

Improvisatory Home Heating: The Gap between Intended and Actual Use of Radiators and TRVs

by

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Abstract

Ongoing modification and change is core to how domestic and built environments function. Thus occupants' domestication and development of home heating practices around low-carbon technologies is likely to exceed what building engineering sciences have the ability to plan ahead for. Yet, environmental policies and low-carbon industry approaches to sustainable energy consumption are characterised by a high degree of technological determinism. Disciplinary approaches to sustainable energy consumption tend to separate home heating into stable, routine interaction with control points, environmental factors and socio-demographic drivers. Framing low-carbon technical change in isolation from domestic environments often leads to a gap between intended and actual use of technologies. By focusing on TRVs (thermostatic radiators valve) and radiators, this thesis takes an interdisciplinary turn to jointly examine the social and environmental elements of households' energy use. A turn to sensory ethnography and 'practice-place' relationships offers a way to better understand how people use energy for space heating in relation to the buildings they live in and how improvisatory uses of technologies emerge from flows of material, domestic, sensory and physical contingencies of the home. Combining home video tours with building energy monitoring in eight homes, the thesis demonstrates that home heating is a 'place-event' of the home because heating systems and energy consumption are woven into the fabric of everyday life. Environmental elements show that the 'social' and 'technical' are inseparable in energy used for space heating and individual elements imply that the domestication of technologies is highly unpredictable. The thesis synthesises findings into a taxonomy table of irregular radiator and TRV use. On the one hand, irregularities indicate that improvisatory uses of technologies are productive sources of sustainable change because they can be potential sites for co-design. On the other hand, the interwoven character of the 'social' and 'technical' in households' energy use critically challenges how environmental policy, low-carbon industry and disciplinary approaches frame intervention into sustainable energy consumption. The thesis argues for the value of logic of intervention and sustainable change that is collaborative, system-focused and gradually uncovers interrelationships.

Key words: Low-carbon society, sustainable energy consumption, energy efficiency, low-carbon design, environmental policy, interdisciplinarity, technology domestication

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Introduction

Energy use in buildings has increased dramatically in recent years and the building sector is one of the main consumers of energy in Europe. Therefore, transforming the systems of energy supply and reducing energy use in buildings is key to minimising CO₂ output into the atmosphere. Home heating is an ordinary but fundamental activity in households' everyday life and it is a pressing challenge for Europe's energy security. In the UK, space heating accounts for the largest share of energy consumption in homes (Figure 1.). In 2012 it accounted for 66% of total consumption with water heating accounting for 16%, lighting and appliance use for 15% and cooking for 3%.

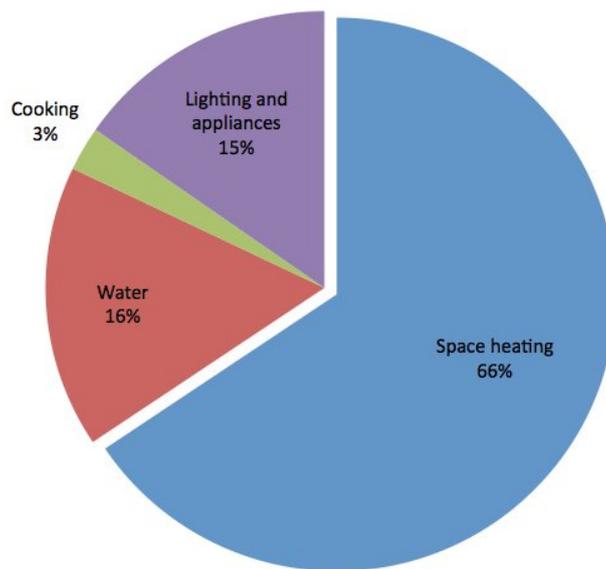


Figure 1. Energy Consumption in the United Kingdom, Domestic Data Tables, DECC 2013

The UK's Residential Building Stock

In 2013 there were 23.3 million dwellings in the UK, out of which 63% (14.8 million) were owner occupied, 19% (4.5 million) were privately rented and 17% (4.0 million) were rented from social landlords (DECC: 2011). Residential buildings in the UK can be separated into five building types, namely semi-detached, terraced, detached

houses, flats and bungalows. The housing stock distribution, illustrated in Figure 2, shows that semi-detached and terraced houses are the most common housing types in the UK, followed by flats and detached houses. In building energy consumption it is important to consider housing types because energy used for space heating is related to external wall surface as well as window and floor area. Detached houses have more external walls and windows, whereas flats typically have fewer compared to their floor area, leading to less heat loss in the winter.

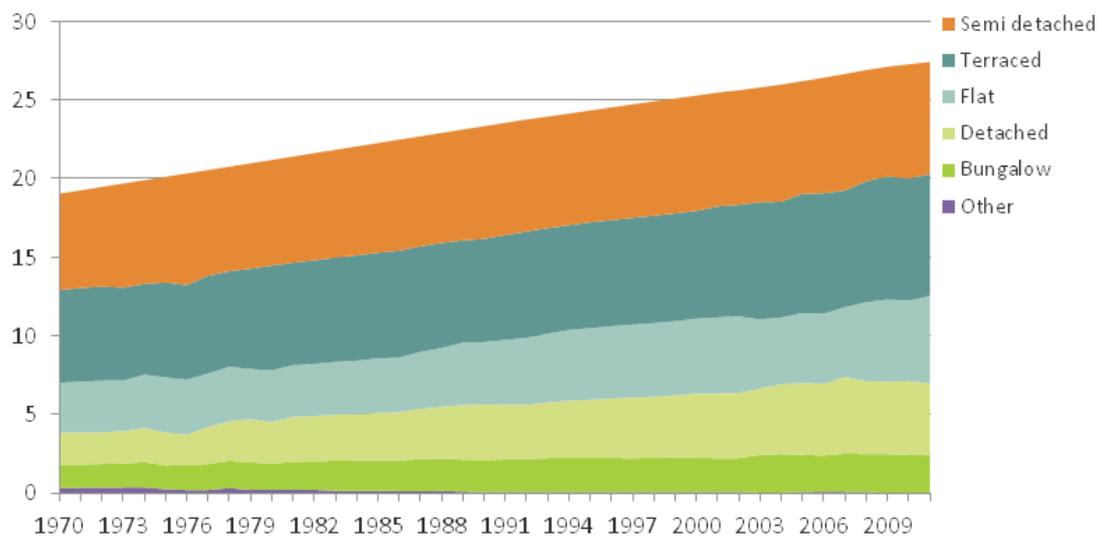


Figure 2 UK housing stock distribution by type (millions) (DECC: 2013)

In the residential sector, the age of the buildings is also strongly linked to energy consumption because older homes generally have poorer insulation and less efficient heating systems. Among the EU countries, the UK has one of the largest proportions of older buildings (BPIE: 2011). As illustrated in Figure 3, the majority of UK homes were built before 1975 (DECC: 2013). Therefore, energy efficiency improvements are key to reducing carbon emissions from the existing building stock.

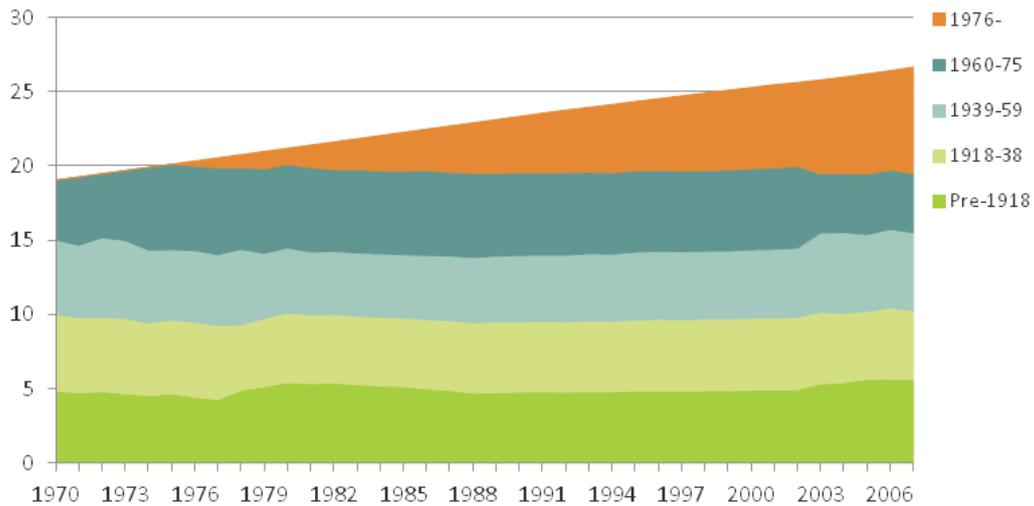


Figure 3 UK housing stock distribution by age (millions) (DECC:2013)

There is a growing need in building engineering sciences to link occupants' everyday heating activities to buildings' energy use and low carbon technological change in order to secure the sustainability of the domestic building stock. An increasing body of engineering literature documents that the domestic uptake of low carbon technologies is characterised by a high degree of uncertainty because technologically driven interventions often lead to a gap between the intended and actual use of technologies in everyday life contexts (Caird et al.: 2008; Stevenson et al.: 2010; Gupta and Dantsiou: 2015). This may significantly contribute to the 'building performance gap', a mismatch between the assumed and the actual measured energy use of new and retrofitted buildings. To date, insufficient attention has been paid to understanding low carbon technological change in everyday life contexts and variations in household energy use.

Low Carbon Technological Change in Everyday Life

Energy used for space heating is a joint outcome of occupants' activities and sensory experiences, the building fabric's condition, energy consuming systems and technologies (e.g. heating and hot water systems, lighting, appliances, micro renewables), and the local climate. In governmental energy policy initiatives and in the low carbon design industry, technological change in domestic environments is

often viewed as a linear, one-off technological adoption, followed by a complimentary behavioural change. Intervention in reducing energy use in homes is particularly challenging because home heating is not one unified practice. Space heating goes beyond number of heated hours, adjusting room thermostats or opening windows. Occupants' use of home heating technologies is highly interwoven with the everyday life as it is lived. Morning and evening routines, clothes drying or showering are all intertwined with how we heat our homes. Moreover, home heating is not only made up of stable routines and habits but more ad-hoc, improvisatory and irregular activities (e.g. use of supplementary heaters, erratic use of indoor spaces). Energy used for space heating in homes is inseparable from the body's sensory perception and surrounding physical environment. The body exchanges heat with the environment via radiation, conduction, convection and evaporation, making the relationship between home and built environments even more complex. Furthermore, home heating is also part of the aesthetic of everyday life in the home and of how we tacitly know, experience, navigate, sense and learn about our home environments.

Despite the interwoven nature of energy consumption and everyday life, environmental policy, building engineering and social science disciplinary approaches to domestic energy consumption tend to separate energy used for space heating into social and environmental factors. Energy consumption is either considered to be an outcome of socio-demographic drivers (income, number of occupants in households), of separate environmental factors (air temperature or relative humidity) or practices being made up of stable building control routines (e.g. thermostat settings). Less is known about how the 'social' and 'technical' elements of energy consumption interrelate in the flow of everyday life, and how the use of low carbon technologies develop in sensory, material, physical and social intersections of the home. This thesis therefore goes beyond separating 'technical' and social analysis of energy consumption. It moves away from taking practices as primary units of analysis for the elements of everyday life in forms of energy demand and comfort (Shove: 2008; Gram-Hanssen et al.: 2012). Instead, the thesis engages in a more system-focused approach aiming at understanding interrelationships between low carbon technological change, households' energy use and buildings' physical characteristics.

The thesis therefore turns to phenomenological anthropology and ethnographic knowing to understand domestic environments as constituted by multiple flows – people, material flows and immaterial resources – through the concepts of ‘place-making’ and sensory aesthetic of the home (Pink: 2007, 2012, Pink and Leder Mackley: 2014). These concepts put the interrelationships of place/environment, movement/practice and senses/perception in the centre of analysis and by doing that, they allow for disciplinary collaboration. Attending to the ongoing and emergent character of everyday life brings to the fore the open-ended ‘place-event’ (Massey: 2005) and ‘meshwork’ (Ingold: 2011) of home, where creativity and improvisation are at the core of how the everyday unfolds (Ingold and Hallam: 2007). Home becomes an adaptation in its own right because occupants are active agents who can make ongoing interventions as part of their day-to-day lives. ‘Making’ of everyday becomes an active correspondence between occupants and the built environment, bound together by movement, awareness and trace of materials (Ingold: 2010). In this thesis I show that correspondence is particularly important for understanding human activity and the built environment because it is reflective of the diversity and potentialities of the everyday as it is lived.

Energy use in buildings is a joint outcome of various non-technical and technical elements. Therefore, in the thesis, I aim to create an integrated framework that jointly accounts for these elements to better understand how we might work towards achieving sustainable energy consumption in homes. The approach I take here is interdisciplinary, in that it focuses on the ways in which the challenge of sustainable energy consumption has been framed in different scholarly traditions. Due to the interdisciplinary nature of this work it communicates to a range of different audiences. It may be of interest to building engineering professionals and energy researchers because it addresses the complexity of actual energy use, showing that a close collaboration with the social sciences is key to understanding how low-carbon technologies are implemented and taken up in everyday life contexts. It also communicates to social scientists because it opens up room for new collaborative potential between social science and engineering methodologies. In the social sciences, a growing body of literature is concerned with sustainable social and technological change outside of the ‘behaviour change’ and technologically driven models of interventions. The notion that energy is used as part of everyday practices

has opened up new directions for research seeking to understand how human activities come about, change and could become more sustainable. Departing from a focus on the continuity and ongoing nature of activities and their interconnectedness with the wider environment contributes novelty by capturing how irregularity, variation and unanticipated forms of change may unfold. Lastly, this work is of relevance to designers. I re-conceptualise the emerging gap between the intended and actual use of technologies by situating it as a product of relations between occupants and their built environment. Unanticipated uses of low-carbon technologies are often perceived as barriers to overcome because they cannot be scripted. But, as I argue, even though irregular uses of technologies might be unpredictable, they are valuable and productive sources of sustainable design and change because routine, everyday making of environments and unintended uses of technologies can be engaged for co-design.

Why Radiators and TRVs are Important?

I have chosen to focus on radiators and TRVs because the design of these technologies has not changed significantly over the past decades, although they are core to understanding how home heating activates are organised. Also, these technologies are mundane and often unnoticed in our everyday lives, and therefore, their role in domestic energy consumption is understated and rather taken for granted. There is a considerable amount of literature on occupants' use of home heating control, residential thermostats, window opening or uptake of home heating controls. Yet, how people actually use radiators and thermostatic radiator valves (TRVs) on the level of everyday life in relation to buildings is relatively unexplored. It is important to note that installing thermostatic radiator valves is now a legally binding practice for every new built and existing property with a boiler replacement in the UK (Planning Portal L1A; L2A: 2015). The normative expectation would be that installing thermostatic radiator valves decreases energy used for space heating by reducing overheating and increasing occupants' use of radiators across the home. While the *Green Deal* supported the uptake of underfloor heating and TRVs, radiators were excluded from the measures, although they are still the main source

of heat emitters in UK homes. There are three types of radiators, namely convectors, panel radiators and convection radiators, which are convectors with a front plate giving out radiated heat. Radiators emit heat through radiation but not through air movement or convection until the surface temperature reaches about 40°C. Convectors emit heat through convection and convection radiators emit a smaller part of heat through radiation. Due to the various ways heat is distributed in a room, we experience heat from radiators differently under different indoor conditions. And while radiators are fairly mundane in how we create and experience the comfort of the home, we interestingly all have a story to tell about them because they are essential to how we create and maintain the sensory aesthetics of our homes.

TRVs are designed to automatically adjust the amount of hot water by regulating the flow of water coming through the radiator according to the air temperature in the room. TRVs consist of two parts; the thermostatic head senses the surrounding air temperature around the valve body, whereas the thermostatic head regulates the flow of water in the radiator, which they are fitted to. There is a sensor in the thermostatic head that contains either wax or liquid material. This expands as the room temperature goes up and contracts when it cools down. The sensor is connected to a valve seat inside, which opens as the sensor expands and closes as the sensor contracts. When the TRV opens for more water to flow through the radiator, heat starts to be given out and when the TRV closes and limits the flow through the radiator, less heat is given out. TRVs have a range of temperature settings and are designed to save energy by allowing for individual rooms to be kept at different room temperatures or be switched off in unoccupied rooms. TRVs mostly have a range of numbers, where higher numbers provide more heat and lower numbers provide less heat in the surrounding area.

In this thesis I demonstrate that there is often a gap between the intended and actual use of radiators and TRVs. I examine questions related to how occupants bring this gap into existence and why some people are seeking to make changes from the intended uses. To do this, I draw on a series of sensory ethnography and building energy monitoring studies conducted in eight homes. I show that improvisatory use of technologies is central to how we go about our day- to-day lives (Ingold and Hallam: 2007). The concept of improvisation helps to move away from understanding

irregularity as a form of resistance, risk and unpredictability of human action, suggesting that it is more than a destructive mechanism that breaks down order and careful planning. I propose that we can use improvisation for our advantage if we situate it in relation to specific environmental, material, sensory and physical configurations.

Thesis Outline

By introducing the 'building performance gap' and critically discussing the *Green Deal* policy, **Chapter 1** presents a collection of engineering and social science literature to demonstrate that interventions in reducing domestic energy consumption are largely technologically driven. Energy consumption tends to be viewed in relation to purchase decisions and consumers' rational energy use, a way that does not capture the full reality of how people use energy in the everyday as it is lived. The chapter discusses research into the usability of home heating controls and future of 'smart' energy consumption, arguing that unintended consequences are central to technological change.

To review how the social sciences have engaged in sustainable energy consumption, **Chapter 2** introduces a collection of literature from the social sciences and starts by discussing critically the notion of 'behavioural change' in psychological approaches to sustainable energy consumption. It then gives an overview of the sociological 'practice turn' in energy research, to better understand how intervention into sustainable energy consumption has been understood in relation to the analytical categories of 'practices-as-entities' and 'practices-as-performances'. By turning to phenomenological anthropology and ethnographic knowing, the chapter turns to theories of place and senses to account for variations in households' energy use in relation to individual and environmental elements.

Chapter 3 introduces the nature and practice of interdisciplinary research and reflexively discusses the author's experience of interdisciplinary learning. By demonstrating that there are various routes to interdisciplinary knowledge, the chapter demonstrates that knowledge synthesis is not a uniform mode of doing

research. Rather, it is an evolving and gradually developing learning process that is open to knowledge sharing and methodological innovations.

Chapter 4 begins by introducing the methodological divide between the 'house' (quantitative) and the 'home' (qualitative) in energy research. It presents existing research that uses mixed methodologies of building energy monitoring and qualitative interviewing before presenting findings from a first-year pilot study. New methodological combinations (e.g. thermal imaging and home video tours), data collection phases, monitoring equipment and ethical considerations are reviewed.

Chapter 5 focuses on two 1930s semi-detached buildings' energy consumption. By jointly using video tours and monitored data, I investigate occupants' sensory experiences of radiant and convective heat, and introduce ways of developing TRV control and radiator use in relation to buildings. I show in the chapter that there is a continuous heat exchange between the body and its surrounding environment, which demonstrates that the 'social' and 'technical' elements are inseparable in occupants' domestication of home heating controls and in a building's energy consumption.

Chapter 6 focuses on the underlying individual elements to understand how the body engages in improvisation in the actual moment of movement. By looking at how occupants learn about their heating systems, air temperature and indoor climates we can see that home heating activities are deeply rooted in the non-verbal and interconnected human senses. The chapter presents a set of individual elements (hybrid cultural identity, risk perception, memory or knowledge of scientific facts) to demonstrate that occupants can connect to the movement they create, which makes improvisatory movement a unique event. Individual elements show that the place-event of home is about 'correspondence' and about making everyday life advancing rather than repeating. However, this processual and ongoing change of home environments makes the development of new practices around low-carbon technological change highly uncertain.

Chapter 7 shows that improvisatory performance of home heating can be a productive source of sustainable change. Home heating goes beyond stable routine interaction with control points and always involves a certain degree of improvisation. Irregular control of TRVs and radiators is relational and irregularity arises from a complex interrelationship between the sensory, material, domestic and physical

environment of the home. Improvisatory home heating and irregularity can have four characteristics: they are co-creative of the home's sensory aesthetics; integrative of the building fabric's and heating system's shortcomings; they can cluster other domestic practices; they communicate problematic design. Intersections are crucial sites for learning and they imply that technological change is not a one-off intervention, because use alternatives are always in the process of making.

Chapter 8 synthesises findings from the earlier chapters. It introduces an integrated taxonomy table of irregular TRV and radiator use, and discusses the implications for environmental policy and low carbon design. Furthermore, the chapter argues that improvisatory uses of home heating technologies and the gap between the intended and actual use of low carbon technologies can be taken advantage of because irregularities are productive sources of sustainable change.

Review of Literature

1. The Counter Productivity of Technologically Driven Interventions

Introduction

This chapter brings together literature from the engineering and social sciences to show that environmental policy and low carbon industry approaches to sustainable energy consumption are still dominantly techno-centric in character. I argue that technologically driven interventions do not take into account how people use low-carbon technologies on the level of everyday life, and that a more active engagement is needed from the social sciences to understand better the long-term effects of technological change. In particular, unanticipated uses of home heating controls have been documented for over three decades. However, the gap between the intended and actual use of home heating controls is often attributed to consumers' lack of knowledge or irresponsible energy consumption habits. I begin the chapter by introducing the building performance gap and the *Green Deal policy*, the UK government's initiative for encouraging owners to improve the energy efficiency of their homes. I then challenge the normative standpoint in environmental and energy policy, which views householders as rational actors and conceptualises energy consumption as a matter of choice people make.

By bringing together a collection of literature on the use and usability of domestic heating controls, I show that low-carbon design plays a key role in reducing energy consumption and home heating technologies should be designed to harmonise better with user's everyday lives. Smart energy consumption by automation is expected to restructure households' engagement with energy consumption, and intelligent control systems are projected to make occupants develop rational and efficient practices. But, as I argue in the last section, the domestication and use of low-carbon systems and products in everyday life is not a straightforward and

calculable process. By introducing empirical studies, I show that technologies may be used in ways that are not anticipated by their designers. Literature from the social sciences has been showing that the gap between the intended and actual use of technologies is not a source of risk or form of 'irresponsible' consumption, but an emerging process that is inherent to the nature of technological change. Therefore, environmental policy and low carbon design should open up to a wider range of social science approaches to understand better how unanticipated uses emerge, and what they might mean for the transition to a low-carbon society.

1.1 The Building Performance Gap

There is fast-growing concern in the building industry, that low-carbon housing policy can be negatively affected by what has been termed the 'building performance gap'. The performance gap refers to a discrepancy between the predicted and the measured energy use of new, and retrofitted buildings (Sharpe: 2013). It makes the building performance gap difficult to tackle, that we cannot address it through a single factor. A residential dwelling's energy consumption is always a complex and joint outcome of the local climate, building fabric and size, heating system efficiency and the occupant's sensory experiences and domestic activities. Literature on the energy performance gap suggests that there are various contributing factors to why a building may perform differently than anticipated. Predicted in-use performances of buildings can be based on ideal behavior of construction materials, which assume high standard system installation under specific conditions (Topouzi: 2013). The gap can also come from inconsistent communication and coordination between contractors and the design team, incorrect installation or unclear labelling of heating and ventilation controls (Gupta et. al.: 2013). Also, another source of discrepancy may be that actual building use does not match assumptions made during the design process. For instance, buildings can demand higher temperatures than originally anticipated at the design stage (Gill et al.: 2010) and heat energy savings achieved through retrofit measures can also be remarkably lower than calculated. Moreover, houses with similar characteristics can also have significantly different theoretical

and actual energy performances (Haas and Biermayr: 2000; Gupta and Chandiwala: 2010; Audenaert et al.: 2011).

A growing number of empirical research into evaluating building performance shows that occupants play a significant role in the energy performance of buildings (Brown and Cole: 2008; Gram-Hanssen: 2014). As Janda (2009) notes, buildings do not use energy, people do. De Wilde and Jones (2014) suggest two important issues regarding the performance gap. Firstly, the building performance gap evaluation is merely based on non-domestic buildings. Secondly, the actual building use is not well understood, because deterministic measurements do not take into account occupants' use of controls. Therefore, observing occupants' use of buildings would be of crucial importance, especially because energy predictions tend to standardise building use at the design stage.

Traditionally, building performance used to be carried out by physical monitoring or occupancy satisfaction surveys, but at the present time, the need for methodologies that are able to evaluate building energy use 'in use' is growing. Buildings are rarely studied systematically and this may lead to unintended consequences such as repeated design mistakes or lack of standard protocol in performance evaluation (Meir et al.: 2009). Moreover, a growing body of work recognises the value of methodological combinations. Evaluation should combine qualitative and quantitative methodologies that simultaneously attend to the social and technical dimensions of building energy use. Methodologies focusing on energy use should effectively evaluate materials, technology innovation, the construction process and occupants' actual activities (Sharpe: 2013). Stevenson and Leaman (2010) investigate the actual use of a 'zero-carbon' house prototype. They emphasise that assessing building performance in use should evaluate the physical, social and design factors in relation to each other. They conclude that collaborative, multidisciplinary approaches - that involve mixed qualitative and quantitative methodologies such as walkthroughs or video interviewing - can deliver more in-depth insights into occupants' actual use, experience and understanding of their homes.

Gupta and Chandiwala (2010) evaluate occupant feedback in the management and design of low-carbon and whole-house refurbishment in order to narrow the building performance gap. They argue that collecting feedback before the refurbishment

stage can be valuable to the design team, the clients and the occupants. Feedback should combine physical monitoring and energy assessment to reveal variations in buildings' energy use in real life context. Briefing requirements should cover technical and occupant perspectives on comfort, satisfaction and expectations. Similarly, Gupta et al. (2015) share some lessons from the *Retrofit for the Future Program*, which targets the social housing sector. They carry out a systematic evaluation of 86 dwellings. Each project combines short-term physical tests of the building fabric, post-construction review of construction quality, long-term physical monitoring of energy consumption and standardised post-occupancy evaluation of occupant experiences. Although the project used a holistic 'whole-house' approach, it was technologically focused, driven by physical energy models. Social dimensions were either marginalised or not addressed at all. They suggest that future programmes must adopt an approach that simultaneously takes into account the social and technical dimensions of energy use to better understand the relationship between buildings and occupants.

We learn from the engineering literature that building energy consumption is a joint outcome of social and technical elements and that evaluating building energy use 'in use' lacks interdisciplinary evaluation methodologies. Most building evaluation methodologies are based on technical and demographic surveys, or assessments of psychological factors (e.g. environmental attitudes or values). However, these methodologies cannot deal with the uncertainty of low-carbon technological change because they do not pay attention to how built and domestic environments intersect. Therefore, new and innovative methodological approaches should focus on in-use performance of buildings to bridge the gap between the technical and social dimensions of building energy use. The next section reviews how UK residential energy policy and low-carbon industry have been engaging with the social dimensions of sustainable energy consumption and technological change.

1.2 The Failure of Green Deal Policy

The *Green Deal* (GD) policy entered into practice in 2013 January and stopped being funded in May 2015 due to households' low uptake of energy efficient

measures. The GD applied to non-domestic and domestic properties. In the domestic sector, it was expected to drive a new market to improve energy efficiency. It was a private sector finance mechanism that removed upfront cost barriers for energy efficiency measures that were later repaid by energy savings. The cost of retrofit was attached to the property and not the occupant. The loans were supposed to be paid back by electricity bills and would have been collected by the energy suppliers and later returned to the GD provider. Energy savings were assessed against the 'golden rule', which assumed that expected savings would exceed the payments for installed measures (DECC: 2012a). The ECO (*Energy Company Obligation*) ran alongside the GD to bind large energy suppliers and companies to support domestic energy efficiency for more disadvantaged social groups. ECO replaced previous initiatives such as CERT (Carbon Emission Reduction Target), CESP (Community Energy Saving Programme) and the Warm Front Scheme. CERT and CESP both expired in December 2012 and the Warm Front Scheme provided the upfront costs for low-income private and rented households. GD providers offered energy efficiency measures to occupants, combining upfront cost from both ECO and GD financing. GD covered forty-five technological measures, including insulation (solid wall, cavity wall or loft insulation), heating and controls, draught proofing, double glazing and renewable energy generation.

The GD has received a high level of critical attention from engineering and environmental policy research because it was technologically driven and marginalised the complexity of building energy use. It assumed that technological innovations automatically reduce energy use on the level of everyday life, and domestic energy consumption is a simple technical challenge. Rosenow and Eyre (2012) argue that the GD considered cost and householders' decision-making to be the primary - and almost only - barrier to the uptake of energy efficiency measures. Consequently, the GD did not overview comprehensively account for the way people use, understand and relate to low-carbon technologies. It largely defined refurbishment and sustainable energy consumption by economic and technical terms (Rosenow and Eyre: 2013). Generally, retrofitting the existing building stock in government policies has been seen as a comprehensive, one-off technological step that is expected to automatically reduce energy use (Fawcett: 2011). Furthermore, paying back the cost of energy efficiency investments tends to be based on

estimated rather than actual energy savings (Dowson et al: 2012). In essence, the failure of the GD indicates that domestic energy use goes beyond financial incentives and householders' purchase decisions. Energy policies should capture the social dimensions of domestic energy use instead of neglecting important details on low-carbon technological change.

1.3 The Controversy of 'Ethical' Energy Consumption in Everyday Life

It has been a normative standpoint to view householders as rational actors in the UK's energy efficiency policy since the 1970s (Mallaburn and Eyre: 2014). Economic approaches to resource consumption assume that people are rational actors, they know their best interest and they act based on that knowledge. Environmental and climate change policy frameworks on social change and sustainable energy consumption have been primarily influenced by economic and psychological disciplinary approaches. But these approaches limit the understanding of consumption processes on the attitude, behaviour and choice model of individuals (Shove: 2010). Behavioural economics in residential energy consumption generally focuses on three areas, namely curtailment and lifestyle of occupants, investment decisions in energy efficiency, and pro-environmental behaviour. It is a model of social change that proposes a linear relationship between pro-environmental behaviour, environmental knowledge and householder's awareness. Moreover, this model assumes that consumer education directly translates into awareness, encourages pro-environmental behaviour and brings about energy saving actions. Because this model focuses on individuals, individual responsibility has been conceptualised in climate change campaigns and in relation to social change towards sustainability as a duty to act upon (Bovens: 2012). Environmental policy frameworks are based on the idea that people as consumers are accountable for a significant proportion of the environmental pressures. Therefore, they must make the 'right choices' by regulating their consumption ethically, rationally and instrumentally. Much of the academic and policy discourse on changing attitudes and behaviours generate the impression that there is a coherent vision on what people ought to be

changed to (Owens and Driffill: 2008) and what the future of a low-carbon society should look like. Psychological approaches to consumption embrace the idea of how to 'fix' individuals, suggesting that consumers are irresponsible, excessive in their consumption habits and if they could behave everything would be fixed (Bovens: 2012).

Furthermore, there tends to be a binary formulation between ethical and non-ethical consumption, but the definition of these terms in relation to everyday life is rather problematic. Pellandini-Simányi (2013) argues that the 'ethics' of ethical consumption is contradictory because discourses of ethical consumption set different normative standpoints. From an environmental perspective, consumption is conceptualised as irresponsible and destructive both practically and morally. From an everyday point of view ordinary consumption sustains and reproduces values of everyday life that are essential in maintaining the notion of care, home and family. Normative standpoints and the definitions of ethical consumption emerge partly from local ethical traditions that are biased towards particular groups, and by doing that, they make it impossible for some to become an 'ethical' consumer. Another binary formulation is central to the notion of environmental responsibility. As Fontenelle (2013) argues, consumers tend to be portrayed as irresponsible and engaged poorly morally with their consumption habits. The two key players in 'fixing' environmental and social challenges are science and technology and the growing role of companies. In this loop, consumers play a vital role in turning to a more responsible consumption by purchasing the right products from the right companies. Akenji (2014) calls this binary formulation between sustainable and unsustainable consumption "consumer scapegoatism" arguing that 'green consumerism' opens up the definition of 'green' merely to be shaped on the production side. Moreover, a number of empirical research studies problematise the assumption that ethical consumption is a simple matter of choices people make. Discourses on ethical consumption often fail to address the complexity, mechanisms and dilemmas people face on the level of everyday life (Conolly and Prothero: 2008, Adams and Raisborough: 2010; Gibson et al. 2013).

We learn from the literature, that there is a controversy between ethical energy consumption and energy consumption in everyday life. Consumers are not rational actors or 'passive dopes' as Slater (1990) argues. Rather, energy consumption

should not be separated from everyday life because “social agents skillfully use resources (language, things, images) to deal with their needs” and consumption “necessarily involves reinterpretations, modifications, transgressions – and can be used to culturally challenge as well as culturally reproduce social order” (Slater: 1990: 148). Therefore, recognising that social agents are active players in the process of consumption is not enough, because actions are shaped in various other ways such as by structures of power, social relationships or the design of technologies. The next section therefore continues by introducing a body of literature on the design, use and usability of home heating controls

1.4 The Usability of Domestic Heating Controls

There is high potential to improve the energy efficiency of the residential building stock using advanced heating controls, but up until today, little is known about how occupants use controls on the level of everyday life in relation to the buildings they live in. The earliest study that notes problematic usability goes back to the 1980s. Kempton’s (1986) ethnographic study shows that there is a gap between the occupants’ intended and actual use of home heating controls. His observations reveal that people develop their own ‘folk’ theories on how home heating controls work. Folk theories do not reflect on institutionalized scientific knowledge, they develop based on word of mouth or users’ experiences from day-to-day interactions with systems. He explains that people build relations between object and actions through experience so they can conceptualise very differently why a house, for instance, maintains a steady temperature or why a higher thermostat setting is commonly thought to indicate faster increase in room temperature.

Evaluation of controls is key to determining whether they are operated effectively in regulating building systems. However, environmental control systems are typically not well integrated (Bordass et al: 2007), and occupants do not use them if they are hard to understand (Leaman and Bordass: 2007). This can affect the energy consumption of a building. Stevenson et al. (2013) test the usability of heating and hot water controls in two newly built low-carbon housing development in the UK.

They focus on the relationship between usability and occupant's practice, and note that the most common usability issues come from the lack of hands-on demonstration, poor access, or inaccessibility of controls. These usability issues also imply that, generally, there is failure to communicate design intent to users.

Another group of study on home heating controls focuses mainly on residential thermostats. Meier et al. (2010) use interviews to study modern programmable thermostats. They conclude, that they are complicated and difficult for users to understand. People may also use programmable thermostats in unanticipated ways such as an on and off switch, which can lead to errors in operation alongside wasted energy. Similarly, Combe et al. (2011) focus on digital programmable thermostats and they reveal that elderly users may get frustrated with experiencing difficulties when programming heating controls. As a consequence of dissatisfaction, many users in the study opted for not using these products, reducing the potential to heat their homes efficiently. They also argue that designers, for instance, often do not consider users' visual abilities or the needs of elderly people during the design process. Peffer et al. (2011) suggest that users often get confused about residential thermostats due to complexity, small size of buttons, unknown symbols and the multiple steps needed to program the device. While some people are afraid to touch the thermostat others prefer having daily manual control over their heating system.

Karjalainen (2009) compares thermal comfort in Finnish offices and homes. His findings indicate that occupants in offices are often dissatisfied with the thermal environment and control options because thermal comfort levels in offices tend to be lower. In homes, when occupants feel hot, opening a window is the most common action performed as a response to thermal discomfort, whereas windows are often not openable in offices. Karjalainen (2012) also suggests that there are gender differences in thermal comfort because females express more dissatisfaction with the same everyday thermal environment than males, especially in cooler conditions. Therefore females have more need for individual temperature control and adaptive practices. Lastly, Meier (2012) observes a number of 'folk labels' around the world on heating and lighting controls in public and private buildings. In hotels it is often possible to find a regular interface with a folk label, guiding guests how to operate the controls. He calls these folk labels signs of problematic operation that implies design failure.

We learn from these empirical studies, that various usability issues have been documented over the past decades. The enduring presence of these usability issues in low-carbon design indicates, that less is known about the actual use of home heating technologies on the level of everyday life in relation to buildings. Usability after domestic retrofits is generally surrounded by a lack of feedback and knowledge that makes designers' decisions badly informed (Heaslip: 2012). Also a growing number of research studies recognise that mass-produced prototypes assume ways without rich insights into how people engage and interact with products and systems (Jeppesen and Molin: 2003; Franke et al.: 2010). Consequently, design and installation of technologies have so far marginalised the social dimensions of everyday life, and from the perspective of design, there is a growing need for scenarios that pay attention to individual variation. Therefore, it is important to better understand households, in order to explore ways in which design can synchronise with everyday environments and open up different forms of technology use (Roy et al: 2007, Redström: 2008, Haines et al.: 2012).

To summarise, the literature review on the use and usability of home heating controls suggests that the design of home heating technologies has overlooked the diverse needs and everyday life of households. In order to design home heating controls that do not emerge against the background of everyday life, design requires a deeper understanding of the complex interplay of factors relating to occupants' use of home heating technologies in relation to the buildings they live in. Furthermore, most usability studies on home heating controls focus on room thermostats but not much is known about the use of TRV and radiator in relation to buildings.

1.5 The Promise of Automation and Smart Energy Consumption

The concept of smart consumption has come to indicate profound changes in the way occupants engage with buildings on the level of everyday life. Smart phones, tablets and PCs offer non-stop network connection for more sophisticated resources and solutions to manage energy use in buildings. Making a home 'smart' includes

four elements. A smart home should have a communication network by which various devices can talk to each other, intelligent controls for managing the system, sensors that collect information and remote control (Scott: 2007). However, making home environments 'intelligent' is a vision that has been around nearly three decades. Yet, environments that offer the full range of intelligent ICT-based energy management solutions are not yet tested in everyday contexts (Paetz et al.: 2012). There are two frequent concerns in the engineering literature regarding heating, ventilation and air conditioning automation. The first is central to the promise that automation eliminates energy waste by reducing the potential for human error. The second questions whether sustainable energy use can be achieved if smart home controls are designed without user diversity and everyday complexity in mind.

In engineering and technical literature, smart technologies are designed to learn, manage and replace decision making on behalf of consumers. (Wilson et al.: 2013). Automation is considered a tool that frees people from the potential of making errors by reducing personal autonomy over manual control and repetitive tasks. However, the right balance between automation and manual control is not well understood yet. Hamill (2007), for instance, challenges the assumption that smart devices should be as human as possible. He argues that smart automation may be counterproductive because people want to be freed from repetitive tasks as much as they want to stay in control. The right balance should be found between the independence of the machine in the home and manual control. Lewis (2011) notes that a user can get confused over why, for instance, his boiler is not running when it should be. Therefore, a system may be more understandable if it could explain its automatic behaviour in a way that it makes sense to the user. Furthermore, realising energy efficiency gains through smart home technologies has not been fully explored yet, due to the complexity and diversity of systems, badly engineered and configured installations and suboptimal control strategies (Reinisch et al.: 2011). As Baxter et al. (2012) argue, the irony of automation partially comes from the process of system development that is still largely driven by technical engineers. It lacks interdisciplinary inputs from a diverse range of social science disciplines, which could bring vital perspectives to the development process.

Strengers' (2013) work reveals that unlike earlier assumptions, automation is not turning out to be a passive 'bystander' in everyday practices, indicating that

integrating automation into everyday practices is unlikely to be seamless and unproblematic. The promise of automation, she argues, is based on a unified view that economics, engineering and computer science have jointly pictured for the future of energy consumption. She calls this imaginary “smart utopia”, where the old irresponsible and wasteful energy consumers are “fixed” by smart technologies and are able to act in a rational, functional and instrumental manner to exercise full control over their environment. She calls the industry-envisioned consumer “resource man”, who is characterised to be male, well educated, rational and tech-savvy. However, a future of an efficiently and rationally managed time-saving domestic life and energy consumption might be unrealistic to fulfil. Similarly, Hargreaves and Wilson (2013) argue that low-carbon industry’s vision for smart consumption is isolated from the everyday life of energy consumption. They show that there is a gap between the academic research and the industry representation of smart home consumers. They suggest that the industry does not differentiate between categories of users, and it represents everyday life as being made up of stable routines that do not change. Therefore, smart consumption needs further elaboration to include the nature and circumstance of how devices and technologies are taken up and used on the level of everyday life.

1.6 The Unintended Consequences of Technological Change

Energy strategies generally assume that society is subject to a linear process of improvement, and that one-off interventions deliver the expected rate of energy reduction. According to Caird and Roy (2008), the energy efficiency market is dominated by a techno-centric model of innovation that views consumers as ‘rational actors’ who have set preferences, make decisions instrumentally and start using energy saving technologies efficiently once they are aware of the environmental and financial benefits of products and services. A growing number of empirical studies suggest that occupants’ use of low- and zero-carbon technologies in domestic

environments is not scriptable. People can take up and use products and systems differently than anticipated by the designers.

