

Practices and technological change:

The unintended consequences of low energy dwelling design

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‘A renewal of social theory which informs energy consumption and conservation is called for in the face of environmental challenges.’

Harold Wilhite (2001, p. 331)

‘the sources of changed behaviour lie in the development of practices themselves.’

Alan Warde (2005, p. 140)

‘We shape our dwellings, and afterwards our dwellings shape us.’

Winston Churchill, speech on rebuilding the House – 28 October 1944.

Abstract

There is an urgent need to reduce domestic energy consumption, particularly due to climate change. Domestic energy policies and research have been dominated by the assumption that technological provision will linearly save energy. Conventional attempts to move away from this approach have not gone far enough, tending to still assume that technological usage is a linear outcome of an individual's rational decision-making.

This thesis takes a significantly different approach by drawing on social practice theory and focusing on how everyday life is performed. Specifically, a Passivhaus housing development is adopted as a case study in investigating the everyday consequences of advancing dwelling design. Passivhaus is a German energy efficiency building standard, employing very different technologies relative to conventional UK housing. Specific attention is given to how unfamiliar technologies influence domestic practices more generally, as well as appliance-using practices and designing and constructing practices more specifically.

This thesis has significant empirical, methodological and theoretical contributions. Empirically, everyday examples illustrate the unintended consequences of new technologies, providing insight on how such technologies could change practices in the future. Methodologically, by treating quantitative consumption-related data (e.g. building monitoring, appliance ownership, construction data) as by-products of performing practices, an innovative mixed methods approach provides unique insights on everyday practices. Theoretically, the potential usefulness of a practices approach is emphasised; in particular, in developing a detailed and contextual understanding of how everyday life is constructed and how it is open to change (often in unexpected ways).

This thesis reiterates that research and policy should focus on practices, rather than technological performance or what individuals think about technologies. It concludes by: discussing a re-framing of policy expectations; outlining how energy saving interventions could target domestic practices and its influencing elements; and providing a series of new research ideas that have been generated by this thesis.

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PART I.

Scene-setting and context

Chapter 1 – Introducing the thesis

The overall title of this PhD thesis, ‘Practices and technological change’, attempts to immediately convey that practices (i.e. routinised social activities) are intimately intertwined with technologies. Changing one always has the potential to change the other. By acknowledging this, the linear assumption made by many policy-makers and researchers that technological provision will lead to energy and carbon savings inherently falls down. It is the intimate connection between technologies and practices that makes technological provision anything but predictable and linear. This is the rationale behind the thesis’ sub-title, ‘The unintended consequences of low energy dwelling design’.

Understanding how new technologies are interpreted and used is dependent on understanding how these technologies fit within the existing way everyday life is organised and practices are performed. On this basis, the broader consequences of making advancements in the technological design of dwellings can be considered. Indeed it is from this position that the following two central research questions, which are the focus of this thesis, are formed:

QUESTION 1: What are the consequences on practices of advancing dwelling design to reduce residential energy consumption and carbon emissions?

QUESTION 2: Can a practices approach help to understand these consequences? And if so how?

The very fact that I am even questioning the assumption of technological provision (i.e. the effectiveness of technologies in linearly achieving energy savings) is in itself going against dominant research and policy approaches. In making this deviation, and by firmly embedding theories of practice within the central research questions (and thus the very purpose of this thesis), the usefulness of operationalizing and applying practices thinking to issues of everyday consumption and technological change are made clear. The potential of practice-based approaches are considered with regard to enhancing understanding and directing domestic energy and climate change mitigation policy.

Through answering these research questions, as well as these theoretical contributions, this thesis will also provide numerous empirical and methodological contributions. Empirically, tangible everyday examples are provided of how both households and industry experience cutting-edge (and unfamiliar) low energy technologies, and how this can often result in those same technologies influencing everyday practices in somewhat unexpected ways. Methodologically, new ways of researching practices and everyday influences are employed. In particular, treating quantitative consumption-related data as the by-products of performing practices enabled technical methods to be combined with the qualitative methods that traditionally dominate practices studies.

Such contributions are achieved, and the research questions answered, by investigating the following four aims, which are also the basis of each results and analysis chapters (5-8):

AIM 1: Investigate the influence of a new and very unfamiliar domestic technological configuration on residents and the performance of their energy consuming practices.

Addressed in Chapter 5.

AIM 2: Investigate the potential utility of using theories of social practice in conjunction with building monitoring to further our understanding of how everyday practices are performed in dwellings or, indeed, any built environment.

Addressed in Chapter 6.

AIM 3: Investigate how appliance-using practices, and thereby appliance ownership levels, respond to new technological surroundings.

Addressed in Chapter 7.

AIM 4: Investigate how the embodied energy and carbon of a housing development is influenced by designing and constructing practices.

Addressed in Chapter 8.

Table 1.1 provides a chapter-by-chapter breakdown, and a summary of each chapter's respective purpose. This is to clarify the structure and approach of the thesis, and thus the journey that it takes.

No.	Chapter title	Purpose
<i>PART I. Scene-setting and context:</i>		
1.	Introducing the thesis	Clarifies the overall direction of this thesis and explains how it is structured.
2.	Theoretical and policy context	Contextualises the thesis in the relevant policy and theoretical contexts, en route to identifying a research gap and deriving research questions for the thesis to answer.
<i>PART II. Research design:</i>		
3.	Methodology	After outlining my ontological and epistemological positioning, I present my methodological approach. I consider the merits of case study research design and broadly discuss the specific methods utilised in this thesis, before summarising the steps taken to adhere to ethical research principles.
4.	Passivhaus	As the case study adopted to answer this thesis' research questions, the Passivhaus energy efficiency building standard is detailed. This chapter includes: origins, definition, Passivhaus in the UK, past research, and why its case selection was appropriate.
<i>PART III. Results, analysis and discussion:</i>		
5.	Living with Passivhaus technologies: An everyday practices perspective	Addresses thesis aim 1.
6.	Investigating the performance of everyday domestic practices using building monitoring	Addresses thesis aim 2.
7.	Turning houses into homes: Investigating how everyday domestic practices influence appliance ownership	Addresses thesis aim 3.
8.	Investigating how the designing and constructing practices influence embodied energy and carbon	Addresses thesis aim 4.
<i>PART IV. Conclusions:</i>		
9.	Conclusions	Integrates all of the separate conclusions from <i>Chapters 5-8</i> , as part of answering the two central research questions of this thesis. In addition, methodological reflections, the applicability of my findings to policy and the potential for future research is considered.

Table 1.1 - Thesis chapter breakdown

Table 1.1 reveals how the next chapter delves deeper into the theoretical and policy context that underlies the two central research questions, en route to discussing these research questions in more detail and detailing how they can be answered through investigating the four thesis aims. The methodological approach and research design of this thesis is then presented, within which the merits and pitfalls of the methodologies and methods employed are more generally discussed. This more general discussion is to complement the much more targeted discussion of methods (relating to each specific thesis aim) in each of the results and analysis chapters (5-8) that form the core of this thesis. In a similar way, each of these chapters also begin with a more targeted review of the literature which justifies how addressing each thesis aim helps to fill a knowledge gap in itself, as well as in the context of the central research questions that underpin this thesis.

The four results and analysis chapters are significantly based on the following four separate papers, which have been or are currently going through the peer review journal process:

- Foulds, C., Powell, J.C. and Seyfang, G. (2013) 'Living with Passivhaus technologies: An everyday practices perspective', Submitted for journal review.

An earlier version was also peer reviewed as part of a 2012 conference proceedings:

Foulds, C., Powell, J.C. and Seyfang, G. (2012) 'Encountering Passivhaus technologies: A UK occupant handover perspective', Paper presented at the Nordic Conference on Consumer Research (NCCR) 2012: Making Sense of Consumption. 30 May – 1 June 2012, Gothenburg, Sweden.

These form the basis of Chapter 5.

- Foulds, C., Powell, J.C. and Seyfang, G. (2013) 'Investigating the performance of everyday domestic practices using building monitoring', *Building Research and Information*, **41** (6): 1-15.

This forms the basis of Chapter 6.

Chapter 1

- Foulds, C., Powell, J.C. and Seyfang, G. (2013) 'Turning houses into homes: Investigating how everyday domestic practices influence appliance ownership', Submitted for journal review.

This forms the basis of Chapter 7.

- Foulds, C. and Powell, J.C. (2013) 'Investigating how designing and constructing practices influence embodied energy and carbon', Submitted for journal review.

This forms the basis of Chapter 8.

Chapter 2 – Theoretical and policy context

This chapter provides the background context to this thesis and, in particular, to this thesis' central research questions and subsequent aims. This is achieved through discussing the research priorities and knowledge gaps associated with domestic energy consumption and the different theoretical perspectives on how domestic energy demand can be reduced. Particular attention is given to how much technologies can be relied upon to reduce energy consumption, and how occupants consume energy in the way that they do. This chapter also serves as a platform for the more targeted literature reviews, which relate to each of the four thesis aims and introduce *Chapters 5-8*.

Being a researcher whose interests lie in energy and technologies need not dictate that one must focus on energy and/or technology. As the late Lee Schipper warned, 'we have analysed energy. We should have analysed human behaviour' (Charfas, 1991, p. 154). It is vital that the underlying influences of energy consumption are understood as clearly as possible, which justifies the journey this chapter takes: from the drivers for cutting domestic energy use, to the various theoretical perspectives that could inform how such cuts could be achieved. Furthermore, by finishing this chapter with the argument for opting to study practices, instead of behaviours as Schipper suggests, I end up with a very different focus and unit of inquiry (practices) than where I now begin this chapter (energy).

2.1 Drivers for cutting domestic energy use

This section briefly outlines the rationale behind why reducing energy consumption and the carbon emissions of UK dwellings is of importance, and indeed warrants further investigation and discussion. I begin by outlining the link between energy consumption and climate change mitigation, before considering other challenges that make addressing domestic energy a priority. This section then finishes by discussing current and past domestic energy trends.

2.1.1 Climate change

The growing scientific consensus is that rising atmospheric greenhouse gas (GHG) emissions, of which carbon dioxide (CO₂) dominates, has increased global mean temperatures. GHGs enhance the Greenhouse Effect by absorbing infrared radiation and, thus, warming the Earth's surface and lower atmosphere. Although natural causes do contribute to these trends, anthropogenic emissions must be accounted for to explain recent changes in temperatures (e.g. mean surface temperatures rose by $0.74 \pm 0.18^{\circ}\text{C}$ across 1905-2005; Forster *et al.*, 2007). Indeed, fossil fuel combustion likely contributed to three-quarters of the radiative forcing that underlies these recent temperature rises (*ibid*). In 2011, 85.9% of the energy consumed in the UK was through fossil fuel combustion (IEA, 2013a), with the remainder attributed to nuclear and renewable resources.

Even if the atmospheric GHG concentration remained constant at 2000 levels, a 0.05°C per annum warming would be anticipated (Forster *et al.*, 2007). However recent data shows the average 2012 global GHG concentration to be 6.6% (24.3ppm) higher than 2000 levels (NOAA, 2013). The NOAA dataset also shows the year-on-year increases in global GHGs to have risen. Such trends have led to many experts trying to re-frame the climate change mitigation (i.e. reducing emissions to slow temperature rise) debate around projected temperature rises of $4.0\text{-}6.0^{\circ}\text{C}$ by 2100 from 1990 levels, unless radical and rapid step changes are made to the way society consumes energy (e.g. Anderson and Bows, 2011, 2012; New *et al.*, 2011; PWC, 2012).

