6	21.8	21.4	23.7	24.7	-
Minimum temperature (°C)	-	17.4	21.8	18.3	23.7	24.7	-
Maximum temperature (°C)	-	18.3	21.8	24.7	23.7	24.7	-
Standard deviation	-	-	-	1.6	-	-	-
				Summer			
Number of votes	0	0	1	38	10	6	0
Average temperature (°C)	-	-	23.4	24	24.1	25.7	-
Minimum temperature (°C)	-	-	23.4	22	22.4	24.7	-
Maximum temperature (°C)	-	-	23.4	25.8	25.8	26.9	-
Standard deviation	-	-	-	1.1	1.2	1.0	-

Thermal preference

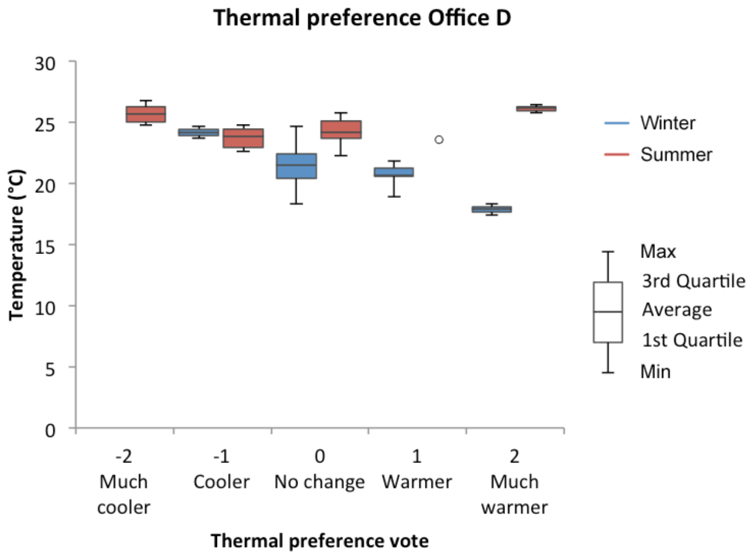


Figure E.6 Box-and-whisker plot of winter and summer thermal preference against temperature for office D.

Table E.6 Summary of winter and summer thermal preference votes and temperature for office D.

			Winter		
	-2 Much cooler	**-1** Cooler	**0** No change	**1** Warmer	**2** Much warmer
Number of votes	0	2	32	4	2
Average temperature (°C)	-	24.2	21.5	20.7	17.9
Minimum temperature (°C)	-	23.7	18.3	18.9	17.4
Maximum temperature (°C)	-	24.7	24.7	21.8	18.3
Standard deviation	-	-	1.6	1.3	-
			Summer		
Number of votes	4	9	39	1	2
Average temperature (°C)	25.7	23.7	24.1	23.4	26.2
Minimum temperature (°C)	24.7	22.4	22	23.4	25.8
Maximum temperature (°C)	25.7	23.7	24.1	23.4	26.2
Standard deviation	1.0	0.9	1.1	-	-

Office E

Thermal sensation

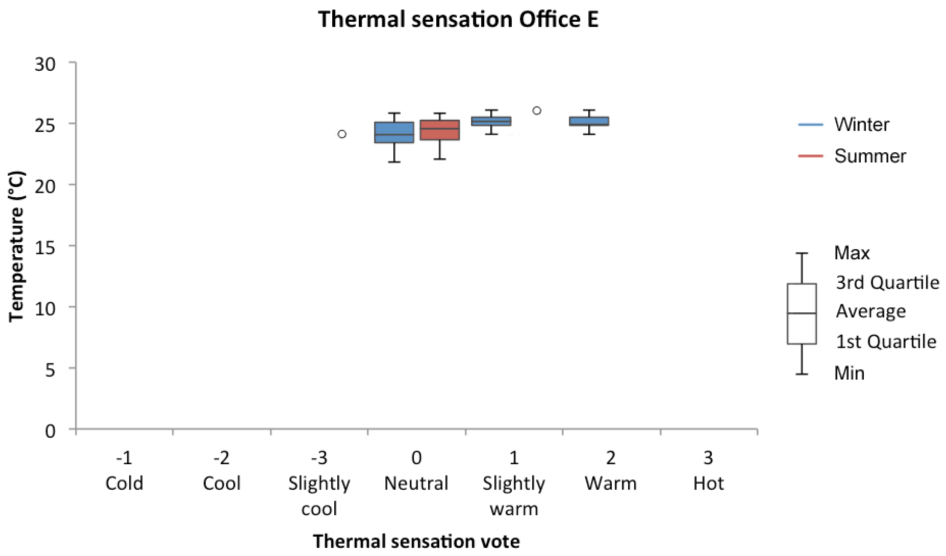


Figure E.7 Box-and-whisker plot of winter and summer thermal sensation against temperature for office E.