Hyysalo et al. (2013) examine user modifications, hacks and add-ons for heat pumps and wood pellet burning systems in Finnish homes. They find that most “user inventors” explore locally appropriable possibilities and incorporate facets that mass products neglect, even though they would give clear benefit to users. They find 192 inventions or modifications (e.g. inventing part and sub-systems or adding self-made controls) that based on the evaluation of technical experts, improved either the efficiency, suitability or usability of the heat pump. Behar (2014) investigates how occupants engage in using ventilation technologies through components like boost switches, trickle vents, windows, doors and extract fans in low carbon social housing schemes. Her work challenges deterministic views that changing the type of ventilation in homes automatically reduces energy use. Ventilation practices are inseparable from the wider domestic environment of the home and are “tied to” mundane objects such as curtains, wardrobes or pets and insects. The REFIT (*Personalised retrofit decision support tools for UK homes using Smart Home technology*) project also challenges deterministic views pointing out that the relationship of technologies and practices are not linear and calculable (Hargreaves et al.: 2014). Occupants’ adoption or rejection of ICTs is subject to a range of non-linear relationships between technologies and user practices. Similarly, Henning (2005) discusses the significance of gendered spaces in relation to the location of pellet burners in Swedish homes. The acceptance of the location of pellet stoves and boilers might be problematic if it interferes with the domestic order of the household or reduces the aesthetic attractiveness of a living room. Gender neutrality and stereotypical view of users in low-carbon design has also been a re-occurring problem (Clancy: 2008). Offenberger and Nentwich (2013) show that sustainable heating technologies and their market distribution continuously reproduce gender inequalities by proposing gender scripts. Masculinity is often neutralised as economic rationality, independence, power and control, while femininity is interwoven with discourses on vulnerability, care, responsibility, solidarity and comfort.

We have learnt from the literature review in this chapter that low-carbon design has been critiqued in the past for being over-deterministic and over-optimistic on the role of technological fixes. I have shown that social science disciplines are still marginalised, indicating that low-carbon design and energy research is still more technology than problem oriented (Sovacool et al.: 2015). We have also learnt that visions on low carbon futures propose conflicting normative standpoints. Governmental discourses on ethical energy consumption create a conflicting tension between ethical consumption that places environmental responsibility on the individual and ordinary consumption that sustains everyday life. On the contrary, low-carbon industry proposes a vision of smart consumption where householders will not have to adjust their energy consumption habits because the smart environment will take care of repetitive tasks, learn users' behaviour and do the thinking for them (Oksanen-Särelä and Pantzar: 2013). Underlying these conflicting visions, empirical evidence suggests that there is often a gap between the intended and actual use of low carbon technologies.

In the social sciences, 51 years ago, Jacques Ellul (1964) critiqued the linear assumption that the application of technologies makes human practices rational, calculable and efficient. He notes that there is often a "misfit" between technologies, societies and everyday life and describes the gap between intended and actual use of technologies as something inherently unavoidable. "Technique" he writes is "the means of apprehending reality of acting on the world that neglects all individual differences, all subjectivity" (1964: 131). The rigorous objectivity, he argues, does not take into account that adaptation is always present in technological change. Similarly, Tenner (1996) argues that technologies can "bite back" and they always have side effects, opposite results or unintended consequences. Tenner suggests that more consideration is needed to the environment of application because:

"If we learn from revenge effects we will not be led to renounce technology but we will instead refine it: watching for unforeseen problems, managing what we know are limited strengths, applying no less but also no more than is really needed (1996: 15)."

These early sociological accounts of technological change show that technologically-driven interventions are likely to fail because they put forward technology as a autonomous force that rationalises practices. However, technologies are never value

free and they cannot pre-script the development of practices because technologies are not taken up in isolation from lived environments. Moreover, if unintended consequences are “inherently unavoidable” then it is inevitable to better understand why so often low-carbon technologies emerge against the background of everyday life, how the gap between intended and actual use of technologies develops and what it means for sustainable innovation and social change.

Conclusion

Based on the reviewed literature, it can be concluded that there is a high degree of technological determinism in energy policy and low carbon industry approaches to sustainable energy consumption. Both approaches view technologies as autonomous forces that either rationalise practices after take-up, or eliminate human error in repetitive daily tasks. These approaches equate technological change with social change. As we have learnt from the literature, this view of sustainable change isolates social contexts and everyday environments from energy consumption. The GD narrowed down energy use in everyday life and interaction with domestic heating systems into purchase decisions and uptake of new products and technologies. The discourse of ‘behavioural change’ in governmental sustainability dialogues addresses the concept of ‘rational energy use’ as a normative standpoint in ‘ethical’ energy consumption, assigning environmental responsibility to the individual. I have shown in the technical literature that there has been a lack of user centred practice in low-carbon design for over three decades and both governmental and industry approaches to sustainable energy consumption attempt to reconfigure the way occupants use, understand and relate to low-carbon technologies. This is counter-productive because pre-scripting how people take up and relate to novel technologies does not accommodate a wide range of social realities on how people use technologies on the level of everyday life. Rather, it pre-defines technological solutions without fully understanding the nature, complexity and variation in households’ energy use. Empirical studies on the usability of home heating controls has clearly demonstrated that there is a lack of systematic and collaborative evaluation that simultaneously accounts for social and technical dimensions in

building energy use. As a result, there has been a limited understanding of technological change on the level of everyday life. This implies that UK energy policy and low-carbon industry approaches have been overlooking inherent uncertainties of low-carbon technological change. The next chapter therefore discusses how various social science approaches have been engaged in the problem of sustainable energy consumption. It also situates how the present thesis departs from the existing social science theories.

2. Social Science Disciplinary Approaches to Sustainable Change

Introduction

In this this chapter I bring together a collection of literature from the social sciences to show how various disciplines have framed interventions into domestic energy consumption and social change. The chapter starts by introducing the notion of behavioural change in psychology before it moves on to review energy feedback techniques and smart metering, which is currently the UK government's main initiative for reducing energy consumption in the residential sector. The review then draws on empirical studies from sociology to discuss critically the effectiveness of these interventions. By introducing the sociological 'practice turn' in energy research I present how intervention in sustainable energy consumption has been understood in relation to routine habits, social norms and larger infrastructural relations. There is no unified practice theory approach in social sciences (Schatzki: 2001), because practice theory is based on a diverse body of theories taken from the disciplines of philosophy and sociology, as well as cultural studies and science and technology studies. Therefore, the collection presented herein outlines the core concepts taken from this body of theory. After presenting an overview of social theories of practice, I introduce the analytical separation of practice as entity and performance. I show that domestic energy research has focused mainly on how entities configure performances on the household level. I argue further that understanding technological change and energy used for space heating in households requires an interdisciplinary understanding of how practices develop and change in relation to buildings. Research into social practice in energy studies typically does not use anthropological methods so I therefore review the anthropological framework of technology domestication showing that despite the critical attention paid by practice theoretical approaches, the framework still has enduring relevance to understanding how practices change. Lastly, to account for the development of practices around new technologies in relation to buildings, the thesis turns to theories of space (Ingold:

2011), to the concepts of 'place-event' (Massey: 2005), 'place-making' and the 'sensory home' (Pink: 2012). By building on the concept of improvisation, I establish a more relational understanding between place, irregularity and creative engagement with technologies, and I show that improvisation can be a productive source of sustainable change, because it is a potential site for co-design.

2.1 Behavioural Approaches: Energy Feedback and Smart Meters

Behavioural approaches to energy consumption seek to improve building energy use by integrating systems and people. The primary intervention point involves motivating occupants to adopt energy conservation attitudes and practices. Current efficiency strategies for encouraging behavioural change, and for integrating conservation practices, recognise that energy is largely invisible in modern societies, i.e. for most people the only visible sign of their energy use is a monthly aggregate bill where consumed energy is translated into monetary units, without revealing detailed information about its use. Increasing transparency in energy consumption via feedback techniques is an educational intervention directed at facilitating awareness and a more active and participatory way of using energy.

Feedback techniques generally assume that raising energy literacy leads to higher levels of energy consciousness and energy efficient behaviour, which translate directly into energy conservation. However, empirical studies of behavioural intervention and feedback techniques show varying degrees of success. Darby (2006) assesses how feedback can influence behaviour and identifies four factors that are crucial in effectiveness: general context, the scale and timing of usage, synergies between feedback and other forms of information as well as timing. She concludes that immediate direct feedback is potentially the most useful tool for generating energy savings, albeit it is essential to take into consideration the context of the household. Fischer's (2008) findings suggest that interaction and choice may become a source of motivation in reducing consumption and that longer-term feedback may be more effective in shaping energy conservation habits in

households. Generally, there are five types of feedback distinguished in home energy use, namely direct (self-meter reading, direct display, etc.), indirect (more frequent bills etc.), inadvertent (community energy conservation projects), utility-controlled feedback (smart meters) and energy audits (undertaken by a surveyor on the client's initiative or carried out on an informal basis by using freely available software) (Darby: 2006). The various types of feedback techniques suggest that effectiveness and ineffectiveness are not straightforward concepts, because they depend on several other contextual factors. And that is partially the reason why the success of smart meters has been delivering ambiguous results in reducing domestic energy consumption.

The UK government has introduced a plan for every home in Britain to be equipped with electricity and gas smart meters by the end of 2020 (DECC: 2012a). Smart meters send meter readings electronically from households to energy companies, thereby eliminating the need to carry out actual meter readings, because they are linked wirelessly to energy monitors. Based on energy display units, householders can see the cost of their own energy use when, for instance, appliances are on around the house. Although smart meters provide information on immediate energy consumption and accurate feedback from frequent billing, their effectiveness in directly reducing energy consumption is somewhat ambiguous (Darby: 2010). By visualising energy use, people may become more aware of their consumption activities, but the displayed energy information alone will not result in reduced energy consumption (Stevenson and Leaman: 2010). Information alone is not likely to lead to increasing control or to the formation of less energy intense use of appliances.

Bartiaux's study (2008) of Belgian consumers challenges the linear relationship between providing information and taking action. Receiving information, he argues, is not a process of linear diffusion, as it is open to multiple interpretations and configurations. How information flows into everyday ways of life, how it is interpreted and how new practices develop around low-carbon technologies and energy systems is less understood, even though it may be essential in understanding why providing information may be effective in one context but ineffective in another. Moreover, as Hargreaves et al. (2010) argue, there is currently a limited understanding of driving principles regarding what a smart meter's display design should show. On the supply side there is a lack of information on the diversity of

users and standards that would suit household needs and expectations, whilst on the occupant's side there is a lack of knowledge and experience about how to manage smart systems and whether they are a good investment, as equipment and systems are currently expensive. Nonetheless, there are further barriers that have been identified in the uptake of monitoring and control technologies: for instance, trustworthiness and transparency could be sources of problems while the design of energy consumption displays is not tailored in accordance to households' activity patterns (Wood and Newborough: 2007).

Other empirical studies suggest a more individualised way of intervention and gaining an in-depth understanding of energy-related behaviour. The principles of 'tailoring' and 'customisation' (Steg: 2008, Palm: 2010), and the need for understanding users' individual behaviours, indicate that the focus should not be not only on the most appropriate technical solutions, but on the harmonisation process between occupants' everyday lives and technological solutions. Hargreaves et al. (2013) report on how UK householders interact with feedback on their domestic electricity consumption based on real-time displays or smart energy monitors. Findings suggest that smart energy monitors gradually become 'backgrounded' within normal household routines and practices. The monitors do increase householders' knowledge of and confidence with the electricity they consume, but, beyond a certain level and for a wide variety of reasons they do not necessarily encourage householders to reduce how much energy they consume. By focusing on energy and water demand, Strengers' (2011) empirical study of 28 households notes that there are a number of negotiable and non-negotiable practices on the level of everyday life that home displays do not take into consideration.

However, the main source of controversy in the effectiveness of energy feedback is that it does not change practices linearly because it focuses directly on energy (Strengers: 2013). Everyday life in its lived reality consists of a broader set of practices and multisensory experiences through which energy consumption becomes meaningful. Therefore, it is a prerequisite of the customising, tailoring, personalisation approach to take the context of energy use into consideration (Darby: 2006). Context is also important, because it provides the background of everyday life, whereby values, knowledge, attitudes, practices, experiences and habits interweave. So on the level of everyday life, accounting for context may show us how to

understand people's responses - not from a technology-oriented perspective but on their own terms and based on their own practices. Therefore, to understand prospective users' reactions to emergent technologies, it is important to account for the background of everyday life against which new technologies emerge. The next section therefore reviews the sociological 'practice-turn' in consumption and energy research that turns from 'behaviour' to the routine and habitual character of everyday life.

2.2 The Sociological Practice-Turn in Energy Research

Practice theory argues that social practices are better sites of intervention into sustainable energy consumption and social change than behaviour or technological innovations alone. Social theories of practice in energy studies are concerned mostly with how human action intersects with utilities, technologies, infrastructure, resource consumption and the challenge of sustainable development. I start this section by overviewing earlier social theories of practice. I then discuss how practice theories have entered into consumption studies, and I outline empirical case studies relating to the role of infrastructures and institutions in energy use on the household level. I then review how practices as entities and performances change. I end the chapter by arguing that a more interdisciplinary understanding is needed to account for the interrelationships between the development and irregularity of performances and the built and domestic environments.

2.2.1 Overview of Social Theories of Practice

Postill (2010) divides practice theories into first- and second-generation theories. The first generation, in the 20th century, is occupied primarily with the dichotomy of structure and agency, the macro and the micro and the role of individual action within social structures. Human actions are typically viewed from a more 'top-down' approach and as part of larger social systems. Social practice theories draw on Bourdieu's work on practices and Giddens' structuration theory. Bourdieu forms a

theoretical model of social practice in *Distinction: A Social Critique of the Judgement of Taste* (1984), in which he recognises that practices are not only outcomes of individual decision-making, but they also originate from larger structures. He defines 'habitus' as something that "generates meaningful practices" and recognises that practices are diverse in character, as they are located in time and space, characterised by tempo and requiring a new approach where "one has to break with linear thinking" (1984: 107), due to their complex nature. Giddens (1984) in *The Constitution of Society*, characterises social structures as having a dual nature. This duality enables and constrains action at the same time and these are simultaneously the 'medium and outcome' of the practices they recursively organise. By moving away from individual experience, routine practices of the everyday become the most fundamental unit of analysis within social structures.

The second wave of practice theory continues to move beyond the structure-individual opposition in sociology. Practices are generally defined as "embodied, materially mediated arrays of human activity" that are "centrally organised around shared practical understanding" (Shatzki 1996: 11). The individual in this account becomes the carrier and observer of practices, and the body is seen as a locus of routinised actions and performances. This generation of theories has started to analyse practices by decomposing its elements and interconnections. Shatzki (2001) defines social order not in terms of mechanical rules but more through the dynamic and elastic arrangements of people, organisms and artefacts. Social practices are viewed as "collective accomplishments" that are linked together by interdependencies rather than the aggregate of individual habits (Barnes: 2001). Reckwitz (2002) defines practice as a routinised unit made up of various interconnected elements: bodily activities, mental activities, material things, understanding, know-how, emotion and motivational knowledge. Individuals are the locus of how these elements come together, but he considers the individual as a more passive agent who is rather confronted with - and not active creator of - how routines change.

Warde (2005), who outlines the first works for consumption studies, conceptualises consumption as an element within practice. And because it is an element, it is practice and not taste or individual choice that underpins demand and consumption logic. Consumption therefore cannot be reduced to pure market exchanges; rather, it

is a process where different forms of utilization take place. There is an internal differentiation of practices showing how individuals and groups engage and carry out the exact same practice. The social differentiation of practices originates from various sources: people's varying competencies and capabilities, the contribution of agents to the reproduction and development of the practice or, for example, various understandings or performances of the same practice. Consumption becomes a process, a 'moment' integral to the practice. In this moment, people are caught up in appropriating items, because appropriation itself is governed by the norm of the practice. Considering consumption as an integral part of practices has opened up a new way to approach environmental sustainability and Warde's work has been fundamental to how the intersection of technologies, utilities, resource consumption and sustainability has developed up to today (Halkier et al: 2011).

2.2.2 Elements of Practice

To date, most practice theoretical accounts have understood the social based on the repetitive, stabilised and routine character of human actions. Shove et al. (2012) reflect on this approach by drawing a general distinction between the analytical categories of practices as entities, and practices as performances. Practices become collectively recognised entities when they move beyond particular individuals and form an entity that is identified by many members of a society. Practices as entities can be analysed from a temporal dimension focusing on changing patterns over time, or trajectories of how practices emerge and spread across societies. Practice as performance is an individual's expression of an action and transitions in practice reflect changes in the composition of elements that make up a practice. Shove et al. (2012: 23) narrow down practices to the integration of materials (objects tools, infrastructures), competence (knowledge and embodied skills) and meanings (cultural conventions, expectations and socially shared meanings) to make the circular relation visible between practices as entities and practices as performances. The performance of practices thereby becomes conditional, because all three of these elements need to be present and integrated in order for a given practice to come into existence. The process of change and development in the entity and

performance takes place through 'reconfiguration' and the way connections between elements are made, sustained, broken and reformed (Shove: 2009). Trajectories of entities and performances are ongoing processes of integration, where the main unit of analysis moves from the individual relationship with a given material object to the configurations of practices. This allows for a direct analysis of stability and change over time, without focusing on the divide between agency and structure.

Gram-Hanssen (2010, 2011a) adds technology as another element that holds practices together. By looking at the energy performance of identical building types, she highlights that technology can influence energy performance because it can guide the performance of a practice in a certain direction by design. She proposes the following four elements: *institutionalised knowledge* and *explicit rules* that involve expert-derived information, rules and recommendations regarding how to perform a practice, *know-how and embodied habits*, consisting of practical understanding through tacit learning and experience of performing practices, and *engagement* in social expectations, symbolic meanings, motivations, norms, attachment and *technologies*, including things that make up the physical environment. She stresses that the way technologies relate to everyday life should be understood as part of a larger socio-technical system of networks and infrastructures, because practices are linked on many different levels. The practice of standby consumption, for instance, is a mutual constitution of embodied habits (turning devices on/off), knowledge (knowledge about the amount of electricity certain appliances consume), engagement (contact with energy advisers), technologies and material structure (televisions, computers) (Gram-Hanssen: 2010).

It is important to note that contemporary social practice theories are in dialogue with Actor-Network theory (ANT) that generally analyses how actors organise the world into sensible but provisionally stable forms. ANT does not separate human agents and natural objects with pre-given properties; the focus stays on entering into relationships through interconnections. Actors are 'heterogeneous assemblages', or socio-technical apparatuses, that are maintained by diverse material objects with shifting properties, meanings, understandings and rules, spatial arrangements and temporal sequencing. Similarly, practice theory has been concerned with how ways of doing things are assembled and stabilised in routine forms. However, the entry point of the analysis is different because while ANT is concerned with emergence,

practice theories concentrate more on the stable reproduction of structures and habits.

2.2.3 Theories of How Social Practices Change

Practices-as-performances are the observable actions of individuals, and practice theories typically understand the change of individual actions (performances) by treating entities as primary entry points into interventions. As Figure 4 shows, entities can be distinguished from performances, because an entity is the accumulation of all performances at any given moment, whereas performances are defined as individual observable behaviour.

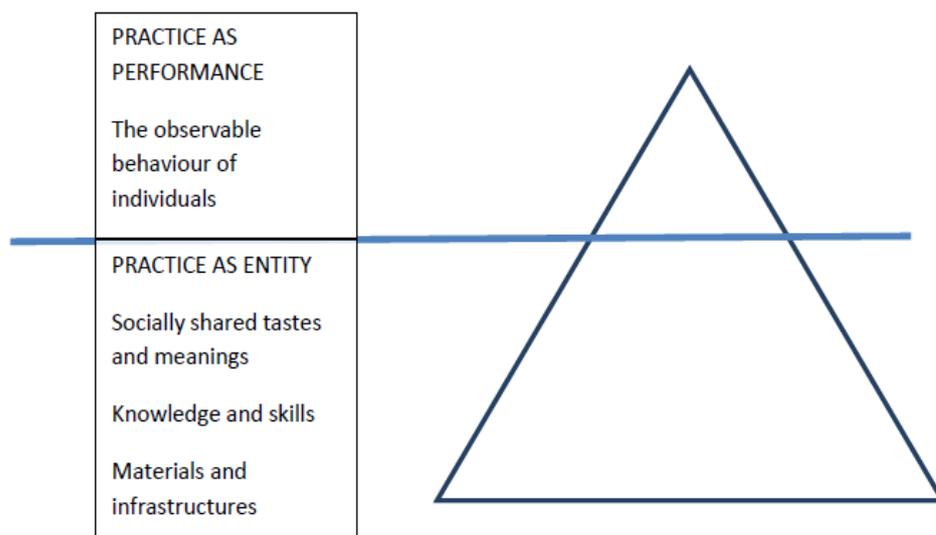


Figure 4 Practices as entities and performances (Spurling et al.: 2013)

By focusing on how entities emerge, a practice approach can account for the history, trajectory of practices, the diffusion of new practices or the establishment of different forms of practices. For instance, Shove's work, *Comfort, Cleanliness and Convenience* (2003), argues that heating and air conditioning are not merely a matter of installing and using technologies. Social norms, or the way people come to think that buildings should be kept at a certain standard temperature, are also

assumptions made based on material choices, efficiency standards or building regulations. Shove et al. (2014) also show that the spread of air conditioning around the world has created new demand for energy (e.g. nursing patients in hospitals, office environments or staying in high-end hotels). Bartiaux et al. (2011) examine the impact of the *Energy Performance of Buildings Directive* on the renovation of buildings in four European countries. The practice of building energy renovation, which is in the process of evolution, configures differently across countries, depending, for instance, on the know-how of energy advisors or building labelling.

Spurling et al. (2013) distinguish three points of intervention into practices as entities: re-crafting the elements of existing practices, substitution (new or old) practices and changing how practices interlock. Re-crafting practices refers to changing the elements that make up practices, in order to reduce their resource intensity. Showering as a practice becomes linked to material arrangements and infrastructural relations – by, for instance design - that shape how an individual performs a practice. Hand et al. (2005) show the infrastructural arrangements and material resources that are associated with the resource-intensity of routinised showering in households. They account for infrastructure of showering (e.g. piped water), electrification and the instantaneous availability of hot water, the shifting public-private status of showering, social norms (the relationship between the body and self, cleanliness, immediacy and convenience) and materials (from hand pumps to the design of power-showers). Changing the resource intensity of the performance of showering in households would require a systematic approach that intervenes in the elements to phase out the more unsustainable elements. Substituting practices encourages a more sustainable version of practices (e.g. replacing showering with bathing, by equipping new flats with bath tubs instead of shower rooms), and changing how practices which interlock through their synchronisation and sequences. Considering the synchronisation of practices is a key requirement for peak energy loads or morning rush hours (Shove et al. 2009), since sequences relate to the performance of practices in a particular order (e.g. shopping, storing, cooking, preparing, eating and disposing).

Instead of classifying energy consumption by direct end-uses (gas, water, electricity), this body of literature was successful in directing attention to the role of routines and habits in everyday life. Thus, the attention has been drawn to a variety of practices

that entail consumption in the forms of laundry, showering or heating. Because practices as entities are shaped and reproduced by dominant structural arrangements - like institutions or infrastructures on larger scales – this approach has provided new knowledge and a more relational understanding of how embedded structures at higher levels shape the performance of practices on the level of everyday life. Therefore, taking a practice theory approach in energy studies tells us more about how social practices stabilise, reproduce or configure the performance of practices. Nonetheless, we know less about how practices-as-performances may actualise practices-as-entities and how variations and transformations are implicated in the process.

I have argued in the first chapter that there is a growing need to understand better low-carbon technological change and energy used for space heating at the level of single buildings. Accounting for the gap between the intended and actual use of low-carbon technologies requires a more interdisciplinary approach to assessing variations in household energy use. I have also pointed out in the first chapter that energy consumption for space heating in residential buildings is a joint outcome of occupants' activities, the building fabric's condition and heating system efficiency. We have learnt from the literature on theories of social practice that an analytical focus on practices as entities is generally concerned with how practices 'reproduce' and configure performances. To date, insufficient attention has been paid to interrelationships between how home heating practices develop in relation to buildings and to the surrounding physical environment. Moreover, an analytical focus on practices-as-entities boils out the ongoing complexities of how individual (subjective) or environmental (physical) elements contribute to the emergence, irregularity and change of practices in relation to new technologies.

I have also emphasised in the first chapter that accounting for irregularity and variations in occupants' use of home heating technologies is key to designing energy efficient technologies that better meet the needs of users. To date, there has been more focus on how social norms and larger infrastructural or socio-technical relations configure performances of practices in domestic energy consumption and less attention has been given to what more performances of practices in relation to buildings could say about the sustainability of energy consumption. Research into social practice in energy studies typically does not use anthropological methods.

Thus, to investigate further how the design of energy efficient technologies could be a point of intervention into reducing energy used for space heating, the thesis now reviews the anthropological framework of technology domestication that is still being engaged in understanding the intersection of new technologies and domestic environments. It then re-situates the concept of domestication in theories of place (Ingold: 2011), using the concepts of 'sensory home' and 'place-making' (Pink 2004; 2012) to understand the improvisatory character and the performance of practices in relation to place.

2.3 Technology Adoption and the Framework of Domestication

The concept of technology domestication partly originates from anthropology and partly from consumption and media studies from the 1990s. It focuses on the uptake, rejection and use of technologies in domestic environments and it has developed as a response to technology diffusion models that treat the uptake of new technologies as a linear, calculable and rational processes. Domestication focuses on the various ways in which users develop relationships with technologies characterising the processes that surround and influence how new functions settle into their everyday lives. The concept of domestication started from a focus on media technologies in domestic environments, but it has spread to other technologies such as the car (Sørensen: 1991), mobile phone (Caroll et al.: 2003) or small-scale renewable energy systems (Juntunen: 2012; Hyysalo et al.: 2013).

Silverstone, Hirsch and Morley (1992) provide one of the earliest empirical studies of communication and information technologies in homes by conceptualising households as a "system of economic and social relations" where people's engagement with technologies is creative, active and is characterised by a mutual shaping process. They distinguish four interrelated stages in the household uptake of technologies: *appropriation*, *objectification*, *incorporation* and *conversion*. *Appropriation* is the stage in the household uptake of a technology when a commodity enters a household. It is the start of the ownership as well as the stage, at which a commodity transforms into a household object by gaining significance. It also involves a process whereby meanings are created and assigned to entering

objects by people, but this meaning is not necessarily identical to its original intended meaning and becomes open to individual creativity and construction. The concept of appropriation recognises the role of variety and innovation for a new product, which is not necessarily the same for all individuals and will have a tendency to increase over time with the diffusion of the given product (Daghfous et al.: 1999). The stage of *objectification* is a classification process, by which objects or artefacts enter into a physical environment. This stage involves various elements, such as aesthetic preferences, values, beliefs, norms, identities or self-representations, which are translated and manifested into how technologies or objects are brought into use. For instance, in a domestic setting the transformation of a kitchen involves not only material transformations, but also ideas and conceptualisations of how an ideal kitchen should appear and how it may 'fit' with someone's way of living (Clarke: 2001). *Incorporation* encompasses all the utilising the new technology; it is the stage at which artefacts are put into practice. Functions may be numerous, but in order to "become functional a technology has to find a place within the moral economy of the household" (Silverstone et al.: 1994:24) as well as within the flow of everyday life. Therefore this stage is a process that may involve trials, negotiations and the establishment of new practices.

The framework of domestication has been widely recognised in technology design because it emphasises that the uptake and use of technologies are crucial to understanding fully a user's relationships with new technologies. The actual use of technologies cannot be pre-determined, because users may develop unanticipated uses that can be significantly different from the envisaged use (Hynes: 2009; Hyysalo et al.: 2013). Routarinne and Redström (2007) identify domestication as a promising design intervention into understanding variations in the use of prototypes. They follow the domestication processes of energy curtains in various households to examine the gap between design intentions and people's reactions, in order to see how they perceive, interpret and integrate them into households. In certain households the installed energy curtains were reinstalled and functioned differently in three out of four settings.

Domestication theory has been gaining critical attention from a practice theoretical perspective, because it focuses on single objects, considers the process of technology adoption as a one-off process and provides too much of an individualistic

account of how practices change (Warde: 2014). Moreover, it fails to take into account how power relations influence practices (Macrorie: 2012). Yet, the process of domestication is important since it studies how domestic practices co-develop with and around new technologies (Røpke: 2009). Technological change is not autonomous and is inherently unpredictable because it is inseparable from social contexts. In a domestic environment new technologies become caught up in a matrix of interrelations where people can make improvements and modifications; i.e. they re-invent the innovation for their own purposes so it fits better with their everyday life, and in doing so they exercise and develop strategies to control, manage and interact with artefacts (Haddon: 2006; 2011). Therefore, new technologies do not 'script' practices; rather, they encourage patterns of use by allowing space for individual interpretation and reconfiguration.

We have learnt from the domestication framework that unanticipated practices can develop around new technologies and that these practices intersect with various elements in domestic environments (e.g. meaning, innovativeness, aesthetic preference, etc.) To understand better how irregularity and change emerge around low-carbon technologies in the home in relation to buildings, the thesis now turns to theories of place and interconnected senses. By focusing on interrelations between the formation of practices and the physical characteristics of buildings, we can take into account how the formation of new practices interrelates with and emerges from the surrounding domestic, sensory, physical and material environments. I use concepts from three thinkers: theories of place-event from the geographer Doreen Massey (2005), the concepts of 'meshwork' taken from anthropologist Tim Ingold (2011) and the concepts of 'place-making' and 'sensory home' from the anthropologist Sarah Pink (2004: 2012). I then draw on the notion of improvisation to understand how low-carbon technologies are domesticated through the process of improvisation, and how improvisation brings about variations, modifications and changes in the performance of practices.

2.4 Beyond Practices: the 'Place-Event' and 'Meshwork' of Place

Massey (2005) is concerned with re-thinking place as the dynamism of change. She points out, that places are “entities in formation” (2005:9), and she develops the concept of “place-event” relationships. Places as sources of change have three characteristics. Firstly, place is the product of *interrelations*. Therefore, we can recognise place as being “constituted through interactions, from the immensity of the global to the intimately tiny”. Secondly, place is the sphere of the possibility, coexisting *heterogeneity* and the existence of *multiplicity*; because it is “the sphere in which distinct trajectories coexist”. Thirdly, place is always *under construction* - it is “always in the process of being made. It is never finished; never closed”; rather, it is open-ended and is continuously in the process of becoming. Place is therefore not static. It is an event, an ongoing achievement and a “thrown togetherness” that is never the same from one moment to the next. This ongoing change also indicates that places are always unique and made up of relations and trajectories where “the negotiation will always be an invention” as well as room for learning and improvisation (Massey 2005: 162).

To illustrate the entangled texture of a world that is always in the process of formation and is made up of interwoven lines, Ingold (2011) uses the concept of ‘meshwork’, which represents a shift away from thinking of environments to entanglements where beings do not simply occupy the world; instead, they inhabit it and in so doing they actively contribute to its ongoing formation. It is the movement of wayfaring that characterises the meshwork, where beings are not passive and instead move along a way of life. Beings “thread their way through and among the ways of every other” and in the process they improvise a passage and create another line. Place therefore exists as a “knot tied from multiple and interlaced strands of movement and growth” (Ingold: 2011:75). Action in a world of formation emerges from the interplay of forces that are conducted along the lines of the meshwork and to be able to perceive or to ‘dwell’ in the world, beings are immersed in material media.

Engagement between beings and the environment, as Ingold (2011) proposes

couples movement, action and perception. To perceive is to employ the senses that are active constituents of movement. Senses are skills that are inseparable from engagement, because they develop from interrelationships between the practitioner and the environment. Skilled practice is responsive to the environmental conditions, because it arises from processes of goings-on, development and bringing a place into being. However, this means that all action, to a varying degree, is skilled and the skilled practitioner can continually attune his or her movements to the perceived environment. Although skills do not come ready-made:

“[they] are not techniques of the body considered objectively and in isolation. They are properties of the whole systems of relations constituted by the presence of the practitioner in his or her environment. Skilled practice is continually responsive to changing environmental conditions and to the practitioners’ relation to the material as the task unfolds. Also, they are refractory to codification in the programmatic form of rules and representations. Skills are not learned through transmission but through a mixture of imitation and improvisation in the setting of practice” (Ingold 2011: 401)

Skills develop as part of an organism’s own growth and development within an environment. Therefore, development and growth are fundamental processes for acquiring skills and exercising agency. A world in formation, as Ingold (2011) contends is never the same from one moment to the next, and people are not observers but participants immersed in the process of formation. Movement in a world in formation is a way of knowing and a form of ‘correspondence’ that relates to and draws together the world. Furthermore, correspondence, as Ingold (2013) defines, is “movement in real time”, characterised by awareness of the flows and currents of animate life. The essence of wayfaring is to carry on that which lies in the indistinguishable nature of how sentience and materials entwine around one another. Environments continually come into being in the process of our lives, and there is a mutual shaping between the body and its environment. Materials are also active constituents in a world-in-formation, because living things are immersed in material media. To interact, beings must be immersed in a kind of force field that is set up by the currents of media that surround them. Thus, living beings are continuously in touch with their surroundings, because to be ‘in touch’ is to be able to correspond.

2.4.1 The 'Sensory Home'

By building on the notions of 'meshwork' and 'place-event' Pink (2012) further develops the 'place-event' relationship concept to understand domestic environments. She proposes that domestic environments are events that are made, sustained and remade by the diverse configuration of multisensory, material, individual, social and environmental elements. Place, we learn, is "a combination of processes and things that create the world", and is "both the context of practice and the product of practice" (2012: 24-27). A core concept of place-event relationships in domestic environments is the notion of 'sensory home' (Pink: 2004), which refers to the home as a multisensory place made up of different sensory elements (smell, touch, taste, vision and sound). There has been a 'sensory turn' within the social sciences (Howes: 2003; Vannini et al.: 2013) that changed the sociological understanding of experience. The sensory turn has brought a mode of thinking that not only engages all the senses, but also sees sensing as an active and interpretative process in the formation and engagement with place.

Pink (2004) takes sensory experience as a point of departure into understanding how the performance of domestic practices in everyday home environments intersects with gender identities. By creating the sensory home in the process of doing olfactory work, for instance, women develop creative practices to appropriate diverse smells during housework. Sensory experiences of smells such as perfume, 'cooking smell', 'unclean smells' or dust simultaneously express self-identity, are sources of creative engagement and are active creators of home environments. Sensory experiences and sensory knowledge are therefore fundamental elements in how everyday domestic practices are performed because they create emerging feminine and masculine identities:

"These sensory practices continually maintain and/or transform the textures, smells, sounds and sights of their homes within the constraints set by their sensory and material environments. Attached to particular 'traditional' moralities, the practices not only serve to create and maintain the home, but are performative of culturally specific housewifely identities – identities that are constituted and reconstituted

through the everyday repetition of their sensory embodied practices of home” (Pink 2004:138).

In order to understand how variations emerge from interrelationships between multisensory practices and places, Pink (2012) further investigates ‘place-event’ relationships, in order to identify the details of domestic practice in relation to place. By starting from the kitchen as a ‘place-event’ and focusing on washing up and kitchen cleaning she shows that practices, materialities and self-identities are constantly shifting in the process of movement. We can understand from the analysis of washing up that the movement of things is a fundamental condition in the process of making and remaking the kitchen as a place. Practices are part of how places are made, sustained and remade by the diverse configuration of multisensory, material, individual, social and environmental elements, because people shape and bind together various individual and environmental elements in the performance of practices. Laundry practice is another example where Pink (2012; 2013) focuses on ‘laundry lines’ to show how making the home, and the performance of laundry practices, intersects with the sensory aesthetics of the home and eventually with energy consumption:

“[...]if we think of home being a place-event with an intensity of the interrelations of persons, things and sensations, we can understand energy use as an essential part of the making of the home. Energy is consumed in practices that are integral to the movement and renewal of constituents of place” (Pink 2012: 70).

‘Laundry lines’ form a complex ‘meshwork’ (Ingold: 2011) in which various elements such as materials (towel, laundry basket), sensory experiences (textures and scents) or the weather play a role in making and maintaining the home’s sensory aesthetics. And it is the formation of the meshwork, and the process of place-making, that opens up space for creativity and innovation and breaks down the normativity of practices. Essentially, we learn from these studies that the performance of practices is not detached from places because they are performed in relation to domestic and home environments. This implies to a certain extent, that creative engagement with technologies is embedded in spatial, material and sensory relations.

To understand creative engagement further, in the next section I build on the concept of improvisation, which offers a window to local interactions by uncovering how change emerges in real time (Larsen and Bogers: 2014), showing how people adapt in complex environments in the performance of interacting with the world (Montuori: 2003). To understand better improvisation in relation to 'place-making' and the 'sensory home', I show that it can be a source of mundane creativity, modification and learning.

2.4.2 Creative Engagement as Modification and Learning

We learn from 'practice-place' relationships and from following pathways of movement in everyday domestic environments that the performance of practices is subject to renewal, because it combines various individual and environmental elements. We also learn that a continuous correspondence with the surrounding environment, and the renewal of various elements in the performance of practices, can open up space for individual creativity and improvisation.

Improvisation, as Hallam and Ingold's (2007) suggest, is a dynamic learning process that emerges from flexible structures, repetition, knowledge and skills. Since the world is never the same from one moment to the next, change emerges in the form of improvisation - a process of making and a form of 'correspondence' between living organisms and their environment. Consequently, creativity does not develop from nowhere as a spontaneous idea; it develops by being involved in activities and in the process of mastering skills. Furthermore, creativity is about continuous creation, learning, skills and active engagement with the surrounding environment, which suggests that improvisatory practices are reactionary and that the definition of novelty in improvisation is not synonymous with innovation. Whereas improvisation emphasises the processes of creativity and learning, innovation refers to its actual products as outcomes. Hence, they imply two different directions in the process of formation whereby improvisation focuses on the process of development as a forward reading of creativity, while innovation focuses on the consumable products reading creativity backwards. Therefore, creativity lies not in innovation but in

improvisation and improvisational creativity thus implies a world in the process of development and a world in motion that is always in the 'making' rather than a world that is already created (Ingold: 2013).

Improvisation is also a learning process that shows that specific guidelines, rules, codes, norms, particular contexts and conditions cannot anticipate every possible circumstance. Hallam and Ingold (2007) distinguish four characteristics of improvisation. Firstly, improvisation is generative because it is not only something radically novel that can bring about innovation. 'Copying', or 'imitation', is more than mechanical replication because of the attention, effort and problem solving that goes into the process. Copying is a process of creation, because it always gives rise to alignment, adjustment and modification in the performance of practices. And it is from this alteration work where improvisation emerges. Secondly, improvisation is relational. Creativity is not an outcome of individual agency. Social life is about 'keep going' rather than repetition, because being engaged in a world of formation involves being entangled in mutually responsive fields of relationships. Thirdly, improvisation is temporal. Reading creativity backwards is innovation and forward is inherently temporal. Reading innovation forward always involves a certain degree of improvisation, meaning that it is always a line that grows and advances like a root. Fourthly, improvisation is mundane, because it is essential to the way we work. Life, and the activities that develop around new technologies, cannot be scripted and so to keep on going, life has to be open and responsive to continually changing environmental conditions. To be able to 'correspond', one needs to coordinate perception and action that can only be achieved through practice. This coordination process distinguishes the skilled practitioner from the novice, and it is the essence of improvisation.

To understand how improvisation relates to routine movement, Pink and Leder Mackley (2014) study the intersection of lighting, electricity consumption and the sensory aesthetics of the home in everyday routines. They identify improvisation as a "moment in movement" and show that nothing that people do repeats exactly the same way, because individuals form unique pathways and engage in idiosyncratic forms of 'place-making' that becomes habitual. Consequently, all repeated movements and routines involve a certain degree of improvisation, modification and change. Thus, improvisation becomes a form of dialogue between order and

disorder, tradition and innovation, provisional structures and new routine, problem solving, alternatives as well as continuous change. Moreover, it places creativity, innovation and novelty within the process of learning and correspondence with the surrounding environment.

In the humanities and social sciences, there are two dominant ways of how improvisation has been conceptualised. Firstly, it has been associated with resistance, a “powerful form of rebellion against exclusion” as well as injustice and oppression (Fischlin and Heble 2004: 4-8). It has come to be used synonymously with risk, unexpected occurrences and the unpredictability of human action but mostly it is thought of as a form of opposition to expectations and a deviation away from normative behaviour that moves away from the pre-scripted and the pre-determined. It is perceived to be somewhat destructive, thought, because it breaks down order and careful planning and as such it is more of a metaphor for dysfunction and failure that undermine predictability and preparedness. The second interpretation originates from music studies. Here, improvisation has been associated with creativity, spontaneity and innovation. In this form, improvisers are active and creative agents, because they break away from the script by creating something novel. Hence, improvisation in music studies becomes a form of provocation and liberation that brings novelty as a form of response to set structures and pre-established rules (Benson: 2003). These definitions suggest that improvisation is either a form of ‘resistance’ or a process of ‘spontaneous creation’ but to move away from these definitions, I re-conceptualise it as a productive source of change arguing that it is fundamental to the continuity of everyday life because it can be a site of design intervention and co-design.

2.4.3 Improvisation as a Site for Design Intervention

Improvisatory uses of technologies have been linked to design anthropology and co-design practices because of design anthropology’s interdisciplinary collaboration and focus on the ‘making’ (Ingold: 2013), ‘textile’, emergence and ongoing change in everyday life. Design anthropology is a new field that focuses on the design of technologies. It is interdisciplinary because it brings together a wide range of fields

form from industrial design, human movement studies, ecological psychology and sociocultural anthropology. Gunn and Donovan (2012) point out that design anthropology moves away from a problem-oriented approach towards designing that includes many contexts and practices. It centres on the entanglement of people and their environments and builds closer relations between using and producing, designing and using, people and things. From an anthropological perspective it is concerned with four areas: exchange and personhood in the production and use of new technologies, the understanding of skilled practice, anthropology of the senses and the aesthetics of everyday life. It differs from material cultural studies, because it distinguishes production from consumption and the precedence of design over use. Design anthropology is concerned with different ways of designing and different ways of thinking about designing and using. A further core focus they argue is a better understanding of how people intervene in configuring products and systems in the very processes of their consumption.