The need to reduce fossil fuel combustion, and in turn energy consumption and its associated GHG emissions, is especially pressing because of the impacts of rising temperatures on both the natural and human world. These range from disruptive meteorological events and changes in biodiversity to detrimental impacts for human health and global food production (Solomon *et al.*, 2007).

Whilst GHGs are often interchangeably referred to as carbon, carbon dioxide, CO₂, or carbon dioxide equivalents (CO₂e), it is the unit of CO₂e that has come to be the most

frequently used. This is because GHGs include a wide range of gases with different climate forcing and, since CO₂ is the most dominant GHG, different GHGs are usually normalised on the basis of CO₂ (e.g. 21 kg of methane equals 1 kg of CO₂e) (DEFRA / DECC, 2012). Indeed, such is the dominance of CO₂, that carbon footprints are sometimes restricted to include energy consuming activities that only emit CO₂ (Wiedmann and Minx, 2008).

To address climate change concerns, the UK Government (2008) made the Climate Change Act law in November 2008. It contains (as a world first) an ambitious and legally binding carbon reduction target of 80% by 2050 from 1990 levels. An interim 2020 target of at least 26% from 1990 was also set. To ensure the UK remains on course to meet its target, the Act specifies the requirement of four-year carbon budgets, which the Committee on Climate Change (CCC) advise upon.

It is estimated that 15% of the UK's GHG emissions (provisional figure of 74MtCO₂e) in 2012 were a result of residential energy consumption (DECC, 2013a). Since it is deemed more feasible to reduce domestic emissions relative to other economic sectors (e.g. aviation), domestic emissions are set to be cut disproportionately (thus more than other sectors) in the coming decades. DECC (2010a, p. 7) states that 'to help meet the carbon budgets we need to cut emissions in our homes and communities by 29%' by 2020 from 2008 levels. Indeed, to reach the 80% reduction target, almost every dwelling needs to be operationally near zero carbon by 2050. This is emphasised by nearly all of DECC's (2013b) sample 2050 scenarios involving very significant reductions in domestic energy demand (e.g. up to 60% less energy used by appliances and lighting). It is exactly this – the size and scale of the energy reduction challenge – that has led to the residential sector commonly having a prominent place in the UK Government's (largely technical) energy policy (e.g. HM Government, 2009, 2011; DECC, 2012a).

In summary, climate change represents a major challenge to human society on a global scale. Action is urgently required to mitigate climate change through reducing fossil fuel energy demand. The UK has and is continuing to put in place policies that address this, with considerable attention given to reducing energy usage in dwellings.

2.1.2 Other domestic energy-related challenges

There are additional salient challenges that are also triggering calls for a reduction in domestic energy demand.

As a nation with relatively few fossil fuels for its population, the UK has been increasing its fossil fuel imports. In 2009, the UK imported 45.2% of natural gas, 58.2% of oil, and 78.3% of coal used within its borders (IEA, 2013b, 2013c, 2013d). Experts project that the UK will soon switch from being a net exporter of fossil fuels to being a net importer of fossil fuels (Asif and Muneer, 2007). This is inevitable if the UK continues to rely on fossil fuels for energy generation whilst its own supplies dwindle. Relying on an insecure energy supply such as this is unsustainable economically since the finite nature of fossil fuels will ensure energy prices remain volatile. Indeed domestic standard tariff electricity prices have risen in real terms by 59.8% between 2002 and 2012 (DECC, 2013c), with gas prices increasing by 114.7% over the same period (DECC, 2013d).

Rising energy prices have thrown and are continuing to throw more householders beyond the fuel poverty threshold, at which point they spend more than 10% of their income on energy bills to maintain adequate warmth. Before 2004 fuel poverty had been in decline, but due to increasing energy prices the number of fuel poor households has risen from 1.2 million in 2004 to 4.5 million in 2011 (DECC, 2013e). This is despite the UK Government having aimed to eradicate fuel poverty in vulnerable households by 2010, en route to ensuring no household was fuel poor by 2016 (HM Government, 2000; BERR, 2001).

In addition to fuel poverty eradication, adherence to the Decent Homes standard is another primary driver for social housing landlords to take action on energy reduction (e.g. by improving existing dwellings or building new low energy dwellings). The Decent Homes standard is a minimum standard used to trigger social housing improvement, and one of its four criteria is that 'a reasonable degree of thermal comfort' is provided (DCLG, 2006). The original objective was that all social housing be 'decent' by 2010, however

recent estimates suggest 100% decency will not be achieved until 2018-9 (National Audit Office, 2010).

A potential gap between energy supply and demand is another salient issue that is driving domestic energy reduction further up the agenda. The UK's energy supply system is going through a decarbonisation transition at present (i.e. moving away from fossil fuels towards renewables), and it is important that throughout this transition 'UK consumers have access to the electricity, gas and oil they need to keep their lights on, their homes warm and their transport moving' (DECC, 2012b, p. 5) – the UK Government are thus putting in place strategies with the sole purpose of sustaining our everyday life.

To summarise, in addition to climate change, there are other pertinent issues that further contribute to the argument that reducing energy consumption in the residential sector is vitally important.

2.1.3 Domestic energy consumption

This subsection serves to provide a brief outline of energy consumption in the residential sector, in particular in the UK. It starts by detailing how much energy the sector is responsible for consuming and how that breaks down across various end-uses, before going on to discuss how UK domestic energy consumption has risen across recent decades despite the provision of energy efficient technologies.

Globally, the residential sector was responsible for consuming 15,240TWh of energy in 2010. Business as usual projections indicate residential energy consumption will increase in *absolute* terms by 57% between 2010 and 2040. In 2040 it is projected that the residential sector will be responsible for 14% (24,032TWh) of global energy consumption, which is *proportionally* very similar to amount of energy currently consumed in homes (EIA, 2013).

The UK domestic sector consumed 43.15mtoe of energy in 2012 alone, which amounted to 29.12% of overall UK consumption (see Figure 2.1 for a breakdown of energy end-uses). Although overall UK energy consumption has only increased by 3.69% between 1970 and 2012, the 2012 domestic consumption is actually 17.00% higher than 1970 and 5.88% higher than 1990 (Figure 2.2; green undashed line) (DECC, 2013f).

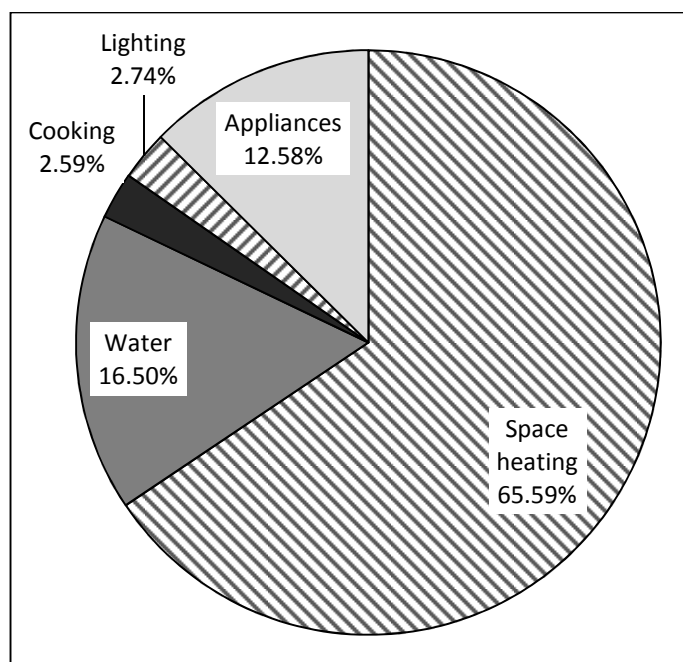


Figure 2.1 – Breakdown of UK domestic energy consumption, per end-use. Produced using DECC (2013g) data; appliances category includes pumps and fans.

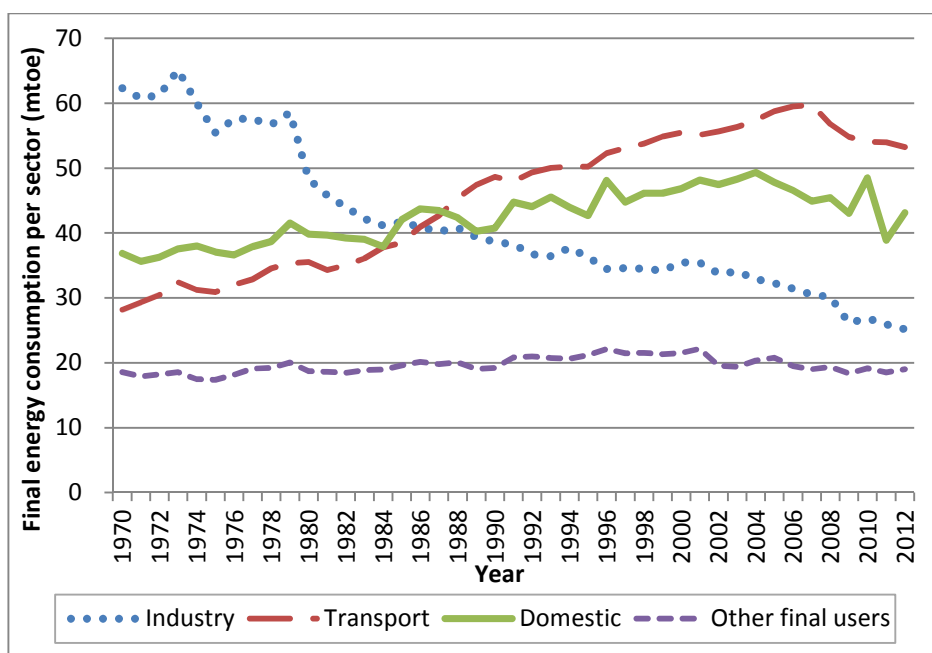


Figure 2.2 – UK historic energy consumption per sector, produced using DECC (2013f) data.

However these consumption levels only account for the energy directly used inside dwellings, hence do not include any of the energy embodied in technologies that households may utilise in their dwellings (e.g. through manufacture and construction). Moreover, the globalised nature of trade systems mean that none of the other UK sectors included in Figure 2.2 completely account for embodied energy either. This explains how significant reductions in the energy consumption of UK Industry (blue dotted line) have not contributed to a sector-wide rise. Indeed the Carbon Trust (2011a) reports that 40% of emissions attributed to UK consumption in 2004 occurred in other countries as a result of production, 12% of which to Europe and 28% to the rest of the world. Therefore in addressing the challenges that were outlined in *Subsections 2.1.1* and *2.1.2*, embodied energy (and carbon) needs to be considered in addition to operational energy (and carbon).

Returning to operational energy; there have been significant social as well as technological changes in recent decades, much of which has shaped domestic energy consumption levels, and thus the increasing trend illustrated by Figure 2.2. DECC (2013g) raw data tables can be analysed to provide some insight into such changes. For example, there was a jump from 31.56% in 1970 to 97.24% in 2011 of housing stock with central heating systems. Of this 2011 total, 82.81% of centrally heated homes are fuelled by (relatively low cost) gas which has become the norm. Average internal temperatures have increased from 12.0°C in 1970 to 17.60°C in 2011 (47.23% rise), in large part because central heating and cheap gas have allowed one to heat a whole house as opposed to just one room. This all suggests that technological change had profound implications on how one's home is thermally managed, as a consequence of technologies influencing broader thermal comfort conventions. Whilst this could be talked of in terms of energy consumption (17.00% increase over 1970-2011), hopefully this indicates that technologies play a significant role in shaping everyday life, and thereby to fully understand potential changes in energy consumption, potential changes to the everyday should also be explored. The two – energy and everyday life – cannot be separated.