Table E.7 Summary of winter and summer thermal comfort and sensation votes for office E.

				Winter			
	-3 Cold	**-2** Cool	**-1** Slightly cool	**0** Neutral	**1** Slightly warm	**2** Warm	**3** Hot
Number of votes	0	0	0	11	8	7	0
Average temperature (°C)	-	-	-	24.1	25.2	24.9	-
Minimum temperature (°C)	-	-	-	21.8	24.1	24.1	-
Maximum temperature (°C)	-	-	-	25.8	26.1	26.1	-
Standard deviation	-	-	-	1.3	0.7	0.7	-
				Summer			
Number of votes	0	0	1	19	1	0	1
Average temperature (°C)	-	-	24.1	24.6	26.1	-	25.8
Minimum temperature (°C)	-	-	24.1	23.1	26.1	-	25.8
Maximum temperature (°C)	-	-	24.1	26.9	26.1	-	25.8
Standard deviation	-	-	-	1.1	-	-	-

Thermal preference

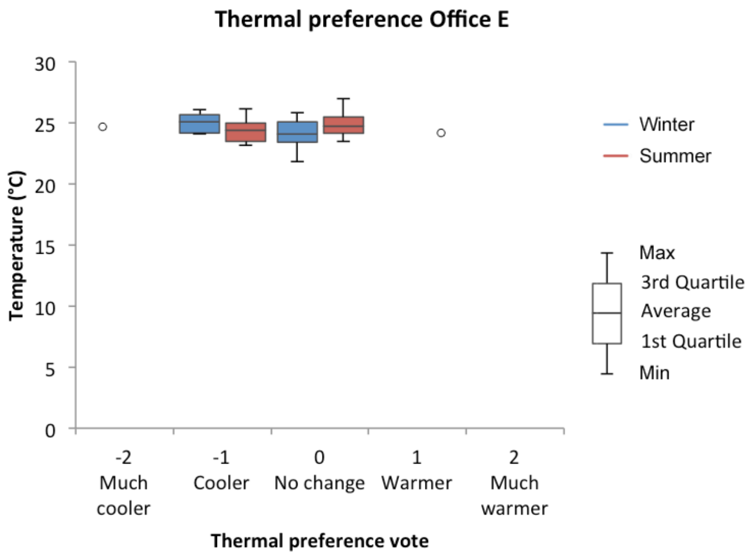


Figure E.8 Box-and-whisker plot of winter and summer thermal preference against temperature for office E.

Table E.8 Summary of winter and summer thermal preference votes and temperature for office E.

			Winter		
	-2 Much cooler	**-1** Cooler	**0** No change	**1** Warmer	**2** Much warmer
Number of votes	1	14	11	0	0
Average temperature (°C)	24.7	25.1	24.1	-	-
Minimum temperature (°C)	24.7	24.1	21.8	-	-
Maximum temperature (°C)	24.7	26.1	25.8	-	-
Standard deviation	-	0.8	1.3	-	-
			Summer		
Number of votes	0	3	19	1	0
Average temperature (°C)	-	24.3	24.7	24.1	-
Minimum temperature (°C)	-	23.1	23.4	24.1	-
Maximum temperature (°C)	-	26.1	26.9	24.1	-
Standard deviation	-	1.6	1.0	-	-