Rolfstam and Buur (2012), for instance, show that often there is a mismatch between designers' intended and users' actual use of technologies. By building on the example of joysticks for backhoe loaders, they argue that design sets the rules and prescribes solutions in institutionally defined contexts. In the institutional analysis, user improvisation becomes an indicator of a mismatch between a design and the user. But how can design take into account at least some aspects of future uses that will be unknown to the designer? They introduce two examples in the design of joysticks. In the first example, the designers did not take into account the possibility of user improvisation. For designers, operator improvisation was a wrong way of using the machine but for operators, the primary aspect was to get the job done. In the second example, the design team allowed improvisation from the very start of the design, and as a result they acknowledged that alternative uses exist and they might emerge during use. This makes the designer a subsidiary designer and a negotiator rather than a decision maker.

Improvisation as a design intervention, on the one hand, implies a world that is always in the process of making, because users actively negotiate on design judgements and as a result nurture growing tension between the intended and actual use of technologies (Gunn and Clausen: 2013). On the other hand, improvisation as a design intervention in domestic environments implies that more attention needs to

be paid to the details of practice in relation to place, because individual differentiation happens in between the social, technological and temporal components of everyday life in the home (Pink: 2012). An analytical entry point into improvisation through a 'practice-place' approach moves away from placing the individual as a passive recipient of indoor climates; rather, it places occupants as active agents who become co-creators by interacting with the surrounding physical environment. Improvisers in this thesis all have a story to tell, because they have a unique relationship with the movement they create, coordinate and modify. Therefore, following Ingold and Gatt (2013), the focus on co-creation is placed on the ongoing creation of environments and people's ability to respond to circumstances, in order to understand improvisation as the user's way of contributing to the design process.

2.4.4 Capturing the 'Ongoingness' of Home Heating

I identified in the previous chapter that there is a growing need to develop collaborative methodologies that better understand actual building use in use because energy predictions tend to standardise building use at the design stage and buildings are rarely studied systematically and this may lead to repeated design mistakes. This thesis therefore develops a sensory ethnographic understanding in collaboration with building engineering methodologies to take into account locally embedded opportunities and challenges to inform co-design for potential applied design interventions. It focuses on the continuity of what is already happening in the households and what are the existing improvised and active ways of using radiators and TRVs in the process of creating, maintaining and recreating the home's sensory aesthetics and indoor climate conditions. Because sensory ethnography focuses beyond practices as analytical units it offers new ways to understand the ongoing nature of home heating activities in relation to buildings. It is inclusive of the interactions between systems, users and spaces and can simultaneously attend to the physical, technical, spatial and social aspects of energy use. Moreover it calls attention to how home heating practices are situated in and interconnected with the wider built and sensory environments and with other domestic practices. Energy consumption happens in movement thus attending to the senses and places in

relation to home heating practices can bring to the fore how people sense and maintain environments and indoor climates. Therefore an understanding of the continuity of everyday life environments and actual energy use makes us turn to think about how movements and activities are intertwined with energy used for space heating in a variety of forms. Following this approach does not contradict practice theory. Instead it can be complimentary because it focuses on sensory perception, experience and the ongoingness of how interrelationships form between occupants' domestic activities, building fabric and heating system conditions. Taking practice-place relationships as a unit of analysis moves away from focusing upon activities that directly surround a one technology. A sensory ethnographic approach can bring a new form of understanding by showing how and why occupants need to consume energy used for space heating in the process of creating a specific sensory aesthetic of home. It is in the ongoing sensory and emplaced process of making the home 'feel right' where idiosyncratic uses, contextually dependent characteristics and nuanced qualities become visible. Thus accounting for practice place relationships can help to better understand technological change at a household level because occupant interaction with products and systems are situated in wider interrelationships between the built, physical, sensory and domestic environments. Being open to idiosyncrasies and the unexpected brings new understanding to how variation unfolds real time from a nexus of interrelated processes including movement of occupants and things, home heating and other domestic activities, sensory perception and atmospheres, the physical characteristics of buildings and the efficiency of heating system. This allows sensory ethnography to produce a set of novel insights for applied energy demand reduction. It adds a level of detail that allows us to sense moments and spaces in which energy for space heating is being used and contributed to larger aggregates (e.g. annual) of gas and electricity consumption.

Conclusion

Following the first chapter, which argued that energy research needs more engagement from a variety of social science approaches, in order to characterise

low-carbon technological change, this chapter has reviewed the literature from the social sciences. I have shown that behavioural approaches, energy feedback and smart metering are still the most dominant modes of intervention for reducing energy consumption in homes. I have presented empirical studies that question the straightforward success of smart meter deployment and these have highlighted that energy feedback focuses directly on practices that may offer limited possibilities for reducing energy consumption on the level of everyday life. The chapter has introduced the sociological 'practice turn' in energy research which has been a pioneering alternative to behavioural approaches, because it has directed attention away from individual behaviour to the routine and habitual character of energy use in everyday life. The practice approach has been particularly productive in understanding the role of social norms and larger infrastructural relations in how practices as entities change over time. I have introduced the analytical separation of practices as entities and performances and noted that taking practices as the primary unit of analysis, to understand how the performance of practices develops on the level of everyday life, offers a limited insight into variations in household energy use. As I have shown in the first chapter, energy used for space heating in domestic buildings is a joint outcome of local climate, occupants' activities, the building fabric conditions and heating system efficiency. To understand variation in household's energy use, interdisciplinary methodologies are needed to understand 'practice-place' relationships. The thesis therefore situates its theoretical departure in theories of place and interconnected senses and establishes a more relational understanding between place, irregularity and creative engagement with technologies. I have used the concept of improvisation to account for how technologies are domesticated through the process of improvisation, and I have argued that improvisation could be a productive source of sustainable change, because it is a potential site for co-design. The next chapter continues by reviewing the nature and practice of interdisciplinary research, its qualitative turn and its potential for methodological innovation between anthropology and engineering sciences.

3. Learning Routes to Interdisciplinary Knowledge Exchange and Integration

Introduction

In this chapter I show that interdisciplinary knowledge integration is not a unified way of doing research. I reflexively discuss the ways in which I engaged with interdisciplinary research in my own work to show how it impacted on the process of knowledge integration and on the research itself. I begin by introducing my own collaborative experience and journey from cultural studies to building energy research, to demonstrate how I developed routes to the synthesis of disciplines. I then outline the core philosophy of interdisciplinarity, present various definitions and a number of standpoints on the relationship between interdisciplinary research and established disciplinary traditions. Most complexity-related research has been developed through a positivist framework but I introduce problem orientation as a specialisation of interdisciplinary research that has brought about a 'qualitative shift'. Problem orientation in interdisciplinary research typically addresses issues of social, technical and policy relevance, because the research aim is more concerned with a context-specific description of complex problem and less with producing discipline-related outputs. As a consequence, the mix of disciplines involved open up room for collaboration and methodological innovation in the knowledge synthesis process. On the other hand, finding the right balance between disciplinary depth and expertise makes problem-focused interdisciplinary research open to tension. Critiques of interdisciplinary research often regard problem focus as an orientation that undermines academic research (Lyll: 2008). Moreover, various practical barriers have been encountered in research management, knowledge exchange and interdisciplinary knowledge integration. Yet, as I argue in this chapter, undertaking interdisciplinary research and encouraging greater collaboration can break down barriers between science and society by engaging with disciplinary differences, achieving dialogue, developing shared understanding, appreciating various ways of knowing and encouraging new, innovative modes of thinking.

3.1 The Role of Self-Directed Learning

I come from a multidisciplinary humanities and social sciences academic background. I gained my first experience in interdisciplinary energy research as a research assistant in 2010 on a Central European project called EnSure (Energy Savings in Urban Quarters through Rehabilitation and New Ways of Energy Supply)¹. The project aimed to create an integrative method for energy efficient urban development from a financial, technical, social and policy perspective. It involved cities in five Central European countries and various academic departments, ranging from urban planning, sociology, policy and building engineering. The project mapped opportunities and barriers to developing district-specific sustainable energy action plans for public and residential buildings in historical city centres. My role as a research assistant was divided between the Centre for Socio-Spatial Development Studies and the Department of Building Engineering at the Budapest University of Technology and Economics. Whilst taking part in the data collection phase I conducted qualitative interviews with municipalities, stakeholders and property developers, in order to map motivation and barriers for energy efficient refurbishment schemes. The pilot project for the study involved the refurbishment of a residential building block of flats but the evaluation of residents' in energy efficient residential developments was based on information provision, attendance on civil forums and surveys on environmental awareness. There was no investigation into assessing their experiences associated with learning about new technical developments.

I prepared a PhD proposal based on this observation, emphasising that paying attention to how people develop practices around new technologies may be useful in further curtailing energy consumption in residential buildings. After submitting my application I received an interview invitation for an interdisciplinary PhD programme run between Loughborough University and UCL. I entered the interview room and sat down in front of a panel of six scholars with mixed disciplinary backgrounds, ranging from physics, building and mechanical engineering through to economics and architecture. I did not really know the extent to which I needed to prepare for

¹ <http://www.ensure-project.eu/>

technical interview questions. I mentioned in my proposal that I came from a multidisciplinary cultural studies background and that I had developed an interest in the social and technical dimensions of sustainable energy consumption. Yet, I was a little nervous, because I expected a communication gap due to my lack of technical knowledge. All of my technical knowledge was based on six months of collaborative research experience combined with residual knowledge from high school science classes. I was asked two specific questions at the interview. First, I was asked to explain the mechanics of how a heat pump works. Second, I was asked to list some influential factors that impact human thermal comfort inside buildings. I could not provide an adequate explanation and I was rejected from the programme, following which I realised how important it was to advance my technical knowledge and engineering vocabulary. Weeks later I was contacted by one of the panel members presenting an alternative opportunity for submitting a research proposal for a Graduate School competition at Loughborough University. That is when I decided that building up a technical expertise and skill set for integrating the social and technical dimensions of household's energy consumption could be a fruitful learning route. Thus, I opted to register with the School of Civil and Building Engineering and not in the Department of Social Sciences.

In the first year of my PhD I closely followed the London-Loughborough programme, and I requested permission to register on building engineering modules. Over the two semesters I gained insights into the multidisciplinary use of models, system approaches to energy modelling, low-energy design problems, strategies and methods for modelling energy use. I studied Energy Theory, Measurement and Interpretation, which provided insights into building physics as well as into the influential drivers of dwellings' energy performance. I was also given the permission to complete the module's coursework, which covered methodologies, techniques for measurement and the analysis and interpretation of empirical evidence pertaining to energy use in houses. I was able to familiarise myself with monitoring equipment used for data collection and I learned to use temperature data loggers and sensors, an infrared camera and participated in blower door tests to assess airtightness. The monitoring exercise turned into a pilot study for my research where I have developed new methodological combinations for my own fieldwork. This is discussed in more detail in the methodology section.

By registering in the School of Civil and Building engineering I did not aim to re-train as an engineer. Opting for a three-year learning experience in building engineering has been helpful in building effective communication with engineers by gaining a whole new vocabulary. In more practical terms, learning new techniques for energy monitoring, and using a wide range of equipment and software has given me more room to innovate when looking to combine methodologies. It has also given me the opportunity to step outside of the social sciences. By engaging in another disciplinary tradition I can develop awareness of how building engineering views domestic energy consumption and makes assumptions about the role of human action. In the process I was able to better understand disciplinary differences, gain an overview of how social science and engineering frame sustainability challenges and target interventions into socio-technical change. Moreover, by understanding the perspective of each relevant discipline I identified space of differences that allowed me to employ and accommodating multiple ways of knowing. Self-directed learning have therefore played a key part in developing the research, knowledge synthesis and balance of disciplinary perspectives.

3.2 The Core Philosophy of Interdisciplinarity

Interdisciplinary research areas have grown rapidly since the 1990s as a response to humankind's 'wicked' problems (Rittel and Webber: 1973). Climate change and sustainability propose new types of challenges that need to deal with nonlinear complex systems. These problems are characterised by interdependence, multi-causality and social complexity. And because they are intractable and resistant to being solved by traditional linear approaches, they are characterised by a new type of Mode 2 knowledge production. Nowothny et al. (2001) propose the concept of Mode 2 science to show that interdisciplinary knowledge production has some characteristics different to discipline-based knowledge production. Firstly, Mode 2 knowledge is generated within the context of application. Thus, the context of application describes the environment from where the problem arises, methodologies develop, outcomes are disseminated and uses are defined. Secondly, there is a growing heterogeneity in the types of knowledge production because of the

greater diversity of sites therein. Lastly, Mode 2 knowledge is highly reflexive, because the problem-solving environments often influence the research design and the end uses. It therefore examines interactions in complexity by moving away from reductionism to context-sensitive science and consequently it is capable of grasping interrelationships between a full range of underlying causal factors.

Up until now, no consensus has been reached about the precise meaning of the term 'interdisciplinarity' (Hoffmann et al.: 2013) but it is generally agreed that its basic goal is creating something novel through blending, linking or synthesising of existing disciplinary knowledge. However, interdisciplinary research can take various routes on the 'blending process', depending on what is being blended and to what extent. In a broader sense, 'interdisciplinarity' can either mean "any form of dialogue or interaction between two or more disciplines" (Moran 2002: 14) or it can also consider the analyses, synthesis and harmonisation of "links between disciplines into a coordinated and coherent whole" (Alvargonzález: 2011).

Barry et al. (2008) draw attention to the limitations of understanding interdisciplinarity primarily as the sum of two or more disciplinary components, or as achieved through a synthesis of two or more disciplines. They distinguish three modes of interdisciplinarity to show its innovative character and multiple logic that go beyond unity. The *integrative-synthesis* mode blends knowledge from two or more disciplines to gain insights into the causes of complex problems such as climate change. The *subordination-service* mode refers to a hierarchical division and a form of arrangement where there is imbalance with a service and a 'master' discipline. This can be the case with social sciences, making it possible for the natural and engineering sciences to address and include 'social factors' in the process of analysis. In the *agonistic-antagonistic* mode interdisciplinarity sets up a dialogue between established disciplines. The aim is to challenge traditional disciplinary thoughts by contesting the epistemological and ontological assumptions of the given discipline. Similarly, Repko (2012: 23-25) proposes that it is the spaces of differences that confront and create a comprehensive understanding of a particular problem. As a result of confrontation, interdisciplinary knowledge critiques taken-for-granted assumptions through which it establishes common ground despite disciplinary differences. The various modes of interdisciplinary synthesis suggest that research projects are characterised by a unique combination of disciplines,

insights and theories, because knowledge and problems are considered context-specific.

3.3 Problem Orientation in Interdisciplinary Research

Interdisciplinary research has become associated with problem orientation because it interferes with the public sector, especially with decision-making and political processes. It is characterised by a qualitative turn, because it provides a more context-specific description of complex social problems. Moreover, problem-orientation is a “pre-condition for dealing with problems” (Zierhofer and Burger: 2007), because it informs actions in their social context, in an attempt to understand structural elements. Therefore, the nature of problem oriented research differs slightly from applied research. Whereas applied research aims at using available scientific knowledge such as analytical models, conceptual schemes or instruments for relatively specified purposes, problem orientation deals with inherent uncertainties. These uncertainties are related to prognosis, complexity and contingency, and they inform decisions that do not have established foundations (Conrad: 2002). Unlike in most disciplinary research questions or hypotheses that grow out of a theoretical framework, this orientation attempts to develop innovative solutions (Kueffer et al.: 2012) through, for instance, a product, policy or technology.

In problem oriented interdisciplinary research the generated knowledge should not be expected to create new and generalised interdisciplinary theories. Rather, problem oriented interdisciplinary offers system, target and transformation knowledge (Schmidt: 2011), or functional explanations and systems of control. Thus a key but problematic step in problem-oriented research is identifying the nature of the problem, because the problem itself is a vague notion. Schmidt (2011) characterises ‘problem’ in problem-oriented research as inherently social in nature, because it is:

“[...] predefined by society (politicians, stakeholders, lay people) and tied to perceptions and interlaced with problem framing and agenda setting. Those who talk about problem-oriented interdisciplinary cannot talk at the same time about value

freeness. Therefore the notion of problem can be regarded as a reflexive term that calls for an explication of who is considering what as a problem and why. Problems are seen as negative, as indicating a deficit state that needs to be addressed, problems have to be eliminated.”

Similarly, Kueffer and Hirsch Hadorn (2008) identify three types of question that problem oriented research tends to include namely a) the causal understanding of a problem, b) relevant conflicts, interests and values and c) the extent to which these should be considered in the research process. Whereas inherent conflicts are considered to be one of the main limitations of problem oriented research, they can provide a range of complementary outputs in that they can either reflect on the needs and qualities of each of the disciplines involved (Strang: 2009) or they can deliver valuable information and multiple data sets that lower interpretation bias (Miller et al.: 2008). To achieve complementary outputs, it is important to keep a focus on how various disciplinary insights can inform each other, by finding ways of analysing datasets that do not subordinate but complement each other. However, keeping a balance between datasets is also not straightforward and it is likely to involve deliberation, negotiation, and the effective exchange and use of information across diverse disciplines, whilst various disciplines may contribute differently to the question at hand. One could provide facts, while others contribute with value-related arguments or alternative perspectives. Nevertheless, it is crucial to appreciate different ways of knowing, in order to overcome privileging one epistemological approach or one set of values over another. Most importantly, the act of balancing differences indicates that interdisciplinarity should not be viewed as a unified synthesis of integrative disciplinary approaches. As Barry et al. (2008) argue, it is a “space of differences” with a potential to be innovative, especially for the production of new objects and practices of knowledge. Space of differences, however opens up tension between disciplinary and interdisciplinary research, because problem orientation is often regarded as a direction that undermines academic research. The next section therefore reviews critical approaches to problem oriented interdisciplinary research. I also reflect on how my own research has engaged with these conflicts.

3.4 The Tension between Disciplinary and Interdisciplinary Research

Disciplines are generally held together by a common epistemology, shared assumptions about the nature and accumulation of knowledge and agreed methodologies for analysing information and rules about what constitutes evidence or 'proof' (Seipel: 2002). The disciplinary model is based on specialisation, allowing specialists within a discipline to construct theories, methods and technologies as well as defining the boundaries of that field. Interdisciplinarity typically focuses on problem solving amongst science, technology and society, specialising in integration that draws on already existing disciplinary insights. Most enquiries in interdisciplinary research deal with issues and problems that go beyond disciplinary boundaries to establish a joint knowledge production for collectively diagnosing a problem. Conrad (2002) points out that because problem-oriented research is focused more on utilising general knowledge on social problems, it tends to stretch over disciplinary categories. Therefore, one of the core issues arising from this research approach is finding the right balance between sufficient theoretical orientation and sufficient problem concern. Problem-oriented interdisciplinary research tends to lack an appropriate theoretical framework, maturity and consensus, whereas theoretical orientation may slice up problem orientation back into existing disciplinary categories. Another critique of interdisciplinarity is its relationship with disciplinary research. Jacobs and Frickel (2009) argue that interdisciplinary knowledge does not have superiority over disciplinary knowledge, because the already existing disciplines are not as isolated as it is often suggested. Furthermore, established academic disciplines are open to development and building bridges between fields. They also point out that interdisciplinarity may not advance knowledge integration, because numerous interdisciplinary projects fail to succeed and instead of integrating knowledge they may actually generate new differentiations.

Other standpoints emphasise that the difficulty of problem orientation and knowledge integration is rooted much deeper than disciplinary tension. Differences originate from the long-standing conflict between positivism and interpretivism. Much complexity-related science occurs within a positivist framework, in which different

epistemologies remain largely unexplored. Holland (2013) argues that the reason why knowledge integration often fails is a problem of 'knowledge' and 'knowledge production'. The main point is not the extent to which integration is successful but what is being integrated, and how. Interdisciplinary research often fails and ends up as being multidisciplinary, because both social and natural sciences undermine knowledge integration. There are inconsistencies in both scientific practice and in philosophical theory, because none of these is adequate enough to deal with inherent complexities. Even though interdisciplinary knowledge integration is a challenging task I further argue that it does not undermine academic disciplines. Rather, interdisciplinary research is beneficial to existing disciplines, because it is able to develop conceptual links, modify or extend existing or critically develop frameworks that lead to new perspectives. In the next two sections I discuss some practical difficulties of knowledge integration and reflect on my own research to present how I engaged in finding balance between disciplinary depth and expertise.

3.5 Practical Difficulties of Knowledge Integration

Several practical difficulties have been encountered in generating new knowledge through research collaboration between disciplines. Problem-orientated interdisciplinary research have emphasised a paradigm shift to disciplinary collaboration between the natural and social sciences; yet the extent to which academic institutions and science in particular have become more interdisciplinary in collaboration is ambiguous. Porter and Rafols (2009) investigate interdisciplinary changes between 1975 and 2005, including long-established disciplines such as mathematics and newly formed disciplines such as neuroscience. Their findings suggest that interdisciplinary efforts are growing slowly, because it is mainly the neighbouring disciplines where cross-citations have increased. Unevenness among the disciplines is found to be an additional barrier in the development and application of interdisciplinary approaches. The majority of energy research projects, for instance, are conceived from an engineering science perspective that views social science data as being supplementary and needing to somehow 'fit into technical projects' (Henning: 2005:). Other frequent barriers may involve incompatible styles of

thought, different research traditions, clashing methodologies, or for instance, vocabulary that is difficult to translate across disciplinary domains (Jackobs and Fricke: 2009). Nonetheless, dealing with differences is core to the process of the integration and identification of conflicts:

“This is necessary because these conflicts stand in the way of creating or discovering common ground, and, thus of achieving integration. One cannot integrate two things that are exactly alike or that have identical properties. Integration can be achieved only between things that are different, whether those differences are seemingly small or impossibly large. In other words, integration arises out of conflict, controversy and difference” (Repko 2012: 248).

What Reisinger (2011) calls an “interdisciplinary handshake” has been particularly difficult to align with knowledge integration across qualitative and quantitative data sets. The synthesising element can be difficult because of contradictions emerging from the sort of knowledge to be produced or the researcher’s disciplinary background. In addition, interdisciplinary teams may have language barriers that could affect the research process. By emphasising the importance of mutual learning, Hargreaves and Burgess (2009) suggest that social scientists and engineers may use different vocabularies that can create miscommunication when collaborating even though they share more common ground than originally assumed. Therefore, building bridges across the disciplines should start through mutual learning. It is not only engineers who should be expected to incorporate social science concepts it is also the social scientists who should broaden vocabularies and enrich theories by engaging with the engineering sciences. Thus, innovative new combinations of methodologies from both disciplines can potentially create new knowledge. And the dialogue between social and engineering sciences would become easier if there were more opportunities for the diffusion of new knowledge.

Other views emphasise the starting point of interdisciplinary research as a crucial step in the research process. Visholm et al. (2012) suggest that industry collaborations and firms are more likely to engage in problem-oriented research projects. Although the research projects’ point of departure is not rooted in a discipline but in a specific problem, firms that collaborate with universities are not always involved early on in the formulation of the research. This indicates not only

that their inputs reduced, but also that their participation may be peripheral, similar to social science and humanities. Lattuca (2001: 113), for instance, highlights that interdisciplinary knowledge integration is problematic to measure and that we should focus on the extent to which the researchers involved in the projects understand the nature of the work:

“Some have tried to measure integration by examining the processes by which interdisciplinary research is accomplished, for example by noting how often researchers on interdisciplinary projects meet to coordinate their work. Others have attempted to judge the final product of an interdisciplinary project typically relying on the judgements of participants or the researchers themselves. If interdisciplinary projects, however, are born and not made, that is, if they begin as I have argued, with interdisciplinary questions, then such attempts are misguided because we must look to the point of origin to understand interdisciplinarity”.

Because interdisciplinary research is not a unified way of doing research and the relevant mix of disciplines tends to be problem or project specific, I would also see interdisciplinary research as a learning process, because it requires the researcher to learn from the other discipline. In the first two years of developing this thesis, learning about building engineering went beyond learning technical vocabulary. It involved developing skills and learning about new methodologies, use of temperature sensors, concepts, and modes of processing and analysing data. I will describe the use of temperature sensors in details in the methodology chapter. But it is important to emphasise that learning, is integral to occupy and understand different disciplinary perspectives to approach a shared problem. Thus, interdisciplinary knowledge integration is an emergent process and a way of working (Leder Mackley and Pink S: 2013) that opens up space for negotiating differences. It challenges existing modes of thinking by making us reflect on our disciplinary roots.

3.6 Balancing Disciplinary Depth and Expertise

One of the other core challenges of knowledge integration in interdisciplinary research is finding the right balance between required expertise and disciplinary depth. Golding (2009) distinguishes two different kinds of interdisciplinary researchers based on disciplinary expertise. Interdisciplinary researchers without

disciplinary depth are able to either identify relevant information from multiple disciplines, to synthesise information, or they are able to bring together various disciplinary perspectives and general methodological skills to design and carry out research. Interdisciplinary skills in this mode of research are based on basic disciplinary knowledge across the arts and sciences. This is particularly useful for accessing information as well as for translating and synthesising multiple disciplinary methods and perspectives. The second type of researcher has disciplinary depth. One example would be a researcher who works on a collaborative project across disciplines. Another example would be a more 'cross-disciplinary' or 'hybrid' researcher, who uses their disciplinary background to do research in another discipline. The third example would be an interdisciplinary team working on a common problem with researchers from various disciplinary backgrounds. The final example would be a disciplinary researcher who brings together perspectives from other disciplines to contribute to the base discipline. The various ways of practicing interdisciplinary research indicate that there are multiple possibilities for establishing 'common ground' between disciplines. Repko (2012) proposes four general techniques to bridge disciplinary conflicts. *Redefinition* refers to differences in academic jargon. Interdisciplinary researchers need to identify what concepts different disciplines could have in common and how areas may overlap. *Theory extension* refers to bringing a concept from one discipline into another, such as the concept of sustainability from economics and moving it to environmental studies. *Organisation* refers to pointing out how various concepts or disciplinary insights might be related. Lastly, *transformation* challenges opposing views or axioms by placing concepts on a continuum. It embraces contradictions by asking why opposing views occur and how both views could make sense when examining the same problem.

We have learnt from earlier sections that the design and integration of datasets in interdisciplinary research is highly heterogeneous. I have shown that knowledge integration faces various difficulties and that learning about the roots of disciplinary differences is key to successful knowledge synthesis. Finding the right balance between disciplinary depth and expertise has been a challenging aspect of this thesis, because household energy use spans across building engineering and the social sciences. Developing an interdisciplinary framework to understand energy

consumption in domestic buildings has taken away disciplinary depth and sufficient theoretical orientation. But because the problem of sustainable energy consumption in residential buildings cannot be firmly situated within one discipline, it was key to develop disciplinary bridges. Thus, disciplinary learning, new skills and engineering methodologies have been essential to move beyond disciplinary boundaries. And it is also important to highlight that building an interdisciplinary framework by developing a specialisation - where engineering and social science intersects - has not undermined either of the disciplines. Rather, the process reconfigured existing disciplinary knowledge by connecting disciplinary insights in novel ways. The framework has been driven by the complexity of the problem and the understanding of how occupants use low-carbon technologies in relation to the buildings they live in.

Conclusion

This chapter has shown that interdisciplinary research is not a unified way of doing research, because there are not any set rules for knowledge integration across the disciplines; rather, knowledge integration is open to learning from other disciplines because the integration process grows out of the space of disciplinary tensions as well as from the different problem framings. I have introduced problem-oriented interdisciplinary that is associated with a qualitative shift in addressing questions of sustainability, because it offers unique opportunities for the social sciences to engage with and develop links between science, technology and society. I have argued that one of the main advantages of undertaking problem oriented interdisciplinary research is that it challenges disciplinary assumptions about how a given problem is framed because collaboration may help to understand what other disciplines perceive, by looking at the same problem space from different perspectives. In this chapter I have reflected on my own interdisciplinary learning experience departing from cultural studies and argued that knowledge integration across the disciplines is open to innovation. Moreover, I have defined interdisciplinary knowledge integration as a process of learning and an essential pre-requisite for making connections among disciplines. In the next section I discuss new

methodological combinations that emerged from interdisciplinary learning and knowledge synthesis.

4. Methodological Combinations

Introduction

This chapter discusses the separation between the concepts of 'home' and 'house' in energy research and demonstrates that sensory ethnography and building energy monitoring can work together productively despite their epistemological differences. I begin the chapter by introducing a set of existing studies that combine qualitative research methodologies with building energy monitoring. Although interviewing is currently the most frequently used qualitative research methodology for understanding the role of occupants in domestic energy consumption, I introduce ethnographic studies and outline what more they can tell us about energy monitoring in buildings. To show that building energy monitoring and ethnography can work together productively, I present a pilot study conducted in the first year of my PhD, which combines building energy monitoring, qualitative interviews and home video tours. I discuss the conclusions drawn from the study regarding the methodological challenges I experienced in relation to qualitative interviewing, and I present the advantages of using sensory ethnography in domestic energy research. I show that sensory ethnography is open to interdisciplinary exchange and methodological innovation. I have developed a methodological approach that combines video tours and thermal imaging. Jointly, these two methodologies attend to how occupants experience and develop how they use heating systems in relation to the physical and spatial qualities of the home. At the end of the chapter I review the data collection and sample size. I present a table summarising the characteristics of the eight houses involved in the study and I also describe the sensors I used in the fieldwork phase. Additionally, I explain how the body exchanges heat with the surrounding environment and why I used these sensors. The recruitment process and ethical considerations are also discussed.

4.1 The Separation of ‘House’ and ‘Home’ in Domestic Energy Research

The literature review section pointed out the growing need for multi- and interdisciplinary methodologies in domestic energy research and building performance evaluation. Yet, to date, the social sciences have been underrepresented in energy studies, because there has only been a slight increase in interdisciplinary input from qualitative research methodologies. Over the past 15 years, out of 4,444 articles from leading energy journals between 1999 and 2013, only 12.6% used qualitative research methodologies, and out of 90,079 references less than 5% of citations were attributed to social science or humanities journals (Sovacool et al.: 2015). Also, blending social science research methodologies into domestic energy research has not been unproblematic. Ellsworth-Krebs et al. (2015) break down the scope of domestic energy research, noting that the notions of ‘house’ and ‘home’ have been treated as separate matters in domestic energy studies. Research on the ‘house’ is concerned with the physical aspects of buildings, ranging from construction to energy supply, heating or cooling systems or appliances. Research tends to be undertaken by building scientists, engineers or architects using quantitative and applied methodologies (surveys, modelling, statistics). Consequently, understanding occupants’ use of buildings is based mostly on positivist methodological assumptions that do not - and cannot - account for the complexities of social context and everyday life. They map the major point of distinctions between ‘house’ and ‘home’ on four axes, as illustrated in Figure 5.

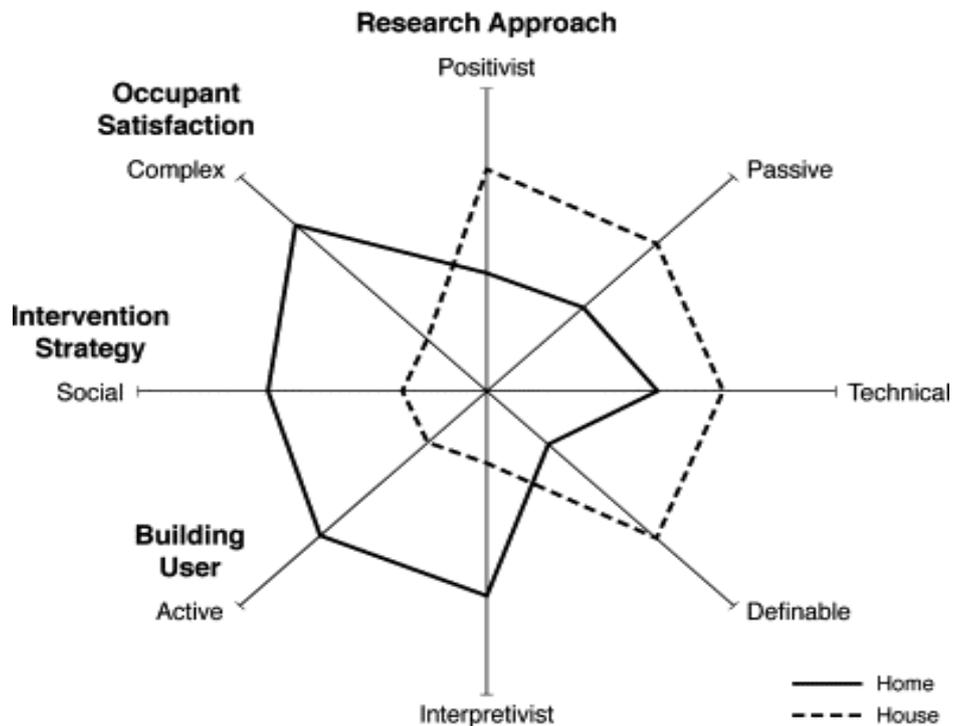


Figure 5 Comparing the house and the home in domestic energy research (Ellsworth Krebs et al.: 2015)

The four axes comprise a research approach, occupant satisfaction, intervention strategy and building user. The research approach refers to a continuum between positivist and interpretivist traditions and the methodological distinction between studying the natural and social worlds. Occupant satisfaction refers to how comfort is defined in domestic energy studies. There may be a general acceptance that building performance goes beyond energy consumption and is influenced by an occupants' comfort, but one aspect breaks comfort down into separate factors (temperature, humidity, lighting etc.) while the other views comfort as a complex set of domestic and material interrelationships. Intervention strategies range from social to technical the latter of which refer generally to psychology and economically informed behaviour change campaigns, whereas the technical is concerned with innovation and design. Socio-technical approaches are somewhere closer to the middle. The human dimension of building energy research or the building user is either left to social science disciplines to deal with, if perceived to be active, or occupants are considered to be passive users of buildings.

Distinctions between the 'house' and the 'home' are also underpinned by epistemological differences. Disciplines are held together by a shared epistemology, whereby assumptions about the nature and ways of generating knowledge are commonly acceptable. Also, a discipline shares methodologies for generating and analysing information and the rules of what constitutes evidence of proof. Nikitina (2002) describes the orientation of humanities as "contextualising" and of sciences as "conceptualising". Contextualising invests disciplines in time, culture and personal experience, aiming to "humanize knowledge". Conceptualising focuses on quantifiable connections between core concepts (e.g. physical laws) where abstracting data bring visibility to common patterns and processes aiming at understanding laws that operate regardless of human perception or experience. In positivism, the investigator and the object of investigation are independent of one another, because objective reality exists beyond the human mind. In interpretivism, knowledge of the world is intentionally constituted through lived experience, and the research process is inseparable from the interactions of the researcher and the research participants. Positivist research typically starts with a hypothesis following which structural experimentations are used to test empirically the hypothesis, in order to determine relationships between variables and generalise regarding the studied phenomena.

Due to this dichotomy, enquiries into residential energy consumption are likely to take conflicting methodological approaches. Building engineering is interested primarily in quantifying the potential for energy efficiency by identifying and analysing factors that affect energy consumption (such as average outside or inside temperature, floor area, number of occupants, thermostat set-points, window opening habits, etc.). Determinants imply the search for knowledge on independent elements that are predictable and quantifiable regardless of time, space or context. Anthropology, in contrast, offers detailed empirical insights into real-life social contexts as well as comprehensive and careful attention to detail, a focus on heterogeneity, local understanding and a more holistic view of systems. It immerses into local meaning-making, showing a particular social setting and cultural context with an interest in processes of change. Knowledge exchange may be more straightforward among disciplines that are epistemological neighbours but it can be

more problematic among disciplines that do not share basic assumptions, orientations and methodologies.

The differences in orientation between understanding the lived everyday and the built physical and technical environments appear to conflict with one another; however, conflicts between disciplinary insights should not be seen as a source of inconvenience (Repko: 2012), since conflicts naturally arise when a complex problem is viewed from different perspectives or from “wide interdisciplinary” (Klein: 2012) standpoints. Yet, different paradigms, conflicting assumptions and not agreed upon methodologies are inevitable and central to fruitful integration. It is in the nature of interdisciplinary research that learning about context and understanding causal structures are equally important. It may appear as conflict in the first instance, but as Krohn (2012) describes, this refers to the need for a combination that finds a balance between understanding the specific features of just one individual context and the scientific search for generalised, context-independent features. The balance, however, needs to pay particular attention to uniqueness and incidental aspects.

4.1.1 Combining Qualitative Interviews and Building Monitoring

Research into building energy use has concentrated largely on the engineering, economics and psychology disciplines, but sociological approaches are now gaining increasing attention. For instance, the DEMAND research centre² utilises combined sociological and engineering approaches to study energy demand. Still, up to now, energy research methodologies have been based on surveys to study the socio-demographic and behavioural aspects of energy use. However, surveying occupants on their attitudes, actions, energy conservation behaviour, environmental values and energy-efficient products is often characterised by a gap between what people say they do and what they actually do. The literature review has also pointed out that social science research is usually featured in technical projects as a component to reflect on behaviour or policy practice. The most commonly used qualitative social science research methodologies in domestic energy studies are semi-structured

² <http://www.demand.ac.uk/>

interviews and focus groups. The following sections introduce lessons learnt from studies using qualitative interviews.

Mixed methodologies can be used with more market research orientation and consumer segmentation across households. Rubens and Knowles (2013) use diary self-reporting, in-home interviews and temperature logging among retired singles and couples, working age singles and couples and family households to explore how households use and what they want from their heating controls. Temperature logging was carried out in 21 households, and loggers were placed on or near the thermostats as well as in the most and least frequently used rooms. It was the participants' task to place the loggers and upload the monitored data every seven days. In-depth interviews were carried out in the participants' homes to discuss what participants do at home, and why. These interviews were also used to discuss the monitored data and to identify consumer types across households. The final phase was a participatory-design workshop in which occupants could rate themselves against emerging user types and could discuss smarter heating controls such as automation, zonal control and remote control.

The DEFACTO (*Digital Energy Feedback and Control and Control Technology Optimization*) project (Mallaband et al.: 2014) focuses on both technical and social aspects of domestic energy demand. It departs from understanding how householders use heating energy and smart heating controls in homes to inform the design of future feedback and control devices and to quantify errors in energy saving predictions and models. In recruited households existing heating system controls were replaced by new digital controls. Householders were sent a questionnaire and a set of temperature data loggers prior to the installation of new heating controls. Householders were interviewed before the new digital controls were installed. The associated monitoring consisted of temperature sensors in each room, coupled with gas and electricity monitoring. Heating schedules, heating set-points at five-minute intervals and manual overrides were identified from the recorded data. In the DEFACTO project the points of departure for understanding householders' interactions with their heating system were the monitored data and the associated gas consumption. Narratives from the interviews were used to support the monitored data. Social components were considered to be how participants set their heating controls, what they perceived to be the most efficient way of heating their home and

how they heated different rooms. One of the main challenges identified in the research in relation to the social aspects is that occupants are unable to discuss the more tacit and unconscious dimensions of their home heating use (Mallaband et al.: 2014).

4.1.2 Mixed Methodologies with Practice Theory Orientation

There is a smaller body of domestic energy research that focuses on space heating along with a practice theoretical orientation. In terms of a methodological approach, they combine building energy monitoring and qualitative interviews. Gram-Hanssen (2011b) shows that heating consumption is more dependent on the characteristics of the building, whereas electricity consumption is highly influenced by the number, size and use of appliances. Gram-Hanssen (2014) uses mixed methodologies including surveys, technical monitoring, and qualitative interviews for 1,000 Danish terraced houses. Qualitative interviews took place in homes, focusing on occupants' everyday routines. As she points out, data combined from the interviews and monitoring should not be used for the interviews to validate the monitored data. Rather, she aims at understanding how measurements relate to residents' understanding and perception of an indoor climate (indoor temperature, humidity, air exchange) and practices. In some cases there is correspondence between the narratives and the monitored data, which can be related to annual energy consumption for heating.

Kane et al. (2011), as part of the 4M project (*Measurement, Modelling, Mapping and Management: An Evidenced-Based Methodology for Understanding and Shrinking the Urban Carbon Footprint*), combines temperature monitoring and qualitative interviews to account for variations in indoor temperature and heating practices in UK dwellings. Temperature sensors were placed in 481 households to monitor indoor air temperature hourly from July 2009 through to February 2010. In total, 469 households had their living room and main bedroom monitored. The mean temperatures of 292 households were calculated. Dwelling types were separated, and the mean living room temperature was calculated based on measurements taken at various times of the day (morning, day, evening and night). The findings suggest that evenings are warmer and they are the most occupied times of the day.

Average evening temperature during occupied periods was also calculated, showing a variation of 10°C across all house types, a finding that is attributed partially to occupants' heating practices besides the efficiency of buildings, heating systems and outdoor climate.

Foulds et al. (2013) focus on the relationship between the performance of heating practices and building energy data to improve methodological integration between qualitative interviews and monitored energy datasets. The authors collected data from a UK passive house development for 16 months after post-occupancy, starting from July 2011. Passive house dwellings are designed without conventional heating systems. This design principle is based on minimising heat loss and maximising internal heat gain through, for instance, the body heat or solar gains. Temperature data therefore become more reflective of the performance of practices than in conventional dwellings, because it is more separable from the buildings' fabric condition. Data collection included the monitoring of humidity, internal temperature, total electricity consumption and CO₂ sensors. Data on gas and water usage were not available. Narratives were used to identify discrepancies between what occupants say they do and what they actually do (e.g. appliance use). Monitoring is used as a way to measure the 'by-products' of individuals performing practices. Building energy data are considered to be a record of energy consumption that is the result of householders performing practices.