Indeed it is most likely that the changes to everyday life, and thus how one makes decisions and chooses to act, explain why energy efficiency technological improvements

(e.g. average annual energy consumption of new fridge-freezers decreased by 49.72% over 1990-2012) have been unable to prevent an increase of 148.27% over 1970-2012 in the energy consumed by domestic lightings and electrical appliances. There have been broader social changes which have changed the way technologies, and in this case appliances, are used. Indeed these changes have in part manifested themselves through a substantial and relatively rapid uptake in domestic appliances. The following figures are based on the proportion of UK households owning at least one appliance type (DECC, 2013g):

- DVD player increased from 31% to 88% during 2002-2011
- Home computer increased from 27% to 79% during 1996-2011
- Microwave increased from 67% to 92% during 1994-2011
- Dishwasher increased from 18% to 41% during 1994-2011
- Washing machine increased from 65% to 97% during 1970-2011

This provides an initial indication that technological (e.g. efficiency) improvements may not yield the anticipated energy savings that are demanded by climate change mitigation, fuel poverty and energy security concerns. The inference being that the situation is far more complex than many would credit.

2.1.4 Background summary

This section has sought to briefly demonstrate the importance of the domestic energy issue, in particular the importance of reducing consumption and its resulting emissions. Since 29.12% of UK emissions can be attributed to dwellings, this appears to be a sizeable task. Furthermore, the challenge is not straightforward, with both embodied energy in addition to the intimate connection between technical and social dimensions needing consideration.

Relating to this, the following sections explore some of the different approaches to reducing (and understanding the influences of) domestic energy consumption – in

particular, the differences between how each theoretical perspective connects social and technological dimensions.

2.2 The techno-economic paradigm

2.2.1 What is the techno-economic paradigm?

Techno-economic approaches to reducing energy consumption typically focus on technical and economic factors. The paradigm has been widely adopted by the international community of energy researchers. Whilst critique of the techno-economic paradigm largely began in the late 1990s and early 2000s (e.g. Lutzenhiser and Shove, 1999; Guy and Shove, 2000), the shared techno-economic understanding across this international community is still contributing to a shared set of research priorities and underlying theoretical perspectives. Of particular interest here is how humans are accounted for in energy research, and how human action can be led in less energy/carbon intensive directions. For instance, what role can technological provision play? Here I discuss assumptions associated with technological usage and uptake that are inherent to the techno-economic paradigm.

Figure 2.3 details the linear process that is implicit to the techno-economic paradigm; from the research that optimises technological performance, to the sorts of policies that are put in place to enable its uptake.

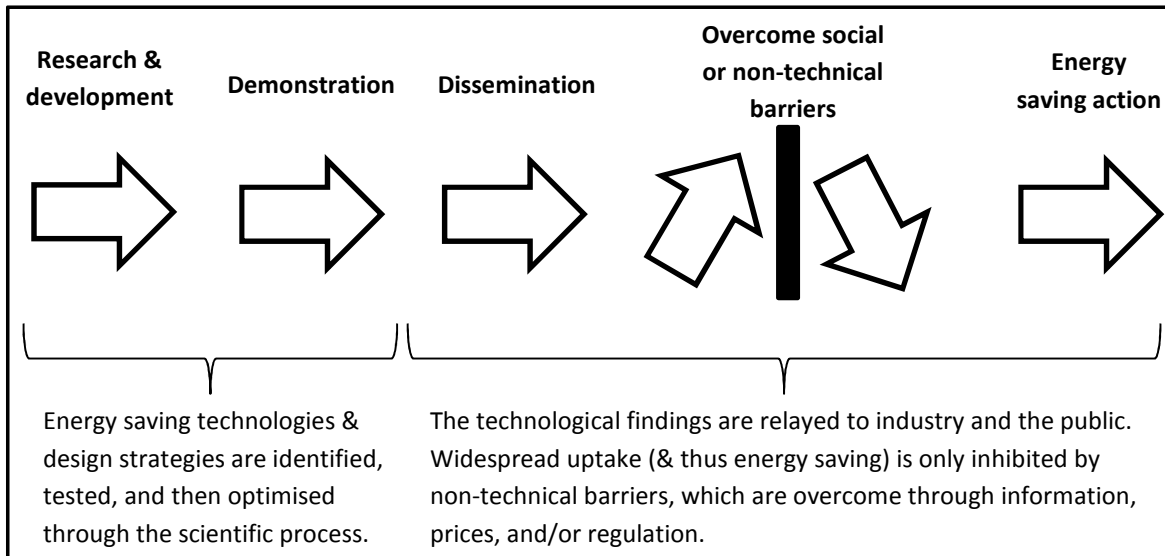


Figure 2.3 – The linear techno-economic model of technology transfer (adapted from Guy and Shove, 2000, p. 62).

As Figure 2.3 shows, a technological fix mentality clearly exists. It assumes that a well-researched energy saving building technology will indeed save energy if only it is installed. Technologies are therefore used exactly as the designers and building engineers had assumed (Brand, 2012), with the world of building science research flowing directly into the real world. This puts the focus on technology transfer; by simply having the technologies installed, energy will be saved. Strategies targeting energy management improvements have therefore – as Lutzenhiser stated in the early 1990s, with arguably little changing since – ‘focused almost entirely on the physical characteristics of buildings and appliances’ (Lutzenhiser, 1993, p. 248), so that the energy saving potential (and technological performance more generally) is optimised.

Techno-economists strongly believe in the capability of technologies to reduce energy consumption because either individuals will use the technologies as expected or the technologies are able to bypass the individual in yielding savings. It is this strong belief that contributes to attention (beyond that given to technical performance) primarily being given to ways of overcoming the ‘social or non-technical barriers’ (Figure 2.3) that can inhibit uptake. It is in this way that the techno-economic paradigm could be regarded as a slightly confused paradigm because it combines individualistic notions (regarding

linear uptake and usage of technologies) with more structural notions (regarding how technologies, not the individual, will save energy).

2.2.2 Overcoming techno-economic barriers

I now go onto discuss the approaches that techno-economic researchers and policy-makers endorse. Specifically, how they understand individual rationality can be exploited so as to improve the rate of technological provision, and hence reduce energy consumption and associated emissions.

Regulatory and voluntary building standards are commonly employed to initiate technological transitions. Indeed, the need to reduce energy and emissions has been used both explicitly and implicitly by the UK Government in their calls for improvements to UK Building Regulations (i.e. minimum requirement for new builds or refurbishments) (e.g. DEFRA, 2007; DECC, 2012c). Similar rhetoric is employed by the energy and buildings community when advocating and outlining the benefits of designing and building to voluntary building standards, such as Passivhaus (e.g. Passivhaus Trust, 2011), Building Research Establishment Environmental Assessment Methods (BREEAM; e.g. BRE, 2013a), and Leadership in Environmental and Energy Design (LEED; e.g. USGBC, 2013). Whilst mandatory and voluntary building standards often do not specify a particular type of technological provision, there is no doubt that many techno-economic policy-makers and techno-economic researchers alike assume a certain degree of linearity (towards energy saving) will accompany whatever technologies are employed to meet the standard.

In general, techno-economic researchers would acknowledge that voluntary and mandatory technological standards alone are unlikely to lead to the required level of energy savings. It is regarded that more proactive policy measures are needed so as to ensure a sufficient uptake of energy saving technologies. This is where the *economic* component of techno-economic makes itself clear. The paradigm assumes that a linear process of technological diffusion is possible because of a shared understanding of the role and function of technologies across individuals in society. This is through the

assumption that all individuals are 'self-interested, knowledgeable, and economically calculative when considering energy measures' (Guy, 2006, p. 647). Therefore 'the view is that economically rational actors, replete with the necessary technical and economic information, will consistently put [building] science into practice' (Guy, 2006, p. 647). With this view of individual consumers, policies attempt to enable technology transfer through either demonstrating or altering the balance between the costs and benefits of purchasing a technology.

Monetary incentives are typically used to alter this cost-benefit balance in favour of the benefits. Indeed the UK government have recently and are continuing to try and encourage uptake of energy efficient or low carbon domestic technologies through: loan schemes (e.g. Green Deal: UK Government, 2013a); grants (e.g. Low Carbon Buildings Programme: BRE, 2013b); lower tax rates (e.g. VAT exemption: HM Revenue & Customs, 2013); subsidised capital costs (e.g. Carbon Emission Reduction Target: OFGEM, 2013); and even householder payments for simply using the technology (e.g. Feed-in Tariffs: UK Government, 2013b).

On the basis of individuals being considered as utility-maximisers, who rationally weigh up the costs and benefits prior to making a decision, another commonly used approach is to demonstrate the benefits of having or using a technology in a certain way through information provision. Therefore knowledge transfer is seen to be a direct enabler of technology transfer and correct usage. For example, general information campaigns have attempted to show how using a technology (e.g. boiler, lighting, appliances) in certain ways (e.g. turn off standby; turn down thermostat by 1°C) will save the occupant money and help the environment (e.g. Act on CO2 campaign: DECC, 2010b; awareness posters: Carbon Trust, 2013a). There has also been a focus on providing information through technology labelling, such as: the Energy Performance Certificate (UK Government, 2013c); EU energy label (European Commission, 2013); Energy Star logo (Energy Star, 2013); Energy Saving Trust recommended logo (Energy Saving Trust, 2013); and the Carbon Reduction Label (Carbon Trust, 2013b). Such labelling schemes aim to gradually transition technologies to a less energy consuming level. Within this is the assumption that not only will individuals take notice, read and understand the labels, but that this

knowledge will then lead to the purchase of the least energy consuming technology, which will then linearly save energy during its operation. Therefore it assumes that the day-to-day usage of an older, for instance, television will be very similar to how a newly purchased energy efficient replacement television is used. Yet, as this thesis goes on to show, the interpretation and use of technologies is not as predictable as these theories would credit.

2.2.3 Further critique

The evidence presented by this techno-economic review has so far shown how: (1) the techno-economic paradigm sees improvements to technological structures as being an effective way of reducing energy consumption (either through individuals using the technologies exactly as intended, or technologies bypassing the individual altogether), and (2) that this can be enabled by pulling on the rationality of individuals (e.g. information, financial incentives) so as to ensure that the provision of these magic bullet technologies is as widespread as possible. In direct relation to these fundamental assertions, I now go on to discuss some of the limitations of the techno-economic approach more explicitly.

I begin by returning to the previous subsection's line of discussion, regarding overcoming techno-economic barriers. Guy and Shove remark that,

‘ways forwards are generally thought to lie in the hands of key decision-makers and other autonomous individuals.’

(Guy and Shove, 2000, pp. 62–63)

And it is because of this that,

‘Levels of energy consumption in the built environment are believed to be the consequence of ‘thousands’ of individual judgements by ‘property owners and other decision-makers’ (Olson, 1988, p. 17). All these are taken to be free agents, able to commit themselves at will to a more or less sustainable urban future.’