E3. Cross-case results

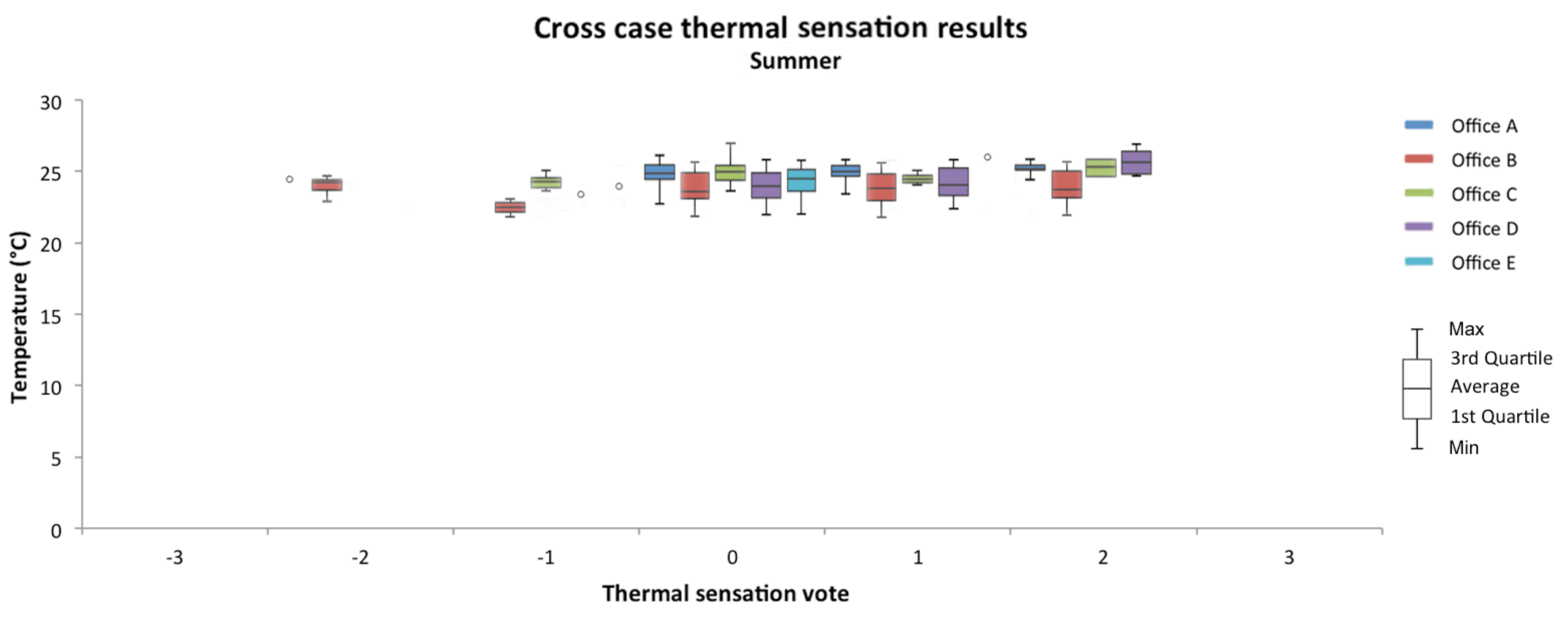


Figure E.9 Cross case thermal sensation box-and-whisker plot graph during a week in summer.