Mixed studies using qualitative interviews and energy monitoring point illustrate that the methodology of interviewing can be challenging, because people do not always do what they say they do. Interviews often take a supplementary role in evaluating monitored datasets or interpreting gaps in monitored building energy datasets. But interviewing cannot attest to how people develop home heating practices in relation to the buildings in which they live in i.e. it does not encounter people as they live out the more invisible and sensory elements of everyday life. Consequently, it cannot explore the environments of which we are a part and does not enable us to situate energy used for space heating as part of place, movement, practice and perception. The next section moves on to bring together research that entails an ethnographic point of departure in understanding home energy consumption.

4.2 Ethnography and Building Energy Monitoring in Domestic Energy Research

The use of ethnographic inquiry into domestic energy studies has been marginalised over the past decade, and there is only a small body of ethnographic research into domestic energy use that emphasises the complexity of home environments and the interrelationship between the physical and social dimensions of energy use. By using the example of bio-pellet stoves, Henning (2006; 2008) employs ethnographic approaches to discover the importance of home environments and creating the right atmosphere in indoor climates in home heating. She emphasises the complexity of home environments, revealing that we need to account for more invisible elements (e.g. gender or emotions) when we research energy use in households. There is an even a smaller body of ethnographic research in domestic energy studies that combines energy monitoring. Barron and Sinnott (2013) explore the energy use patterns of six dwellings, by combining monitored electricity consumption with participant observation and interviews. They use the combination of ethnography and monitoring to measure high-resolution energy use on the appliance level, revealing the purpose of appliance use and how it fits into the occupants' everyday life. Their study, however, is more concerned with finding influential drivers of energy use and providing feedback for occupants on their energy consumption.

With a more industrial and design focus, Lockton et al. (2013a; 2013b) combine qualitative ethnographic data with energy monitoring in the SusLabNWE project. By integrating qualitative findings and quantitative datasets they aim to better understand the role of occupants in household energy use. Householders are asked to walk through their routines at a particular time of a day, to reflect their actions in context whilst explaining the products and services they use. Home energy data are used to focus on householders' specific actions, especially where unusual patterns of use are identified. Timescapes are used to create a timeline of householders' actions, and emotional values are attached to activities overlaid with energy data collected in the same timeframe. This produces relational maps linking interactions with monitored data.

What we learn from these ethnographic studies is that we need to attend to the physical, material, tacit, sensory and verbalised elements of the home as well as how they are experienced. We also need an interdisciplinary approach that captures complex interplays between people and their homes and goes beyond occupants' direct interaction with control points. Essentially, we need an approach that brings together building monitoring techniques and the tacit, sensory and unspoken dimensions of energy use and everyday life. As Henning points out (2005: 12), "we must also be prepared, and equipped, to collaborate and communicate with other than our own charmed circle of social scientists". A sensory ethnographic approach offers a way of collaborating, because it builds bridges between disciplines. Therefore, the research methodology in the thesis takes a different point of departure into understanding domestic energy consumption in that it takes sensory ethnography and video tours as a route to interdisciplinary knowledge. Before describing the nature of sensory ethnography and the video tour method in domestic energy research, the next section introduces a pilot study from the first year of my PhD study.

4.2.1 Methodological Conclusions from a First-Year Pilot Study

The 'Energy Theory and Measurement' module I took in the first year of my PhD study involved an optional coursework, which was an opportunity to familiarise myself with measurement techniques, analysis and the interpretation of empirical evidence on energy use in residential buildings. The assignment set out to identify a house where a series of measurement activities was carried out. A research strategy needed to be developed and implemented, and this included collecting, analysing and interpreting data relevant to the chosen house's energy use. Based on the empirical evidence, the task was to identify occupants' impact on the building's energy use.

I teamed up with another PhD student, Emily Prestwood³ from the School of Civil and Building Engineering to carry out the pilot project. Emily's PhD research looks at the macroeconomics of residential energy use, and she was particularly keen on understanding the 'social factors' of home energy consumption. I was interested in learning more about the various 'technical factors' that influence home energy consumption. We chose a 1970s detached three-bedroom, two-bathroom (one en-suite bedroom) property. The house was on the outskirts of Loughborough, and it was rented to three PhD students. I first prepared a semi-structured interview guide and later took the lead on the home video tours. Emily selected, organised and installed the sensors. We used Hobo pendant data loggers to monitor indoor temperature at intervals of 10 minutes between October 2011 and March 2012. These were placed in the following rooms: bedrooms, living room, kitchen, corridor and stairway. The loggers were placed away from external walls, sunlight, lamps or any source of heat. IButton devices - computer chips enclosed in a stainless steel can - were placed on the inlets and outlets of the radiators and on the hot and cold return flows of the boiler. Data from the Hobo loggers and IButtons were collected in two-weekly cycles. After I familiarised myself with the sensors, we took turns in visiting the house to download the data. Weekly temperatures were plotted and compared in three bedrooms in order to explore variations in indoor temperatures. Loggers were numbered, recorded and organised into an excel spreadsheet.

Due to the limited availability of two occupants, the study used qualitative interviews with two and a home video tour with the third PhD student. The pilot study was therefore able to provide a source of comparison between the two methodologies. The interviews were semi-structured and were grouped into three general areas of interest. The first area was concerned with the routines of the occupants. They were asked to talk about the amount of time spent at home, describing their daily, weekly and weekend routines. The second group of questions was concerned with managing the heating system. They were asked to describe the timing, schedule and temperatures they were aiming to achieve across the house, together with the radiator valve settings they used. The third group of questions was related to the occupants' activity level, clothing preferences as well as food and drink intake. They

³ Emily Prestwood gave consent to write about the project and to mention her name

were asked to talk about the type of clothes they wore at home, including differences between weekend and weekdays, what type of exercises they did, what type of food they purchased and prepared during the winter and whether they kept any seasonal differences.

The interviews were able to reflect on the routine habits that structure home heating. Narratives from the interviews revealed that because the property was rented and it was a more temporary form of accommodation, the occupants made use of spaces slightly differently. For instance, the living room was rarely used, the kitchen was a more functional space and the occupants spent the majority of their time in their bedrooms. They also talked about how the thermostat was programmed, how they tended to manually override the thermostat settings, what their daily routines were, how daily routines intersected with thermostat schedules and what their temperature preferences were in their bedrooms. Narratives indicated that because the routines were more personalised and less synchronised in this household, the occupants often manually overrode the programmed settings and sometimes even each other's manual settings. Narratives were correlated with the monitored temperature data. The heating systems' on and off times were identified from the monitored temperature data gathered from the IButton sensors placed on the boilers' flow and return pipes. Weekly plotted monitored indoor air temperature data in the living room and bedrooms, combined with narratives and follow-up interviews, showed active and inactive occupancy hours, indicating that evenings were the most occupied periods. Six-month averaged temperature data across the three bedrooms revealed differences in the upstairs, downstairs and en-suite bedrooms that could be related to the occupants' temperature preferences and thermal comfort.

Yet, what remained unexplored were some of the core questions and the underlying structuration logic of heating the household. The combination of interviewing and monitoring could not uncover how the occupants experienced the spatial and sensory qualities of the building. Consequently, some of the questions on how they interacted with the control points (schedules, manual override, regularity and irregularity of TRV use), developed from the interplay of sensory experiences and spatial qualities, were unreachable through the interviews. The next stage of the pilot study explored sensory ethnography, using a home video tour with the third

occupant Alison. However, before introducing some of the connections made between data from the home video tour and data from the technical inspection, the next sections introduce sensory ethnography and the visual methodology of the home video tour in building energy research.

4.2.2 Going beyond Narratives: Sensory Ethnography in Building Energy Research

Sensory ethnography places the sensory aesthetics of place at the centre of analysis. Pink (2004) developed the analytical category of a sensory home that captures how various sensory elements of touch, smell, sight and seeing come together in experience, knowledge and domestic practices within the home. A sensory environment is present in any home but it is an analytical category that goes beyond socio-demographic variables or geographical locations. It is concerned with the processes of creating, maintaining and re-creating home environments. Sensory ethnography presents senses in the light of complex interconnections and interrelations, because it views the home as a “site of sensory consumption” (Pink 2007: 164), where occupants’ experiences of the surrounding built environment can be understood in its multisensory reality.

Pink (2015) discusses a set of principles for undertaking sensory ethnographic research, by focusing on place, perception, knowing, memory and imagination. Thinking about place as an ‘event’ represents a shift away from considering it as something static to something fluid that is always in flux. Researching place as a process of change implies that participants and ethnographers are always part of social, sensory and material contexts that they “experience through their whole bodies and that are constantly changing” (2015: 38). The concept of ‘emplacement’ implies that in doing sensory ethnography, learning and participation are key elements in the research process. The researcher seeks not only to know more about the emplacement of others, but by being emplaced, he or she also participates in practices and environments. By experiencing participation in other people’s homes, an embodied experience can provide insights into environments, and this helps to understand meanings, practices and subjectivities. In order to explore the relevance

of sensory experiences, categories and meanings, researchers need to find ways of understanding the socialities and materialities that make up the context of these sensory experiences.

Being involved in how places are made, by exploring the context of sensory experiences, is therefore a learning process. It involves learning from and learning with the participants. This learning process was distinctly important in understanding how energy is used for space heating. The occupants' sensory experiences opened up a form of tacit knowledge that provided valuable details about the physical particularities of buildings. I came to understand these physical particularities by learning about the occupants' sensory experiences by, for instance, touching uninsulated wall surfaces and cold radiators or feeling the draught coming from windows and corners. Moreover, participating in others' lived environments gives the researcher the opportunity to invite his or her reader into the places and multisensory experiences of the ethnographer and the research participant.

The concept of 'ethnographic places' is about discovering interrelationships. Researching lived environments, by using sensory ethnography, was particularly useful in understanding interrelationships between the occupants' sensory experiences and the performance of home heating activities as they evolve in relation to various building fabrics' condition and heating system efficiency. As sensory ethnography is attentive to complex processes of relating, it is able to follow how sensory experiences relate to ongoing negotiations and problem solving in creating home environments. Therefore, understanding how occupant-building interactions unfold in real-time uncovers a process of discovery in research environments that is often spontaneous and unanticipated. It is a learning process where the senses access a form of tacit, non-verbal knowledge that is invisible and not usually verbally reflected on. Environments are often sensed rather than verbally expressed.

4.2.3 The Role of Multisensory Emplaced Learning and Reflexivity in the Researcher's Emplaced Engagement

Engaging in the daily lives of households requires the researcher to be in some way part of the household's lived environment. In classical ethnographic research there are different levels of participation, ranging from 'pure' observation to 'active' participation. In sensory ethnographic research reflexivity is a core component, because the ethnographer engages in the research process by using his or her own sensory experiences through which he or she explores environments, sensory experiences and relationships. Sensory "intersubjectivity of the ethnographic encounter", as Pink (2015) notes, is essential to sensory ethnographic research. Bodily sensations are used reflexively here to collaborate with participants and to produce a shared understanding, which is then presented to offer the opportunity for readers and audiences to engage in the environment of research.

Understanding other people's environments, activities, experiences and knowledge requires a "reflexive appreciation of one's own sensorium" (Pink 2015: 59), which not only involves an awareness of one's own 'sensory subjectivity', but also reflexivity about how this subjectivity is involved in the production of ethnographic knowledge and in the learning process about other people's sensory ways of knowing. Multisensory emplaced learning (Fors et al: 2015) provided a form of engagement that connected me to the 'place-event' of homes. My own sensory experiences made me engage directly in participants' experiences, actions and home environments. Therefore, my own sensory experiences provided bridges to the ongoing nature of lived everyday realities, sensory aesthetics of home environments and to the roots of improvisatory practices. On the one hand, my own sensing body helped me to learn about the context of where and how improvisatory home heating activities develop. By spending time with occupants I participated in everyday movements and daily routines and I learnt about how morning routines (e.g. making a cup of coffee, taking a shower) or evening routines (cycling home from work, cooking and having dinner) intersect with energy consumption and the use of radiators, room thermostats or TRV controls. By experiencing the moment of movement I could attend to sources of idiosyncrasies and interpret why the same practice may be performed differently. I

participated in perception and sensory ways of 'making sense', and I was able to understand the embodied knowledge participants utilise in their everyday activities but do not necessarily talk about. I learnt about how occupants make their home environment feel 'right', using my own sensory experiences. I experienced with my participants how, for instance, heat escapes from the body nearby draughty windows or external walls that lack insulation and radiate cold. Moreover, my own sensory experiences helped me to make sense of interrelationships between buildings, heating systems and the sensory aesthetics of homes. By grasping interrelationships between movement (routine/practices), place (home environments and the physical characteristics of buildings) and perception (sensory experiences and the sensory aesthetics of the home), I was able to 'move along' the route of how improvisatory home heating develops. Therefore, my own body, movement and senses enabled me to immerse immediately into everyday lived environments and embodied ways of perceiving, in order to follow how movement unfolds in relation to the surrounding built environment.

4.2.4 Home Video Tours: Capturing the Invisible Elements of Domestic Energy Consumption

By using novel and innovative methodologies in the form of digital media, sensory ethnography moves away from classical participant observation and from watching and listening. It goes beyond what people say, because it recognises that not everything can be expressed through words. Furthermore, it rethinks ethnographic interviewing by suggesting that interviews are "social, sensorial and affective encounters" that give an embodied nature to the interview process, thereby engaging the performative and sensory body in the environment that is being researched (Pink: 2015: 75). Applying a video-ethnographic approach offers a way to capture the more invisible dimensions of how domestic energy consumption is implicated in making home environments feel right. First of all, home video tours combine movement and narrative whereby the researcher and occupants:

“[...] move through their route they unavoidably verbalise, engage with and draw together a series of ideas, sensed embodied experiences, emotions, material objects and more. That is not so much the gathering of data that the researcher will take away to analyse, but rather it is a process of bringing together which involves the process of accumulation of emplaced ways of knowing generated not simply through verbal exchanges but through, for example, cups of tea and coffee, comfortable cushions, movement or performance, odours, textures, sounds and images” (Pink: 2015: 79).

Walking routes in sensory ethnography are essential ways of coming to know about ‘place-event’ relationships, because it is the occupants who bind together material, social, sensory and physical elements, which are interrelated and often inseparable. A video tour therefore offers a way of understanding how the home environment is made, how it changes, how it is experienced and how energy use is caught up in the process. Pink and Leder Mackley (2012) define a video as a “route through which seeing and hearing can lead researchers and viewers to empathize with and imagine multisensory embodied experiences and not simply the aural and visual worlds of others.” Moreover, it is a form of empathetic engagement and an ethnographic description of a context that explores with the camera and with one’s own body how occupants create a home’s sensory aesthetics and how they create demand for energy. As Pink and Leder Mackley (2012) continue to outline, video creates a trace of routes through a given sensory environment. Although it does not record invisible elements like warm air, humidity level or indoor air temperature, it does record how occupants reflect on invisible elements and what they may say about it, their facial and bodily expressions and performance. Video recording can invoke empathetic responses to these experiences.

4.2.5 Building Interdisciplinary Bridges

Sensory ethnography in building energy research can potentially help in understanding the home and built environments, activities and experiences of occupants by discovering interrelationships between sensory, material, domestic and physical settings. Focusing on the senses as a route to knowledge and human experience opens up sensory ethnography to interdisciplinary collaboration and methodological innovation. Based on an interdisciplinary research project – between

social scientists, engineers and designers – called Lower Effort Energy Demand Reduction (LEEDR <http://leedr-project.co.uk>), based at Loughborough University, Leder Mackley and Pink (2013) review experiences of joint knowledge production between sensory ethnography and building energy monitoring. The first point of clarification occurred when the roles of home video tours were discussed, because they were interpreted differently across the disciplines. In building engineering sciences sensory ethnography was thought to offer insights into 'real-time' activities of the home that run parallel with monitoring. Conversely, from a sensory ethnographic point of view, home video tours are not records of what people do and when. They can be defined as:

“[...] audio-visual manifestations of co-constructed ethnographic encounters. As such, they cannot be seen as monitoring tools in the same way as households' energy use sensors but as entry points into people's lifeworlds and experimental realities, which can be interrogated from a number of angles. They document and evoke the ethnographic encounter and thus serve as aide – memories for the emplaced sensory and social experience of the researcher...”

Sensory ethnography, as they point out, does not take monitored data as a point of departure to understand domestic energy consumption; rather, it is the creation, recreation and maintenance of home environments and making the home environment feel right that may implicate different energy uses.

Accessing other people's 'knowing' and 'interior worlds' is not a simple task but as Hogan and Pink (2012) demonstrate, by combining art therapy and interdisciplinary visual methodologies, innovative use of new methodologies can offer insights into interior worlds. Home video tours combined with thermal camera use in this thesis were particularly useful in identifying interconnections between occupants' sensory experiences, buildings' fabric conditions and heating systems. Home video tours helped to map out the complex sensory, affective, routine and contingent aspects of the everyday, and they also helped to understand how home environments are created in relation to the spatial qualities of buildings and how the performance of home heating activities grow from these interconnections. Findings from the pilot study's second phase introduce some of the initial connections between spatial

qualities and the processes of making the home environment in one of the bedrooms feel right.

4.2.6 Combining Home Video Tours and Thermal Imaging

The initial technical inspection of the rented property included a blower door test and a thermal image inspection. A blower door test involves attaching a fan to the frame of an exterior door. The test is used to determine a home's airtightness. The fan extracts air out of the house, thus lowering the air pressure inside. The higher outside air pressure then flows in through cracks and openings in the fabric of the building. A smoke pencil was used to detect air leakage paths and to identify air movement. An infrared camera was used in conjunction with the blower door test to acquire a visual illustration of air leakage. Thermal imaging cameras detect energy in the infrared range and produce visual representations of infrared energy emitted by objects. Every object above absolute zero radiates infrared light. Infrared is a type of light that is invisible to the naked eye and the warmer an object, the more heat it emits, and it appears more brightly in the infrared. Cold objects emit less heat and appear less bright in infrared images. Thermography therefore makes it possible to see and document energy losses and variations in temperature in a home in real time. Air leakages appear as dark areas in the infrared camera's viewfinder.

Alison is a PhD student, who rented out an upstairs bedroom located underneath the attic of a three-bedroom detached house. When walking up the stairs, Alison told me that every time the heating came on in the house she would keep her bedroom door closed. At the top of the staircase, right in front of her room, was a pulldown staircase that went up to the attic. If she left the bedroom door open, the heat would escape quickly because the roof lacked insulation. The following thermal image (Figure 6.) shows the pulldown attic stairs. The dark spots in the corner of the stairs illustrate air leakage paths.



Figure 6 IR image of air leakage paths via the attic stairs

Alison explained further that she actively uses the curtains as part of her heating regime in her bedroom. She shuts the curtains in winter evenings and opens them every morning when she wakes up. The window is draughty. She invited me near the window to put my hands close to the frame. I could feel the slight draught of cold air coming through and around the frame. The following two infrared images show leaking air around the window frames in Alison's bedroom.



Figure 7 IR image of the air leakage paths in Alison's bedroom

Alison's bed is placed in the right-hand corner of the room. She employs various techniques of how to keep herself warm, because her room cools down very quickly on winter nights. At night, she tends to sleep facing away from the window, because

the cold air reaching her face makes her nose and shoulders freezing cold. She sometimes sleeps with a hot water bottle that she places on the left side of the bed near to her lower back. She often goes to bed wearing more than one thick jumper. Instead of buying a winter double duvet, she bought two lighter weight duvets. She can either remove one for summer months or she can split them into two, if she has guests over. The dark blue corners on the next thermal image show an air leakage path through the ceiling, due to missing insulation.



Figure 8 IR image 2 of the air leakage path in Alison's bedroom

Knowing the routes of cold airflows into the bedroom helped to understand some of the sensory experiences that cannot necessarily be articulated in words. Thermal imaging provided an entry point for exploring the occupants' environmental knowledge in relation to the physical particularities of the house. Moreover, combined with home video tours, it made a joint contribution to exploring how the physical and spatial qualities of the house are involved in creating indoor climates and the 'right' atmosphere of the bedroom. Additionally, thermal images, combined with Alison's sensory experiences, explained how some of the heating activities (closing curtains, using a hot water bottle) developed from the interconnection of sensory experiences and spatial qualities.

The conclusions of this pilot study indicated that sensory ethnography and home video tours are able to disclose more about occupants' experiences on a non-verbal level. The combination of home video tours and thermal imaging reflects on occupants' sensory experience of buildings. And building use 'in-use' reveals interrelations between occupants' sensory experiences, knowledge perception, buildings and heating systems.

4.3 Data Collection

The next sections introduce the data collection stages from the home video tours and building energy monitoring, including the sample size and recruitment process, borrowed equipment, data organisation and data storage.

4.3.1 Sample Size and Recruitment

The research sample comprised eight dwellings, out of which three had energy consumption monitored for a period of three months. The characteristics of these buildings are summarised in the table below:

Table 1 Summary of participating houses

	H1	H2	H3	H4	H5	H6	H7	H8
Type	Semi-detached	Semi-detached	Mid-terraced	Detached	Mid-terraced (pitched roof)	Detached	Mid - terraced	Mid-terraced
Size	70 m2	85m2	90m2	160 m2	65m2	118m2	60m2	82m2
No of bed/ bathroom	2 /1 conservatory (living room converted into bedroom)	3 /2 conservatory	3/2	5 /4	2/1	4/3	2 /1	3 /1
Year built	1930s	1930s	2012	2001	1880s	1991	1890s	2013
Occupants	3	3	1	5-6	1	1	1	1
Boiler	Gas/combi-boiler in kitchen	Central-heating gas boiler in the kitchen (2006)	Combi boiler in the kitchen	Gas central heating with hot water storage,	Bosch Worcester Greenstar 30 Si 2007	1998	Sime super90 combi boiler	Combi-boiler in kitchen
Controls	1 electronic thermostat in kitchen	1 electronic thermostat downstairs	2 electronic thermostats (1 upstairs and 1	1 electronic thermostat in kitchen	1 wireless portable thermostat	1 manual thermostat in	-	2 electronic thermostat (1 upstairs

	downstairs)				hallway		and 1 downstairs)
Retrofit	Boiler replaced in 2012 October	TRVs, living room thermostat	Boiler replaced in 2012 October	Loft insulation PV panels TRVs (2012)	Boiler, radiator TRVs	Planned retrofit: boiler TRVs, heat pump	Planned retrofit: boiler

Table 2 summarises what was monitored in each home. H1, H2 and H3 were monitored for a period of three months. H4, H5, H6, H7 and H8 only participated in home video tours. The sample size comprises of 8 buildings because the research focused on the in-depth understanding of social and technical dimensions of building energy use.

Table 2 Summary of monitoring

	H1	H2	H3	H4	H5	H6	H7	H8
Annual gas and electricity consumption	X	X	X					
Indoor temperature	X	X	X					
Relative humidity	X	X	X					
IR camera	X	X	X					
Home video tours	X	X	X	X	X	X	X	X

The sample size comprises of eight households, which may be considered a small sample in building energy research. But because the thesis combines building energy monitoring and home video tours, it focuses on the interrelationship of practices and places to gain an in-depth understanding of how people use home heating technologies in relation to the physical characteristics of the buildings they live in. From a sensory ethnographic perspective the research comprised of touring eight homes to immerse in occupants experiences of the home and explore the

invisible material, physical and sensory elements of home heating. Although only three buildings (H1, H2 and H3) engaged in building monitoring and home video tours, a wide variety of energy use data were collected and home environments were observed. Sensory ethnographic observations also captured movement, “feelings” and responses to home environments and indoor climate conditions whereas the monitored energy data and the IR camera images revealed information about the physical characteristics of buildings. This extended the focus from buildings, practices or direct interaction with home heating controls to the ongoingness of activities and to the interrelationship of practices and buildings. It also included close attention on domestic artefacts to see how objects and technologies move around and contribute to the creation and maintenance of home environments and indoor climate conditions. Following the routine movement of occupants made visible experiences and interactions with home heating controls ‘real-time’ as they happen besides engaging with people’s embodied engagement and skilled knowing. A small sample size therefore allowed a more even ‘balance’ between engineering and social science insights and co-produced a joint understanding between everyday domestic activities and their physical context.

In order to recruit participants, an advertisement email was circulated among Loughborough University staff, and printed leaflets were given to larger local sport facilities. A recruitment advertisement was also sent to the energy-sub group of Transition Loughborough, a local community that supports residents in both reducing their energy usage and in making increased use of low-carbon and renewable energy sources. Five participant households were recruited from Loughborough University staff, two households were recruited from snowball sampling and one household was found via leaflets. Initially the research aimed at finding similar building types, but the study instead recruited a range of house types in terms of age, size and occupancy.

4.3.2 Home Video Tours and Field Notes

Home video tours were carried out in eight homes, and each tour lasted between 45-80 min. A camera recorder was borrowed from the Department of Civil and Building

Engineering. Video footage was downloaded into a password-protected environment and edited and stabilised with IVideo version 1.33. Video footage was only partially transcribed. Screenshots were taken from the videos and were used for illustration in the thesis. The use of images is explained in more detail in the *Ethical Considerations* section. The data collection included an initial visit to the households to get a general introduction on the first time and to estimate the number and type of equipment needed for the three households. Three households (H6; H7; H8) received two visits, while the rest of the households had follow-up visits after the first home video tour. Further field notes taken in the households included photos, hand-written notes and voice-recorded iPhone memos, to remember initial personal impressions and feelings upon entering these environments. Hand-written notes included some analytical ideas on how to connect monitored temperature datasets with video footage.

4.3.3 Sensors and the Body's Heat Exchange with the Thermal Environment

Thermal comfort of the human body is broadly defined as “that condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ASHRE Standard 55: 2013). Thermal comfort is fundamentally about how people interact with their thermal environment and how they respond to the transfer of heat from their body to their surroundings and to the quality of the air within a given space. There are various personal and environmental factors that influence how the body balances heat production (CIBSE KS06: 2006). If the balance is not even, people start to feel uncomfortable. If the body loses more heat than it generates, people feel cold, but if the body cannot lose heat fast enough, then people feel hot. Heat is lost from the body in four ways, namely evaporation, radiation, convection and conduction, though conduction tends to be negligible. Evaporation heat loss takes place via respiration, insensible perspiration (continuous evaporation on the skin's surface and from the lungs) and by sweating. Radiation and convection heat losses take place on the skin's surface. In order to be in thermal balance with the surrounding environment, heat loss from the body must equal to the amount of heat generated. This thermal balance is dependent on personal and

environmental factors. The personal factors are physical activity and clothing. Metabolic rate is a form of energy production where the human body uses oxygen to metabolise food and convert it into useful forms of energy. The body produces heat all the time, but the amount depends on the level of activity so one way to influence the body's thermal balance is by increasing activity. The other one is by putting on or taking off layers of clothing.

Thermal comfort is also affected by the surrounding environment. The body's heat loss through each of the routes described above varies according to internal conditions. In well-insulated buildings, for instance, relative heat loss is typically around 24% by evaporation, 38% by radiation and 38% by convection, because air temperature and radiant temperatures are similar values. In moderate environments the body can lose around 25% of heat by evaporation, 45% by radiation and 30% by convection. The following two images (Figures 9-10) show how the body loses and gains heat from the surrounding environment.

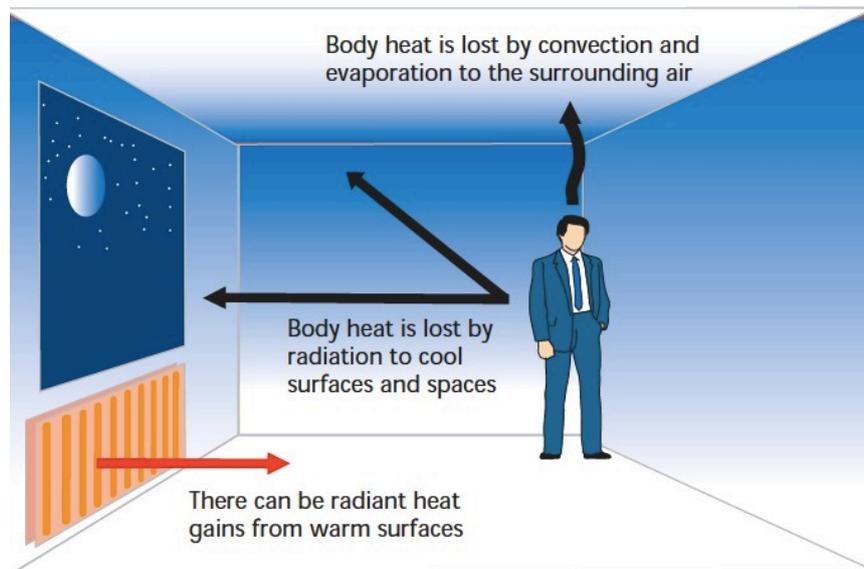


Figure 9 Heat gain and heat loss routes at night (CIBSE: 2006)

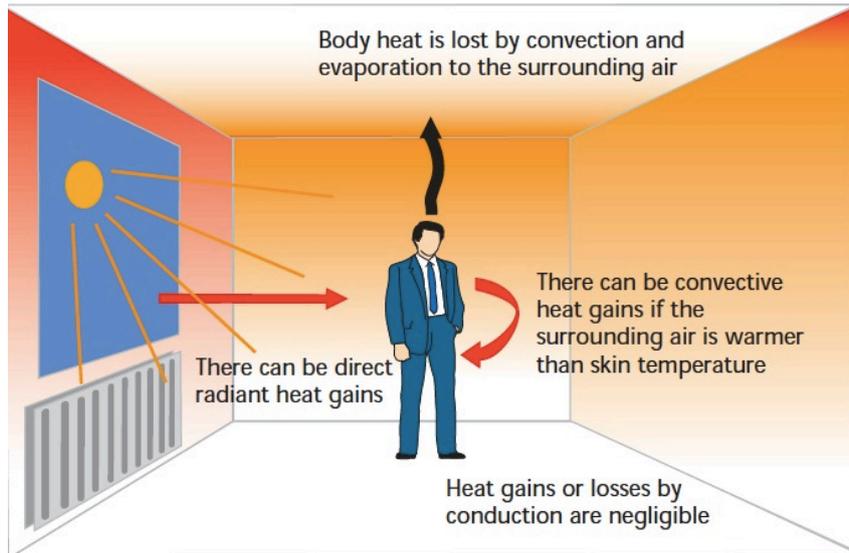


Figure 10 Heat gain and heat loss routes during daytime (CIBSE: 2006)

In buildings, the key internal environmental factors that affect thermal comfort are air temperature, air relative humidity, air movement and air quality.

By monitoring the energy consumption of three homes, (H1; H2; H3) various equipment were borrowed from the Department of Civil and Building Engineering to record indoor climate conditions.



Figure 11 Data loggers

Thirty Onset Hobo temperature pendant data loggers (top left on Figure 11) were used to monitor indoor air temperatures across bedrooms and living rooms. Four

Onset Hobo temperature and relative humidity data loggers (top right on Figure 11) recorded relative air humidity. Relative humidity measures moisture in the air and the concentration of water vapour in the atmosphere. A value of 0% refers to completely dry air, whereas 100% would be fully saturated and moisture would condense out. Humidity has no major effects on feeling warm, and people do not actually perceive relative humidity itself; rather, they perceive the dampness or dryness of their own bodies in reaction to relative humidity. One hundred iButton thermochron temperature sensors were borrowed to monitor the flow and return temperature of radiators.

Three buildings were monitored from March 2013 through to May 2013. The Onset Hobo pendant data loggers recorded internal temperatures across bedrooms, living rooms and occasionally bathrooms while the Onset Hobo temperature and relative humidity data loggers recorded indoor temperatures and humidity in one bedroom and three living rooms. Data loggers were numbered in each of the homes and recorded on Excel spreadsheets to keep track of the monitoring equipment.

	A	B	C	D	E
9	Upstairs Bedroom (A)	Internal Wall	Hobo Pendant temperature Logger	8	
10	Ensuite bathroom	Internal Wall	Hobo Pendant temperature Logger	9	
11	Upstairs Bedroom (B)	Internal Wall	Hobo Pendant temperature Logger	10	
12	Outside Back Garden	Washing line	Hobo Pendant temperature Logger	11	
13	Hallway	Bathroom Internal wall	Hobo Pendant temperature Logger	12	
14	Dining	Out Tru	Ibutton	1	
15	Dining	In	Ibutton	2	
16	Bathroom	Out Tru	Ibutton	3	
17	Bathroom	In	Ibutton	4	
18	Kitchen	Out Tru	Ibutton	5	
19	Kitchen	In	Ibutton	6	
20	Living	In	Ibutton	7 replaced by 20	
21	Living	Out Tru	Ibutton	8	
22	Downstairs Bedroom	Out Tru	Ibutton	9	
23	Downstairs Bedroom	In	Ibutton	10	
24	Upstairs Bedroom (A)	Out Tru	Ibutton	11	
25	Upstairs Bedroom (A)	In	Ibutton	12	
26	Upstairs Bedroom (B)	In	Ibutton	13	
27	Upstairs Bedroom (B)	Out Tru	Ibutton	14	
28	Gas Supply		Ibutton	15	
29	Boiler Kitchen	Flow (Hot)	Ibutton	16	
30	Boiler Kitchen	Return (Cold)	Ibutton	17	
31	Downstairs hallway		Ibutton	18	
32	Downstairs hallway		Ibutton	19	
33					

Figure 12 Listing the monitoring equipment

Sensors were set up at the same time to begin recording temperature and humidity data. They were also set up to stop logging when the memory filled up, otherwise the devices would have continued recording by overwriting older data records. All devices were set to log at an interval of 10 minutes. Hobo pendant and humidity data loggers were placed away from direct sunlight and heat sources, to ensure the measurements related to air temperature. Hobo sensors are waterproof and small enough to provide easy placement across homes. The occupants helped to suggest places for the sensors to be placed, to reduce the likelihood of damaging them and losing data. Households were visited in every two weeks for data collection. Data from the Hobo temperature sensors were uploaded manually one-by-one using an optic USB base station and Hoboware software. Each file was then saved to Excel sheets as raw data for later analysis. The temperature sensors were calibrated by the department.

Thermal imaging was used in three homes to detect heat loss and insulation defects on the building fabric. Building fabric images were taken after sunset at around 9-10 pm, in order to reduce the effect of solar radiation on the building facade. Outside ambient air temperature was measured between 0°C and -2°C at the start of each survey. More images were taken indoors of the surface temperature of the radiators, which had both digital and thermal images taken. These were saved next to each other for comparison. Storage media were checked the day before to ensure that the memory did not run out of room while saving the images. All windows and doors were closed during thermal imaging.

Monthly average temperatures were taken from the UK Met Office's Sutton Bonington station. Yearly gas and electricity consumption data were collected for two of the households, while meter readings were provided by the occupants.

The iButton thermochron temperature sensors were attached to the inlet and outlet pipes of the radiators to monitor the temperature of water flowing in the pipes. A side-by-side test of the iButtons was first carried out to determine the most accurate way of measuring the surface temperature of the radiators. A side-by-side test was conducted for a period of seven days, from 02.25.2013 to 05.03.2013, to determine the most efficient way of attaching the iButtons to the radiators and thus minimise

heat loss between surfaces. The iButtons were attached to a radiator pipe surface in different ways for a period of one week to test the best material for heat conduction. I tested foil (blue line), a cable tie (red line), thermal compound (green line) and Sellotape (purple). The thermal compound provided the most efficient heat transfer material and was selected to minimise heat loss between surfaces.



Figure 13 iButtons on the radiator

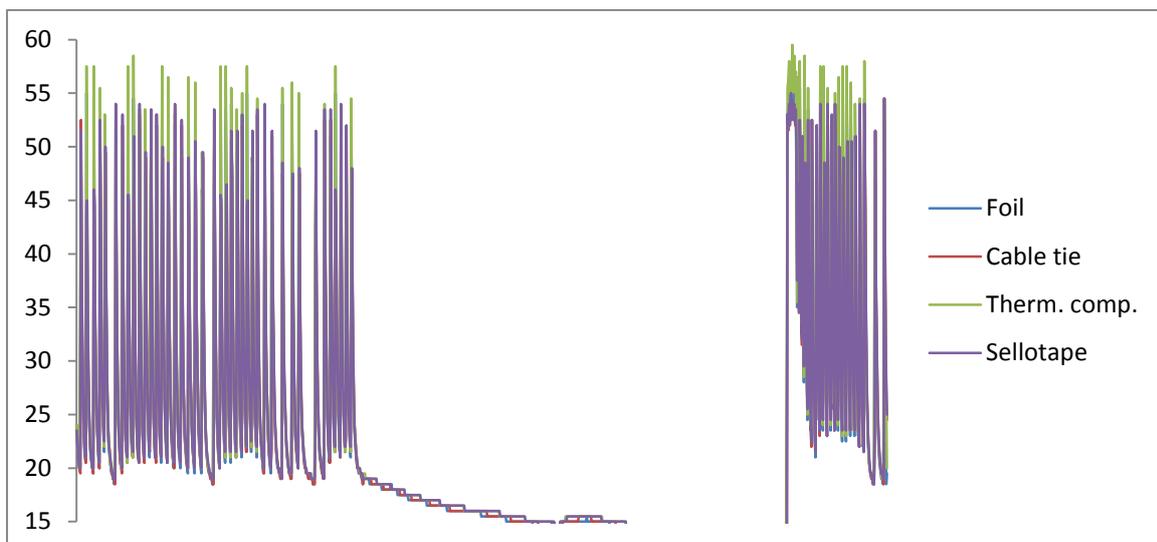


Figure 14 Results of materials for heat conduction

iButtons were downloaded manually every two weeks using a wire-to-USB adapter. OneWireViewer software was downloaded to read the data from the sensors. Data were then uploaded and stored in Excel format, following which the iButtons were reset with a delay to start at the same time with a log interval of 10 minutes and without data rollover.

4.4 Ethical Considerations

Full ethical approval for the fieldwork was given on 8th April 2013 by the university's Ethical Advisory Committee. Prior to the fieldwork, participant information sheets had been signed by the participants and the researcher. The information sheet explained the purpose of the research, described the various stages and stated the estimated time participants would need to spend on the research. The information sheet discussed potential benefits of the research procedures to maintain confidentiality and anonymity, and a statement that householders could refuse to participate or withdraw at any time.

Home video tours were conducted in participants' homes. Contact details of participants (address, phone number, email or Skype ID) were stored in a password-protected environment, in order to maintain confidentiality. Names of the interviewees were changed to provide full anonymity. Two of the participants were uncomfortable with being recorded on camera. Therefore, in two of the households, the camera was directed away from them, capturing the home environment only.

Dissemination of the research data was discussed with the participants in two stages. Before the home video tours the participants were asked in the participation sheet if they agreed to research publications using video footage and screenshots from the research materials. All of the participants agreed to the publication of screenshots in research conferences, but none of the participants agreed to publishing video materials online or in academic journals. Videos were therefore used as data to be analysed and then destroyed. Video footage will be destroyed within three months

following the completion of the PhD viva. In the second stage, screenshots from the videos used in the thesis and at conferences were shown to the participants prior to their publication. Participants were given time to look at the screenshots and consider whether they wanted these materials to be published or not. Monitored temperature datasets and thermal images were also stored in password-protected environments, while temperature datasets were organised and stored on Excel sheets. These datasets will be deleted within three months following the completion of the PhD viva.

Conclusions

This chapter has highlighted that there is an epistemological separation between the engineering and social science approaches to domestic energy consumption. By introducing a pilot project from the first year of my PhD study, I have shown that a sensory ethnographic departure into domestic energy use can be open to methodological innovations. In order to understand interrelationships between domestic (everyday) environments and built (physical and technical) environments, I needed to consider different types of knowledge. In the pilot project I experimented with putting together types of 'knowings' like puzzle pieces, to reach a more complete picture of how occupants create, maintain and experience indoor climates in relation to the physical characteristics of the buildings in which they live. Starting from a sensory ethnography approach has also resulted in a shift away from the standard procedure of science that places knowledge outside of the world he or she seeks to know. A sensory ethnography approach puts this in reverse, because knowledge grows from observational engagement with materials, beings and things. Reversing the direction of knowledge generation restores the immediacy of our own sensory engagement with everyday life. The arrangement of the next three chapters reflects on this reversed direction. Chapter 5 starts by examining and experiencing how the body exchanges heat with the surrounding physical environment in relation to buildings. Chapter 6 is more concerned with movement and the performance of improvisatory home heating activities, while Chapter 7 focuses more on the irregularity of TRV control and radiator use, in order to understand how a sensory

approach reframes and alternates disciplinary assumptions about domestic energy consumption.

5. Environmental Elements of Home Heating

Introduction

This chapter looks at the energy consumption of two 1930s semi-detached buildings to demonstrate that the 'social' and 'technical' are inseparable in occupants' domestication of home heating controls and in a building's energy consumption. Instead of analysing data across the whole set of households, I compare these two buildings to gain an in-depth understanding between the social and technical dimensions of energy use. I investigate occupants' sensory experiences and ways of developing TRV control and radiator use in relation to buildings. The first part of the chapter introduces the two houses. In order to gain a more comprehensive overview of the relationship between occupants' sensory experiences, home heating activities and the buildings in which they develop the chapter brings together building energy data and home video tours. A thermal imaging camera is used to scan buildings and to detect areas for air leakages and insufficient insulation alongside diagnosing the condition of radiators. Monitored temperatures and humidity represent data on indoor climates, to show the environmental conditions the occupants create, immerse themselves in and respond to. Home video tours reflect on how occupants create and maintain the home's sensory aesthetics and perceive and experience environmental conditions.

In House 1 the investigation focuses on the condition of the building fabric and heating system efficiency. I show that environmental elements such as relative air humidity, indoor temperature or radiant asymmetry of surfaces play an active role in occupants' sensory experiences of an indoor climate. I also show that the condition of the building fabric and radiators is essential in learning how the body loses heat and experiences convective or radiant heat. In House 2 I demonstrate that when the body's heat increases through routine movement (cycling or cooking), it is an active element of how occupants experience indoor climates and structure the use of

radiators and TRVs. I also show that occupants can appropriate heat flows from radiators to problem-solve and deal with the sensory experience of draughts or to dry laundry. Based on these two houses I argue that the domestication of home heating controls and a building's energy consumption is the joint outcome of a complex interplay between the human body and its built, physical environment. Consequently, energy consumption figures for gas and electricity – which I present and compare to national data at the end of the chapter – should be evaluated as joint outcomes of social and technical dimensions.