(Guy and Shove, 2000, p. 63)

This positions rational individuals as the solution to technical change and reducing energy consumption. However, the linearity associated with rational decision-making is too simplistic. For instance information, whether customised or not, is not directly translated into the performance of everyday life, with it instead being a much messier affair (Bartiaux, 2008). Behaviour is not based solely on rational choice. As Owens notes (2000, p. 1143), 'while greater knowledge may be worthwhile in its own right, barriers to action do not lie primarily in a lack of information or understanding'. Therefore, it is perhaps unsurprising that Gram-Hanssen *et al.* (2007, p. 2886) found people to not be 'empty recipients' of information presented by building energy labels. Decisions were shown to be made on the basis on broader social influences that shaped how the information was interpreted and put (or not) into action.

In drawing upon regulation and/or pricing, in addition to the failings of information provision, there are numerous other critiques supporting the argument that consumer rationality is not representative of how and why everyday actions are undertaken (e.g. Seyfang, 2009). Indeed, in illustrating exactly this argument, Guy and Shove (2000) present the uptake of insulation technologies as an example of an "efficiency gap" between current practice and what is technically and economically sensible' (p. 76). They argue that the gap exists because of insulation being regarded as a linear fix that is neatly governed by individual rationality, and is thereby unrealistically 'independent of any social or cultural setting' (p. 92).

If individual rationality is not accepted as the sole cause underlying behaviour, then the *economic* of techno-economic begins to fall down. However, on closer consideration, the *techno* component (i.e. that technologies will save energy, come what may) should also be approached with caution. Even if technologies were imposed or if uptake could be guaranteed (thus bypassing the need to utilise individual rationality), the amount of energy saved by a technology cannot be easily predicted. Indeed, the community of techno-economic researchers has conducted a significant amount of research into what they term the *energy performance gap* (i.e. between expected and actual energy performance) (e.g. Menezes *et al.*, 2011; Cutland Consulting, 2012; Carbon Buzz, 2013).

For instance, the Carbon Trust's (2011b, p. ii) case studies showed operational energy consumption was 'up to five times higher than estimated during design'. However, instead of being an indication that technology alone cannot be relied upon for reducing energy consumption or that behaviours cannot be easily and linearly predicted, much of the performance gap research has only served to reinforce the techno-economic paradigm further. Suggestions for closing the performance gap have centred around improvements to technological design, which would enable the occupant to be bypassed entirely or for the technology's interface to be easier to understand so as to facilitate rational decision-making (e.g. Bordass *et al.*, 1993, 2007; Bordass and Leaman, 1997). However these techno-economic solutions will in turn have their own energy performance gap: they do not represent a quick or easy fix, and thus such performance gaps debates seems to form a central part of a somewhat enduring and self-reinforcing research cycle.

In addition, all of the techno-economic policy measures discussed so far focus on the occupant only – even discussion regarding decision-makers still tend to focus on how their decisions affect the occupant – and hence often fail to recognise the broader set of users that influence the installation and use of a technology. As a consequence, the policy focus is also on operational energy/carbon, not that embodied within the construction of the building itself – another assumption, or rather potential oversight. There is thus a dominant line of thinking that users are the end-users (building occupants), when in all actuality there are an array of different types of users across the life cycle of any one technology (e.g. designers, manufacturers, installers, occupiers), all of which both directly and indirectly shape the energy consuming actions of one another. As Rohrer (2006, p. 64) highlights, the user concept is a 'rather ephemeral category changing its shape depending on the context and perspective we look at it'.

2.2.4 Dominating UK Government policy

Despite all of these concerns, the UK Government continues to put in place plans, strategies and targets that sustain the techno-economic paradigm. Therefore, despite

decades of critique, the paradigm still dominates with its unrealistic linearity firmly embedded in energy policy.

Taking the UK's 2011 Carbon Plan as an example; all four energy reduction scenarios are almost completely technological (HM Government, 2011). Moreover, its section on 'Changing behaviour to reduce [energy] demand' (p. 38–39) gives no consideration to how these technologies may actually be interpreted or used. Instead, with regard to the domestic sector, this section focuses on information provision and better technological design. Information provision so as to provide knowledge that will enable individuals to know which energy saving technology to purchase (e.g. Energy Performance Certificates). The assumption here is that information and feedback (e.g. smart meters) 'will enable people to understand their energy use and maximise opportunities for energy saving' (HM Government, 2011, pp. 38–39). In addition, better technological design is advocated so that the individual, using 'smarter' heating controls as an example, has 'greater control and flexibility over the way in which they heat and cool their homes' (pp. 39). The assumption here is that inappropriate design and lack of knowledge are the main factors preventing occupants from saving energy. These assumptions ally closely with the characteristics of the techno-economic paradigm.

The techno-economic paradigm is also usually firmly embedded within carbon dioxide emissions abatement targets. For instance, take the UK's 80% emissions reduction target for 2050 from 1990 levels. The Committee on Climate Change (CCC), as the community of experts responsible for advising on target-related issues, predominantly refer to technological solutions in discussions as to whether the 2050 target is achievable or not (e.g. CCC, 2008, 2010). Although the scenarios underlying the target, as Professor Julia King (CCC member) states, 'have been tested for do-ability' (Pile, 2009), the remit of this 'do-ability' test is limited to being technical only (Pielke Jr, 2009). Again, the assumption here is that the technologies will be utilised as expected without any problems or unintended consequences. It is this sort of thinking that has led policy-makers to target an end-point that can be worked towards, rather than regarding reality as much more fluid, dynamic and ever evolving.

2.2.5 The need for an alternative perspective

Subsections 2.2.1-2.2.4 have attempted to reiterate the failings of basing research and policy on techno-economic principles. More research is thus needed into how technologies are used and interpreted, and how that actually influences energy consumption. This is especially important given that technologies may well be introduced with the common expectation that the provision of certain technologies will reduce energy consumption. Calls for such research are not new, as indeed Lutzenhiser commented on almost 20 years ago:

‘Investment in research concerning the human dimension of technical change is long overdue, and necessary in order to reduce the impacts of consumption on energy systems and natural environments.’

(Lutzenhiser, 1994, p. 875)

It is the investment in innovating this ‘human dimension’ (away from individual rationality and all-governing technologies) across recent decades that forms the basis of discussion for the remainder of this chapter. Indeed it is clear that an alternative approach to energy and buildings research and policy is needed, but the question remains regarding what is the most appropriate alternative. The following sections explore theoretical perspectives associated with the psychology of individuals (2.3) and social structures (2.4), en route to advocating theories of social practices (2.5) as an insightful alternative for domestic energy research and policy.

2.3 The psychological approach to individual agency

In this section, I explore the overarching theoretical perspective of psychological approaches to behaviour change (e.g. regarding saving energy and reducing emissions). The psychological theoretical perspective that I discuss here, as I go onto explain in more detail, is characterised by focusing on the decision-making responses of individuals to a range of external factors. In this way, the psychological perspective is fundamentally

similar to the *economic* component of the techno-economic paradigm, only with more externalities factored in.

There is an implicit acknowledgement within this psychological perspective of some of the failings of the economic perspective (regarding rational choice) that is inherent in much of the techno-economic paradigm. Its common critique is that the attitudes, values and beliefs of individuals are not considered with regard to how individuals behave (e.g. regarding technological usage). Despite this, the psychological perspective still understands individual behaviour in a fundamentally very similar way to the economic perspective. Indeed such is their similarity that Burgess *et al.* (2003, p. 269) discuss them together under the banner of ‘cognitive perspectives’. In demonstrating this similarity in addition to critiquing the psychological perspective more broadly, I begin by briefly outlining four different theories as an illustration of how this perspective understands individual behaviours (see Jackson (2005) for a review of psychological theories).

First, the Theory of Planned Behaviour (TPB; Ajzen, 1991) which developed from previous work on the Theory of Reasoned Action (TRA; Fishbein and Ajzen, 1975). The TPB assumes people’s behaviour is rational because ‘the immediate determinant of behaviour is the individuals’ intention to perform, or not to perform that behaviour’ (Davis *et al.*, 2006, p. 119). This intention is said to be influenced by: an individual’s attitude as to which behaviours are (un)favourable; the subjective norm (as perceived by the individual) to behave in a certain way; and a perceived control of the ability to behave in a certain way. Use of the TPB has spanned a wide range of topics, making it arguably the most used behavioural model (Armitage and Conner, 2001; Jackson, 2005). The TPB has thus been widely considered and applied in domestic energy research (e.g. Faiers *et al.*, 2007; Martiskainen, 2007; Gill *et al.*, 2010).

Second, the Technology Acceptance Model (TAM). Mathieson (1991) compared the TPB to the TAM that had been previously developed by Davis (1989). Whilst it has not been widely adopted within the context of domestic energy research, it has been applied in technology-related research. According to Mathieson (1991), the TAM predicted use of information technologies well, with the TAM and TPB supplying very general and more

specific information respectively about users' technological opinions. The TAM is a theory that shows how users develop an acceptance of a technology and in turn how that shapes usage. Compared to the TPB, it is similarly very rational with perceived usefulness (costs and benefits of using the technology in a certain way) and perceived ease of use (how much hassle will it be to use the technology) shaping attitudes, intentions and actual usage accordingly (Davis, 1989).

Third, the Value-Belief-Norm (VBN) theory. The VBN theory was developed by Stern *et al.* (1999), which built upon the previous work of other theorists (e.g. Dunlap and Van Liere, 1978; Schwartz, 1994; Dietz *et al.*, 1998). The VBN theory challenges the rational behaviour assumptions of the previous two theories that were dominated by an individual's intentions. It instead considers behaviour in relation to three personal values: (1) biospheric, regarding threats to non-human species and the biosphere, (2) altruistic, regarding concerns to the collective good, and (3) egoistic, regarding self-enhancement. These values link to pro-environmental behaviour through the mediation of certain beliefs that shape one's sense of obligation to act.

Fourth, the Theory of Interpersonal Behaviour (TIB; Triandis, 1980). Although it is similar to the TPB and TAM as it is based around an individual's intentions, it has the caveats of facilitating conditions (context) and habits (shaped by the performance of past behaviour) also directly affecting behaviour. From my literature search, it is the only psychological theory that employs habit. Indeed the acknowledgement of the TIB that past behaviour shapes current and future behaviour is relatively unique within this body of literature. However, the whole ontology of this body of literature, and thus the TIB, renders such an acknowledgement moot. This ontology is now explored for the remainder of this subsection. Nevertheless, on the point of learning from past behaviour, this is a valid critique of the other psychological theories and is indeed fundamental to the practices approach (although on the basis on a very different ontology) which is explored in more detail in the following section (2.3).

These psychological models have usually been explored using correlation exercises between questions that target each specific factor (e.g. values, attitudes) underlying

intentions or beliefs, with questions regarding actual action. The most frequently applied models tend to be the simpler models, but as Jackson notes,

‘the ability of these simpler models to offer robust explanations for, or predictions of, different kinds of behaviour is limited. For example, the explained variance associated with Stern’s Value Belief Norm theory was less than 35% (Stern *et al.*, 1999) in empirical studies.’

(Jackson, 2005, p. 100)

Indeed attempts to theorise behaviour on the basis of intentions or values are theoretically problematic. The principle issue here is that rises in the willingness to act or in levels of environmental concern do not actually lead to rises in pro-environmental behaviours. Blake’s (1999) work on environmental concerns not being followed through in actuality led to this disparity being termed, the ‘Value-Action Gap’ (p. 257).