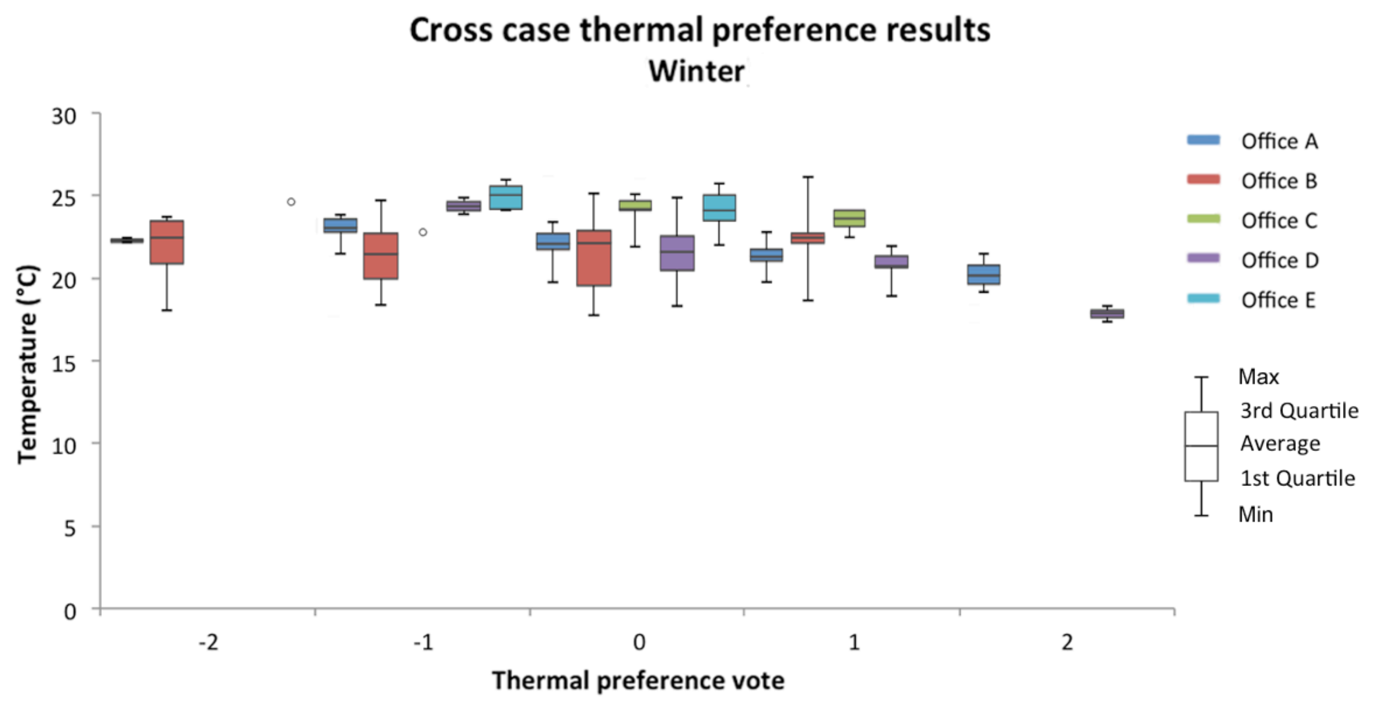


Figure E.10 Cross case thermal preference box-and-whisker plot graph during a week in winter.

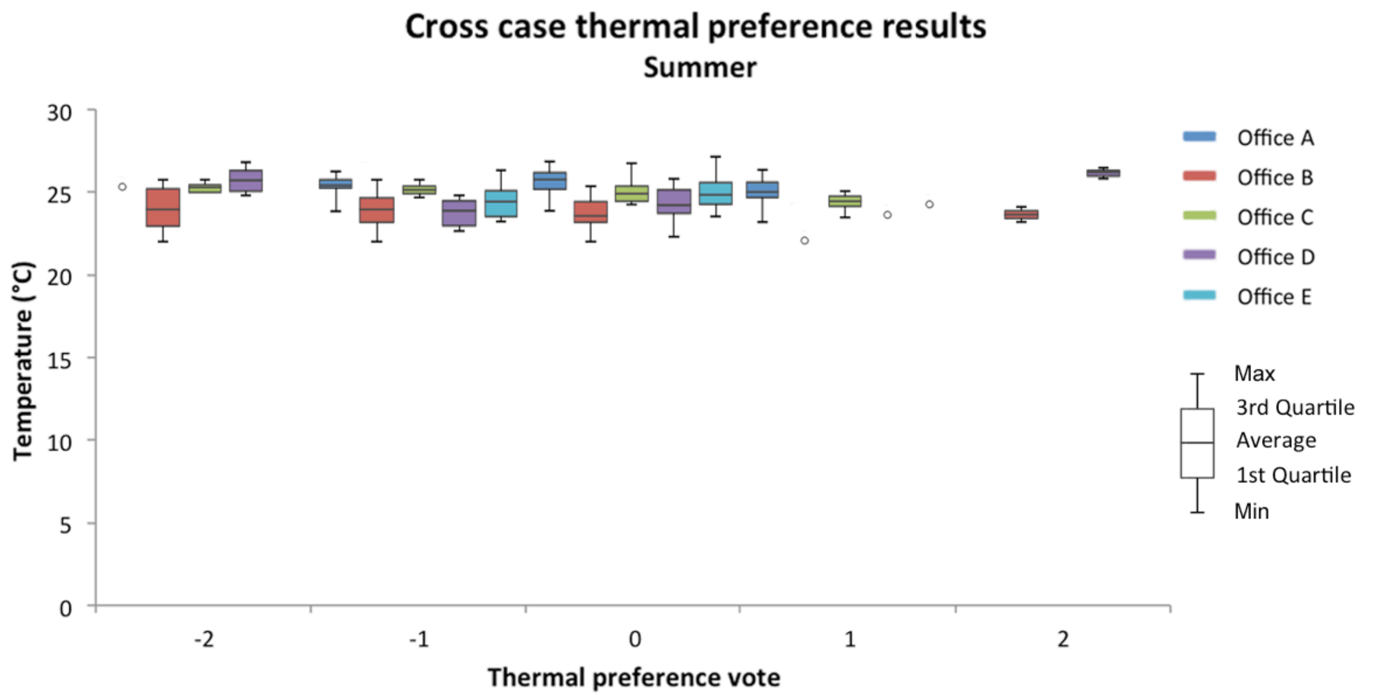


Figure E.11 Cross case thermal sensation box-and-whisker plot graph during a week in summer.