5.1 House 1

It is a frosty March early afternoon, and it has taken me only five minutes to walk to the first house, which is located in an East Midlands market town near to the town centre. It is a semi-detached 1930s two-bedroom and one bathroom 65 m² property, but the living room downstairs has been converted into a third bedroom. It is not the most comfortable arrangement, but it significantly reduces the rent for the two occupants, as the landlord only stays in the house over the weekends. I enter a small hallway that opens up onto the downstairs bedroom, downstairs bathroom and the kitchen. The walls in the hallway are old, dark grey and rich in hairline cracks that run all the way to the edges. There are smaller and larger holes in the wall below waist height, and the light-brown laminated floor is covered by drywall dust in the corners. Elena is one of the occupants in the house. She invites me straight into the kitchen and asks me to keep my shoes on, because nobody in the house walks around barefooted downstairs. The terracotta red stone gets freezing cold in the winter, because the floor is not insulated. Elena is dressed cosily, wearing furry slippers, chunky knitted long grey thermal socks, black leggings, a colourful stripy jumper and another long, thick woollen knitted cardigan over the top. She offers me a hot herbal tea, and while she is preparing the tea and putting the kettle on, she quickly turns around and switches on the electric fire heater. The kitchen is one of the coldest areas of the house, and if we stayed there for more than five to ten minutes without the electric heating on, we would start to shiver.

There is a combi boiler and an electronic thermostat in the kitchen, which is set to 14.5°C. They do not set or adjust it regularly, because many of the radiators in the house do not work.



Figure 15 Street view of the property



Figure 16 Boiler



Figure 17 Thermostat

The L-shaped kitchen, with the large windows at both ends, has plenty of natural light. The front dining room windows overlook a quiet residential street and are shaded by white hand-made linen curtains. Elena made the curtains herself. They are thin and do not stop the draught coming through the windows, but they at least create a sense of privacy by preventing pedestrians from looking in to the dining area.



Figure 18 The kitchen's single-glazed front window



Figure 19 The kitchen's double-glazed back windows

The double-glazed back windows that had been fitted two years previously overlook the garden and the conservatory. There is a floor-to-ceiling glazed walkway between

the conservatory and the kitchen, and the door leading to the conservatory is mostly left open. As the living room is used as a bedroom, it brings more daylight and openness into the kitchen. On sunny days, Elena uses warm air from the conservatory to heat the space. The use of the conservatory is also rather seasonal. In the summer it turns into a living room, which is pleasant for dining or hosting guests but in the winter it can be biting cold, and because it is not heated it turns into a bicycle storage area and extra fridge space for fruits and vegetables.



Figure 20 Conservatory as a living room



Figure 21 Conservatory as bicycle storage



Figure 22 Conservatory as an additional fridge space

It takes time for the dining area to heat up, which is why every time Elena comes downstairs she puts the kettle on to first make a cup of warm tea. I sit at the dining table nearby the draughty single-glazed front window, and while I am still rubbing my hands together to warm up, Elena starts explaining that the house is not in a good condition. They had experienced several problems with the boiler and the radiators:

“Although the house has a new boiler, the radiators do not work... they do not get warm. It takes a long time for the house to get warm. And it does not stay warm for a long time. From mid-December until early April we had the heating on 24/7, we never turned it off... the boiler, I mean.”

The boiler was replaced and TRVs were added to the radiators in early October 2011 at a cost of £3000. They could have lived with more fan heaters, but there was no hot water in the house. The radiators and pipes should have been changed all over the property, but this would have been prohibitively expensive. Besides, there would have been a great deal of disruption to put up with. To fix the entire system, they were told that the internal walls would have to be knocked down in most rooms. Changing the boiler was a temporary solution, but an electrician and a plumber were enough to fix it, and the inconvenience only lasted a day and a half. But keeping the air warm on a daily basis becomes a challenge because the heat in the kitchen is uneven. There is a spot where you feel the heat when you stand near to the electric fire; it feels significantly warmer than the surrounding area. But when you step away from the heater, to sit at the dining table, you start cooling down. This is rather exhausting, because one continuously moves through drastic changes in air temperature. But warm spots are always felt in the same place, so you know where to move to stay warm.

The monitored temperature data do not register this temperature difference, they do show that the daily average temperature from March 22nd through to April 22nd is 17.1°C. The morning hours from 7am to 9am are the coldest periods, when the temperature drops to an average 15.4°C, and the evening hours from 5pm through to 11pm are the warmest periods of the day at 17.8°C. It is important to note that the conservatory is likely to drain heat from the kitchen. Despite the general belief that conservatories regularly supply warm air, they do tend to be a source of heat loss (Oreszczyn: 1993).

Table 3 Breakdown of kitchen temperatures

	Whole Day	7am - 9am	9am- 5pm	5pm- 11pm	11pm- 7am
Kitchen/ Living room	17.1 °C	15.4 °C	16.7 °C	17.8 °C	17 °C
	±2.3				
	RH 44.7%				

Based on ASHRE standard 55-2004 (2009: 12) there is an upper limit of 60% and a lower limit of 25% for relative humidity in comfort zones. The overall average humidity level in the kitchen was 44.7% with an occasional spike of humidity levels that generally occurred around cooking activities in the evening periods.

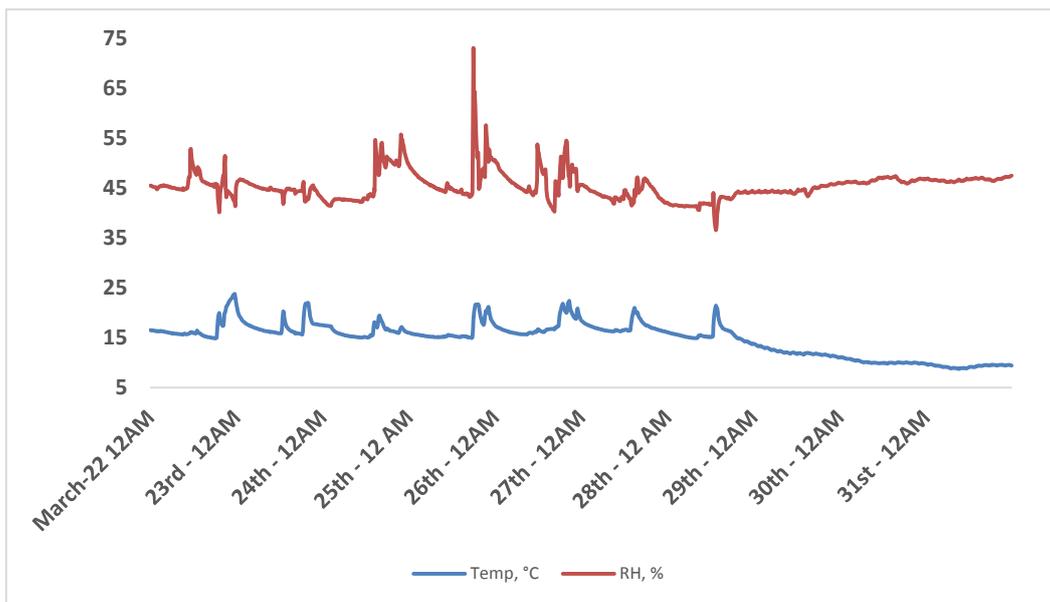


Figure 23 Humidity and temperature data from the kitchen

5.1.1 Condensation and Mould Growth

Elena occupies the double room upstairs. She is 36 years old, was born in Greece and is of Filipino descent. She works at the local university and has been living in England for over six years. Her bedroom is very bright and has a garden view. Upon entering the bedroom I immediately notice that the room is organised very unevenly and that different corners project different atmospheres. The desk, the chest of drawers and the top of the wardrobe are heavily stuffed with personalised objects, whereas other surfaces are bare. For instance, the top of the dark-brown wooden drawer next to the door is cluttered with jewellery, perfume, makeup and cosmetic products and other small ornaments. The desk is overcrowded with books, notepads, a wooden messaging board and photos of Elena's family and past modelling. The reason why the room is – as Elena calls it – 'disorganised' is because she only has these small spaces to make use of; she cannot keep her belongings too close to the window or to the external walls because of condensation.

Condensation is the "removal of heat from the system in such a way that vapour is converted into liquid" (Collier and Thome 1994:1), which occurs when warm, moist air comes into contact with a cool surface, following which water vapour causes dampness and water droplets start to become visible on surfaces. To cope with condensation, Elena keeps a little gap between the drawers and the wall, because she does not want any of her belongings to get wet. Once, there was black mould hiding behind the shelf and spreading all of the way onto the back of the drawer and her books. It had a distinctively musty and intoxicating odour which irritated the throat and caused coughing, but now it was just a faint smell. It can still be detected every now and then, when one moves closer to the furniture. I step close to the external wall and see the dark, wet patches. Because the water droplets have soaked into the wall, this captures the wet smell. It is intensely cold to touch, because it is forcefully draining heat away from my body. It is a penetrating damp that is not only isolated to one area of the wall – it has spread to the other end.

We can see the back of the house in the thermal camera image below, with Elena's window in the top-left corner. The cavity wall is not insulated, which in turn increases

the prevalence of cold surfaces and allows condensation to form, thus making it fairly difficult to maintain a consistent internal temperature.

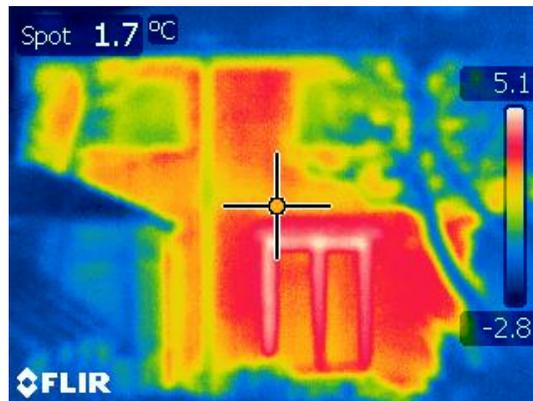


Figure 24 IR image of the outside of the house, taken from the back garden

The lack of cavity wall insulation and condensation affect how Elena makes use of spaces in the bedroom, but it is also key to how she develops her sleeping routine. Elena stores a white double mattress behind a chest of drawers that is used when guests sleep over. She does not have a bed frame, and so she sleeps on the floor, using a light blue blanket and a red throw that are now curled up in front of the wall. She had started encountering back problems when she was living in student halls sleeping on soft mattresses, so she now uses blocks of multi-coloured jigsaw floor puzzle mats to create “the right” firmness. She covers the floor mats with a thick cotton rug that adds an extra layer of softness. She keeps a small summer futon between the wall and her head. The rolled futon protects her head by ‘sucking up’ the radiating cold air that otherwise would cause a striking headache or stiff neck in the morning.

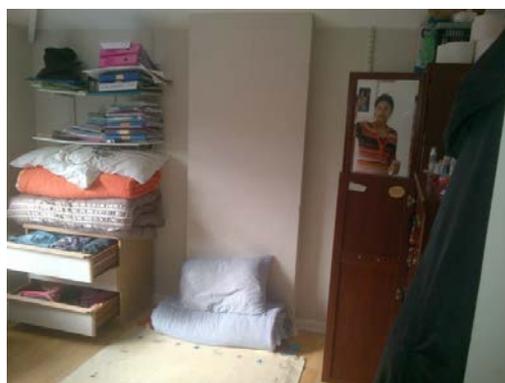


Figure 25 Elena's futon arrangement

5.1.2 Radiant Asymmetry of Surfaces

Elena spends most of her weekdays working from home, and she makes use of the bedroom space based on imbalances in temperature. She divides her days into blocks of 60-90 minutes. After each block she goes downstairs to make a cup of tea and to warm up. She keeps her yoga mat in her bedroom, where she spends at least an hour every day exercising to keep warm. And she pulls her desk close to the radiator in the corner, even though she wanted to put it under the window so the desk would get more natural light:

“It’s damp, especially in the evening... a few hours after the sun goes down it becomes very damp on that side of the room [pointing to the futon and the external wall]. The weird thing with this room is... I know this from my sister, as she lived in this room before me... temperatures here near the radiator, where I have chosen to put my desk to study, are OK. I work right beside the radiator, but only half of the radiator works.”



Figure 26 Positioning of the desk in the corner

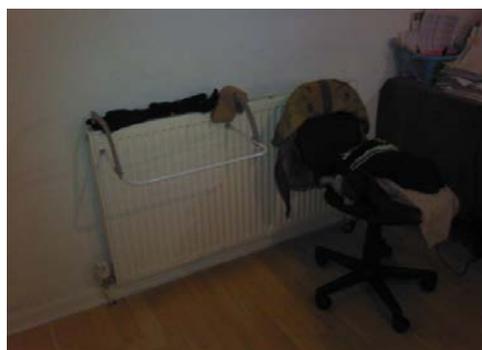


Figure 27 Bedroom radiator

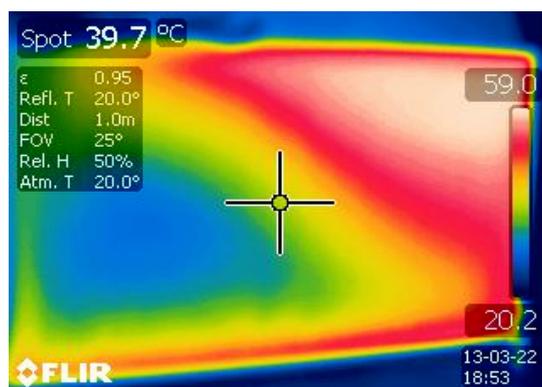


Figure 28 IR image of the radiator

We can see on the thermal image that the radiator is 39.7°C, whereas the cold walls on the other end of the room radiate cold air. This causes radiant asymmetry, putting the human body in a state of discomfort, because it is exposed to low temperature sources such as cold walls or cold ceilings (Fanger: 1985). Moreover, the bedrooms and the bathroom upstairs have laminated wooden floors, which is one of the reasons why Elena decided to rent a room in the house. It feels cleaner, because it does not collect as much dust as the carpet would. But the wooden floor can feel icy cold when crossing the room barefooted in the winter.

5.1.3 Sensory Experiences of Convective Heat

The air temperature in Elena’s bedroom drops at night in the winter at around 11-12 pm, and the challenge to manage humidity indoors starts in mid-autumn:

“Now that the days are longer and that there is some sun, it’s not so bad. But on a dark day with no sun, even at 9 o’clock in the evening with temperatures of 14-15°C outside, it’s still very damp and cold.”

This reflects in the temperature data (Table 3) and the humidity data (Figure 29). Generally, there is a risk of mould and mildew growth at higher relative humidity, whereas lower relative humidity tends to cause eye irritation, a stuffy nose, dry skin and may aggravate allergies or asthma (CIBSE: 2006). Table 2, below, shows the

temperature averages for Elena’s bedroom for the whole day, i.e. morning, afternoon, evening and night time. The standard deviation is 2.7°C, indicating that 68% of the monitored temperature data fall between 17.7°C and 23.1°C. The average relative humidity level of the bedroom is 46% with a standard deviation of 1% that falls within the recommended ASHRE standard 55-2004 (2009: 12), thus suggesting an upper limit of 60% and a lower limit of 25% for relative humidity in the comfort zones. This excludes unoccupied days. Table 3 shows relative humidity levels between 22nd and 31st March and indicates that increases in humidity levels occur when the air temperature drops at night time.

Table 4 Temperature data breakdown for the bedroom

	Whole Day	7am – 9am	9am- 5pm	5pm- 11pm	11pm- 7am
Master Bedroom	20.4 °C	18.8 °C	20.6 °C	21.5 °C	20.3 °C
	±2.7				
	RH 46%				
	±1 %				

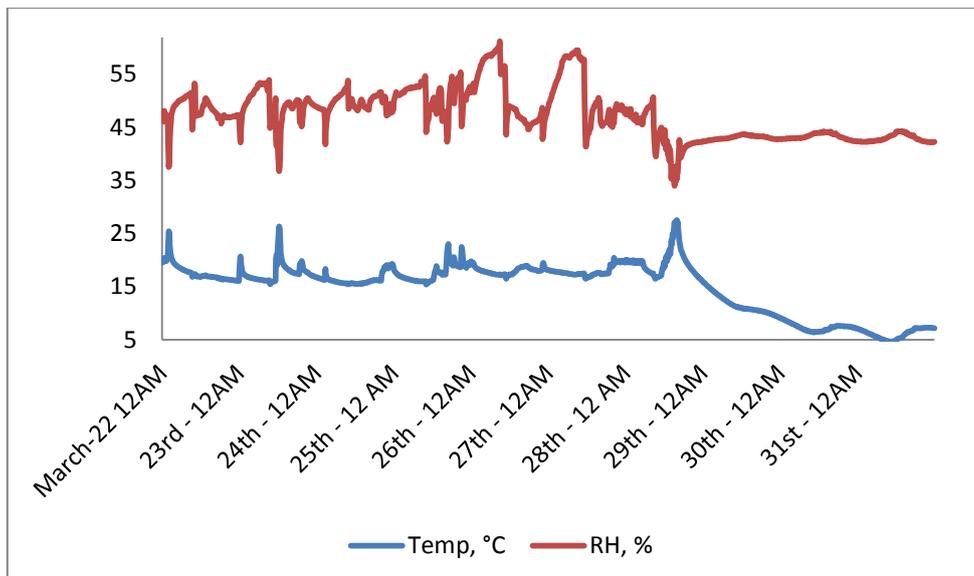


Figure 29 Relative humidity and temperature data for the bedroom

To cure damp, control condensation and prevent mould growth, Elena uses a fan heater (Figure 30) every day to 'dry' the room:



Figure 30 The fan heater

The fan heater stands on two books so it does not overheat. It is a little noisy, but with the music playing the sound just fades into the background. It does not take up much floor space either, and it is handy because it heats the room horizontally and vertically at the same time. I first sit further away from Elena on the carpet, but she warns me that I will probably need to move closer to the fan heater because I am in what she calls the “cold zone.” Whenever her sister visits she tends to sit in the same spot with her laptop, but she always moves within minutes. I underestimate the radiating cold coming from the walls, and after a little while I start getting goosebumps. I can feel the cool air spreading across my shoulder and my nose is getting cold. My clothing is useless as insulation, so I decide to move closer to the fan heater to reheat. Fan heaters warm the air by blowing out convective heat. Convection is the transfer of thermal energy from one place to another through the movement of fluids or gases. The direction of the flow of heat within the air is turbulently upward, somewhat sideways but never downward. Because the blown warm air circulates upwards, it heats the space from the top down. By sitting near to the fan heater it is apparent that it raises the air temperature of the bedroom quicker than the radiator; however, it gives an uneven sensation of heat, because it only

makes the air temperature warmer close to the heater. If I stand a few steps away from the heater, I can still feel the warm air movement on one side of my body, but I can already 'touch' the cold air.

It takes time to experiment and find the most comfortable setting for the fan heater. Setting it to level 6 dries out the air in the room too much, but setting it at 4 is just 'right' for the air to warm up, without the room becoming too dry. Besides curing damp, the fan heater has two other functions. Firstly, it is used to warm up Elena's chilled feet and fingers during the day:

“During the day, because I just sit by the desk without moving for hours, my feet start to get cold. I turn the fan heater on and I put it towards my feet for a few minutes and then turn it off. It has six settings, but when I heat my feet I leave it on setting 2.”

Secondly it turns into a drier. At night, before Elena goes to sleep, the fan heater dries up the moisture and warms up the futon bed. Also, it helps to dry the laundry in winter, when clothes do not fully dry within a day or two.



Figure 31 Drying clothes on the floor

Living in this house feels draining, because it is a daily sensory experience to move constantly through pleasantly warm and strikingly cold zones. No matter how many times you reheat the body, the heat escapes from the skin in a blink of an eye once you cross a cold spot. It takes time to learn how to keep the body warm, but Elena has experienced all the routes, and by now she knows how to move around in the

house. She could move out and find another house with a better heating system, but location is a priority. The house is equidistant from the farmer's market in the town centre and the university. Besides, she has been coping with moisture since childhood:

“I lived in a very damp house from when I went to school when I was around 7 years old through to when I was around 18. And it's just a matter of getting used to it. Like you wore your jeans in the morning and it was really cold. My dad used to put the jeans near the radiator before we woke up. So when we wore them they were warm. I do stuff like that in my house, too.”

5.1.4 Sensory Experiences of Radiant Heat

The downstairs living room has been converted into a bedroom. Alex, a 25-year-old student from a small island from Greece, occupies this room. He also works at the university and moved to England over a year ago. He rents the room from Chris, the owner of the property, who is a 32-year-old professional. He works in London and travels between London and Loughborough on a weekly basis. He has been trying to sell the property since 2012, because he wants to buy a house in London to settle down with his partner. He decided to rent out two rooms in the house in 2010. He does not want to make a profit on renting the property; he only wants tenants to cover the bills until the house is sold.

The air in Alex's room feels a little stuffy. The keys to the door leading into the garden got lost and, at the moment, he cannot open it to let fresh air into the room.



Figure 32 Locked door from the outside

One of the main problems with the room is that there is no insulation under the floorboards. Having rugs is not an option either, because the condensation would ruin them. The second problem is that the radiator in the room does not work well. It is a large double panel radiator, but it just does not give out enough heat. The thermal camera image below shows that the surface temperature of the radiator is only 37.9°C, even though the TRV is left on the maximum setting of 5.



Figure 33 Image of the bedroom radiator

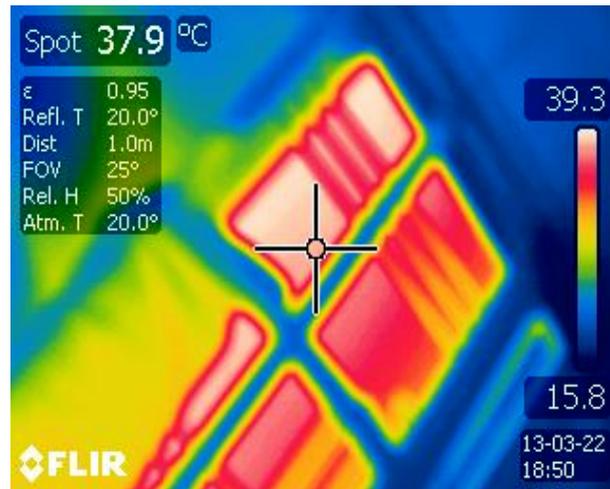


Figure 34 IR image of the radiator

Because the radiator operates at a low temperature, Alex invented a solution to “use up” the small amount of heat that comes from the radiator. He positions a wooden board in front of the radiator to hang his towel after taking a shower. He also places a small three-storey clothes horse in front of the radiator so his laundry can dry on colder nights. However, by finding a temporary improvisatory solution by chance he can keep the radiator up and running for some time:

“I adjusted the pressure of the boiler, so once the pressure was higher, something that was stuck in the radiator system must have got pushed and water started going through the radiator. So this radiator works for some time but then it stops working, and then I have to adjust the pressure of the boiler again. And then in about a month or a month and a half’s time it will stop working again. Every now and then I have to adjust the pressure back up so my radiator works at a higher temperature.”

To compensate for the dysfunctional radiator Alex purchased a portable panel heater (Figure 35.) that he rotates between his bed and his workstation. This maintains warmer spots in the room on winter nights, due to its higher surface temperature of 73°C.



Figure 35 Portable radiator

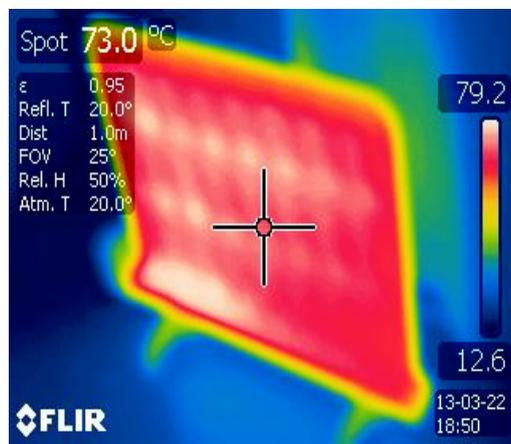


Figure 36 IR image of the portable radiator

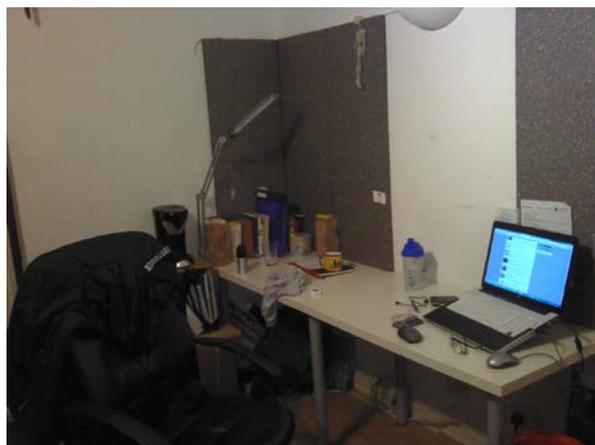


Figure 37 Work station

The body perceives and senses radiant heat differently from convective heat. Transferring heat by radiation involves carrying energy from an emitting heat source to the space or objects surrounding it. This energy is carried by electromagnetic waves and, unlike in convection, it does not involve movement, so the hotter the object, the more it radiates. Therefore, heat from a panel heater transfers heat from one surface to another, thereby warming people and objects rather than the air directly.

When the heater is closer to the workstation behind the chair, it stops one feeling the cold air pouring inside from the external wall. But we are wearing shoes because the heater does not stop us feeling the cold air coming from the floorboards. In the evening, when the panel heater goes in between the bed and the external wall for a few hours, it prevents wet, cold air by warming up the bedding by the time Alex is ready to retire.

These drastic temperature differences feel draining to live with, and this bedroom is the coldest room in the house. Table 2 below shows that for the whole day the average indoor air temperature is 16.4°C with a standard deviation of 2.1°C.

	Whole Day	7am - 9am	9am- 5pm	5pm- 11pm	11pm- 7am
Downstairs Bedroom	16.4°C	16.3°C	16.3°C	16.6 °C	16.6 °C
	±2.1 °C				

Table 5 Bedroom temperature breakdown

These findings about how people heat their homes imply that home heating is not a single uniform practice and goes beyond direct interaction with control points. We see from how Elena and Alex create the sensory aesthetics of their rooms that there is a continuous heat exchange between the body and its surrounding environment. Sensory experiences of convective and radiant heat have demonstrated two heat exchange routes that maintain the body's heat balance. Each of the heat exchange routes varies according to internal conditions and can be affected by environmental elements such as air relative humidity, air temperature or the mean radiant

temperature of surfaces. This form of ‘correspondence’, or “practical and sensuous engagement with our surroundings” (Ingold: 2013: 7), shows that occupants have a reciprocal relationship with the material and physical media in which they are immersed. The surface temperatures of walls and wooden and stone floors can all influence the extent to which the human body loses heat to the surrounding air or cool surfaces. This makes surfaces such as radiators, walls and floors ‘places’ where there is a continuous interchange between the materials, the body and the environment. Therefore, heat exchange and sensory experiences are active elements of how the home’s sensory aesthetics are created. Whereas with **House 1** I have focused more on the body’s heat loss, **House 2** looks at how the body generates heat in the actual process of movement and how TRV controls and radiator usage develops from the wider configurations of material flows and sensory experiences.

5.2 House 2

The second house is also near to the town centre. It is a 1930s semi-detached property located only a short walk away from the first house. It has three bedrooms and a total floor space of 87 m². There is an en-suite bedroom, two double bedrooms and a bathroom upstairs, a kitchen, an open plan living and dining room and a conservatory downstairs. The heating system runs on central heating. There is a gas boiler in the kitchen, installed in 2006 (Figure 39) and an electronic thermostat in the living room downstairs (Figure 40).



Figure 38 Front view of the house



Figure 39 Boiler



Figure 40 Thermostat

Mark is in his late thirties. He is from Central Europe and has been living in the UK for almost 15 years now. He bought the house in the summer of 2012 and had two new radiators fitted in the living room. He had TRVs added to all the radiators apart from the living room.

5.2.1 Gaining Heat: Cycling and Cooking Dinner

I meet the owner Mark just outside the main entrance. He gets off his bike, opens the garage door, lifts up his bike and puts it in the bike stand in the corner. His cheeks

are red and he is breathing heavily, because it takes him about 20 minutes to cycle home from work. He cycles every day unless the roads get icy, and then he takes public transport. It is a good way to get a daily workout, he says, and he can also change routes so he mixes up more or less steep roads. We walk outside the garage and enter the house from the back door that leads into the laundry room. Mark takes his backpack and shoes off and places them near to the radiator so they dry off by the next morning. He keeps his slippers near to the radiator so they absorb the heat by the time he gets home and puts them on.



Figure 41 Drying the shoes

Mark says that cycling home used to be even more useful before he had the remote control system. He used to come home, put the heating on and then go upstairs to take a shower before preparing dinner. Cycling used to keep him warm until the house heated up. But now he has got remote heating and the house is warm by the time he gets home. When he goes upstairs to the bathroom to take a shower, a slightly warm towel is waiting for him, ready to be used, which he folds and puts onto the towel rail every day.

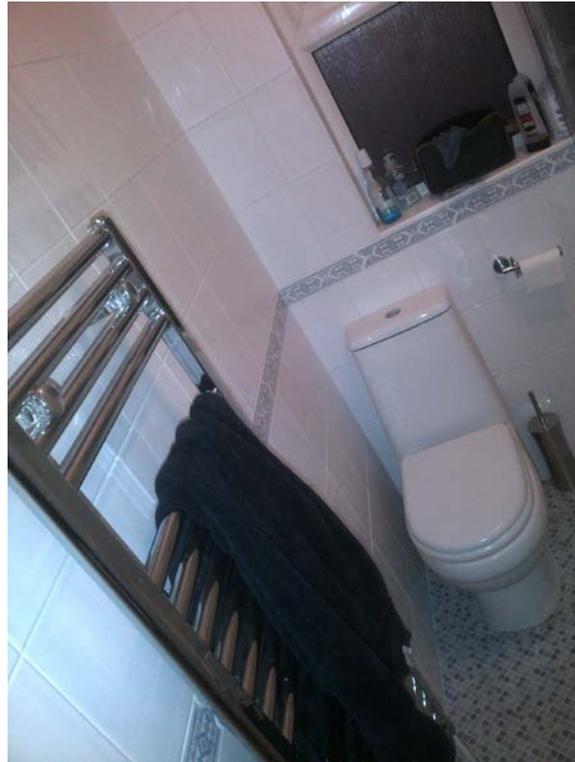


Figure 42 Towel rail in the bathroom

After taking a shower Mark goes downstairs to the kitchen to prepare dinner. He cooks every day apart from Fridays, when he eats out with his friends. He opens the fridge and takes out a can of beer. Then he turns around and grabs the box of minced meat he left outside in the morning to defrost. He is cooking lasagne tonight. He opens the kitchen cupboard and takes out a frying pan for the meat, a square glass baking dish that will go into the oven and a ceramic pan that he will fill with boiling water later, to soften the lasagne sheets. He first puts the gas on and leaves the pan on a low heat, and then he reaches for the chopping board to cut the onions. By the time he has chopped the onions the pan starts smoking, so the onions can go in to stir. When the onion is golden he adds the meat and breaks it up with a wooden spoon, before he adds the tomato sauce. He then starts twisting the pan to stop the meat sticking to the bottom. He quickly turns around and puts the oven on to 220°C. The kitchen is warming up fast and I can feel the heat coming from the oven. Mark puts the baking pan in the middle, sprays it with baking oil and fills it with layers of pasta, meat and white sauce. By the time he finishes with the layers, the oven is heated up and the tray is ready to go into the oven. These days he mainly cooks “winter meals,” such as soups, stews or oven-baked pastas. He cooks meals that

take longer over the weekend, divides the leftovers into smaller portions and puts them in the freezer to use for occasional dinners. While the lasagne cooks in the oven, he takes out a bread-making machine. He is making German bread, with a distinct sour taste, that he cannot buy in the supermarket. His mother sends him the bread mix from Germany in the post every month. He mixes the bread mix with water and places it in the machine to leave it to bake for about three hours. The bread lasts for a few days, because he makes his lunch and takes it to work the next day. I stand near to the radiator while Mark is fiddling with the settings on the bread maker. The radiator is only slightly warm. The TRV here is left on setting 2, because Mark only cooks in the kitchen. But because he is moving, pottering around and using appliances, the kitchen comes with 'enough' heat anyway, so it does not need to be any warmer.



Figure 43 Image of kitchen radiator



Figure 44 IR image of the kitchen radiator



Figure 45 Dinner table

5.2.2 Appropriating Heat Flows

Mark refurbished most of the house on his own. He ordered, fitted and painted the wooden floor and skirting boards in the dining and living room area as well as in all three upstairs bedrooms. The living and dining room are located in a large open plan space. The walls in the living room are magnolia in colour, with a soft yellow shade. The shelves and cupboards are still empty, as Mark has not yet had all his books and belongings shipped over from his parents' house. This is his first winter here, and he is now getting to know the 'particularities' of the house.



Figure 46 The dining room



Figure 47 Radiator in the living room

Compared to the rest of the house, the living room takes excessively long to heat up. As the thermal image shows below, the front windows are old, draughty and single-glazed.



Figure 48 Living room window

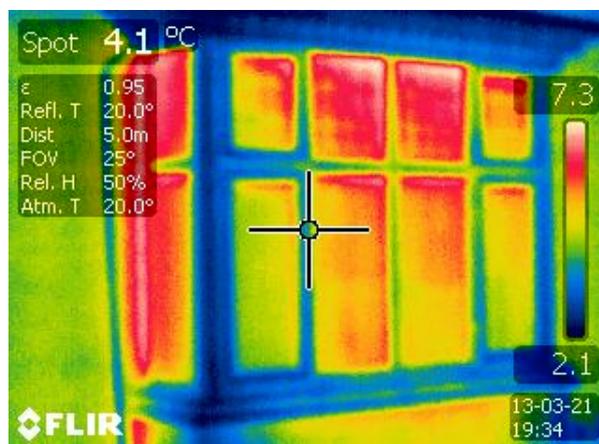


Figure 49 IR image of the living room window

They need to be replaced, but Mark does not have the time or the budget to get it done this year. Instead, he has put up thick curtains to cover up the cold draught coming through the windows. And the thick brown rug underneath the coffee table protects his feet from the coldness of the wooden floor. He got an extra blanket for the sofa, to protect his back from the cold draught running while he is watching TV and he invested in a remote control to heat up the house by the time he gets home from work.

5.2.3 Managing Heat Remotely

Mark was offered a discounted price for the myHome Remote Heating Control system from British Gas. It is a smartphone application that lets him control a linked smart thermostat. Besides the half-price offer, Mark thought it would be a good idea to deal with the draught and balance the long heating up period. This way the living room heats up by the time he arrives home from work. The application's interface is fairly simple, he says. It takes only a slider to move between on, off and automatic:

“The iPhone control is absolutely genius; I can control my heating from work if I have a Wi-Fi connection. It is very simple from the iPhone. You can't really set the schedule day by day, but you can turn the heating on and off, or you can just change the temperature. Before I came home after Christmas, I left the house at, like, 15°C and I turned on the heating at the airport four hours before I came home so that when I was home it would be warm. That's why I use the phone”.

Mark has a stable heating schedule on weekdays. He usually gets home around 5.30pm. He schedules the heating to come on Monday morning at 7am for two hours. It goes up to 18°C, then it comes on in the afternoon at 4.30pm until midnight and goes up to 19°C. Saturday and Sunday are set differently, in that the heating comes on at 9am and stays on through to midnight and up to 19°C. We can see from the air temperature data that the living room is one of the coldest areas in the house with a daily average air temperature of 18.5°C and an average relative humidity of 37% that falls within the recommended ASHRE standard 55-2004 (2009: 12) that suggests an upper limit of 60% and lower limit of 25% for relative humidity in comfort zones.

Table 6 Temperature data breakdown for the living room, master and second bedroom

	Whole Day	7am - 9am	9am-5pm	5pm-11pm	11pm-7am
Living room	18.5°C ± 1.7 RH 37%	17.6°C	17.8°C	19.3 °C	17.8 °C
Master bedroom	18.8 °C ± 1.6	18.4 °C	18.6 °C	18.8 °C	18.3 °C
Second bedroom	17.9 °C ± 1.3	17.5 °C	17.3 °C	18.2 °C	17.7 °C

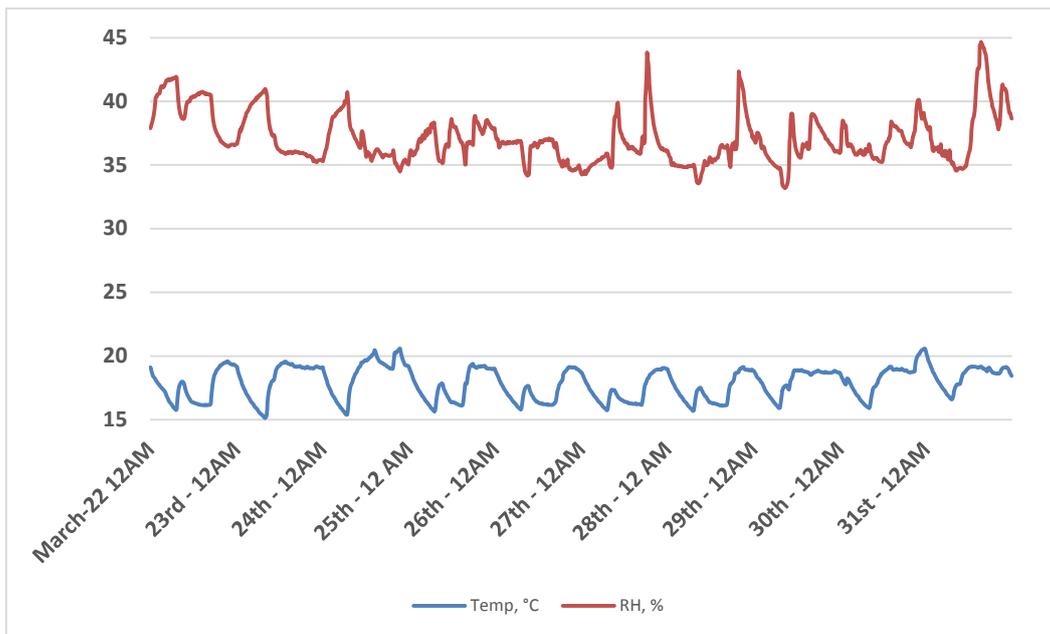


Figure 50 Relative humidity and temperature data from the living room

5.2.4 ‘Absorbing’ Heat

To save some money after all the expenses spent on the refurbishment, Mark decided to rent out two of the bedrooms in the short term. Jon is a 25-year-old

professional who occupies one of the bedrooms upstairs. The bedroom is slightly colder than the master bedroom, because it is on top of the garage. The average air temperature here is 17.9°C with a standard deviation of 1.3°C.

We enter Jon's bedroom, and his double bed is pushed all the way to the corner near the radiator. His curtains are open, but he draws them in the evening. The windows are large, and keeping the curtains closed makes a noticeable difference. It keeps the heat in and stops the colder air from circulating around. It also prevents him from having to do what he calls "bed camping." It might sound bizarre but he used to find it much easier to stay warm in bed at night. So when you go to bed you normally get into a freezing cotton-sheeted bed. With 'bed-camping' you make a little tent by pulling the cover over your shoulders all the way up to your head. Then you tuck the bedding in tightly to keep the cold air from coming inside. You curl up and hold your hands together, and the breathing warms up the little space so you can pop your head back out again in 5 minutes. You then keep the duvet wrapped around tightly, to keep the heat inside. It also helps to keep an extra layer on top of the duvet, to stop the heat escaping through the gaps. Gaps are everywhere when you roll over in the night, but this way it stays warm. In this bedroom, Jon pushed his bed into the corner near the radiator to make use of the heat. Near to the heater the cotton sheet and duvet absorb much of the heat that keeps the body warm at night.



Figure 51 Radiator in the second bedroom

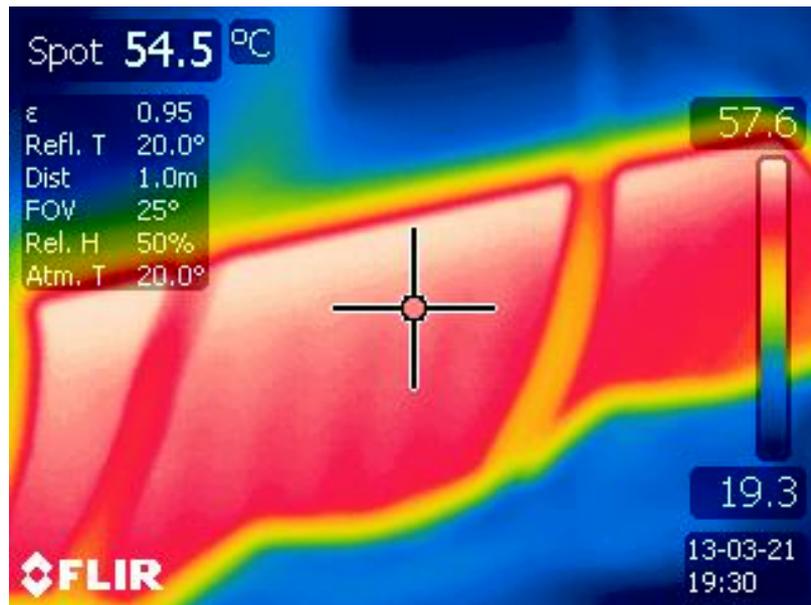


Figure 52 IR image of the radiator in the second bedroom

Jon does not adjust the TRV in the bedroom, because he needs to pull the bed away from the radiator every time he wants to reach the control. He also uses the heat of the radiator to dry his clothes, and he moves the clothes horse near to the radiator when he does his laundry twice a week.