Researchers working in this body of literature often then tend to search for additional factors for inclusion in (either existing or new) theories, so as to increase the degree of correlation and enhance the predictive power of the model (regarding actual actions). Taking the TPB as an example, Ajzen (1991, p. 199) states that the theory is open to the inclusion of additional predictors providing that they can significantly influence its explanatory capacity for intention or behaviour. Indeed, the TPB itself is largely an expanded version of the TRA because the TRA did not account for perceived behavioural control (Ajzen, 1991). As such, the TPB has been developed by others who argue that its predictive power will be improved by inclusion of further variables (e.g. self-identity was added by Mannetti *et al.* (2004)).

Although many social psychologists acknowledge that a gap exists between people’s intentions and behaviour, instead of abandoning the intention-behaviour link altogether, attempts are made to find new variables that can help to minimise the gap. They thus commonly pose, either implicitly or explicitly, questions such as:

‘how big is the “gap” between intentions and behavior, and what psychological variables might be able to “bridge” the intention–behaviour gap?’

(Sheeran, 2002, p. 1)

However, as Jackson (2005, p. 100) highlights, ‘as the conceptual complexity of the models rise, however, their empirical applicability diminishes’. Jackson illustrates this by pointing out that no-one has ever attempted to empirically apply Bagozzi’s Comprehensive Model of Consumer Action (Bagozzi *et al.*, 2002), which his review found to be the ‘most elaborate attempt in recent years’ (Jackson, 2005, p. 99) to model consumer behaviour. Everyday actions cannot be accurately modelled, however sophisticated the attempts may be and however many additional external factors are included.

In the search for additional variables, there is also a tendency to improve a model or theory’s predictive power through the inclusion of context-specific variables, as the TIB does by including ‘facilitating conditions’ (Jackson, 2005, p. 93). In a similar bid to include context-specific variables, the ABC (attitude-behaviour-context) framework explicitly encourages other psychological research to shift its focus slightly from individuals to looking at individuals in context (Stern, 2000; as discussed in Whitmarsh *et al.*, 2011). However, as a consequence of being based on individualistic theories, this context is only in relation to how contextual changes surround and affect the individual. The focus on the individual (and one’s perceptions, beliefs, attitudes, values, and context) thereby misses out on wider social and structural context that may be collectively steering individuals and their actions (Shove, 2010).

This relationship between an external contextual factor (cause) and how an individual acts and makes decisions (effect) is what gives psychological (and similarly, economic) theories a degree of linearity and simplicity. This is emphasised by the frequent attempts to map out the performance of behaviour in flow charts, as a foundational basis for potential interventions. Indeed many social psychologists would advocate ‘nudging’ (Thaler and Sunstein, 2008) individuals in less energy/carbon intensive directions by utilising this linearity in policy. However, decision-making and everyday actions are not products of a linear process (based on rational or predictably irrational factors), hence why models and flow chart formats can never wholly predict behaviour. Indeed as Spaargaren and van Vliet remark,

‘the search for determinants of environmentally (un) friendly behaviours – grounded in models from social psychology – came close to deception. The environmental impacts of what consumers actually do turned out to be very complex.’

(Spaargaren and van Vliet, 2000, p. 51)

2.4 Moving towards a theory of structuration

The previous sections have discussed two broad paradigmatic approaches to theorising and potentially designing interventions that could target emission savings in buildings. Whilst the psychological theories include more variables in considering the ‘human dimension’ (Lutzenhiser, 1994, p. 875) than the techno-economic standpoint does, both are still based on the assumption that one can understand behaviour from understanding how people make decisions. It is from this standpoint that a focus on individuals and causal factors is generated.

The failings of the individualistic (e.g. economic and psychological) perspectives have, in part, contributed to the development of alternative perspectives. In this section I broadly discuss structural perspectives. Structural perspectives are typically, although not always exclusively, associated with the discipline of Sociology. These perspectives treat context very differently, in comparison to the individualistic perspectives that externalise context as a factor which may or may not affect an individual’s decision-making. In contrast, structural perspectives embed context fundamentally within their understanding of the social world. Individuals are regarded as actors living within the bounds of context-specific social settings (Southerton *et al.*, 2004). Indeed this is the reason for Burgess *et al.* (2003, p. 275) labelling such approaches as ‘contextualist’.

I now turn to two specific lines of inquiry to illustrate the structural perspectives, and in particular how insight can be gained through deviating from individualistic thinking and the externalisation of context. I begin by discussing the role of technologies in structuring opportunities for everyday actions (*scripting*), since that has been a cross-cutting theme of discussion so far. I then follow this with a discussion of *social conventions*, which

similarly provides a useful reference point for comparison with individualistic perspectives. Both approaches also provide a foundation for the later (sociotechnical) practice theory discussion.

I begin with the concept of scripting. My discussion is predominantly based on the work of Jelsma (2003), who developed the concept of *scripting* and its associated terminology (in italics) from the arguments previously put forward by Akrich (1992) and Latour (1992). Jelsma argues that technologies are designed in accordance with designers' particular moral visions regarding future usage. During manufacture these sociotechnical visions are *inscribed* into technologies, producing a *script* that configures the behaviour of those who operate the technologies. This would then *delegate*, in the most part, the challenge of reducing energy consumption to the 'material landscape in which the non-human actors (machines, devices, infrastructures) translate the actions of the human inhabitants automatically' (Jelsma, 2003, p. 104). Examples are given of users unconsciously responding to technological cues (e.g. switches to turn lights on/off), with undesirable behaviour seen to largely come about because of an insufficient number of cues (e.g. which would have made energy consuming behaviour more difficult).

In this way, some synergies exist between scripting and the *techno* component of the techno-economic paradigm which also regards technologies as capable of taking the lead towards a more sustainable society. However, those adopting the scripting approach would fundamentally disagree with techno-economists since they regard individuals as social agents of change (largely due to *economic* component of the techno-economic paradigm). Contrastingly, scripting largely bypasses individuals due to technological structures being regarded as the guiding force behind everyday life. Therefore, as Ingram *et al.* (2007) comment, since 'even the most *prescribed* artifacts remain open to resistance' (p. 9; emphasis added), the concept does not go far enough in considering how individual 'consumers will appropriate and configure objects in all manner of situationally-specific ways' (p. 10). Despite scripting usefully accounting for the broader social structures that underpin society, it therefore fails to consider the free will of individuals in addition to the other non-technological structures.

Social conventions represent a second approach to thinking about the structural characteristics of society. By structuring society in a certain way, conventions can be said to guide how everyday life is constructed and performed. This also means that conventions would shape the societal characteristics that other structural approaches have focused their attention upon. For instance, scripting focuses solely on technologies and non-human agents, the requirements of which would be seen here as being dictated by conventions. Therefore, social conventions essentially encompass an array of foci from different structural approaches (e.g. focus on social discourses: Myers and Macnaghten, 1998) because it is the conventions that are structuring society. This avoids focusing on one single contextual characteristic of society, which would only partially re-contextualise everyday life (as scripting did with regard to technological structures).

Shove's (2003) seminal book avoids exactly this, through a discussion of how conventions sustain and are sustained by different contextual structures. Specific attention is given to 'comfort, cleanliness and convenience' (the book's title), and how these three conventions have changed (becoming more resource intensive) over time. Her discussion reveals how conventions have in many ways standardised everyday life, leading to the argument that to understand patterns of consumption one needs 'to understand the collective dynamics of normalization' (Shove, 2003, p. 199). Changes to 'comfort, cleanliness and convenience' have increased energy consumption, as a consequence of changes to how one heats/cools buildings, washes, cleans, and utilises items of convenience. On the basis of such arguments, a transition to less energy consuming practices can only be achieved through targeting (and in turn transitioning) conventions.

Whether adopting scripting, social conventions or other structural approaches, what is clear is that insight can be gained from broadening the challenges associated with reducing energy consumption (away from the individual, towards the collective). It emphasises that everyday actions are certainly not context-free since actions are dependent on structural context, the inherent dynamics of which take agency away from individuals. Individuals, and their actions, are therefore seen as being pushed and pulled at the whim of these higher level structures. Studies that adopt such a perspective therefore have a unit of inquiry that is associated with society itself (e.g. conventions;

infrastructure). These structural perspectives lack prominence in conventional policy-making (unlike the techno-economic and psychological alternatives), despite what the consideration of broader social structures could offer the design of policy interventions (e.g. stepping back from individual rationality and reconsidering the role of context).

In considering societal structures, the two above illustrations (scripting and social conventions) also emphasise the sociotechnical nature of everyday life. The lack of the hyphen here is both critical and intentional, in that the social is the technical and the technical is the social. They are inextricably linked and so to consider one is also to consider the other. This intimate relationship also makes for a messiness that fundamentally contradicts the linearity of the techno-economic and psychological approaches, thereby also explaining why these approaches usually fail to change everyday life and/or lower energy consumption. All in all, this is a completely different point of departure.

However, whilst the individualistic perspectives are critiqued as giving too much weight to the (usually conscious and voluntary) decision-making of individuals, the structural perspectives could be critiqued as going too far in the opposite direction (i.e. giving too much weight to social structures as the dominant guiding force behind daily life) (e.g. Shove, 2003). Giddens (1984) and his theory of structuration argues exactly this, and thereby proposes that a theoretical perspective be found that acknowledges the roles of both individuals and social structures. In his view, individual 'agents and structures are not two independently given sets of phenomena, a dualism, but represent a duality' (p. 25). Individuals and structures depend upon one another, in that the everyday activities of individuals utilise and reproduce the structural characteristics of the social world. This stance puts practices (as everyday activities) in the spotlight, which I now discuss further.

2.5 Theories of social practice

2.5.1 Moving to a practices approach

This subsection now attempts to outline what a practices approach exactly entails, in addition to considering the merits of focusing on practices as opposed to structures or, in particular because of its dominance, individual agency. Therefore in a similar way to how discussion of the structural perspective (*Section 2.4*) was organised, I will relate much of the proceeding discussion back to the techno-economic and psychological perspectives (as the dominant line of inquiry for policy-makers).

In accordance with the individualistic approaches, support would be offered to the oft-cited quotation – ‘Buildings don’t use energy: people do’ (Janda, 2011, p. 15) – however, practice theorists would disagree with this statement. People do not consumes energy. Instead it is the routinised activities (practices) that people undertake that consume energy. Whilst on this surface this may initially only seem like a subtle nuance, the distinction has profound implications when designing social science research and in interpreting and analysing its results. As Shove (2011) remarks when comparing the practices and individualistic approaches, they have fundamentally different ontologies making them as different as ‘chalk and cheese’ (p. 262).

According to Reckwitz, a practice is:

‘a routinized way in which bodies are moved, objects are handled, subjects are treated, things are described and the world is understood...A practice is social, as it is a ‘type’ of behaving and understanding that appears at different locales and at different points of time and is carried out by different body/minds.’

(Reckwitz, 2002, p. 250)

Examples include showering, laundering, cleaning, driving, cycling, flying, constructing, designing, and policy-making. As Schatzki (1996, p. 89) puts it, a practice is ‘a temporally and spatially dispersed nexus of doings and sayings’. Practices are thus routinised activities which are performed over time and space.

Context is central to a practices perspective. Instead of externalising context as an influencing variable, context is internalised within the very notion of practices. Therefore rather than studying behaviour as a product of externalities, practices are regarded as being intimately related to (as products and producers of) its influences. Everyday life is thus much messier than the techno-economic fixes (*Section 2.2*) or psychological theories (*2.3*) may have originally suggested, as indeed can be inferred from discussing the structural perspectives (*2.4*).