5.3 Developing TRV Control and Radiator Use

What the findings from the two houses have indicated so far is that home heating goes beyond practices and routine interactions with control points; rather, it is part of the 'place-event' of the home, because there is a continuous heat exchange between the body and its surrounding physical and material environment. House 2's data suggest that heat exchange is embedded in the everyday routines of people. Routine movements (cycling, cooking, pottering around the house) can be mechanisms that generate heat and maintain the body's heat balance. We have also learnt that home heating involves a series of processes and elements coming together. For instance, the surfaces of walls, floors or materials are active players in the process of heat transfer. They become 'places' with which the body comes into contact (e.g. cold cotton bed sheets) and where heat exchange happens. Material objects such as

curtains, electric heaters, rugs, clothing, etc. are also inseparable from the process of home heating.

Another finding that emerges from the two houses is that TRV settings and radiator usage develop based on the wider material, domestic, sensory and physical configuration of the home. In House 1 TRV control does not develop due to the low heat output of the radiators, the lack of cavity wall insulation, the high relative humidity, condensation and the sensory experiences of temperature differences within the room. In House 2 TRV settings vary across different rooms. The following thermal images show that downstairs in the living room the TRVs are fully open and are not adjusted on a daily basis because of the sensory experiences of the cold draught in the living room.

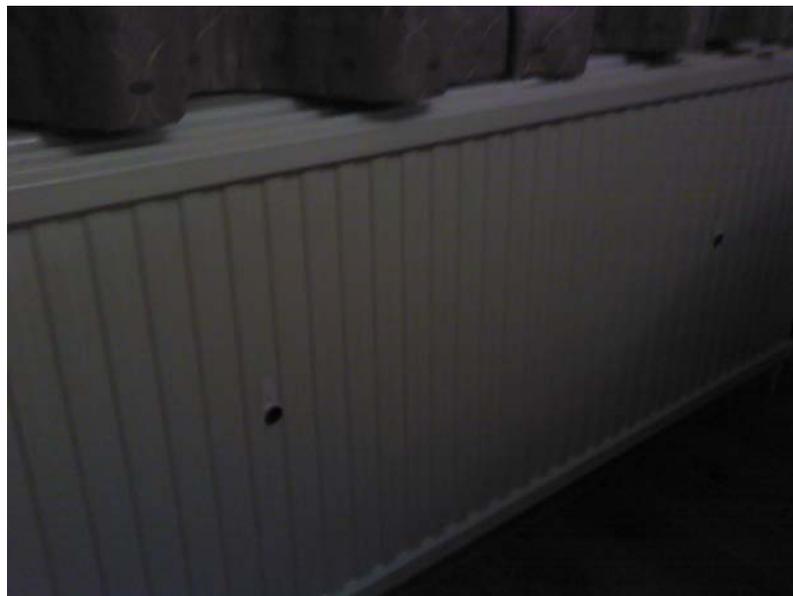


Figure 53 Radiator in the living room

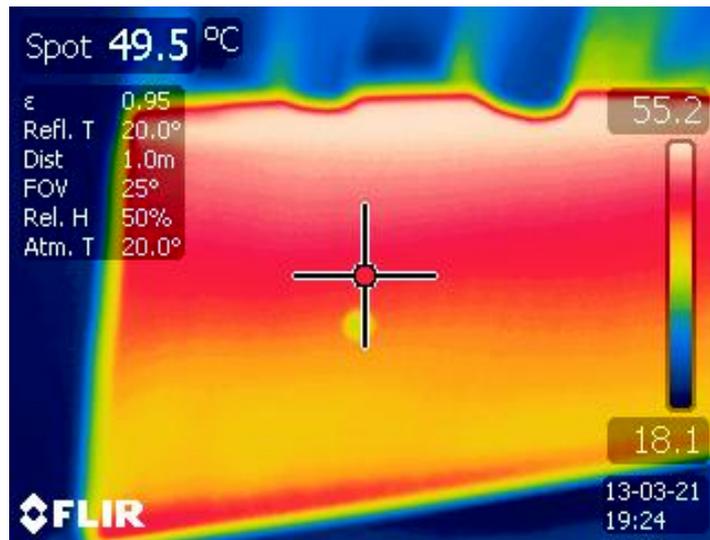


Figure 54 IR image of the radiator in the living room



Figure 55 Radiator in the dining room

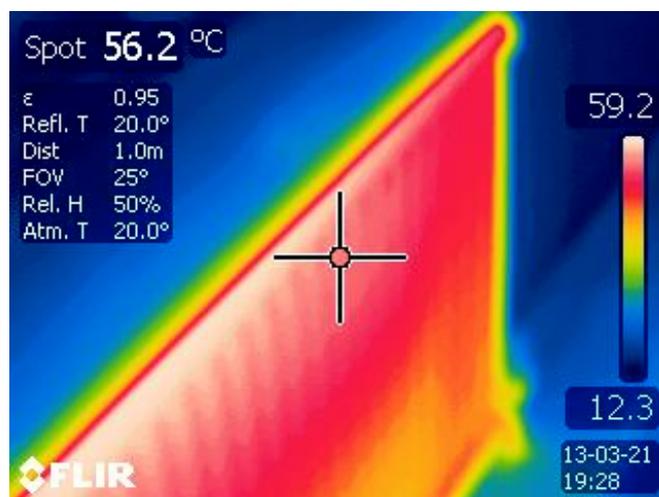


Figure 56 IR image of the radiator in the dining room

Moreover, we learn that the ways in which Mark appropriates heat flows in the living room are inseparable from his sensory experiences of draughts, the surface temperature of walls, the single-glazed window and the heat output of the radiator. These findings therefore also suggest that indoor climates, movements and sensory experiences are simultaneously the products and contexts of home heating activities. The development of improvisatory radiator use and TRV control consequently arises from a complex interplay between the body, sensory experiences, the building's fabric condition and heating system efficiency (e.g. heat output of radiators). The last section compares the energy consumption of the two houses.

5.4 Comparing Energy Consumption Figures

The findings in this chapter have demonstrated that energy consumption for a domestic building is a complex 'meshwork' of various processes. It is the joint outcome of 'social' and 'technical' elements such as occupants' movement (moving through warmer and colder air zones), electricity consumption (putting on the electric heating or the kettle), other domestic practices (making a cup of tea when coming downstairs), material flows (lack of heat output from the radiator), multisensory experiences of surface temperatures (red terracotta stone), physical characteristics of the house (building's fabric condition), heating system efficiency (heat output of radiators) and the local climate.

Based on Leicester's model (2015), which uses the Efficiency Data Framework (NEED), the following two distributions show how the two houses' energy consumption compare to the annual gas and electricity consumption for semi-detached, 1930-1949 buildings with a floor area of 51-100 m² in the East Midlands region.

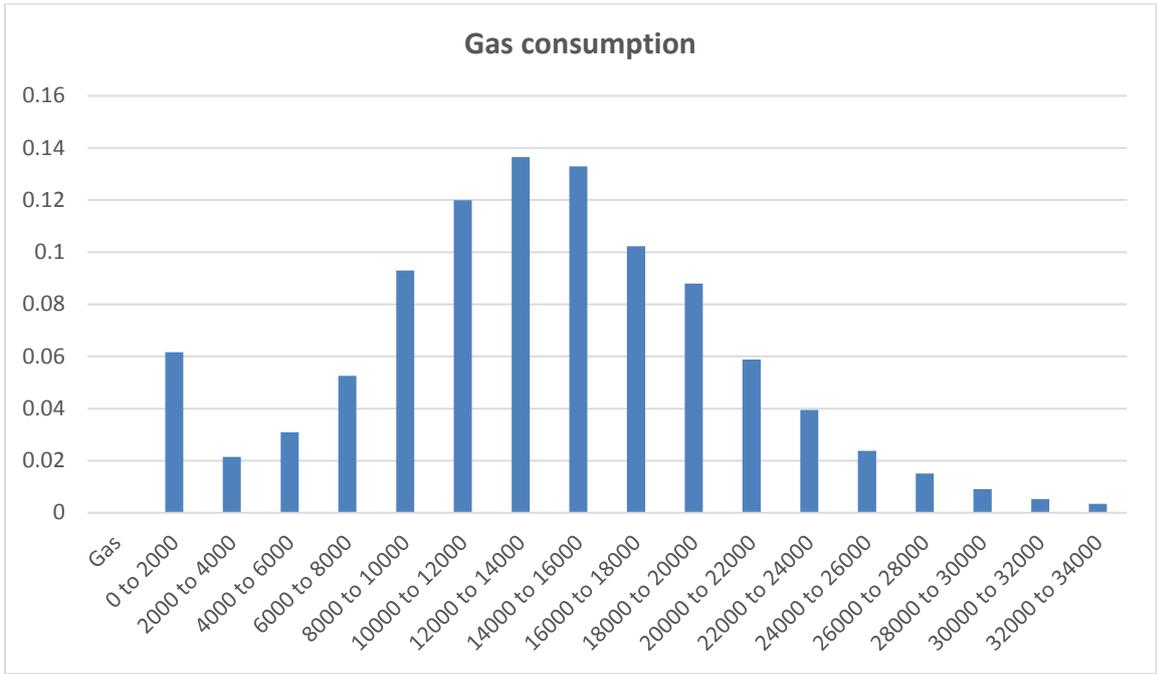


Figure 57 Gas consumption (kWh)

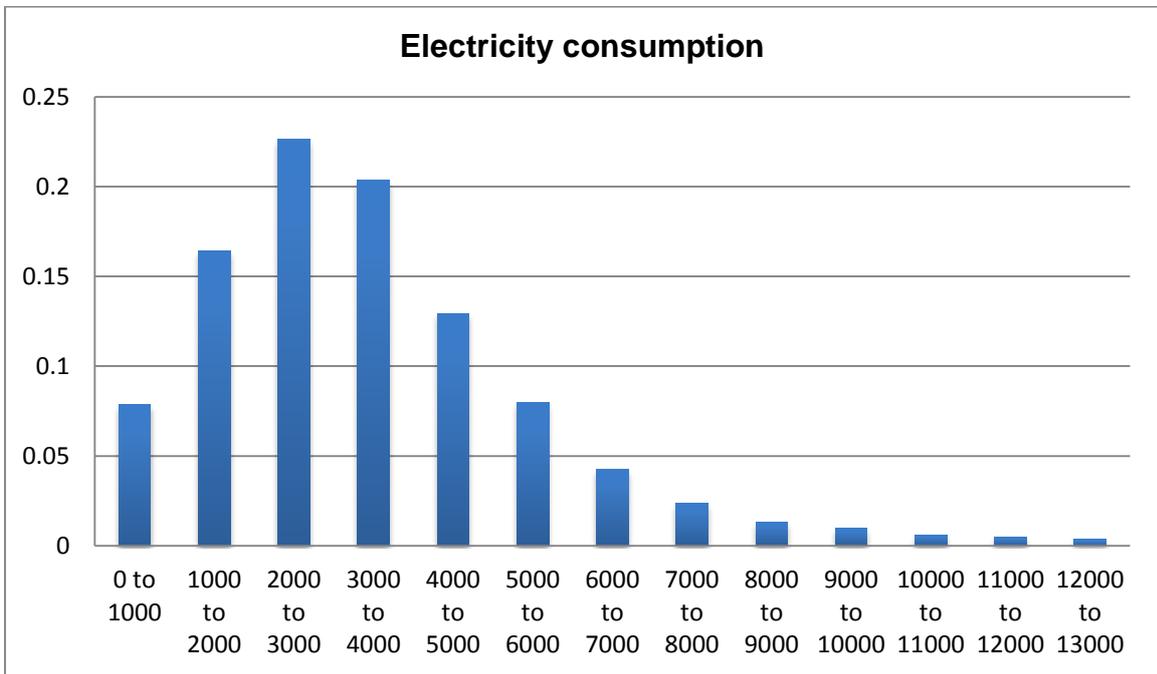


Figure 58 Electricity consumption (kWh)

The standard deviation for gas consumption is 6711 kWh and for electricity it is 2680 kWh. The figures show that there is greater variability of electricity consumption

because of the wider range of end uses (e.g. various appliances) in domestic settings. Also, electricity consumption varies, because some households use it as the main heating fuel whereas others use electricity for secondary heating.

The following table presents the annual gas and electricity consumption of the two houses, along with the number of heated hours:

	Gas	Electricity	Heated hours
House 1	17,146 kWh	4325 kWh	244.35 (11.6 hours/day)
House 2	13,570 kWh	2793 kWh	142 (4.6 hours/day)

Table 7 Comparing the gas and electricity consumption of House 1 and House 2

From February 2013 to February 2014, **House 1** had a gas consumption of 17,146 kWh, while **House 2** had 13,570 kWh. **House 1** is close to the upper quartile, or to the 25% of the gas consumption values (20,600 kWh). **House 2** is closer to the median (13,900 kWh) on the distribution. Annual electricity consumption from February 2013 to February 2014 is 4325 kWh for **House 1**, while it is 2793 kWh for **House 2**. **House 1** is closer to the upper quartile of 6360 kWh, whereas **House 2** is closer to the median of 3660 kWh.

Recorded data from the iButtons showed the flow and return temperatures of the radiators. Based on this dataset, the total number of heated hours between March 22 and April 22 could be calculated. In **House 1** the total number of heated hours for this period is 244.35 hours, with an average daily time of 11.6 hours. The heating was switched off for six days when the occupants were away for the Easter holiday. In **House 2** the number of heated hours was 142 hours, with a daily average of 4.4 hours.

One further influential factor for domestic energy consumption for heating and gas consumption is outside temperature. Although the energy monitoring of the two buildings started in March, the ambient average outdoor temperature in these two months was ideal to record and observe the heating patterns of the houses. In March, the monthly average temperature was 2.4°C, and in April it was 7.8°C.

mm/Avg deg °C	2011	2012	2013
Jan	4.1	5.6	3.4
Feb	6.9	4	2.8
Mar	6.8	7.9	2.4
Apr	11.8	7.45	7.8
May	12.4	11.8	10.8
Jun	14.5	13.9	14
Jul	15.9	15.8	18.5
Aug	16.5	16.8	17.6
Sep	16.05	13.5	14.2
Oct	12.9	9.4	12.6
Nov	9.45	6.7	6.3
Dec	6.1	4.9	6.5

Table 8 Monthly average temperatures in 2011, 2012 and 2013

Conclusion

In this chapter I have focused on the energy consumption of two 1930s semi-detached buildings, to see how radiator usage and TRV control develop jointly from physical, sensory, social and material flows in the home. We have learnt in this chapter that home heating is not a uniform practice, because its performance goes beyond direct interaction with control points. It is inseparable from the body's heat balance, various heat loss routes and sensory experiences of heat emissions from radiators. I have demonstrated that heat balance can be affected by environmental parameters (e.g. air temperature or the radiant temperature of surfaces, air relative humidity) or more individual elements such as movement and metabolic rate (the energy generated inside the body, due to metabolic activity). The body's heat exchange with the surrounding environment is an ongoing process that is core to the sensory aesthetics of the home and the sensory experience of indoor climates. Also, active engagement with the indoor climate implies that environmental elements such as condensation, air temperature and relative humidity are active constituents of home heating activities. Therefore, home heating is part of the 'place-event' of the home, which implies that the improvisatory use of radiators and TRVs is a relational process. This suggests that the domestication of home heating controls and the gap between the intended and actual use of TRVs and radiators is inseparable from indoor climate conditions and the physical environment of the home. The next

chapter moves on to explore how the body engages in the actual moment of movement and how individual elements structure improvisation in the performance of TRV control and radiator use.

6. Invisible Elements of Home Heating

Introduction

This chapter draws on data from home video tours and IR imaging. It looks at the more sensory and invisible elements of home heating by focusing on the links between improvisation, knowing and the formation of movement, to understand better how the gap between the intended and actual use of radiators and TRVs comes into existence. Because improvisation unfolds through perceptual awareness and sensory entanglement with the surrounding built environment, I argue that domestic environments are a shifting constellation of elements and processes and that they are constantly changing. The contingency of “material, sensory, domestic and physical flows” indicates that creative engagements are not scriptable but they are productive sources of sustainable change. To characterise improvisatory home heating, the first part of the chapter looks at the role of senses and “multisensory emplaced learning” (Fors et al.: 2015) in the formation of movement. I first present two examples. I show how occupants learn about their indoor climate conditions and know whether their heating system is on/off, and then I introduce the process of attunement between the internal and external environment of the body. I demonstrate that sensory engagement with the surrounding physical and material environment is a pre-condition of improvisation, because occupants have a unique relationship with the movement they create. To continue this argument, I introduce a set of individual elements in the second part of the chapter. Hybrid cultural identities, childhood memories, eczema, knowledge of scientific facts and resourcefulness represent elements that occupants connect to the formation of improvisatory movement in the creation, maintenance and re-creation of their indoor climates. These elements show that improvisatory home heating cannot be understood separately from the surrounding physical environment and that it is core to how domestic environments unfold.

6.1 Learning by ‘Working’ the Senses

The first interesting theme that emerges from the findings and is central to how people domesticate home heating controls is the process of learning. The next chapter introduces findings from a video tour in two households, to show that learning is central to how people develop practices around radiators and TRVs and that they employ their senses to make sense of technologies and gain knowledge about the surrounding environment. We have learnt from the first chapter that occupants continually make their home environments feel right as they go along. The first section therefore asks the question: Is the heating on? How do occupants know whether the heating is on, and how it comes on, while they are in the process of creating and maintaining their home’s sensory aesthetics? The second section asks how do occupants know something as abstract as the room temperature in their home? How do they navigate, coordinate and acquire the reassurance to know they are on the ‘right track’ with creating the atmosphere they want? The implications of these findings are then summarised and discussed.

6.1.1 “Is the Heating On?”

I am on my first visit to Hamid’s house to take some thermal camera images and inspect the buildings’ fabric heat loss, as well as to find out more about the heat output of his radiators. Hamid is a 26-year-old PhD student of Middle-Eastern and Czech cultural heritage. He owns a three-bedroom terraced house on the outskirts of Loughborough. The house is located on a residential street on a brand new estate. The roads leading further into the estate have not been asphalted yet, because the majority of the properties are still up for sale. Thus, Hamid’s house is easy to find, as it is almost the only one with the lights on. He invites me in and instantly asks me to take my shoes off. The floor has carpets, but the house is slightly chilly. Hamid has just put the heating on, because he only got home 10 minutes before I arrived. We go upstairs to the master bedroom and continue talking about the house as I take the thermal camera out to set it up for inspection. Hamid suddenly turns around and

asks, “Is the heating on? I know I put it on when I got home.” The system in this house is so quiet, he is still just getting used to it. In his previous house he had an “ancient boiler,” and he always needed to make sure that the boiler was on. But there were ways around it. He used to turn up the thermostat for about 25°C just to ‘force’ the boiler on. He wanted to make sure he heard that ‘firing up’ noise, to know that the heating was coming on. When he heard that ‘clicking noise’ he knew it was time to turn it back down to 20-21°C. To reassure himself that the heating is on, he walks up to the radiator. He puts his hand on the radiator to touch the surface on the top corner. He slides his hand all the way to the bottom corner and tells me that he can feel the slight warm up at the bottom of the radiator. The middle and the top are still cold, but it does not take long for the radiators to heat up. The slight warming up and the heat difference re-assure him that the heating has just been switched on.

The following three images show the warming up radiator in the master bedroom. The two thermal images were taken five minutes apart. On the first thermal image the surface of the radiator is 28°C, whereas on the second one it is 37.1°C.



Figure 59 Master bedroom radiator

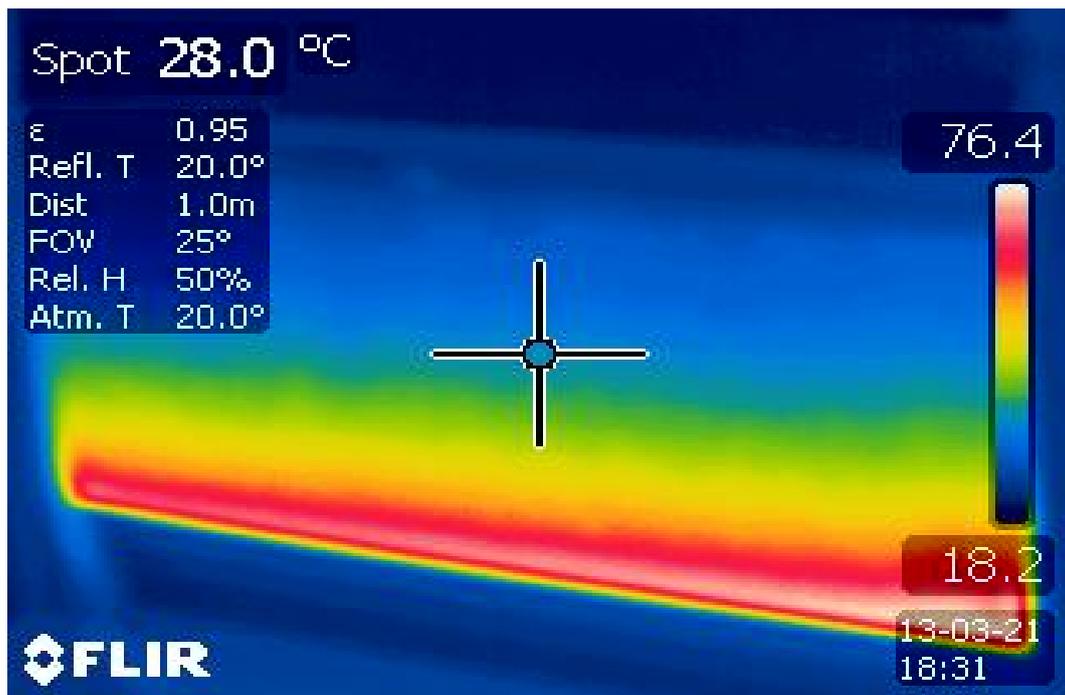


Figure 60 Master bedroom radiator in the process of heating up

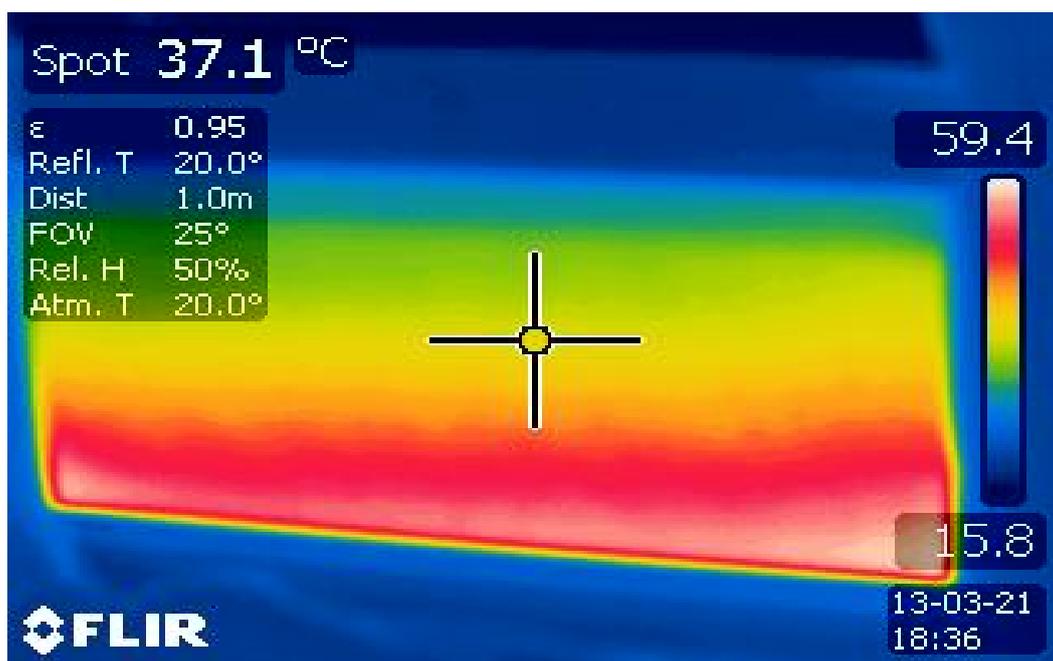


Figure 61 Master bedroom radiator heated up

We walk back downstairs to the hallway, and Hamid points out that the radiators across the house warm up slightly differently. He steps closer to the radiator, lowers his body by bending his knees and puts his hand at the bottom of the radiator. Whereas in the master bedroom it is the bottom of the radiator that gets warm first,

the radiator in the hallway is cold at the bottom. Interestingly, it gets warm around the top first and stays slightly cooler at the bottom. The next thermal image shows the surface temperature of the radiator in the hallway.

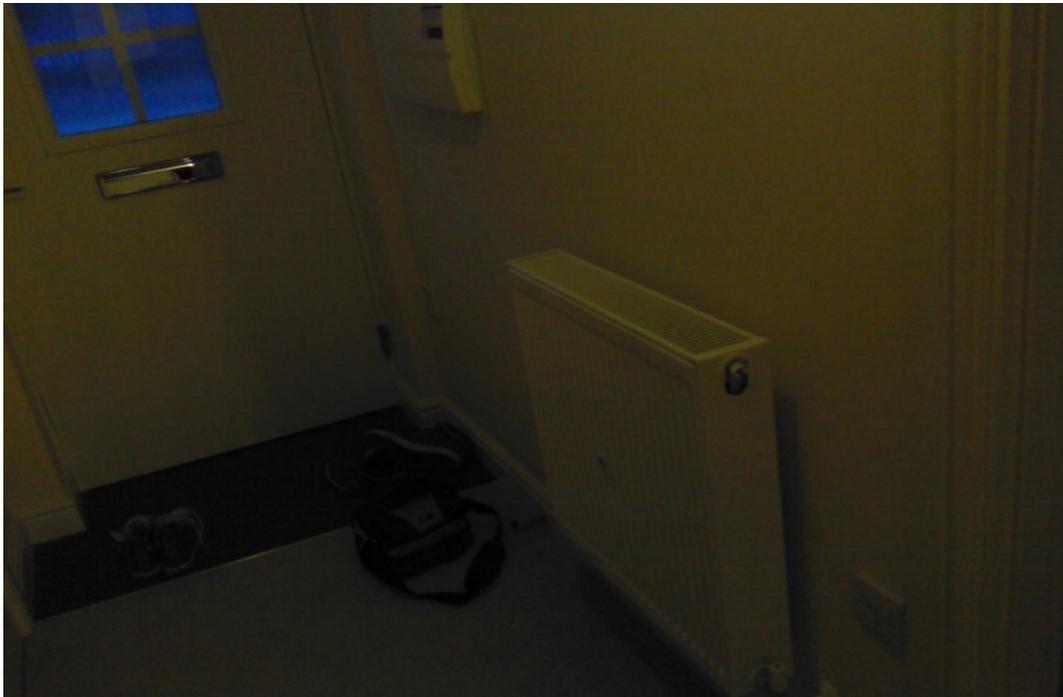


Figure 62 Radiator near the entrance in the corridor

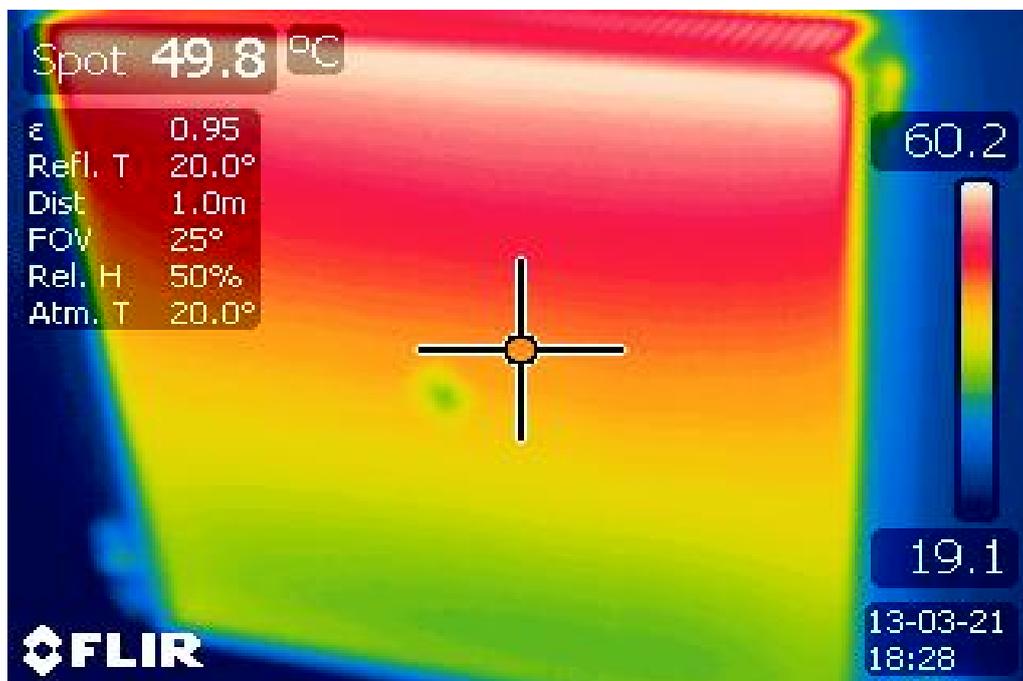


Figure 63 IR image of the radiator near the entrance in the corridor

6.1.2 Knowing the Room Temperature

The second way we learn more about how occupants orient by using their senses comes from video tours of Stephen and Andrew's house. Stephen, a 53-year-old professional who works in the property industry, lives in a four bedroom and three bathroom 1991 detached house. He is divorced and has two sons who live in Australia. He keeps two of the bedrooms upstairs for his sons, because they return to visit him two to three times per year. He has the en-suite master bedroom for himself and keeps another bedroom just for drying laundry. He mainly works from home, and he has a study downstairs where he spends most of his time.



Figure 64 Front view of the property

The heating of the house runs on a programmed setting. It normally comes on at 6 o'clock and goes off at 11 o'clock. It comes on again at 6 o'clock in the evening and goes off again at 11 o'clock at night. Whenever he works from home during the winter he just overrides it and leaves it on all day. The dining room is the least occupied room in the house. He never uses it unless he has guests. The living room is only occupied in the evenings when he watches TV. There is a fireplace in the living room that he tends to switch on if he has got guests visiting.



Figure 65 Living room

When Stephen works from home and walks into the kitchen to have something to eat at lunchtime he usually takes a quick look at the thermometer, which he uses as a source of comparison with the thermostat to know the actual temperature in the house:

“There is only one thermostat and although it is on 20°C you can see the actual temperature on the Swedish thermometer. The actual temperature is 18°C right now although the other says 20°C. So that is not calibrated correctly. This is from my grandmother. And they are next to each other so you can tell that the thermostat is not calibrated correctly. Although I always leave it at 20°C.”



Figure 66 Thermometer

Similarly to Stephen, Anthony, who lives in a Victorian 1930s house, keeps a little temperature sensor in his bedroom. This way he can track temperature differences by comparing indoor temperature with the portable thermostat:

“I have a temperature sensor here, it is quite old, it is like 20 years old. When I bring in the room stat I put them next to each other. It is quite accurate. The displayed temperature is rarely more than a degree out on each other. I’ve never seen it more than a degree out so...that is a kind of reassurance. See, the temperate has dropped. But it is maximum at 20 °C. I turned it up before you arrived just so you can see how the heating system operates.”



Figure 67 Boots temperature sensor



Figure 68 Room thermostat

6.1.3 Attuning to the Environment

I have introduced two examples to understand better how occupants know whether their heating system is on or off and how they learn about temperature, indoor climate conditions and the functioning of heating systems in their homes.

We can see that the process of learning in the examples above happens at the intersection of the mind, body, material and physical environments. We have also seen that learning about technologies and indoor climates has a multisensory dimension, because people are actively immersed in their surrounding environment. Each occupant creates their own sensory routes to understand and navigate the home's indoor climate conditions. Creating sensory routes is a process of attunement, and attunement is an outcome of "wayfaring" (Ingold: 2011), an ongoing engagement with the world through lived experience. Occupants navigate through everyday life in the built environment to proceed along a path of observation, during which time they simultaneously experience and contribute to the formation of indoor climates. Movement (e.g. stepping closer to the radiator, to touch the surface in order to test whether the heating is on or not) becomes a 'way of knowing', a form of exchange and a dialogue between the body and its material and physical environment. This dialogue can be directed by multisensory perceptions, because occupants can switch in between senses of touch, hearing and vision to keep track of indoor climates (e.g. hearing the water flowing through the radiators and feeling its surface temperature). Sensory perception here becomes a process of attunement between the internal and external environment of the body that is characterised by a shifting awareness. And shifting awareness gives movement a unique character, because movement becomes a response and a form of experimentation that puts the body in tune with the senses. Therefore, occupants' observations come from sensory experiences whereby knowledge builds up, or "grows along," movement and experimentation (Ingold: 2010).

Attunement is therefore not only a way of being in touch with the environment, but also a form of "multisensory emplaced learning" that is part of the "event of place" (Fors et al.: 2015). Occupants touch the radiator to gain information about the heat on the surface, they read temperature differences on thermostats and thermometers

and rely on the noise of the boiler to know that the heating has come on. Using the senses becomes a bodily way of knowing which is then translated into a process of tuning, interpretation, coordination and internalisation of information. Occupants therefore rely on their senses to orient, collect and act on information as well as to track, create and maintain the sensory aesthetics of the home. On the one hand, this implies that attunement and sensory experiences can keep the body connected to the environment. On the other hand, it implies that attunement is a form of navigation, shifting awareness and a form of 'emplaced learning' that is a pre-condition of improvisation. Consequently, occupants are engaged in path-making, and as they move through the world they 'thread their way' by contributing to the formation of indoor climates, making them feel right. To understand better how occupants form paths of movement by engaging in improvisatory TRV use, the next section introduces various invisible elements people connect to movement and developing TRV use.

6.2 Connecting to Movement

This section presents four elements that prevent or modify the development of regular TRV use which emerged from the findings from video tours in three households. The occupants all have a unique relationship with the movement they generate, and they connect or 'thread' various individual elements into this movement. The four elements therefore demonstrate the 'in-betweenness' of bodily movement and improvisation by showing how occupants 'weave' more subjective, individual elements into the formation and performance of home heating activities and why the articulation of these individual elements creates modifications and renewal by forming a gap between the intended and actual use of radiators and TRVs. These four elements are hybrid cultural identity, childhood memory, health risk perception, knowledge of scientific facts and resourcefulness.

6.2.1 Hybrid Cultural Identities, Cooking and Heating the Kitchen

The first invisible element that came to the fore and connects movement to improvisatory TRV use is hybrid cultural identity. Cultural identity and hybridity refer to “conditions of in-betweenness” and “complicated entanglement of interculturalness” (Ang: 2003) that in this particular case commingle into a formation of cooking routine that affects how the kitchen is heated and how energy is consumed.

Elena, who I introduced in more detail in House 1 in the first chapter, is 36 years old. She was born in Greece but she has Filipino roots and has lived in England for almost a decade. Cooking is an essential part of “What it means to be Greek,” so she never buys ready-made meals. She prefers to prepare carefully most of her meals from scratch. Besides, cooking for her is closely tied to maintaining health, which starts from the careful selection of ingredients. Homemade food has always been a way of socialising, and it provides a sense of family and togetherness, because everyone shares in the act of preparation before dining together. Eating meat is another important moment in the life of Elena’s household, because it happens only once a week. Cooking lamb or chicken is special, because on these occasions everyone in the household dines together. But this only happens over the weekends.

The kitchen is one of the coldest spots in the house. The floor lacks insulation and there is a double-panel radiator in the kitchen that does not work. This is the first winter they have had to use an extra heater in this room. Previously, Elena had to take the fan heater with her wherever she went. She used to spend a lot of time working at the dining table, using the fan heater to keep warm, but the windows are single glazed and draughty ,so she needed to wear multiple layers of clothing to protect herself from the cold air pouring in. The new heater in the kitchen is named ‘fire’ because it resembles a small fireplace and it projects a glowing light (Figure 70). The thermal image on the left shows that the surface of the radiator is dark blue with a surface temperature of 12°C, because the water does not flow through the pipes.



Figure 69 Radiator in the kitchen

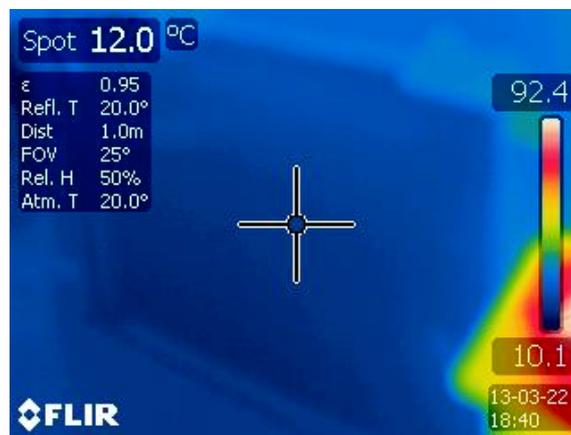


Figure 70 IR image of the radiator in the kitchen

Switching on the heating depends on the volume, duration and types of dishes Elena cooks. If she cooks larger portions – for instance in advance for the coming weekdays – the heater remains switched off. Elena’s younger sister, who also lives in the UK, has recently gained admission to a leading culinary school in London. She spends most weekends with Elena and experiments with new meals that combine Greek, Philippine, modern, ‘nutritious’ and ‘healthy’ cuisines. Both Greek and Philippine food culture has two significant elements: local ingredients and seasonality. Therefore, the sisters go to the local farmers’ market twice a week on Thursdays and Saturdays. They do not like shopping for fruits and vegetables from supermarket chains, because they are highly concerned about the quality of the products. They “lack nutrition and are enriched by preservatives.” Cooking with fresh ingredients generally takes longer, but the sisters get to spend either Saturdays or Sundays together in the kitchen. In the winter they tend to pick either stews or slow-

cooked meats, or they bake. These preparations require the oven to be switched on, which means that the electric heater in the kitchen remains switched off. Moving around and 'using the heat' emanating from the oven supplies enough warm air to keep them comfortable, and if they cook meat they open the door and windows for 15-20 minutes to create a draft between the kitchen and conservatory that takes the 'cooking smell' away.

The cooking routine in this particular household provides an example of how domestic practices are not only interwoven with the material and sensory home (Pink and Leder-Mackley: 2012), but also with individual elements and the physical characteristics of the house. We can see from Elena's cooking routine that she 'weaves' her Greek and Filipino hybrid cultural identities into the fabric of everyday life. She articulates this invisible element to movement around the kitchen that connects to the performance of practices such as going to the market to buy seasonal ingredients or switching the oven on. Bringing the element of hybrid cultural identities into the performance of home heating (e.g. eating meat once a week when the oven is switched on, so the electric heating stays turned off) in this particular case intersects with the dysfunctionality of the radiator, the draughty single-glazed windows and the use of supplementary heat sources.

6.2.2 Childhood Memories, Airing and Mould Growth

Window opening has a large impact on energy use in buildings. Airing may be a mundane and routine practice, but it is closely tied to subjectivities, experiences, knowledge and actual contexts of performance (Hauge: 2013). Window opening in homes is generally considered to be a response to discomfort or people's perceptions of CO₂ levels (Ackerley et al.: 2013). But window opening in Elena's case is interwoven with more sensory, emotional and environmental dimensions of how the home's sensory aesthetic is created and maintained.

Elena lives in a house (the physical characteristics of which are described in more detail in the previous chapter under House 1) where the dysfunctionality of the radiators is a daily problem-solving task to respond to and where ventilating the

rooms upstairs prevents mould growth. Elena's mother used to air the room every morning very strictly at the same time when she was a child, as she wanted to get rid of the air from the night before. Elena says she used to get very annoyed with the fact that no matter what, her mother would enter her bedroom every day precisely at the same time. There was strictly one time to air the house, even if it meant that she was woken up early in the morning from a night out with friends on the weekends. Her mother opened all the doors and windows to let the air circulate through the flat. She starts laughing and says that fresh air is now an equally important part of her own life. Her morning routine now starts with opening the windows before going downstairs to make breakfast in the kitchen:

“And I also lived in a dump of a house from when I went to school when I was around 7 years old through to when I was 18. Like, you wore your jeans in the morning and it was really cold. My dad used to put the jeans near the radiator before we woke up, so that when we wore them they would be warmer. I do stuff such as that here... I open the windows every morning, and that is why I use the fan heater as a blow dryer to get the damp duvet, comforter kind of dry and warm.”

We learn from this section that there are more invisible elements such as emotion or memory that can translate into the performance of airing practices. Also, people experience and manage their indoor climates based on sensory experiences of indoor air. Thus, air becomes an element people correspond to, based on perception and bodily experience.

6.2.3 Risks of Eczema Outburst and Relative Humidity

Another invisible element that came to the fore and influences radiator and TRV use is the perception of health risk. Rob, a 45-year-old divorced father works in the legal profession and bought a three-bedroom terraced house on the outskirts of Loughborough. The property is new, in that it was built in 2013. The house is warm in the winter and is “Very airtight,” he says, but most importantly he pays lower gas bills than in his previous house. The previous house he rented after his divorce was a detached three-bedroom former coach house, but it was not in a good condition. It was draughty and had single-glazed windows. Rob has two children who stay with

him every weekend. They occupy two of the three bedrooms upstairs. His younger son has the single room and his teenage daughter has the double room.



Figure 71 Front view of Rob's property

Rob suffers from mild eczema which, he explains, is a skin condition that is linked to the body's weakened immune system and causes itchy, red rashes and irritated skin. The most affected areas on his body are usually the neck, shoulders, arms and chest. Rob's skin condition is seasonal, because it always occurs in the winter months, from the end of November through to late March. The flare-ups are difficult to determine, but they are generally linked to some sort of allergy. He explains further that eczema outbursts are connected to triggers. He has identified various 'personal triggers' and 'everyday things' that directly or less directly influence an outburst. He suffers from peanut allergy, and if he eats peanuts his reactions are quite severe, including swelling and asthma. The more direct links are lanolin and indoor humidity. Lanolin is a natural substance found in most cosmetic products, and unfortunately it is one of the most common treatments for eczema. The other triggers are too high or too low indoor temperature and humidity. Besides these triggers he has identified unhealthy diet, dust, stress and lack of exercise as triggers that can build up over time. As much as he likes living in the house, the air, he points out, is very dry in the bedrooms during the night. And his skin is the worst it has ever been.

He often wakes up with a dry mouth and cracked skin in the mornings despite his heavy moisturising routine. This is his first winter in the house and, as he says, he is still experimenting, but:

“Comparing with the old house, air quality just has to be planned, and it takes a lot of work to get it right...”

He started sleeping without wearing any layers on top, because combined with the dry air it irritates and dries out his skin even more. He has two options. He can put the heating on and open the windows to create a little draft between his and his daughter’s bedroom, which is a lot of wasted energy, but recently he has started experimenting with switching off the heating around 9 pm during the week, when the children are not with him. He says it stops the bedroom from going too dry at night but the room can cool down enough, which is another trigger for an outburst. Rob has started researching solutions online. He is considering buying a humidifier, but he has not decided whether it is better to buy an electric one or not. Based on a number of reviews the electric ones seem to be noisy, which is why he is thinking of buying a ceramic alternative. These need to be filled with water that evaporates at night while they hang from the radiator.

In Rob’s case, managing the indoor air temperature and relative humidity is a source of risk, because it is associated with eczema outbursts. He ‘weaves’ his perception of risk and experiences of outbursts into the creation and maintenance of indoor climates. Therefore, the performance of some of the practices – such as opening the windows at night upstairs, to create a draught between the bedrooms, or switching off the heating, to prevent the air from drying out – clearly intersect with his perception of risk. Moreover, he connects his sensory experiences of the ‘right’ indoor climate conditions, which keep his skin protected from another outburst, to home heating.

6.2.4 Knowing Scientific Facts and Resourcefulness

The last example of an invisible element I introduce demonstrates how the correct knowledge of scientific facts intersects with the creation and maintenance of the home's sensory aesthetics, appropriating warm air flows, resourcefulness and the building's fabric condition.

Andrew's (53) bedroom is located in an attic of an 1880s Victorian pitched roof terraced house. (The house is introduced in more detail in the next chapter). His bedroom functions both as a study and as a bedroom. There is another bedroom on the first floor that he tends to use more often over the summer, as the attic gets very warm when the sun is out. Andrew's bed is located in the left corner of the room, further away from the radiator. He used to feel cold when going to sleep, and he wanted to "Move around the heat for a more even heat sensation".

Andrew has sheets of A4 print papers attached to the wall below a wooden beam that are supposed to "Deflect the heat around the room." He found that the heat was circulating in a confined area around his desk but never reached over to the other end of the room, especially to the bed area:

"I tend to get into bed on that side of the bed [pointing to the end that is further away from the radiator], so I want the heat to come over, and I found by putting these sheets attached by Blu-tak it throws the heat more into the room."



Figure 72 The wooden beam under the window



Figure 73 Paper sheets under the wooden beam

I ask him to explain how he came to the conclusion that the attached sheets would divert the heat flow to his bed area. He starts explaining that a radiator gives off heat through radiation and convection, but it mostly works through convection. The heated air rises and draws cool air into and through the radiator from underneath. This movement of air sets up vertical currents that will distribute heated air throughout the room. He further explains that:

“Because I was sitting here [at the desk] and I could feel the heat coming down to me while I was typing and I thought that would explain why sometimes it feels quite a lot cooler on the other side of the bed. So these little issues about convection of air can make a big difference. That was because it was getting too warm for me [in the desk area] and it tied in with feeling occasionally moderately cool over there. And now it works well. I think they have been there for about two or three... no, two winters now.”

First of all, what becomes clear from the way Andrew appropriates warm air from the radiators is that he uses his sensory experiences of warm air flows to make sense of how the radiator works. The ‘assimilation’ of scientific facts into everyday life is not a linear and calculable but a dynamic and messy process (Irwin and Wynne: 2004). Scientific facts co-exist with embodied sensory experiences that are inseparable from a building’s fabric condition and the material media in which one may be immersed.

Secondly, the resourcefulness to appropriate warm airflows is an outcome of active engagement with the constituents of the surrounding environment. Resourcefulness in this case becomes an outcome of awareness and response that is rooted in the engagement between the occupant and the surrounding built environment. It is activated by problem-solving, experimentation and acting on circumstances and sensory experiences. Sensory experiences blend with scientific knowledge (radiation and convection) and environmental knowledge (lack of insulation in the roof) and translate into a local solution through resourcefulness. Resourcefulness and problem-solving therefore arise from a continuous interplay of the physical, sensory, material and domestic environment.

6.2.5 The Relational Character of Home Heating

By drawing on home video tours from four households, I have shown that domestic environments are constellations of processes (Massey: 2005: 141) and constantly changing 'place-events', where lives and activities in the home are intertwined with the surrounding built environment. Home heating is inseparable from material objects (e.g. radiators, electric heaters or the oven), other practices (e.g. food preparation, shopping from the market, bedtime routine, window opening), physical processes (e.g. the body's heat exchange with the surrounding environment and occasional heat gains from the oven), sensory experiences of an indoor climate (radiating cold, convective heat, low relative humidity) and building fabric shortcomings (e.g. lack of cavity wall or roof insulation, single-glazed windows, air permeability or the 'breathability' of buildings). In the first household (6.2.1) we saw that occupants' home heating activities in the kitchen are joint outcomes of the dysfunctionality of the radiator, electric heating, draughty single-glazed windows, a lack of insulation in the floors, cooking routines, Elena's Filipino and Greek cultural identities, the body's heat gain from the oven and heat loss to the radiating cold walls. Elena's airing routine also demonstrates that childhood memories can play a role in how she deals with mould and performs window opening. In Rob's household (6.2.3) we have seen that his home heating activities are closely tied to his skin condition and his maintenance of indoor climate conditions. Maintaining steady relative

humidity and air temperature in his home is central to how he protects his skin, experiments with indoor climate conditions and creates the home's sensory aesthetics. In 6.2.4, we have seen that resourcefulness and experimentation are closely connected to the sensory experiences of convective heat and that the correct knowledge of scientific facts does not necessarily translate into regular uses of TRV control. On the one hand, what stands out from these lived environments is that home heating is highly heterogeneous; it is not a unified practice but a collection of more or less visible activities and processes that develop from complex intersections and home environments that are entwined from diverse 'things' and processes (materialities, physical processes, sensory and affective qualities, emplaced multisensory learning, memories, identities, health conditions, risk perception and more). Consequently, home heating activities do not develop independently from places; rather, the 'throwntogetherness' (Massey: 2005) of all these processes and elements constitutes the 'place-event' of domestic environments. Therefore, the development of home heating activities is also inseparable from the building fabric and heating system efficiencies of buildings. But this also means that lived environments are a shifting constellation of things and processes and that they are constantly changing.

So far in this chapter I have discussed how people engage in radiator use and TRV control in the actual moment of movement. I began this chapter by showing that home heating happens partly in movement and that multisensory emplaced learning is an integral part of how people experience, learn and navigate their indoor climates. To demonstrate how occupants engage in improvisation I have distinguished two interwoven processes to which occupants connect when engaging in the formation of movement: "multisensory emplaced learning" (Fors et al.: 2015) and the 'threading' of individual elements into 'path-making'. I started this chapter by demonstrating that occupants actively put their bodies and senses into use to learn about their physical environment. I have shown that the process of multisensory emplaced learning is core to how people navigate and discover their indoor climates through, for instance, touching radiators or reading thermostats or thermometers. I have demonstrated that sensory experiences can engender awareness by keeping the body attuned to the physical and material environments of the home. In the second part of the chapter I have shown a set of individual elements (hybrid cultural identities, childhood

memories, health risk perception, knowledge of scientific facts and resourcefulness) that are connective components between awareness and movement. I have demonstrated that there is agency beyond place and 'place-making' and that occupants can be active and corresponding, because they are able to 'wayfare' by improvising and bringing into existence unique configurations in relation to the performance of home heating practices. As a final step, I continue and end this chapter by discussing what these invisible elements and unique configurations mean in understanding change in home heating practices.

6.3 Implications of Invisible Elements

By showing that there are invisible elements in the formation of home heating practices I have demonstrated that there is agency beyond place and 'place-making' and that households can adapt and modify existing individual elements in their own right. Occupants can bring unique configurations to movement that is central to how improvisation unfolds in real time. On the one hand, the modification of individual elements implies that unique configurations should not be thought of separately from their physical and material environment but rather as an 'open' place and an environment constituted on interrelated flows (Pink and Leder Mackley: 2015). Therefore, 'place-making' in the home implies that domestic environments and indoor climates are always in the process of becoming, as they undergo continuous generation. And in the process of continuous generation, occupants not only bring unique configurations into existence, but they also engage with the contingencies of their home environments by simultaneously creating and being part of indoor climates. In this sense, occupants are not just "carriers of practices" (Schatzki: 2001), but are also active and corresponding agents who cope with new and challenging situations. They are able to learn, navigate and renew the performance of home heating practices by "threading their way through" lines of movement and improvisation (Ingold: 2010). And because occupants are able to connect and bind various elements into movement, they are also able to renew home heating practices to make, remake and modify the spatial and temporal worlds they inhabit.

The ability to modify and renew home heating practices through various individual and often invisible elements suggests that creativity does not necessarily have a linear relationship with improvisation and innovation. Irregular uses of radiators and TRVs unfold from a field of emergent and processual relationships between the body and its physical environment. Improvisation therefore becomes a co-constructive process between the sensory aesthetics of the home, occupants' sensory experiences, indoor climates, physical characteristics of the building and the condition of the heating system and radiators. Moreover, as Hallam and Ingold (2007) point out, innovation characterises creativity and modification backwards rather than forward. They also note that life and 'place-making' are about 'keeping going' rather than repetition, because occupants mingle with the world, and creativity is inseparable from the total mixes of relations into which it is embedded and into which it extends. Therefore, creativity is not necessarily synonymous with the 'new'; rather, it is a process and a 'product' of alignment, adjustment and modification. The merging of elements and processes, as well as the generative character of 'place-making', implies that nothing that people do repeats exactly the same way, and all routines involve a certain degree of improvisation. Home environments are relentlessly on the move, and this constant change brings about shifts and alterations through the recombination of elements and renewal of performances. Occupants actively redefine radiator use and TRV control based on their own needs, perceptions, sensory experiences and the problem-solving task at hand. Modification therefore involves a degree of experimentation, sensing, thinking and developing plans. Furthermore, it does not replicate scripted practices; rather, it is a process of renewal and aligns movements because occupants are always immersed in material, domestic, sensory and physical flows. And because they are immersed, they bring a unique relation to the movement they create.

Creativity is often considered to shift between skills someone is blessed with or a particular skill someone is being taught. However, creativity and the ability to improvise are not only traits of exceptionally gifted individuals who can demonstrate the ability to create something radically novel and extraordinary – creativity can be located in the mundane, because it is created through the way people engage in their everyday activities and it becomes part of the way humanity operates (Sawyer: 2000). Consequently, improvisation in home heating can be understood as an aspect

of functioning and a way of manoeuvring through the everyday. It is an ongoing process of how life unfolds day by day, because it is a constantly emerging practice that is inseparable from the fabric of the everyday. Consequently, creative engagement with technologies is always responsive to the surrounding material, sensory, domestic and physical flows. Therefore, occupants improvise their way through a field of relationships rather than repeating the performance of the exact same practice. And this brings me to the last point, namely that technological change is inherently uncertain, because improvisation is always integrative of the surrounding environment and it is characterised by relationality between the internal and external environment of the body besides receptivity, awareness and responsiveness. As De Spain expresses:

“When you turn your awareness in toward yourself, you come into contact with a mélange of flesh and breadth and mind and desire and everything else that resides in there. When, instead you turn your senses out toward the world around you, you find yourself bathing in unending stimulation from the space and people and sound and energies that compose the life beyond your skin. Then there is the connection, the interaction, the blurry melding of the inside and the outside when the conceptual walls that separate and delineate who we are and who we are not becomes porous. Surely, the infinite potential of these realms provides a lifetime of resources from which to improvise”

(De Spain 2014: 81).

Technological changes in home heating are therefore inseparable from the ‘place-event’ of the home and the ever-shifting constellation of domestic environments. And the development of creative engagements with technologies in domestic environments is inevitable, because they are core to the way in which humanity operates. The mingling up of relationships between the material, sensory, domestic and physical environments makes the development of new practices un-scriptable. As Ingold puts it:

“[...] life is not contained within things, nor is it transported about. It is rather laid down along paths of movement, of action and perception. Every living being, accordingly, grows and reaches out into the environment along the sum of its paths. To find one’s way is to advance along a line of growth, in a world which is never

quite the same from one moment to the next, and whose future configuration can never be fully known. Ways of life are not therefore determined in advance, as routes to be followed, but have continually to be worked out anew. And these ways, far from being inscribed upon the surface of an inanimate world are the very threads from which the living world is woven” (Ingold 2011: 242).

By looking into the individual and invisible elements of home heating we have seen that people are in a process of ongoing engagement with their surrounding environment. They thread ‘subjective’ elements into home heating, radiator use and TRV control, and by threading these invisible elements they are able to connect to new practices. Additionally, by connecting to new practices they can modify and bring into existence alternatives that otherwise would not have come into existence. Modification and renewal are therefore not only intrinsic to how day-to-day life unfolds but, as I have shown, are relational, generative and forward-moving.

Conclusion

By drawing on data from home video tours in four households, and IR imaging in one household, I have introduced multisensory emplaced learning and a set of individual elements to understand how occupants engage in the performance of improvisatory home heating in the actual moment of movement. I have continued to demonstrate that domestic environments and home heating are not made up exclusively of stable routines. Home heating can be irregular, ad-hoc and improvisatory in character. Occupants’ improvisation is a unique movement, because it is integrative of the surrounding physical environment. Moreover, it is a creative engagement, because occupants all have a unique relationship with the movement they create. The process of attuning shows that improvisation can be characterised by multisensory emplaced learning. In addition, there is a shifting awareness between the body and its surrounding material and physical environment. The elements of hybrid cultural identity, childhood memory, health risk perception, knowledge of scientific facts and resourcefulness have demonstrated that occupants can draw on individual and more ‘subjective’ elements to connect to practices through movement. We have learnt that improvisation and the development of new practices can bring into existence a gap

between the intended and actual use of radiators or TRVs, but practices that bring the gap into existence are outcomes of complex and relational processes. Improvisation in home heating is also a form of dialogue between the body and its surrounding physical and material environment. It is simultaneously in tune with the senses and an active composition of the senses, and it involves reading and tracking spatial and indoor climate qualities, perceptions and interpretations of environmental stimuli, dealing with constraints and limitations of imposed ready-made designs and the interplay of creativity and planning. Moreover, I have argued that improvisation is uncertain and is therefore an unavoidable dimension of technological and social change in the 'place-event' of the home. Nonetheless, it is more than risk or the unpredictability of human action; rather, it is reflective of a modification, an alignment and a renewal that is generative and forward-moving. And in the next chapter, I argue further that improvisation, modification and alignment are core to the fabric of the everyday and they can be a source of sustainable change. Ultimately, they are a communicative medium that is an important site for co-design processes.

7. The Productive Functions of Improvisatory TRV and Radiator Use

Introduction

Improvised uses of TRV controls and radiators are forms of irregularity, and in this chapter I characterise the irregular side of TRV control and radiator use to understand how occupants bring into existence a gap between the intended and actual use of TRVs. As the literature review discussed, home heating is generally studied as stable routine interaction with either control points (thermostats, windows), socio-demographic variables (household size, income) or separate environmental factors (temperature, humidity). I further argue herein that home heating, at its very core, is about the sensory, material, physical and domestic relationship with our surrounding built environment. The departure point for understanding irregularity is improvisation in the movement and the sensory aesthetics of the home. Home video tours from four houses, and monitored energy data from one building, show how occupants create home environments and develop TRV control and radiator use in relation to the building in which they reside. The first two households introduce how creating the home's sensory aesthetics intersects with indoor climates and physical particularities of buildings and how these jointly affect the development of TRV use. Two different home environments will demonstrate that making a home environment feel right, and using TRVs, can intersect with keeping even temperature across indoor spaces or with appropriately warm airflows. The third household demonstrates that performing TRV control is inseparable from the wider domestic environment of the home. There are other domestic activities that can influence how frequently TRV control is performed. The last household demonstrates that usability and problematic design features can influence the development of TRV control and radiator use. I argue that using TRVs and radiators on improvisatory ways arises from the intersection of material, physical, sensory and domestic environments. These intersections make occupants' domestication of home heating controls and

low-carbon technological change highly uncertain, but I show that intersections are important sites for learning. Irregular uses of TRVs can be dynamic feedback mechanisms locating ongoing modification and change in the uses of heating controls. I also connect improvisatory home heating to co-design, pointing out that emerging alternatives are future-oriented, and attending to ongoing material heat flows could be productive of the future of sustainable energy consumption.

7.1 Being Emplaced in Intersections

Video tours from the following four home environments show that irregularity always develops through the intersection of sensory, physical, domestic and material environments. By irregularity, I also refer to home environments where occupants do not develop TRV control at all. Based on the unique configuration of home heating in these four environments, I could identify four characteristics of how and why improvisatory uses develop. Occupants' improvisation in home heating is co-creative of the home's sensory aesthetics, integrative of the surrounding physical environment, clusters to other domestic activities and becomes communicative of problematic design features. But emplaced multisensory learning was key to connecting me to the process of how alternative uses move into uncertainty.

7.1.1 The Home's Sensory Aesthetic

I visit Hamid on an early March evening, and only a few of the houses around are occupied and have their lights on. The atmosphere in the house is welcoming. The light-grey carpet flooring and the walls still smell of untouched newness, which is one of the reasons why Hamid likes living here. The property is clean, well-insulated and is far away from the noisy student life of the university. Although construction work in the neighborhood can be very noisy, the nights and weekends are always quiet.

Hamid moved in early January. His mother was staying for over a month to help with furnishing the house. He keeps on repeating how important it is for him to pick

furniture that is functional but aesthetically pleasing at the same time. He had enough of renting student properties and moving every year. He is staying at the university for four years. He would like to stay longer and settle down in Loughborough, but he does not know whether he will succeed in securing a permanent contract after graduation or not. Everything is uncertain at the moment, he says, which is why it is so important for him to create a “Home away from home.” He has considered renting out one of the bedrooms to another PhD student or a young professional. It would be good to have some extra money, but he is hesitant on giving up his privacy.



Figure 74 Hamid is cooking dinner

We enter the kitchen and Hamid proudly shows that he is learning to cook. He used to eat takeaway food and frozen pizza but these days he makes a great effort to buy fresh vegetables and fruits. He is making Iranian lamb stew, rice with saffron and a green salad with mint that is specific to the region he grew up in. He wears shorts, a T-shirt and he is barefooted while I am still just warming up. He says he is now falling into a daily routine of cooking. But first he comes home and immediately changes into comfortable clothes, if he has been working away from home:

“I have home clothes and outside clothes. Home and outside are different worlds. Outside I’m comfortable wearing work clothes, but as soon as I get home I feel uncomfortable wearing the same clothes...I just want to change into home clothes such as shorts and T-shirts. It just gives me that freedom to move around...”

Also, an essential part of being cosy at home for Hamid is being barefooted:

“I never wear shoes or socks if I don’t have to...bare feet make me feel comfortable. I always ask my guests to take off their shoes at the door. I want them to feel at home - and it makes cleaning easier. Wearing shoes in the house just brings in dirt...”

Using my senses while walking across the house and spending time in the kitchen with Hamid made me come to the realisation that there is a connection between coping with insecurity and the sensory aesthetics of the home. The walls and carpets smell of ‘newness’, the warmth of the tile in the kitchen and the comfortable, cosy air temperature helped me to get involved in what it means for Hamid to feel temporarily settled and to create the ‘right’ environment for a home away from home. I understood how elements such as health and cooking feed into the creation and maintenance of the indoor climate. And more or less directly, all these elements are implicated in how energy is consumed for space heating.

Another indoor climate condition that intersects with creating the home’s sensory aesthetics for moving around freely across the rooms is even temperatures. There are two thermostats in the house. One is upstairs and the other is in the downstairs hallway. The thermostat downstairs is set at 21°C while the thermostat upstairs is always a degree or more lower.



Figure 75 Thermostat upstairs



Figure 76 Thermostat downstairs

The logic behind the settings is that Hamid prefers close to even temperatures across the house, because he works from home at least two or three days per week. There are three bedrooms upstairs. He sleeps in the master bedroom and uses the other rooms for guest rooms and a study. Even temperatures across the house provide the 'right environment', because it makes moving across the house easier. He starts his morning routine by going downstairs to make a cup of coffee, but he finds it easier to get out of bed and be able to go straight downstairs without feeling cold and having to fully dress first.

The next four frequency distributions show air temperature data from Hamid's house for a period of two months (March – April 2013). It is evident from the histograms that the most commonly recorded temperature in the three rooms upstairs (master bedrooms, study and guest room) are 19°C, 21°C and 22°C. In the living room downstairs the temperature range varies between 18°C and 21°C. This indicates that Hamid does not control the TRVs across the house to lower indoor air temperature across various rooms.

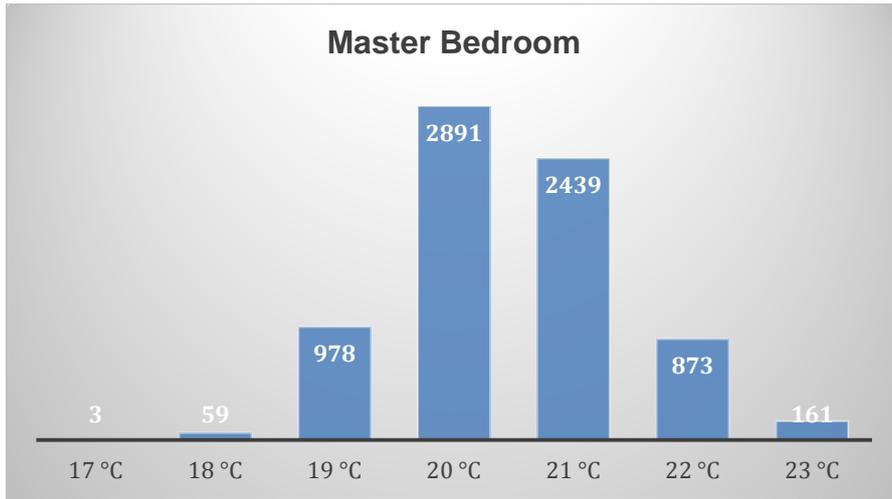


Figure 77 Temperature distribution in the master bedroom

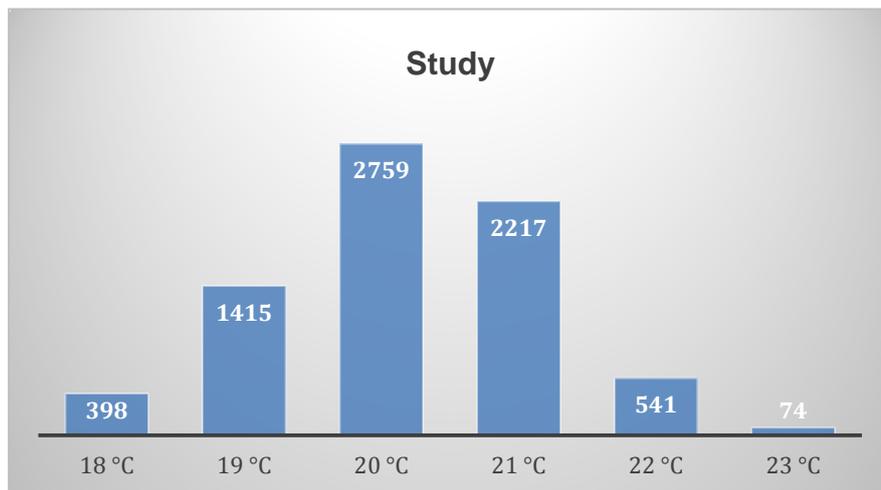


Figure 78 Temperature distribution in the study

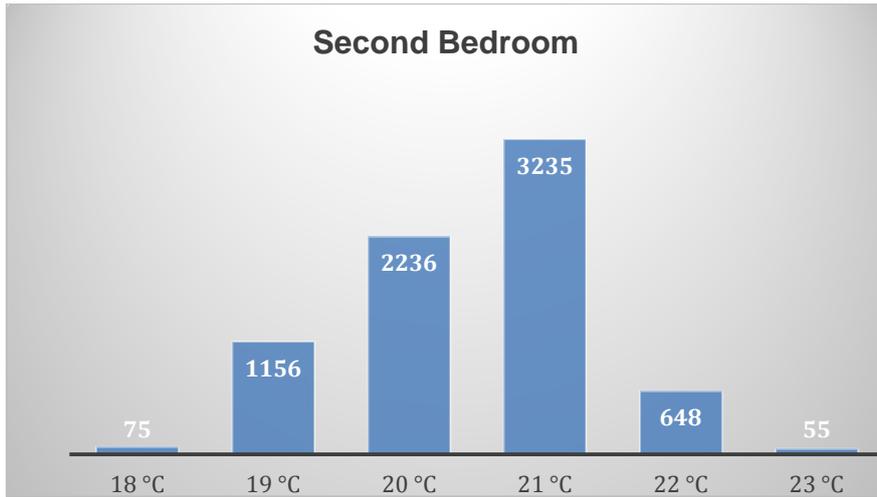


Figure 79 Temperature distribution in the second bedroom

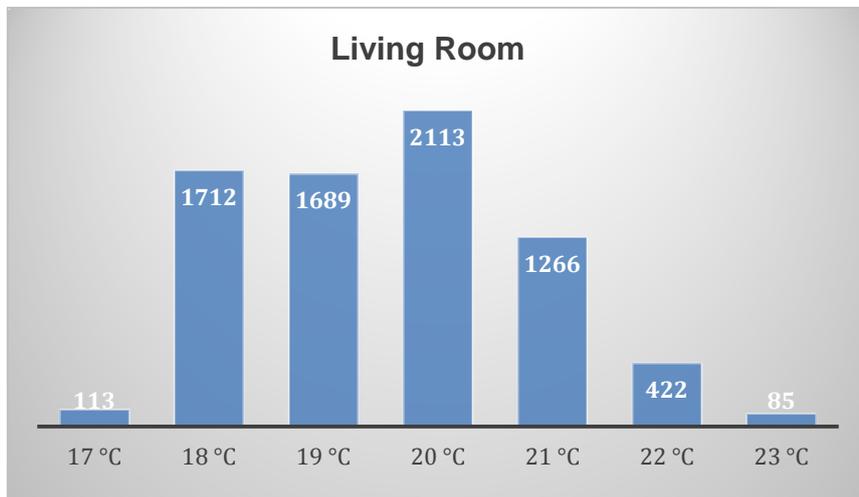


Figure 80 Temperature distribution in the living room

The home's sensory aesthetic intersects with radiator use and TRV settings across the house. In all bathrooms TRVs are set to 4, while in all the bedrooms they are set to the maximum of 5. Hamid never adjusts the TRVs, because this would need repeating several times a day and it is a task that is just 'too time-consuming'. But the positioning of some of the radiators across the house is not ideal, either. In his study room, for instance, the radiator is located behind his desk unit underneath the window. Since he often works from home it was important to create an office environment with a large desk. To make use of natural light, the desk is positioned in front of the window covering the radiator. Thus, every time he wants to adjust the

TRV in the study, he needs to move the heavy desk and the shelving unit attached to the desk so he can climb underneath the desk to reach and turn the control.



Figure 81 Radiator behind the desk unit

Similarly, accessibility is a problem in the living room, where he would need to lift and move the sofa to reach the TRV every time he wanted to adjust it. This is “*Just too much hassle*” to put up with, he says.



Figure 82 Living room radiator

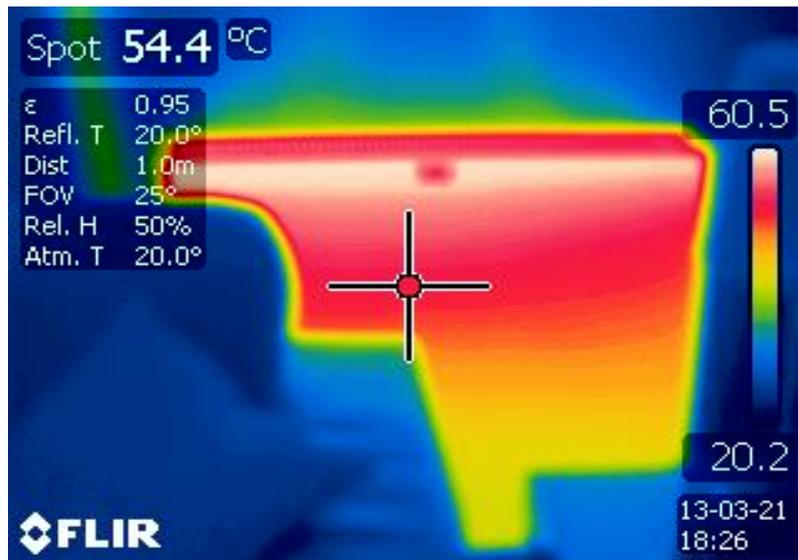


Figure 83 IR image of the living room radiator

What also intersects with the setting of TRVs is indoor air drying and the management of humidity levels. Hamid uses the guest room for drying laundry. He washes clothes twice a week and bedding every two weeks. He uses a triangle-shaped clothes horse to hang the laundry that he places close to the radiator in the guest bedroom. When he finishes hanging the clothes he closes the bedroom door, knowing he would only need to return the next morning to collect the dry clothes. By using the bedroom for drying, and by closing the door, he prevents rising humidity and mould growth developing across the house.



Figure 84 Drying clothes in the second bedroom



Figure 85 Radiator in the master bedroom

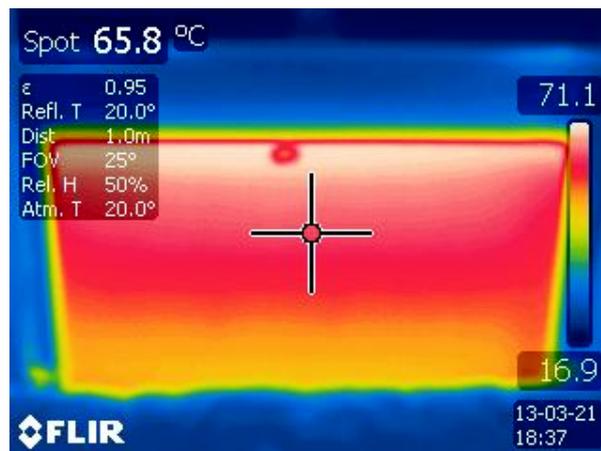


Figure 86 IR image of master bedroom radiator

What we can see from Hamid's household is that TRV settings are not independent practices, because they intersect with the creation and maintenance of the home's sensory aesthetics. Controlling the TRVs cannot develop into a routine daily interaction, because the technology emerges against the sensory aesthetic of the home. Improvisation in this household becomes synonymous with the full lack of radiator and air temperature control. And the full lack of control is tied closely to creating the right texture of warmth. However, the 'right' texture becomes a complex interplay between the body's sensory experiences of surface temperatures (e.g.

floor), consistency of indoor temperature across the rooms, freedom of movement and feeling of security.

7.1.2 Building Fabric and Heating System Shortcomings

Anna is a 37-year-old professional who lives alone. She has been planning to sell her house for over a year now because she wants to move to London. She works in administration and has been trying to change jobs. She opens the door to her 1890s three bedroom mid-terraced house and invites me into the front room. The room is used as a living room. There is a large brown leather sofa and a smaller cream-coloured sofa placed around the fireplace. There are also two smaller light-blue chairs with piles of dried clothes on them. The room feels a little intense. Anna apologises for the messy front room. She has been too busy over the past weeks to clean up. She uses the front room for storage and laundry, unless she has guests over.



Figure 87 Google Street view of the block



Figure 88 Drying clothes in the front room



Figure 89 Drying clothes on the radiator in the front room

She moves the white clothes drier away from the radiator, thereby freeing up some space so we can go through the dining area. The room feels warm but a little dark, because there is only a small window with blue curtains that are almost fully closed. The reason Anna keeps the curtains closed is because the window overlooking the back garden is draughty. If she sits at the dining table with the curtains open she can

feel the cold air reaching her back. Also, because the curtains are shut she tends to use the standing lamp during the day to light up the dining table. Otherwise it is too dark to work. She knows she uses more electricity this way, but the priority in the winter months is keeping warm.

Anna invites me into the kitchen and offers me a cup of tea. I can sense a significant temperature difference between the kitchen and the dining area, because the kitchen is much cooler and the floor has black tiles, unlike the dining area, which has dark-brown carpet floors. She puts the kettle on, turns around and shows me that there are no radiators in the kitchen. Although the window here is double-glazed, the walls lack insulation, so it can get very cold in the mornings. But despite the cold, she is active in the kitchen. She points to the corner where she keeps the collection of her cookbooks. She likes oriental food and she bakes much more in the winter months. The oven tends to heat up the kitchen, so she uses it almost every day in the colder months. Anna's sister visits once or twice a month from London, and they either slow cook meat or bake, which keeps them and the kitchen warm.



Figure 90 Anna's cook books



Figure 91 The kitchen

Anna gives me my hot tea and guides me back to the dining area. It is the hub in the winter months, because it is the warmest room in the house. There is a larger radiator in the room, but the drying clothes are covering it. The radiators upstairs do not work well, so all available radiators are in use. Work clothes dry downstairs on or around the radiators, so they do not get that ‘damp’ smell. The “less important bits” dry all over the house. They can go on the back of the chairs, hang on coat hangers, curtain rails or on the doorframe.



Figure 92 The middle/dining room

Some of Anna's activities in the house change from summer to winter and are organised based on her sensory experiences of the indoor climate. There is a piano in the middle room that she plays every evening. She tends to have it in the front room in the summer, but she moves it back into the middle room in the winter because it is warmer to sit for longer while she practises.



Figure 93 Piano in the living room

There is gas central heating in the house. There are no room thermostats, though, and the heating is switched on and off directly from the combi-boiler, which is in a cupboard in the upstairs bathroom. I walk upstairs with Anna, who opens the cupboard and points to the right side explaining that the timer is broken at the moment. She switches off the boiler to explain the function of each button. When she tries to switch it back on again we cannot see the boiler's green light coming on. She turns around, smiles and says it does this all the time. She then nudges the boiler from the side twice. The light comes on at the third time of asking. Suddenly we can hear a loud bang as if a pump has started working. Anna laughs out loud and says that it is the system making a sharp noise, because her house is like being in "The Dark Ages." Nonetheless, at least the banging noise means that the heating is up and running.



Figure 94 Anna is switching on the boiler

Despite the inconvenience, Anna likes living here. The location is very convenient because the house is near to the centre of the town and it is a short walking distance to the train station. We enter Anna's bedroom and I can see water droplets on the window. The window is old, single-glazed and it lets the cold draught through. But Anna is still 'OK' with the house. She has friends in Sheffield whose house never gets warm, even if they have the heating on full power. In this house, it takes a bit of effort to get the heating system up and running, but once it works she can manage to keep the dining area comfortably warm. To achieve this, Anna also appropriates warm air flows. She keeps all the doors open between the upstairs hallway and the dining room. This way the warm air can circulate downstairs all the way through the staircase. The radiators upstairs and downstairs are fitted with TRVs, but the reason why Anna does not fiddle with them is quite particular to the house's heating system condition:

"If I had a better heating system I would be quite happy to mess with the TRVs. You know, I could play with them but it's not going to make much of a difference on how hot the radiators get. It's not a very good heating system. The bathroom upstairs gets hotter, but the main aim during the winter is to try and get more heat down here. Before a person came around and fiddled with them. After they did that it was warmer and it did make a difference. So I haven't fiddled with them since, because I don't want to make it worse. So it is less about, yeah... not feeling able to or not wanting to fiddle with the radiators. It is more about... you know... about trying to get the optimal arrangement out of a fairly rubbish heating system."

Irregularity of TRV control in Anna's home intersects with the shortcomings of the heating system, the cold radiators and the sensory experiences of drastic differences in air temperature between the kitchen, the dining area and the upstairs bedroom. By hearing the banging noise of the boiler, and by touching the fairly cold radiators, I could understand how irregularity unfolds from the ongoing problem-solving that is a daily part of how Anna creates the sensory aesthetics of her home. Irregularity of TRV use therefore has multiple origins: missing insulation in the walls, the sensory experience of leaky windows, uneven room temperature, missing and dysfunctional radiators or single-glazed windows.

7.1.3 Other Domestic Practices

I visit Nick on a sunny but frosty March Friday morning in a peaceful little East Midlands market town. The house is located minutes away from the main road on the corner of two intersecting residential streets. The house is fairly new, being built in 2001. It has central heating with hot water storage, loft insulation and there are 4 kW PV panels on the south-facing roof. The property is detached and has five bedrooms and four bathrooms. Nick, who works in the energy sector, is in his early 50s. He lives with his wife and four children. He has two sons and two daughters. His wife is an accountant, who often works from home. The sons are away, living in university halls. They only come back home for the holidays. The daughters live at home because they are still at school.

Nick and the family's little cocker spaniel greet me at the door upon entering the hall. I am invited into the kitchen from where we go through to the utility room and straight to the garage. The boiler is here with the hot water control. The pipes run from the back of the garage on the ceiling all the way inside the house, which is a lot of wasted heat, Nick points out. There is a controller in the kitchen that is responsible for the hot water and the heating at the same time. But there is no separate control for the water temperature, which he says is unfortunate. They tend to have really hot water in the winter.



Figure 95 Controller in the kitchen

We return to the kitchen and Nick apologises for the messy counter. The leftover breakfast is still there, the girls have just left for school and he has not had the time to clean up just yet. The kitchen and the dining room are located in an L-shaped open space and have tile-effect beige flooring. The dining area overlooks the rear garden, which fills the space with plenty of natural light. This is the hub of the house. Besides the table occasionally turning into a working space for the day, this is where the family comes together at the end of the day to dine and discuss matters. Also, this is where the girls study and where Nick and his wife bookkeep bills and do financial calculations for the household. Sometimes it functions more as a living room than the actual living room, he says. The interesting thing about the kitchen, he says, is that when the heating comes on, the front area gets hot really quickly and the sitting area takes ages to warm up. It must be something with the pipework: “It is very slow to warm up this room.”



Figure 96 Dining room



Figure 97 Sitting area

The house was built based to 1999 building standards when TRVs were not part of building regulations. In October 2012, they had extra TRVs added to the radiators so they could keep temperature zones in the house. Nick complains that there has been a mix up with fitting the TRVs. Some radiators they do not tend to use, such as the one in the hallway but it had been fitted with a TRV. Other radiators, such as the one in the kitchen, he thinks would have been essential to be fitted:

“Most rooms have TRVs, but the kitchen radiator has never been fitted with a TRV, although that would need it the most, as it is south facing. We were supposed to do the kitchen but I was not here and my wife got mixed up with which ones to do. This is what needs it the most actually, because it faces south, and here is the cooker so it can get very warm. If the radiator stays on through to, let’s say, 4 o’clock it gets very warm because of the sunshine.”

He admits it can be confusing that the house has different sets of TRVs. The master bedroom upstairs, for instance, has a different scale than others across the house. It is set on a low setting in the bedrooms during the day, but in the en-suite bathroom the TRVs had not been fitted. Because the two sons are away at university, their rooms are empty most of the time. They only come back for spring and summer holidays. The two older sons have two separate bedrooms, both equipped with desks. The two girls share a bedroom with two double beds and two desks. Nick and

his wife do not have a separate study; therefore they often rotate between the sons' bedrooms when they work from home. They usually occupy the eldest son's bedroom, as it has an electric heater plugged in close to the desk.



Figure 98 Electric heater in the bedroom

If they both stay home they occupy two different bedrooms during the day. His wife stays in the room with the electric heater and he goes to the other bedroom to work. The rotation between the bedrooms and the unplanned days of who stays home and when often makes the TRV settings unpredictable:

“We have five bedrooms but we are only using three at the moment. We are only sleeping in three, the others are used every now and then for work. So we tend to use the heating quite erratically in those. We turn it on for an hour or use electric heating or something. The TRVs have different settings and symbols; they are not all the same. We use medium settings, usually about 3-4.”

We enter the girls' room. The radiator is placed directly behind the single bed underneath the window, and the TRV is hidden in between the desk and the bed. Nick moves close to the bedframe. He bends down, pushes the curtain to the side and stretches his hand out as far as he can to hold on to the TRV control. He sighs, and by trying to grab on to the head of the TRV his movement betrays a little frustration. He cannot fully grab the head of the TRV, so he pushes it a little bit with his fingers. It is not the most convenient arrangement, but the rooms are small and

the furniture could not have been fitted any differently. We walk over to the younger son's bedroom, where he settled this morning to work for the day. The arrangement is similar to the girls' bedroom. The radiator and TRV are hidden behind the bed and an oak wooden desk. The TRV is located in the far corner. He goes on his knees and climbs underneath the desk. He cannot see the scale exactly, but he knows the setting 'roughly'. Whenever he turns the valve down or up he can feel the resistance, so he knows where 0 and 5 are. To get a setting of 3-4 he turns it up to 5 and turns it back down a little bit. To be able to see the scale, he would need to move the chair, the desk and the bed every time he wanted to fiddle with the TRV.