Whilst ‘there is no unified practice approach’ (Schatzki, 2001, p. 2), the one unifying concept (which brings them together under the theories of practice banner) is that the onus should be on practices. Practices are the unit of analysis adopted in practices research, rather than individuals or sociotechnical structures. This therefore represents a completely different point of departure.

Theories of practice hence shift the focus away from specific ‘moments’ (e.g. Thompson *et al.*, 2011) of individual decision making, towards inconspicuous consumption (Shove and Warde, 2002) associated with the performance of social practices. Individuals are therefore considered as operating as ‘carriers’ (Reckwitz, 2002, p. 250) of practice within a broader sociotechnical landscape. It is the (re-)performance of a practice by individuals that sustains its existence.

Whilst practices are said to recruit individuals and in doing so give a sense of meaning and purpose to their everyday lives, Hargreaves notes that:

‘This does not, however, render individuals as passive dupes beholden to the dictates of practice, but instead conceives of them as skilled agents who actively negotiate and perform a wide range of practices in the normal course of everyday life.’

(Hargreaves, 2011, p. 83)

In this way, practice theories find a middle ground between structural and individualistic perspectives. As Schatzki (1996, p. 13) explains, 'both social order and individuality...result from practices'. In line with Schatzki's arguments, Warde emphasises how:

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

(Warde, 2005, p. 136)

Within this middle ground, the theories of practice literature has developed in broadly three main waves. First, the work of Bourdieu (1977, 1984, 1990) and Giddens (1979, 1984, 1991) who laid the foundations for the theory, in particular its structure-agency positioning. Second, the literature was reinvigorated and developed further by the work of Reckwitz (2002) and Schatzki (1996, 2001, 2002). Third, and currently still ongoing, is the application of these theoretical concepts as part of understanding everyday life. Initially this began by researchers drawing on somewhat abstract examples of practice (e.g. Nordic walking: Shove and Pantzar, 2005). However in recent years the practices community plus its research has developed significantly. Research is now examining more common everyday practices (e.g. standby and thermal comfort practices: Gram-Hanssen, 2010a, 2010b), critiquing existing or prospective mainstream policy approaches (e.g. dynamic energy demand peak pricing: Strengers 2010; visible energy monitors: Hargreaves *et al.* 2013), as well as using practices as the theoretical basis for crossing disciplines and mixing methods (e.g. building monitoring: Bates *et al.*, 2012; segmenting domestic water consumers: Browne *et al.*, 2013). Much of practice theory's latest surge has been discussed in line with the elements of practice, which I now discuss.

2.5.2 Elements of practice

One point of debate amongst practice theorists regards how to best to define a practice itself. Some theorists focus on the links between practices, hence what binds them and glues them together (Schatzki, 1996, 2002; Warde, 2005). Others focus on the bridging position of practices between individual lifestyles and sociotechnical systems of provision

(e.g. Spaargaren and van Vliet, 2000). However this subsection delves deeper into a third proposition: that practices are made up of various elements (e.g. Reckwitz, 2002; Shove and Pantzar, 2005; Gram-Hanssen, 2010a).

Reckwitz explored the notion of key influences of practice, which he termed as 'elements' of practice. As he remarked, a practice:

'consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, "things" and their use, a background knowledge in the form of understanding, know-how, states of emotions and motivational knowledge. A practice – a way of cooking, of consuming, of working, of investigating, of taking care of oneself or of others, etc. – forms so to speak a 'block' whose existence necessarily depends on the existence and specific interconnectedness of these elements, and which cannot be reduced to any one of these single elements.'

(Reckwitz, 2002, p. 249)

Whilst it is not explicitly stated, I sense that he is neither providing an exhaustive list of influences nor is he recommending specific categories of influences for further investigation. Reckwitz merely discusses several interconnected influences to illustrate the sorts of questions that practice theorists should be asking. This also fits with the paper's exploratory nature which proposes a new (practice theory) research agenda, and indeed was hugely influential in this regard. Part of the practice theory agenda that he sets out is the inclusion of materiality ('things') as a central influencing element. As he points out, 'in order to play football we need a ball and goals as indispensable "resources" ' (Reckwitz, 2002, p. 252). He explicitly acknowledges that object-subject relationships are of equal significance as subject-subject relationships, which was contrary to much of the wider sociological literature and, in particular, what prominent practice theorists had previously argued (e.g. Bourdieu, 1984; Giddens, 1984).

Shove and Pantzar (2005), through the analysis and discussion of Nordic walking as a practice, explicitly suggest a 'deliberately streamlined approach' (Shove *et al.*, 2012, p. 24) which focuses on three elements that influence a practice:

- *competences*, encompassing tacit know-how and formally learnt skills;
- *meanings*, including social expectations, aspirations, symbolic meanings;

- *products*, involving anything physical or tangible which composes objects.

The three specific terms have since been used interchangeably with or as well as other terms: skills, procedures, technique [competences]; images, symbols [meanings]; and stuff, materials, technology [products].

A simple example would be baking: whereby one has to possess knowledge and skills regarding how to bake; there must be sufficient meaning attached to baking to engender a willingness (conscious or not) to bake (e.g. relaxation; a good host for one's guests; a good provider for one's family); and this all requires products ranging from baking utensils and an apron to an oven and wider energy infrastructure.

Shove *et al.* note that,

'In putting forward such a reductive scheme we may well have fallen 'prey to the scientific urge to building simplifying, diagrammatic models of social life' (Schatzki, 2002, p. xii). In defence, we contend that this simple formulation is useful in that it provides us with a means of conceptualizing stability and change, and does so in a way that allows us to recognise the recursive relation between practice-as-performance [i.e. how practices are actually performed] and practice-as-entity [i.e. how practices are organised].'

(Shove *et al.*, 2012, p. 15)

They go on to argue that,

'This 'elemental' approach is unusual in provisionally de-centring the human actor (as integrator) but it is, at the same time, consistent with the argument that in the moment of doing, practitioners (those who do) simultaneously reproduce the practices in which they are engaged and the elements of which these practices are made.'

(Shove *et al.*, 2012, p. 22)

Therefore since first presenting the three pronged elements framework (Shove and Pantzar, 2005), Shove has (co-)authored a number of other publications that considers further and/or shows the merit of basing an analysis around these three elements (e.g. Shove and Pantzar, 2006, 2007; Pantzar and Shove, 2010; Shove, 2012; Shove *et al.*, 2012).

Others have also pulled upon this three elements practices framework in their own research (e.g. Kuijer and de Jong, 2009; Scott *et al.*, 2009; Hargreaves, 2011; Browne *et al.*, 2013; Maller and Strengers, 2013).

Gram-Hanssen (2010a, 2010b, 2011a) also explicitly makes reference to elements of practice that influence everyday performances. Based on her domestic energy consuming practices research, she proposed the following four elements of practice:

- *institutionalised knowledge and explicit rules*, involving less intuitive and usually expert-derived information, rules and recommendations regarding how to perform a practice;
- *know-how and embodied habits*, involving a practical understanding developed through tacit learning and experience of performing practices in certain ways;
- *engagements*, including social expectations, symbolic meanings, aspirations, norms, attachments, motivations – all of which shapes, consciously or not, whether one opts to perform a practice;
- *technologies*, consisting of anything that makes up our physical environment.

Engagements are thus very similar to Shove's meanings, and, likewise, technologies are very similar to Shove's products. The key difference from the Shove framework is the competences element, within which Gram-Hanssen makes the distinction between that of tacit learning and expert-derived knowledge.

Relating back to the baking example: institutionalised knowledge and explicit rules could include recipes, serving suggestions, dietary advice, and appliance manuals. Whereas the know-how and embodied habits could include how to go against these rules and recommendations so as to bake something that meets one's own or someone else's specific preferences, which may be judged by a sense of smell or taste that has been developed through baking in the past. Both types of knowledges are interrelated, yet fairly distinct in how they are utilised as part of performing a practice.

This four pronged elements framework has also been used by others in domestic energy research (e.g. Bartiaux *et al.*, 2011; Higginson *et al.*, 2011).

If we now look back to the techno-economic strategies (*Subsection 2.2.1*), whereby building technologies are advanced in a bid to reduce energy consumption and carbon emissions (e.g. constructing low carbon housing), a practices perspective would suggest that such technical fixes or guarantees of rational technological usage are unrealistic. Indeed, as Hughes states:

‘Attempting to reform technology without systematically taking into account the shaping context and intricacies of internal dynamics may well be futile. If only the technical components of a system are changed, they may well snap back into their earlier shape like charged particles in a strong electromagnetic field.’

(Hughes, 1993, p. 465)

As the elements of practice indicate, there are other elements beyond technologies that influence how everyday life is played out and its constituent practices are performed. A change to one element could indeed change how a practice is performed, but, likewise, it may not. The performance of a practice depends on how the technologies element relates to the other elements of practice.

Therefore the policies that attempt to advance or improve technological design – whilst originally arising from a linear intention to change an individual’s behaviours – could thus still change a practice. Behaviour change interventions are thus also interventions in practice, whether they are intended as such or not. In the same way, the organisation and performance of a practice could be transformed by information provision that changes the role of institutionalised knowledge and explicit rules, or financial incentives that change the engagements element.

Shove (2006a) argues that practice oriented design offers a means to successfully target transformations in the way that practices are performed (e.g. so as to reduce energy usage). What it requires is for designers to question what new conjunctions are needed between the various elements of practice to make certain performances *normal*. By giving

practices the onus, a practice oriented design approach more holistically addresses the elements than user-centred design approaches that dominate the techno-economic paradigm (*Subsection 2.2.1*). The user-centred approach attempts to make the user-technology interface easier to use as well as more likely to meet user needs, predominantly through feeding back deemed design failings (e.g. Bordass and Leaman, 2005; Way and Bordass, 2005; Leaman *et al.*, 2010; Stevenson *et al.*, 2013). The inherent assumption of the user-centred approach is that there are barriers to effective design that can be overcome, in this case through feedback. In contrast, those considering practice oriented design would appreciate that, because technologies are nothing without the practices that require their use, technological innovation requires a more deep-rooted innovation in practice (Shove, 2006b).

In summary: it is the dynamics between the elements of one practice, in addition to how they collectively and separately interact with elements of other practices, that shape how practices are performed, how technologies are used, and ultimately whether energy and carbon are saved. The elements framework gives a good basis for exploring these issues, especially in response to interventions which are actively (although perhaps inadvertently) changing inter-element relationships (e.g. through technological provision).

2.5.3 Operationalising and applying theories of practice: Gap spotting

This subsection discusses how theories of practice have been utilised in research to date, with particular emphasis given to specific aspects that have not yet been forwarded in the literature.

The practices literature has had a predominant focus on practices as entities (i.e. social organisation of a practice) rather than as performances (i.e. how practices are actually performed in situ). This is illustrated by the literature's tendency historically to debate how a practice is defined and constructed, manifesting itself more recently through discussions over the elements of practice. However, there have been a number of recent studies that have focused on performances (e.g. Strengers, 2010), and more research is

needed to enhance this stream of inquiry. Specifically, it is important to consider how the elements of practice relate to different performances of different practices across different contexts and through the use of different methods. Through investigating how performances relate to elements of practice, for instance through how performances can change due to changes to the elements of practice (e.g. to technologies), one can hope to critique existing element frameworks. For instance, Gram-Hanssen (2011a) suggests that her elements of practice framework would be a useful basis for investigating how energy consuming practices are performed in the home, but very little domestic energy research has been conducted in response to this recommendation.

It is vital that there is more research into the performances of practices. Theory indicates that there will be unintended consequences associated with the so-called technological or behavioural fixes, but there have been relatively few studies that provide performance-derived evidence to support and substantiate this (e.g. Hargreaves *et al.*, 2010; Ozaki and Shaw, 2013). Such studies help us understand actual ground-level everyday consequences of often overly aspirational policies (e.g. smart meters; step changes to building regulations; low carbon housing standards) and thus also gauge whether anticipated energy and carbon savings can be met. Moreover, developing a good understanding of how innovative technologies influence everyday life provides a basis for developing practice-oriented interventions, which could encourage ways of consuming less energy and reduce the likelihood of unintended consequences occurring. Indeed, as Shove (2010) recognises, to date there has been little work on ways of establishing more sustainable configurations of the elements of practice, and I would argue that investigating performances provides a clear access point for moving this discussion forward.

The policy relevance of a practices approach should be made clear. The journey that this chapter has taken – specifically, from individualistic to practices approaches – emphasises the value of developing the practices literature, as a relatively young research area which is yet to shape policy-making. Shove (2010) discusses how notions of social practice have very little to do with climate change policies that are attempting to change the way people act on a day-to-day basis. This is in stark contrast to the rational techno-economic and psychological approaches which dominate the policy landscape. I would therefore

argue that there is definite merit in furthering the under-developed practices research agenda, particularly if practices can be discussed in a policy relevant context that challenges dominant approaches.

More research is needed on how policy interventions specifically targeting changes to energy demand could influence everyday life. This has been a fruitful line of inquiry for many practices researchers (e.g. Strengers, 2012; Higginson *et al.*, 2013). Demand-side interventions are fundamentally associated with how practices are performed. Therefore it is interesting to explore how everyday life can change (or not) in the pursuit of making everyday life less energy demanding. There is an implicit indication from policy-makers that practice (or as they frame it, behaviour) change is difficult to achieve, in that policies focus more on supply-side technologies than demand-side alternatives (Wilson *et al.*, 2012). These supply-side policies are ‘palliative’ (McMeekin and Southerton, 2012, p. 346) because current demand patterns, and thus current ways of performing practices, go largely unchallenged. The introduction of demand-side technologies, which can mount challenges to everyday life, is a topic of research that needs further work as part of attempts to understand the everyday implications of tackling energy demand (e.g. shifting; efficiency; conservation) policies.

It is important that research is not restricted to occupant practices. Theories of practice acknowledge that building occupants are not living their everyday life as isolated individuals and, likewise, the technologies and broader sociotechnical systems that surround them are not isolated from the individuals (and their performance of practices). In this way the concept of system end-users, which prevails in the individualistic literatures, falls down. Instead, Strengers (2011a) refers to individuals not as end-users but as potential ‘co-managers’ (p. 45) of systems, since a system is co-sustained and co-shaped by the practice they themselves manage and perform. Meeting the call for the consideration of multiple types of users (or, rather, a range of interrelated doers) is facilitated by making practices the central unit of analysis and shifting attention away from specific individual users. Indeed this has led to a number of practices studies, albeit largely implicitly, focusing on how occupant practices are influenced by the practices of other co-managers (e.g. the technological setting that designing/constructing provides, as

Gram-Hanssen *et al.* (2012) did with air-source heat pumps and Hitchings (2011) did with air conditioning). However relatively few have switched the focus around onto, for instance, the practices of the designers or constructors (e.g. Pink *et al.*, 2010). More research is needed here since it is how the designing and constructing practices are performed that dictates many of the technologies that constitute one's home.

The investigation of designing and constructing could also benefit from considering practices in relation to the amount of energy and carbon embodied in the buildings. Any efforts to relate practices in some way to energy or carbon have focused on the operation (rather than the installation, manufacture, maintenance, or disposal) of technologies. As far as I am aware, no research has explicitly related energy and carbon emissions to the practices of designing and constructing. Such studies would, of course, tread a delicate line because one must ensure that the focus remains on practices, not on lifecycle or operational emissions. Moreover, the design and construction of technology (e.g. oven) is sustained by the occupant practices that utilise it (e.g. cooking), making it unlikely that a design and construction study will focus solely on design and construction. Saying this however, certain practices (e.g. designing, constructing) will directly contribute to certain parts of the lifecycle (e.g. embodied in construction of a dwelling) emissions more than others (e.g. cooking, showering). I would thus argue that there is merit in diversifying the technical embodied energy and life cycle assessment literature, so that its underlying influences can be understood in terms of how practices are performed. Such research could be very valuable in considering how best to reduce sector-wide energy consumption.

Opportunities exist for drawing on the methods of contrasting disciplines in the study of practices. Practices approaches are complementary to examinations of energy consumption and carbon emissions, yet there has been little explicit attention given to this. As Warde (2005, p. 137) states, consumption is 'a moment in almost every practice', and as such can be regarded as by-products of performing a practice. Whilst there has been some work already carried out using energy data to investigate energy consuming practices themselves (e.g. sub-metered electricity data: Bates *et al.*, 2012), this remains a vastly under-utilised route of inquiry. Furthermore, some have utilised other consumption

or building monitoring data (e.g. heating energy, temperature: Gram-Hanssen, 2010b) to demonstrate that opportunities exist beyond just energy data. However, monitoring data are rarely given more of a prominent and centrally integrated role when researching practices. Using these sort of data represent an exciting opportunity for researching practices in new ways, particularly since a lot of (predominantly technical-related) research projects are already monitoring buildings.

The possibility exists, more generally, to be more imaginative in how practices are researched. Building monitoring is one such example of this, but others exist too. An example could be using construction site data (e.g. energy consumption; materials used; waste disposal) as records of constructing and designing practices. The use of quantitative methods is significantly less developed in the practices literature compared to the qualitative approaches that dominate it. More work is thereby needed to diversify and mix methods, providing that the focus still remains on practices and not the data collected (e.g. kWh consumed; construction material tonnage). Such methodological novelty could: provide new insights that traditional (predominantly qualitative) approaches may not be able to yield; open up practice theory to a wider academic audience; provide a path for crossing disciplinary boundaries; and explore potential ways (e.g. combinations and scales) of integrating and mixing contrasting methods – all of which can help to stimulate debate within the academy. Therefore there is significant potential for diversifying methods, in particular using quantitative data as consumptive by-products of how practices are performed.

2.6 Summary remarks

In 2012, energy consumption in the home accounted for 29.12% of UK energy demand (DECC, 2013g). Climate change mitigation, in addition to other energy security and fuel poverty concerns, has led to calls for this energy consumption to be urgently reduced. Attempts to meet these calls have largely centred on reducing operational (as opposed to embodied) energy through technological provision and the assumption that rational individuals use technologies as per design intent. Critiques indicate, however, that

individuals do not make decisions (e.g. regarding technological use) rationally. Everyday actions are not steered solely by an individual's desire to maximise utility.

More sophisticated psychological theories provide an alternative to the techno-economic paradigm. Nevertheless, both sets of approaches are inherently linear due to the shared assumption that individual actions can be steered towards less energy intensive ends through the utilisation of identifiable external factors, be they rational or 'predictably irrational' (Ariely, 2009, p. 1). Indeed, as Rohracher and Ornetzeder (2002, p. 74) comment, 'traditional strategies of optimizing either technology or behaviour are often 'blind' about interactions between the spheres of the social and the technical' (p. 74).

In contrast, structural perspectives treat context very differently. Instead of context representing an additional set of external factors that affect individual choice, structural perspectives internalise context within a social world, the characteristics of which push and pull individuals. How society is structured is thus the focus, as opposed to individuals.

By focusing on the activities that make up everyday life, the point of departure for a practices approach finds somewhat of a middle ground between individual choice and social structure. Within this middle ground, the practices approach offers a better and more insightful alternative to the overly technological and/or individualistic approaches that dominate research and policy, in addition to acknowledging that everyday life is not solely directly at the will of broad social structures.

Guy (2006) nicely summarises what progressing from the dominant techno-economic paradigm to a practices (which he also terms, sociotechnical) approach could mean for energy and buildings research:

'The scope of this [sociotechnical practices] research agenda, then, takes us in a different direction to the techno-economic analysis of energy consumption... In developing a sociotechnical approach to energy efficiency..., the aim for researchers is to identify the circumstances in which energy-efficiency practices do or do not flourish... This focus...takes us far from the world of building science and the paradigmatic certainties of the techno-economic perspective, and instead reveals the construction of energy knowledges in

varying social worlds and reflects the contested nature of building design and development and energy-consumption practices.’

(Guy, 2006, p. 657)

In reviewing the practices literature, the following gaps in the application and development of this practices research agenda were highlighted:

1. The practices literature is still relatively new, relative to the traditionally dominant individualistic literatures. Therefore practices research regarding energy use and buildings is an under-researched area.
2. Much of the practices literature has focused on practices-as-entities (i.e. what shapes a practice) as opposed to practices-as-performances (i.e. the in situ performance of everyday life).
3. More application of the elements of practice is needed – using (and perhaps inadvertently testing) certain frameworks, for instance, through studying the performances of practice.
4. More critique of current policy approaches is required. For example, what are the ground-level experiences of imposing techno-economic energy reduction solutions upon those actually influencing and using the technologies in the everyday? Furthermore, what can these lessons tell us about designing more practice-targeted interventions?
5. When investigating technical or behavioural energy saving interventions, there has been a tendency to focus on the practices performed inside the dwellings by the building occupants themselves. Potential exists to further broaden this out, or even turn it around slightly and explicitly focus on other practices and whether those performances (e.g. of designing, constructing) could undermine the very purpose behind, for instance, technological provision (e.g. to save energy and carbon).

6. There is also potential to diversify methodological approaches and mix methods, so as to enhance our understanding of what influences underlie the performances of practices.

In considering these gaps in the practices literature with the research priorities set out nearer the beginning of this chapter (e.g. to reduce energy demand in the home; to question the reliance of technological provision in energy saving initiatives; to not only focus on operational energy and carbon; to cross social and technical disciplinary divides), I am led to a set of research questions which develop and apply theory in new ways, thereby covering new ground theoretically and empirically. These research questions are now discussed in the following section.

2.7 Central research questions and subsequent thesis aims

This thesis is rooted in questioning the assumption, underlying many policy and research avenues, that technological provision will linearly reduce energy consumption and carbon emissions. Looking specifically at the residential sector, the broader consequences of low carbon dwelling design are considered – be it as set out by building regulations, specific building energy standards, or simply a designer/client interested in energy efficiency and conservation. A practices approach is used to disentangle the everyday (and perhaps unintended) consequences of such technological fixes in the residential sector.

The two central research questions of this thesis are:

QUESTION 1: *What are the consequences on practices of advancing dwelling design to reduce residential energy consumption and carbon emissions?*

QUESTION 2: *Can a practices approach help to understand these consequences? And if so how?*

By focusing on dwelling design, there is an inherent focus on technologies and their provision, interpretation and usage. The inclusion and explicit highlighting of ‘advancing’ in the first research question is to deliberately re-flag the dominant technological fix discourse. Here, ‘advancing’ is seen as optimising the provision of technologies through construction and design so as to guarantee lower operational energy consumption and carbon emissions levels. ‘Advancing’ is also highlighted in response to the earlier suggestions (*Sections 2.2 – 2.5*) that a deemed advancement in energy saving technologies may, somewhat ironically, not quite be the advancement that it was initially thought to be (e.g. regarding energy saving or unexpected knock-on implications for household everyday life)

In answering these two central research questions, four subsequent aims are investigated. These aims form the basis for each of the results and analysis chapters, and thus also the core of this thesis. Some of these respective chapters in turn have their own specific objectives, which will be tackled as part of investigating each of their respective aims. These objectives will be justified on the basis of a literature review that will begin each of the results and analysis chapters.