Figure 99 Nick adjusting the TRV in the bedroom



Figure 100 Nick showing where the TRV is

The irregularity of TRV use in Nick's home unfolds from a variety of sources. On the one hand, it comes into existence because TRV control and radiator use are inseparable from other domestic activities such as occupancy, making use of rooms and spaces, work schedules or dining. On the other hand, the performance of control is connected to a set of material objects such as radiators, beds, desks, sofas, electric heaters or the fireplace. The material layout of the rooms also contributes to

the development of irregularity, because radiators tend to be positioned behind desks, beds and sofas, which in turn hampers free movement.

7.1.4 Problematic Design Features

Anthony lives his own in Leicester in an 1880s mid-terraced two-bedroom house. I visit him on a chilly but sunny day early in March 2013. I step into the front garden, where there is a little path made of grey stepping stones that leads to the main door. The front of the building has the originally built red brick wall. Anthony opens the door, greets me in a friendly manner and we squeeze into the little reception room where he stores his city bike. The hall and the first floor stairs are long and narrow, covered with old dark-brown carpets that are ripped off in some of the corners. He asks me to keep my shoes on, because of the white ceramic tile flooring in the kitchen. A slightly fruity and sweet smell fills the air at the top of the stairs. Upon entering the kitchen, he shows me his rhubarb jam in the making. It is his signature dish based on a recipe that has been passed down through many generations of his family. He has also just finished preparing fish pies, which stand in ceramic dishes and are ready to go into the oven. The kitchen is white and very bright, and the large double-glazed window overlooks the outcrop of a long line of terraced houses.

Anthony completed a PhD degree at the local university and he now works for a utility company. He used to rent out one of the bedrooms, but now he enjoys the privacy because he often works from home. Last year the boiler was moved up from the lobby to the bathroom, and an extra double-panel radiator was added to the living room. All radiators had been fitted with TRVs. He had the house modernised just before he moved in. He changed the interior and had some of the walls knocked down. What is a spacious living room now used to be a hallway that was very dark and dingy. The hallway had access to a smaller room that used to be the living room. Now it is a much bigger area that accommodates a fridge, two sofas and plenty of storage space. He unfortunately had to place the fridge right next to the door in the living room, because the kitchen did not have enough space. There is a radiator that is directly next to the fridge, but he cannot control it. The TRV is out of reach because a larger drawer and a set of boxes block the access. There is another

radiator in the living room he cannot control. There is an extra single-panel radiator that was added to the living room. That radiator has a different TRV than the rest of the radiators and it is behind the sofa. There was not more space in the living room to put the radiator. He wanted a smaller radiator, but based on the standard calculations made by the plumber a large size needed to be fitted, albeit he cannot control it.

The old boiler was wall-mounted, he explains, but it needed repositioning. The replacement boiler took up less space. He is slightly shaking his head, sighs and tells me he finds it difficult to understand why no one mentioned the additional costs when he was quoted on replacing the boiler. Some of the costs he thinks are inevitable. For instance, people are “Bound to put in TRVs”. But it is often the case that boilers need to be replaced or repositioned. Anthony tells me that he comes from the northeast of England, from a big coalmining area where back boilers are very common. People have fireplaces where they put coal on the fire, but there is a boiler arrangement behind the fire that heats the hot water for the radiators. People in the past replaced these boilers directly with gas back boilers. This is what his brother has now. But it is inevitable for him to replace this boiler over the next few years. He is probably going to have to put the boiler somewhere else and all the pipework will have to change. A direct boiler replacement is often cheaper, but repositioning means improving the rest of the system, which significantly increases the cost.



Figure 101 Boiler

We walk up another floor from the living room, and we arrive in a little hallway that leads to the spare bedroom. The bedroom has red walls, a single bed and an under-window radiator that is hidden behind a large wooden desk. Anthony has a little sticker note attached to his bedroom door saying ‘remember to switch off’. He is forgetful sometimes and needs to be reminded to turn off the heating upon leaving the house.



Figure 102 “Have you turned everything off?” – sticker on the door

The external walls should be insulated, but they are cold to touch. However, because they only take up a little wall frontage Anthony is not sure if it is worth the time and effort. The top floor accommodates Anthony's bedroom, which also functions as the main study area. There are old, dark-brown wooden beams across the room and plenty of storage units under the triangle-shaped sloped ceilings. The north-facing roof has not been insulated either, whereas the front facing roof was re-roofed a few years ago. It makes a lot of difference, as it no longer gets that hot in the bedroom in the summer. But the insulation unfortunately benefitted him more in the summer than in the winter. When he bought the property there were no radiators in the room, and he used to live downstairs until the heating system was replaced. Now Anthony uses one part of the master bedroom as a study. There is a large double-panel radiator right behind the desk, but he cannot see the settings on the TRV, which is in between the desk and a smaller table where he keeps a printer. It is complicated trying to move close to adjust the settings. He moves the smaller table out of the way by pulling it a little bit further out. He then arches his back, leaning forward with his arms outstretched for support. His left leg supports most of his weight, and this becomes intense after just a few seconds. He leans back, breathing more heavily. Because he cannot fully see the settings, he sometimes relies on his hearing to adjust them, but this can be "A bit awkward" sometimes:

"First of all I find I have to have my glasses on. And there is a click point. The recommended temperature has a click point on it. And to pass the click point I think is setting 4. I think you have to press that little button in. I've got it set to the click point because, to be honest, a lot of the time I use the... I carry around the wireless room stat to control the heating. My problem is when I want to turn off the radiator... like the one in the front room downstairs, because I am using it to do my work when I am working at home. I need to turn it off from the frost setting or back to the frost setting. And it took me a while... it's really difficult to see, because of the scales on the side, and you tend to be looking down on a thermostatic radiator valve, which means it's hard to see the scale. And I have all this furniture in the way. And you need your glasses on. And I'm not very good with anything closer than about a metre or a metre and a half... I can't read very well then. If I'm at work I have my glasses in

the front pocket of my shirt. At home I have got pairs of reading glasses scattered around, but they are never within reach when I want to fiddle with the radiator.”



Figure 103 Anthony reaching for the TRV



Figure 104 Anthony adjusting the TRV

The irregularity of TRV control in Anthony’s home has developed from multiple sources. Irregularity intersects with the positioning of the radiators behind the desk, sofa and storage units, the lack of insulation in the pitched roof, the mixed set of TRVs in the living room, the limited visibility of the scales, moving of the furniture, the clicking sounds of the recommended click point or the difficulty in physical movement that goes into turning the TRVs up or down. But by being in the house with Anthony I could attend to the various sensory, physical and emotional elements he integrates into performing the movement of TRV control. And being present with the occupants indicates that being engaged in the development of irregularity, and irregularity itself can be a source of learning.

Understanding the development of irregularity in TRV control in these homes brings the senses to the fore. Multisensory engagement in these lived environments not only provided a form of empathetic engagement, but it also placed my body and my sensory experiences right in the centre of intersections. By following the morning, after-work, evening and bedtime routines of the occupants, I was able to understand how home heating becomes part of daily domestic life. I could see how domestic activities (baking, dining, having guests over, drying laundry indoors, playing the piano) and material objects (electric heater, fireplace, desk, sofa) connect to home heating activities. I participated in some of the movements that helped me understand the physical work (e.g. moving furniture to access controls) that creates the gap between the intended and the actual use of TRVs. By witnessing and being part of the actual movement and performance of control practices I was able to learn more about the emotional elements that the movement expresses. I sensed the frustration that went into moving furniture, laughing and sarcasm that was part of nudging the boiler from the side and the tiring effect of leaning forward and overstretching to twist the head of the TRV control. By sensing the indoor air temperature I was able to make connections between uncertainty, insecurity, the lack of TRV control, the sensory experience of walking around barefooted and the sensory aesthetics of the home. By being present in these environments I was able to walk with the participants and connect to their route of sensory learning. I also understood the 'history' of some of the practices and the sensory background to why and from where irregularity develops. Additionally I got to know the particularities of various houses by sensing intense temperature differences across various spaces or by witnessing the dysfunctionality of radiators and boilers. I could connect the environmental elements and building fabric shortcomings (missing insulation, single-glazed windows, condensation on windows, missing radiators) to sensory experiences. Also, being immersed in the same physical environment made me sense where in the house the body loses and gains heat. Engaging in how convective or radiant heat feels in a given space gave me clues to understand why occupants move across the house in the way they do.

Being exposed to the same physical environment and multisensory inputs connected me to the constantly shifting place events. I was situated in the ongoing nature of problem solving at hand, and I experienced the skills that are acquired and used to

deal with shortcomings. Multisensory emplaced learning therefore enabled me to absorb the environment in these homes by connecting me to the creation, maintenance and re-creation of the homes' sensory aesthetics. What we have learnt from these lived environments is that irregularity in TRV control in its complexity cannot be understood without multisensory learning. Irregularity – and improvisatory practices that bring irregularity into existence – in this regard cannot be addressed by a single factor. Unanticipated uses of TRVs are joint outcomes. Therefore, improvisation and irregularity are always an intersection of physical, sensory, material and domestic environments. As I demonstrated earlier, the development of practices cannot be scripted, because the performed improvisatory practices emerge from complex, interwoven environments, and this might make the development of TRV control unforeseeable. Whereas this section discussed what can be learned from being emplaced at the intersection of irregularity, the next section shows that irregularity in itself is a communicative medium.

7.2 Learning from Intersections

Environments or systems undergo continuous change, modification and renewal, all of which makes it problematic to predict how occupants develop alternative uses of a given technology. Improvisatory use of TRVs is made up of relationality, namely the relationality of other technologies, services and systems where one element in one environment can change the usability and functionality of TRVs and radiators. This has vital implications for the relationship of sustainability, design and the intersecting systems and environments of which technologies are inherently part. Environments or systems that technologies are part of should be understood through 'real-time' interrelations. If technologies are connected to lived environments that are simultaneously social and technical, the intersection of sensory, physical, material and domestic systems or environments technologies connect to can be better understood.

7.2.1 Irregularity as a Dynamic Feedback Mechanism

Multisensory engagement made me immerse in, experience and, by association, understand how individual and environmental elements connect together 'live' in the performance of TRV control in the 'place events' of homes. We have learnt from these home environments that irregularly controlling the TRVs is always a unique configuration of physical, material, domestic and sensory elements that are particular to home environments. Occupants all have a unique relationship with the movements they make, and although the configuration and the binding processes of elements are unique, irregularity and occupants' improvisation in the way they control TRVs exhibit four common and distinguishable features. And these features become a communicative medium and a dynamic feedback mechanism that expresses disharmony between TRVs and users' everyday lives.

Firstly, irregularity in the performance of TRV control is always interwoven with and co-creative of the home's sensory aesthetics. Creating the 'right' texture for the home cannot be separated from TRV control and radiator use, which might support the creation of 'right' indoor climates or might emerge against the background of the homes' sensory aesthetics. The home's sensory aesthetic is therefore a contingent and ever-shifting constellation of configurations. Performing TRV control irregularly is always tied to occupants' sensory experiences. And sensory experiences of environmental elements (e.g. relative humidity, indoor air temperature) are inseparable from physical processes, such as the body's ongoing heat exchange with the thermal environment. Being in the process of movement comes with occasional heat gains from activities (e.g. being on the move whilst cooking) and appliances (e.g. oven) and heat losses to the surrounding environment (e.g. colder wall surfaces). Moreover, movements involving reaching and adjusting TRV controls cannot be differentiated from the emotional elements (e.g. sarcasm, frustration) that go into the actual performance.

The second characteristic of occupants' irregular TRV control is that it is highly integrative of the surrounding physical environment. Thermal images captured various building fabric shortcomings (lack of insulation in cavity walls, draughty windows, air leakage paths) and service or heating system shortcomings (limited

heat output of radiators, mixed set of TRVs, positioning of the radiators). Developing radiator use and TRV control in all households are inseparable from the building's fabric condition and heating system efficiency. Building fabric and heating system shortcomings are inseparable from indoor climate conditions and occupants' sensory experiences thereof. Responses to draughty windows or un-insulated surfaces are all embodied responses to the surrounding physical environment. And because of the embodied character, they reveal the particularities of a given building. The interplay of sensory experiences (standing bare feet on warm tiles, draught reaching one's shoulder) and physical elements such as condensation or heat loss through the buildings' fabric can all actively come into play in how occupants develop TRV control in relation to the building in which they live. Thirdly, irregularity in TRV control is always clustered with other domestic activities. In all the households, TRV control was inseparable from its wider domestic environment. Occupants perform or do not perform TRV control because of how it relates to other domestic activities. Performing practices in movement (e.g. cooking) brings occasional heat gains that might prevent occupants to turn up their TRVs, but other domestic activities, such as dining, using indoor spaces, working from home, playing the piano, indoor air drying, having guests over or morning routines might be performed in a way that prevents the regular use of TRVs.

Fourthly, the design of TRVs and radiators can create irregular performances in relation to TRV control. The interface design of TRVs generally does not take into account the visibility of scales. The positioning of radiators is inseparable from occupants' use and general usability of TRVs. Radiators are often covered up by curtains or become blocked by furniture such as desks, sofas, beds or drawers. This may not influence the heat output of radiators significantly, but it certainly makes it more difficult to access the controls. Findings across households also revealed that occupants might have limited visibility that might cause problems in finding the right settings. Furthermore, the condition of radiators largely influences the use of TRVs. Radiators across the households often heat up slowly, unevenly or sometimes they stay cold because they do not work at all. This makes irregular TRV use a sign that there is disharmony and a misfit between a given technology and users' everyday lives. However, the gap is a source of sustainable change, because irregularity in itself suggests that there is ongoing modification and change, where alternative uses

are in the process of emerging. The actual alternatives might not be possible to foresee, but the process itself suggests that lines of intersections are about to generate something novel, and occupants are actively renewing existing elements.

7.2.3 Connecting Improvisatory Home Heating to Co-Design

In this chapter, so far, I have shown that occupants' irregular control of TRVs arises from the intersections of sensory, material, physical and domestic environments. I have argued that irregularity communicates disharmony between TRVs and technologies and users' everyday lives. Thinking of irregularity as making, movement, renewal and creative engagement implies that it is a valuable feedback mechanism, because it brings to the fore a conflict and a certain degree of misfit between TRVs and occupants' everyday life. I have also argued that because irregularity and improvisatory uses of TRVs and radiators communicate disharmony, they are a productive source of sustainable change. To build this argument further, I continue by asking what improvisatory use of TRVs and radiators as a processual reality could mean for co-design and low-carbon technological change in domestic environments. I follow Gatt and Ingold (2013), who suggest that design is more about improvisation than innovation, because "the creativity of design is found not in the novelty of prefigured solutions to perceived environmental problems but in the capacity of inhabitants to respond with precision to the ever-changing circumstances of their lives."

In Chapter 6 I argued that improvisatory uses of home heating controls are not sources of resistance but forms of mundane creativity and processes of 'modification' and the renewal of elements in the actual movement and performance of control. Following Ingold and Hallam (2007), I have therefore pointed out that improvisatory home heating is essential to how indoor climates are maintained on a day-to-day basis, since interacting with technologies unfolds within constantly transforming conditions, which in turn make home heating an ongoing, open-ended process where home heating technologies are not stand-alone 'objects'; rather, they are part of making indoor climates. Thus, control technologies can either merge or clash with the formation of the home's sensory aesthetics. Therefore, uses of TRVs and

radiators are inseparable from the home's sensory, material, domestic and physical environments. The processual and corresponding character of occupants' home heating activities suggests that improvisation and irregular uses of TRVs are emergent and that the development of home heating activities is not scriptable. And this makes low-carbon technological change highly uncertain.

However, improvisation in home heating has a dual character, because it simultaneously proposes uncertainty and potential for change. Improvisation, as Pink and Leder Mackley (2014) posit, is embedded in everyday habitual movement, and so such moments/movements are potential sites for generating co-design processes. One way that improvisation could be a useful site for co-design is by reconceptualising improvisation as a processual reality and ongoing 'correspondence'. Williams and Irani (2010) suggest that improvisation is inevitable in design research, as it brings uncertainty to the fore and it helps researchers and practitioners think more flexibly about design methods. They argue that a shift is necessary when design research becomes a form of engagement that allows researchers to follow the people and the technologies as they are "taken up and made meaningful on the move". Co-designing, according to Prendiville and Akama (2013), requires the designer to step in to the 'in-between' space that is "dynamic, emergent and relational," and because improvisatory use and 'correspondence' happen in this in-between space it is particularly useful to connect to it. I have identified irregular uses of TRVs in various home environments as configurations that arise from in-between spaces or intersections of sensory, domestic, physical and material environments. Emplaced multisensory learning about and immersion in the same home environment provide a way to step in to these in-between spaces. By being exposed to the same physical environment and multisensory inputs I could connect to the home environments' continuous present and constantly shifting place-events.

Participating in the movement of control, gaining sensory experience of materials and of heat output of radiators, engaging in movements of heat gain, coming in contact with cold surfaces, where my own body was exposed to heat loss, or witnessing how movements of control can be emotionally charged placed me right at the centre of emergent irregularity. I could attend to the tacit and often unspoken elements of home heating activities that fuel the growth of alternatives. I was able to

step into the ongoing character of correspondence. And I could be part of the continuity of emergence. Therefore, participating in irregularity and improvisatory uses of home heating controls provides a dialogue between occupants' correspondence and the designer's perception of their home environments in becoming. Halse (2013) suggests that ethnography does not speculate on what happens next, and it can rarely project the future, but the "very point of design is a process of bringing into being that does not yet exist." In addition, the continuous present brings together change, creativity and future making. Thus, by engaging in irregularity through the ongoing processual reality of home environments, it is possible to connect to how everyday life might play out differently and how alternative uses of home heating controls grow out of the sensory, material, physical and domestic environments. Emerging practice alternatives in this sense are productive, because they are future-oriented, and they articulate and link possibilities of future material forms that otherwise would not have come into existence.

7.2.4 The Continuity of Heat Transfer

Home heating, as I have shown in earlier chapters, is a series of processes and elements coming together. It is inseparable from building fabric condition, the condition of radiators and occupants' sensory experiences of indoor climates. Occupants' performance in relation to home heating control in the actual moment of movement is a co-constructive process, an ongoing and dynamically unfolding interplay between the body's sensory, physical, domestic and material environments. I have demonstrated in Chapter 5 that there is a continuous heat exchange between the body and its surrounding environment that is core to how people perceive and respond to indoor climates. Heat is constantly moving. The human body's balancing of heat loss and heat production provides a continuous exchange between the body and its surrounding environment. Moreover, the various modes of heat transfer have demonstrated that sensory experiences of heat gain differ with convection and radiant heat. Also, in Chapter 6, I have shown that conduction and coming in direct contact with radiators through touch play a significant role in how people learn about their heating system and indoor climate conditions. Therefore, occupants do not

merely switch their heating systems on and off – they actively and tacitly form an understanding of the material properties of radiators and gain sensory experience of heat flows. They know the extent to which radiators heat up, because they practically experience the properties of materials. Therefore, they know indoor climates through immediacy taken from their own sensory engagement. Scheldeman (2012: 59) defines a surface as a place where “two things meet, where differences are felt and negotiated” and where improvisation happens. He defines ‘friction’ as being key to how we come into contact with surfaces, because “by meeting something outside ourselves we are invited to interact, and in doing so, we are knowingly immersed.” By experiencing the flow of materials, and using our skills, we let this friction work with us, because it is in response to this friction that we discover, develop skills and improvise. Thus, we do not use radiators and consume energy directly in the form of gas. We create indoor climate conditions that keep our bodies in heat balance and we incorporate radiators and TRVs in activities that are involved in the process. So, in terms of design, perhaps an important question to think about is how the design of radiators and TRVs makes heating activities (e.g. sensing the heat output of radiators, learning about indoor climates, turning radiators on and off) unfold while occupants create indoor climates.

Occupants are disconnected from the physical contexts of how energy consumption happens, since the flow of heat is largely invisible and indoor climates are only perceived by the senses. The design of radiators and TRVs in its present form is highly ‘object-focused’, which, as Anusias and Ingold (2013) point out, refers to imposing blueprints and ready-made designs, where the “form reduces our ability to perceive our material involvement with the world around us.” The design of radiators does not acknowledge ties between perception, material form and environmental sustainability. And it does not take into account that people are inextricably linked to their surroundings through energetic and material circulations. Performing practice alternatives, and the gap between intended and actual use of radiators and TRVs, is integrative of the physical environment (e.g. condition of the building fabric and the heat output of radiators). Therefore, material flows represent a form-generating process, since they play an active role in how home heating activities come into existence. As Anusias and Ingold (2013) put it:

“Flows of materials are, which are of critical environmental significance, are infrastitally hidden and accorded low perceptual value. The implication is that local activities should occur within bounded envelopes, largely in ignorance of the physical continuities that surround and sustain everyday life.”

TRVs and radiators are not just passive bystanders in our homes that are used to deliver heat. Radiators are subject to physical processes because they are ‘places’ the human body comes into contact with and gains heat. Moreover, sensory experiences of radiators are not unified, since the material properties of these technologies differ. Whereas heat from a panel radiator transfers heat from one surface to another, radiant heat warms people and objects rather than the air directly. Thus, taking into account the continuous heat exchange between the body and its surrounding environment implies that designers of home heating technologies should think of conceiving environments for life as correspondence (Gatt and Ingold: 2014). And correspondence involves exchange, relationships, tension, responses to environmental stimuli and ways of knowing and doing. Moreover, the design of radiators should attend to intersections where material flows, processes, new relations and configurations come together and where occupants accommodate changes. In this sense, ‘making’ becomes a form of using and designing and a process of carrying on, whereby innovation does not impose closure, because it is never actually finished; rather, we should think of artefacts and technologies as always being on their way to something else.

Conclusion

In this chapter I have introduced four households and demonstrated that to improvise is to bring into existence practices from sensory, material, physical and domestic intersections. I have identified four characteristics of improvisation in TRV control and radiator use. Occupant improvisation can be co-creative of the home’s sensory aesthetics, integrative of the building’s fabric condition and heating system shortcomings, cluster other domestic practices and become a communicative medium of problematic design features. Since alternative and irregular uses of radiators and TRVs emerge from complex intersections, it is unlikely that their

development is scriptable. Yet, improvising and using these technologies irregularly can be highly productive of sustainable change. I have argued that intersections in lived environments are particularly important sites for learning. On the one hand, multi-sensory emplaced learning can provide a form of empathetic and sensory engagement by placing the body in the centre of intersections. Being in the centre of intersections and in the same physical environment provides a connection to the constantly shifting place-event of an environment. On the other hand, irregular use of radiators and TRVs signals that there is an ongoing process of modification, renewal and change. And the ongoing process of modification can bring to the fore interrelationships and new configurations. I have connected the moment of improvisation in home heating to co-design, arguing that these moments provide the potential for occupants to be co-producers of radiators and TRVs by diversifying how indoor climates are created. In their current design forms radiators and TRVs do not put us in touch with our environment. They treat home heating as a series of stable practices and interactions with control points. However, I have shown that home heating is inseparable from home environments. And home environments are events and happenings where material flows play a crucial role in how we navigate in our homes and create our indoor climates. Therefore, rather than blueprinting radiators and TRVs it might be more productive to think of these technologies in the wider context of how we shape the relationship with the homes we inhabit and how we make indoor climates possible in the process.

8. Conclusion: Taking Advantage of the Gap

Understanding low-carbon technological change and variation in households' energy use has been a shared concern of environmental policies, low carbon industry and disciplinary approaches to sustainable change. There is often a gap between the calculated and actual energy consumption of new and retrofitted homes, and collaborative methodologies are needed which engage the social sciences in understanding how interrelationships between inhabitants and buildings influence energy consumption. In this thesis I have engaged practice-place relationships to better understand how variations evolve in households' energy consumption for space heating. I have focused on radiators and TRVs because these technologies are mundane and rather taken for granted in how people use energy in the home. I have showed that the uses people develop, go beyond a simple matter of choices they make. Engaging with radiators and TRVs is inseparable from both the activities and environments of everyday life because they emerge from complex physical, sensory, material and domestic intersections of the home. I have examined the practice-place relationship of eight households through the notions of 'place-event' (Massey: 2005), 'sensory home' (Pink: 2004) and 'meshwork' (Ingold: 2011). These notions, I have argued, offer a particularly useful way to see how people engage with technologies in their home environment in creative and improvisatory ways. By taking an interdisciplinary turn, I have brought together an integrative framework that jointly attends to the social and technical elements of improvisatory and irregular radiator and TRV use. My argument has been that improvisatory uses of technologies are productive sources of sustainable change. In this conclusion, I first present the taxonomy table of irregularities. I then draw together the arguments and findings of earlier chapters to show the value of a logic of intervention into sustainable change that takes advantage of the gap, is system-focused and informs the way we understand sustainable futures in a more collaborative and interdisciplinary manner.

8.1 A Taxonomy of Irregularities

To understand households' energy consumption on the level of everyday life, I have started to focus on the interrelationships of practices and places. Building energy consumption for space heating is always a joint outcome of various contributing elements, namely local climate, building fabric condition, heating system efficiency, occupants' sensory experiences and domestic activities. Thus, I have taken an interdisciplinary turn and, as a result, I have broken down some boundaries between building engineering and social science approaches to energy consumption. Combining social science and building engineering methodologies has been an emergent approach because there are not any set rules for knowledge integration across the disciplines. Rather, knowledge integration became a learning process of technical expertise and a process of trial and error to find set of configurations on how monitored data sets and video ethnographic findings could work together. Exploring how environmental policy, low-carbon design industry and disciplinary approaches conceptualise human action in relation to energy consumption has brought to the fore different problem framings and uneven application of disciplines.

My engagement with interdisciplinary research has been primarily problem-oriented. Problem-orientation, as I have characterised in Chapter 3, has brought about a qualitative shift, offering a unique opportunity for the social sciences to innovatively and collaboratively engage in energy research, share knowledge and combine methodologies with building engineering. As I have emphasised, this opportunity should not be taken to imply that problem-oriented interdisciplinary research would undermine disciplinary research or that the quality of discipline-based research is less important. But because households' energy use is a complex, joint outcome of many contributing social and technical elements, the problem of sustainable energy consumption cannot be firmly situated in any of the disciplines. Rather, it is the interrelationship between the social and technical elements that offer more effective synergetic benefits. Based on the findings from the 8 households, Table 8 summarises the elements that contribute to how occupants develop irregular uses of radiators and TRVs.

Table 9 Taxonomy table of irregularities

		H1	H2	H3	H4	H5	H6	H7	H8
CLUSTERED DOMESTIC PRACTICES	Indoor Air Drying	x	x	x	x	x	x	x	x
	Morning/evening routines (dining, cooking, waking up, playing the piano)	x	x	x	x	x	x	x	x
	Working from home	x		x	x	x	x	x	
	Use of curtains	x	x		x	x		x	x
	Use of supplementary heating			x	x	x	x	x	
SENSORY EXPERIENCES	TRV/Radiator intersects with the 'right' feel of the home (coziness/security)	x		x	x	x		x	x
	Radiant asymmetry of surfaces			x		x		x	
	Perception of dry air/ itchy skin/ eczema			x					x
	Walking around bare feet	x							x

BUILDING FABRIC SHORTCOMINGS	Mould/condensation			x		x	x	x	
	Single glazed window(s)		x	x		x			x
	Missing cavity wall/floor/roof insulation		x	x		x	x		
	Conservatory		x	x					
HEATING SYSTEM SHORTCOMINGS	Cold/slow to heat up radiators			x	x	x			x
	Mixed set of TRVs				x	x			
	Faulty/old boilers					x	x		x
TRV/RADIATOR DESIGN SHORTCOMINGS	Radiator location/hard to reach TRVs	x	x	x	x	x	x	x	x
	Occupant constraint (vision/mobility)				x	x			
	TRV quality (hard to turn/slippy surface)				x	x			
	Adjusting daily is time consuming	x	x		x	x			x

8.2 Characterising Engagement with Energy Used for Space Heating

The table brings together five areas that contribute to the development of irregular use of TRVs: clustered domestic practices, sensory experiences, building fabric, heating system and design shortcomings. In Chapters 5, 6 and 7, I have shown that uses of TRVs and radiators are inseparable from the wider domestic environment of the home. Indoor air-drying, morning and evening routines, work schedules and use of curtains or supplementary heating sources are all domestic tasks that are interwoven with how uses of TRVs and radiators develop. Moreover, home heating is also connected to material objects (e.g. clothes, bedding, hot water bottle) and the sensory aesthetics of the home (e.g. cozyness, security). Creating and maintaining the sensory aesthetics of the home suggests that occupants make their home environments feel right as they engage in domestic tasks and use home heating controls. On the one hand, we can see that home heating is not a unified practice. When it comes to changing practices into a more sustainable direction this is a key finding to further elaborate on. We know, that energy consumption for space heating goes beyond stable and direct interaction with control points, and that energy consumption is implicated in various process or things people do and experience. Therefore, to account for the complexities of how energy-consuming practices develop, we need to jointly understand the ‘social’ and ‘technical’ elements. In Chapter 5 I have shown that sensory experiences are inseparable from indoor climate conditions and the physical environment of the home. There is a continuous heat exchange between the body and its surrounding environment. The body’s heat balance can be affected by individual parameters such as level of physical exercise or metabolic rate. But it is also influenced by environmental parameters such as air temperature or radiant temperature of surfaces. People often need to respond to and innovate solutions for challenging conditions such as missing insulation, mould or draught. We have seen that responding to the surrounding built environment can prevent the formation of stable routines, demonstrating that heating practices can be ad-hoc and improvisatory in character. In Chapter 6 I have focused on the more individual elements of how the body engages in improvisation in the actual moment of movement. Using the concept of multisensoriality and sensory home, I have shown

that occupants' improvisation is a unique movement because it is integrative of the surrounding physical environment. I have also suggested that there is a set of individual and often invisible elements (hybrid cultural identity, childhood memory, health risk perception, knowledge of scientific facts) that may connect to practices through movement. Consequently, interrelations between occupant's everyday activities, experiences and environments as well as a building's physical characteristics (building fabric condition and heating system efficiency) are key determinants of variation in households' every use.

8.3 Implications for Low-Carbon Design

The taxonomy of irregularities has identified the areas of building fabric, heating system and design shortcomings that actively impact on how occupants develop irregular uses of radiators and TRVs. We can see from the table that in terms of building fabric, lack of cavity wall, floor or roof insulation, mould and condensation as well as single-glazed windows have been the most common shortcomings across the eight households. Regarding the heating systems, dysfunctional or slow to heat up radiators have been found in four out of eight households. Typically, the surface temperature of traditional radiators may vary between 55-70 °C, but surface temperatures in many of these households with a TRV setting of 5 have not exceeded 50 °C, suggesting that the condition of radiators may not always be optimal. Radiators were often found to heat up slowly, unevenly or sometimes they did not work at all. Furthermore, I have also showed in Chapters 5, 6 and 7 that radiators play a fundamental role in how indoor climates are maintained and how occupants experience thermal comfort and the sensory aesthetics of the home. The positioning of radiators occurs to be another general problem across households. Radiators are often covered up or become blocked by furniture such as desks, sofas, beds or drawers. This may not significantly impact the heat output of radiators but certainly makes it more difficult to access TRV controls.

In Chapter 1, I have pointed out that it is key to develop low carbon technologies that better meet the needs of users and that advanced home heating controls have an

important role in how households' manage their energy use. I have also shown that the problematic usability of home heating controls have been documented since the 1980s. The findings from eight homes imply that some of the documented common usability issues are still present because two of the households had difficulties with the control interface and almost all the households experienced inaccessibility of controls. Moreover, focusing on 'practice-place' relationships suggest that automation is not likely to make home environments 'smart' and 'efficient' in a linear manner. The findings suggest that in the majority of the households, occupants find the daily adjustments of TRVs time consuming. Automation is certainly an option with high potential but the use of home heating controls should not be evaluated without taking into account occupant's heating activities and sensory experiences in relation to a building's characteristics. In households where TRV use intersects with the sensory aesthetics of the home, or the condition of the radiators, automation may become a bystander in daily control.

8.4 Attending to Improvisation and Domestication

Theories of practice and place have opened up a more relational understanding of everyday life, energy use and technology domestication across a set of different buildings and configuration of things, home heating activities and environments. Interrelationships between building fabric and heating system shortcomings, occupants' sensory experiences, domestic environments and irregular uses of radiators and TRVs imply that home heating is woven into the fabric of everyday life. I have shown in Chapters 5, 6 and 7 that the domestication of TRVs and radiators can intersect with a set of environmental and individual elements and that occupants actively intervene in products and systems to achieve the 'right' feel of the home. The three chapters have shown how attention to the surrounding physical environment, material objects, senses and movement contribute to emerging variations and diversification in occupants' domestication of home heating technologies. On the one hand, we can see that irregular, ad-hoc and improvisatory uses of radiators and TRVs emerge from complex physical, sensory, material and

domestic intersections. On the other hand, the domestication process cannot be scripted and uses of home heating technologies cannot be predicted.

In Chapters 5, 6 and 7, I have demonstrated that improvisation is core to how everyday life unfolds around new technologies. The ability to improvise restores the agency of occupants because they can shift practices and create conditions for modification and change, and because they are able to shift practices, the process of modification and change is not only ordinary, but is an open-ended process. In addition, the open-ended character of technological change in domestic environments implies that home environments may change faster or in different directions than low carbon design industry anticipates. I have outlined in Chapter 1 that this is often framed as ethical 'irresponsibility' in environmental policies and lack of knowledge or irrational energy use in low-carbon design industry. I have argued that occupant improvisation is a productive source of sustainable change. Individual and environmental elements of irregularity in the taxonomy table show that irregularity in itself is a communicative medium, and a dynamic feedback loop that emerges from place-making processes and from the ongoing modification and renewal of home environments. It is a productive source of sustainable change because these systemic categories disclose the existence of a gap between the actual and intended uses of home heating technologies, and the gap communicates disharmony by showing a certain degree of misfit between a given technology and occupants' everyday lives. Moreover, this misfit discloses an even more important gap, which implies that there is another gap between users' aspirations, diverse ways of using these technologies and the possibilities offered by controls and radiators as technologies.

Domesticating home heating technologies through improvisation does not happen in an explicit way. Alternative uses of radiators and TRVs can be situated in forms of correspondence and relationality with the body's surrounding physical environment. Thinking of improvisation as an emerging alternative for the intended use of a given technology opens up the possibility for change, because it suggests where and how co-design might happen. I do not suggest that improvisation necessarily leads to new prototypes, but I imply that occupants can divert away from intended uses by making technologies fit in complex interrelationships between buildings and home environments. Occupants are therefore designers of use alternatives because they

are interwoven with the modification and change they create and they are able to contribute to the design process by articulating the need for adjustment, tailoring and change. Consequently, shifting the focus of design from objects and technologies to interconnections and existing configurations of lived environments may tell us more about how people heat their homes, create the home's sensory aesthetics and domesticate home heating technologies in the process. Given that home environments and use of technologies are always in the process of making, domestic low-carbon design could move from imposing closure to be more sensitive to renewal and interrelationships of place and place making.

8.5 Making Material Flows Visible

By grasping correspondence of occupants with the flows of energy and circulation of materials, Chapters 5, 6 and 7 have shown that home heating activities are processes of movement, perception and materials. In home heating bodily movement, sensory awareness and material flows are entangled, because they are active players of how home environments and indoor climates are made. We have seen that energy consumption partially arises out of the engagement with heat transfer of materials. Occupants do not necessarily interact with radiators - they correspond to them, and this correspondence brings forth the potential of how materials contribute to the formation of indoor climates. Chapter 6 has demonstrated that home heating activities are deeply rooted in the non-verbal and interconnected human senses. Sensory perception is skilled responsiveness because it keeps occupants in touch with their surrounding environment. Occupants actively use their senses to navigate and create their indoor climates, and they tacitly form an understanding of the physical properties of materials. Objects such as radiators, walls or floors are surfaces and 'places' that add or take heat away from the body. The perception of these objects and their physical properties is inseparable from how people develop home heating activities. There is an underlying invisible flow of heat exchange that influences how people perceive and experience their surroundings, but because these flows are tacitly experienced and are invisible, we are largely detached from the physical processes of energy consumption. Making visible the

invisible processes of flow could re-connect people with the spatial and temporal contexts of natural resources and the environmental impacts of consumption (Heidenreich: 2009). I have shown in Chapters 5 and 6, that occupants experience radiant and convective heat differently and that internal environmental conditions influence how the body loses heat to surfaces or exchanges heat with the surrounding material and physical environment. However, correspondence with radiators and TRVs is largely based on sensory perception because occupants make sense of indoor climates based on sensory experiences. Because sensory awareness is inseparable from indoor climates and from the home's sensory aesthetics, low-carbon design could attend to one's tacit relationship with the home environment by taking into account that heating systems and energy consumption are woven into the fabric of everyday life.

8.6 Implications for Intervention into Social and Technical Change

Creative engagement with technologies is core to how new technologies emerge against the background of everyday life. Emerging variations present an opportunity for dialogue and revision to harmonise home heating technologies and their fit with home environments. A route to sustainability in energy consumption can start from 'within' home environments by thinking with, from and through occupants and their correspondence with the built environment rather than just about them. Being emplaced in irregularities can provide a form of empathetic learning that is capable of grasping tacitly known interrelationships between occupants and their home environments. Households, as I have argued throughout this thesis, adapt in their own right, and modification of home heating systems and environments can shift in the performance of practices. Sustainability, everyday life and the domestic uptake of low carbon technologies are shared concerns for social sciences, humanities, engineering and design disciplines. I have shown by combining sensory ethnographic insights with building energy use that insights from the social sciences can have further impact in understanding interrelationships between households' energy use and the built environment. Each problem framing on sustainable energy consumption and social change I have reviewed in Chapter 1 suggests points of

intervention for transitioning toward a low carbon society. But as I have noted, these frameworks assume that technological and social change will occur separately from each other in a rather linear manner. Environmental policy and low-carbon industry approaches treat the social and technical dimensions of energy use as separate matters and independent points of interventions in the form of behaviour change, decision making of consumers or technological innovations. This proposes limitations, because possible targets of interventions are detached from everyday life as it is lived. The empirical studies I have presented in chapter 5, 6 and 7 and the integrative taxonomy table on the elements of irregularity further imply that taking practices alone as a unit of intervention for reducing energy used for space heating in homes detaches the 'social' from the physical characteristics of buildings.

I suggest a more collaborative environment that appreciates multiple ways of knowing and is likely to contribute to possible answers about how to make better interventions. Chapter by chapter I have explored how various individual and environmental elements can translate into the performance of home heating practices. Focusing on interrelationships of home heating activities and individual buildings suggests another possible direction of change from the inside out, which forms an ethical dialogue between disciplinary approaches that contends better with risk and uncertainty of low-carbon technological change. Attending to everyday life as it is lived can remove the assumptions and stereotypes associated with discourses on rational energy use and techno-centric patterns of low-carbon technological development. Moreover, occupants' correspondence with their home environment can open up space to accommodate diversity in how people use home heating technologies in relation to the buildings they live in. I have proposed that learning from the variation of households' energy use for space heating might further our knowledge about how a sustainable energy future might be achieved, because it locates sources of sustainable change in the immediacy and lived correspondence of everyday life. It is my argument that such an understanding needs to be based on an analysis that jointly accounts for occupants' sensory experiences, activities and building characteristics. A broader and collaborative systematic view of practice and place can specify and describe lived environments as systems that are undergoing continuous modification and change. Therefore, collaborative efforts can bring more participatory and engaged methods that by understanding everyday life as it is lived

address a new level of complexity. A higher degree of collaboration implies a new logic of intervention that moves away from techno-fixes to a learning process that gradually opens up interconnections between activities and the environment.

8.7 Limitations and Directions for Future Research

The thesis has been centred on developing an interdisciplinary and integrated framework of irregular TRV and radiator use that jointly understands the social and technical dimensions of low-carbon technological change and building energy use. There have been inherent challenges in taking this approach. On the one hand, gaining familiarity with building engineering was necessary, even though it may have eroded time which otherwise could have been spent on building more theoretical depth into the social sciences. By paying more attention to how engineering and social sciences can work together, I have developed novel methodological combinations that complement each other. On the other hand, when writing across the two disciplines, there has been a lack of coherent language due to the primary aim to develop a connection between building engineering and social sciences. Writing from a sensory ethnographic point of departure has been particularly challenging in discussions about building energy data, but the writing process across disciplines is itself a process of active learning and a challenge in specialisation (Bammer: 2005). I hope my work has overcome this unevenness and that it has showed the innovative aspects of disciplinary collaboration and novel methodological combinations.

There are two particularly important areas where knowledge about occupants could contribute to reducing building energy consumption. Firstly, energy modelling of buildings could develop better inputs for building performance simulation. In building simulation there is a growing interest in applying uncertainty to generate robust model predictions. However, there is also a need to understand different levels of uncertainties. Mapping and integrating elements on household uptake and domestication of technologies into Bayesian modelling could correspond better with predicting possible outcomes for low-carbon technological change. Secondly, moving forward with a collaborative and systematic analysis of interrelationship

between occupants and buildings across various building types (e.g. detached houses, bungalows, apartment blocks, purpose built flats) could help to develop more efficient low-carbon technologies that better meet the needs of users. Furthermore, the methodological combination of sensory ethnography and thermal imaging could be applied to the existing non-domestic building stock (e.g. schools or hotels).

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