First, post-occupancy resident experiences of incorporating different and unfamiliar domestic technologies into their everyday lives are investigated:

AIM 1: Investigate the influence of a new and very unfamiliar domestic technological configuration on residents and the performance of their energy consuming practices.

Addressed in Chapter 5.

Second, technological usage is investigated further through integrating building monitoring methods with the qualitative inquiry that is more traditionally associated with practices approaches. This is in large part a methodological extension to *Aim 1* by exploring how further insights can be gained on how domestic everyday life is influenced by new technologies:

AIM 2: Investigate the potential utility of using theories of social practice in conjunction with building monitoring to further our understanding of how everyday practices are performed in dwellings or, indeed, any built environment.

Addressed in Chapter 6.

Third, consideration is given to how low carbon dwelling design influences which appliances households appropriate their new homes with. New build dwelling design usually focuses on lowering heating fuel consumption (and, usually inadvertently, the practices underlying that consumption), but more explicit attention is needed on electricity-using practices. Therefore how current and prospective household appliances can complement or conflict with new technological surroundings, in the context of everyday practices, requires research:

AIM 3: Investigate how appliance-using practices, and thereby appliance ownership levels, respond to new technological surroundings.

Addressed in Chapter 7.

Fourth, in exploring further how the linear assumptions of technological provision (leading to energy and carbon savings) may be misplaced, the focus is diverted away from the occupying households to the designers and constructors. How the designing and constructing practices are performed directly influences which technologies make up the dwelling itself. Which and how these technologies are constructed and installed shapes the embodied energy and carbon attributed to the dwelling, and thus influences how much energy and carbon is saved in actuality across the life cycle – energy and carbon savings are, of course, what the ‘fix’ is targeting.

AIM 4: Investigate how the embodied energy and carbon of a housing development is influenced by designing and constructing practices.

Addressed in Chapter 8.

PART II.

Research design

Chapter 3 – Methodology

This chapter begins by briefly outlining three contrasting philosophies of science, which are critiqued in turn before advocating the constructivist philosophy. Using these ontological and epistemological foundations, this chapter outlines my broader methodological approach. Specifically, I discuss what a case study entails and why it is a useful research design for answering this thesis' central research questions. Following this, I broadly outline which methods were utilised, why they were utilised, and how their data were interpreted and used. The chapter finishes by considering the ethical implications of my research design.

3.1 Introducing three philosophies of science

This section discusses three contrasting philosophies of science: positivism; critical realism; and constructivism. It is vital that these are reflected upon because they guide how knowledge is created. Each perspective has inherently different points of departure because of their contrasting ontologies (regarding what exists) and epistemologies (what one can know), which consequently shape research methodology (approach to knowing). These *'ologies* are what distinguishes each philosophy of science, and are implicitly shown as being intimately connected throughout this chapter. Indeed the cascading effect between the *'ologies* is clear from Figure 3.1. Moreover the critical nature of the questions posed in Figure 3.1 demonstrates how important it is to understand which philosophy of science one broadly aligns with, and indeed why this is the case.

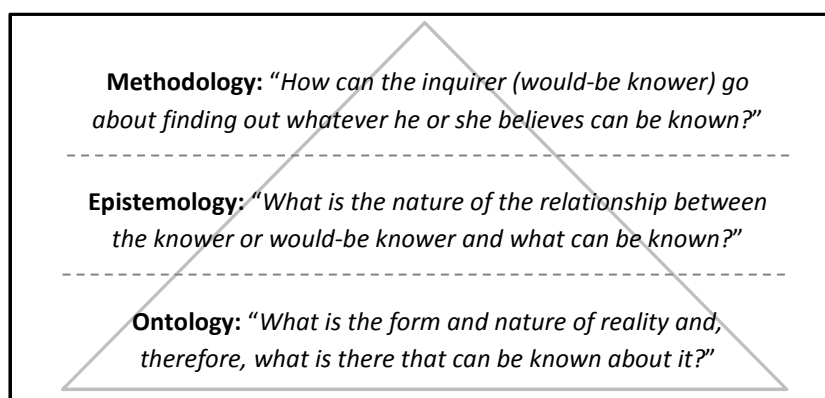


Figure 3.1 – The questions posed by ontologies, epistemologies and methodologies. Quotations sourced from Guba and Lincoln (1994, p. 108).

I now briefly discuss and critique positivism and critical realism, en route to advocating constructivism (in *Section 3.2*). Table 3.1 is provided for context, and can be consulted throughout this discussion, whether it is explicitly referred to or not. As with Figure 3.1, Table 3.1 similarly takes inspiration from the work of Guba and Lincoln (1994).

	Positivism	Critical realism	Constructivism
Ontology	Naive realism – “real” reality but apprehendable	Critical realism – “real” reality but only imperfectly and probabilistically apprehendable	Relativism – local and specific constructed realities
Epistemology	Dualist/objectivist; findings true	Modified dualist/ objectivist; critical tradition/community; findings probably true	Transactional/ subjectivist; created findings
Methodology	Experimental/ manipulative; verification of hypotheses; chiefly quantitative methods	Modified experimental/ manipulative; critical multiplism; falsification of hypotheses; may include qualitative method	Hermeneutical/ dialectical
Inquiry aim	Explanation: prediction and control		Understanding; reconstruction
Nature of knowledge	Verified hypotheses established as facts or laws	Nonfalsified hypotheses that are probable facts or laws	Individual reconstructions coalescing around consensus
Knowledge accumulation	Generalisation and cause-effect linkages		More informed and sophisticated reconstructions; vicarious experience
Goodness or quality criteria	Conventional benchmarks of “rigor”: internal and external validity, reliability, and objectivity		Trustworthiness and authenticity and misapprehensions
Values	Excluded – influence denied		Included – formative
Ethics	Extrinsic; tilt toward deception		Intrinsic; process tilt toward revelation; special problems
Voice	“disinterested scientist” as informer of decision-makers, policy-makers and change agents		“passionate participant” as facilitator of multi-voice reconstruction

Table 3.1 – Comparing three overarching philosophies of science: Positivism, critical realism and constructivism (adapted from Guba and Lincoln, 1994)

Positivism essentially transfers the principles used in traditional natural sciences across into the social sciences (Flick, 2009). Its ontology assumes that an apprehendable social

reality exists, which is governed by universal truths. The generalizability of these universal laws makes them context-free. As such, its ontology is very closely related to its epistemology because what exists (reality) can be easily observed through one's research. Should one's research show a proposed theory not to be true, then that proposed theory will similarly not hold true elsewhere. Having a context-free means of creating knowledge also assumes that the researcher(s) remains objective and has no effect on the study findings through his/her interpretations (Bryman, 2004).

Positivism has traditionally dominated energy and buildings research. Its technical research that focuses on technological performance has an inherent linearity due to the assumption that energy can be saved if only we innovate in the correct way. All that one needs to do is identify what that correct way is, which can then be successfully rolled out as an energy saving intervention across every context. Similarly much of the social science energy and buildings research shares this positivist linearity, whereby context-free rules can be identified and played upon so as to get individuals to save energy. Indeed, the *economic* component of the techno-economic paradigm and the psychological theoretical perspectives (as discussed in *Sections 2.2 and 2.3*) usually assume that reality can be understood through understanding a series of easily identifiable cause-effect relationships. Furthermore, even when these perspectives attempt to account for context, they tend to do so by treating it as an additional factor that helps to *solve* reality. In contrast, as I go onto explain in more detail later, I contend that it is foolhardy to assume reality can be easily understood (and from which more easily pushed and pulled in less energy consuming directions) by identifying universal context-free truths.

Many have rejected positivism in favour of, what is commonly termed, post-positivist perspectives. Critical realism is a dominant perspective within the post-positivist philosophies of science, with many proponents (e.g. Bhasker *et al.*, 2010). Instead of positivism's realist underpinnings (whereby observations equal reality), critical realism regards observations as not always holding all the answers. Whilst it appreciates that observations are fallible, it does nevertheless assume that a reality exists which is independent to how the science is researched. As Sayer (2000) argues, changes to how the researcher(s) perceives the studied phenomenon will not significantly change study

findings regarding that phenomenon. All this explains the realist, yet critical, stance. It is because of this stance that critical realists often attempt to generalize their findings beyond the boundaries of their study, yet in a much deeper and more nuanced manner than positivists. Indeed,

‘Critical realists stress the generalizing task of scientific activity. However, their stand is not to be confused with that of positivism, with its interest in predictable patterns. Instead, critical realism seeks to identify those deeper lying mechanisms which are taken to generate empirical phenomena.’

(Alvesson and Skoldberg, 2010, p. 40)

It is this belief that an external reality exists that leads both positivists and critical realists to formulating research inquiry around the search for explanations. Such explanations are usually as a means for predicting and controlling specific phenomena (Guba and Lincoln, 1994), such as energy saving behaviours. Therefore I would argue that critical realism does not go far enough in significantly differentiating its point of departure from positivism. The relative linearity of research that attempts to predict and control energy saving behaviours I regard as not sitting well with theories of practice that take everyday action as being local and contextual.

I now turn towards another post-positivist philosophy of science: constructivism. Contrastingly, constructivism is interested in furthering our understanding of phenomena, with the acknowledgement that a definitive answer cannot be attained (Table 3.1). Its ontology is based on relativism; hence it assumes that study observations are relative and based on context. This is a fundamentally different point of departure from positivism and critical realism, which view study observations as to some degree *real* and thereby representative of a wider generalizable and independent reality. I now go onto to discuss (and advocate) constructivism in more detail.

3.2 Advocating constructivism

Following on from the previous section's critiques, this section is solely dedicated to constructivism, in particular its appropriateness to my two central research questions and the methodological implications of utilising its principles.

The philosophy of constructivism actually subsumes a range of perspectives, all of which share the same purpose:

'What is common to all constructivist approaches is that they examine the relationship to reality by dealing with constructive processes in approaching it.'

(Flick, 2009, p. 69)

Constructivism regards each research study as a specific construction, set within its own specific contextual circumstances. In this way the notion that positivism and critical realism puts forward – that each study is connected to an independent reality governed to some degree by sets of cause-effect relationships – is inherently disregarded.

Put simply, constructions matter. As Moses and Knutsen comment,

'While many constructivists would agree that the physical world is material, concrete and given by nature, they are loathe to accept the same description of the social world.'

(Moses and Knutsen, 2007, p. 193)

Descriptions of the social world differ because of differences in how study realities are constructed. Taking the central research questions of this thesis as an example, investigating how technologies shape practices depends on an array of contextual influences which differ from household to household, and housing development to housing development. For instance, these could include households having: different social circles (e.g. perhaps some friends live in similar dwellings); different past experience with low carbon technologies (e.g. previous home or through work); different institutional support; different financial circumstances; or different low energy

technologies in their new dwellings. Such contextual differences mean that findings from this thesis may potentially provide lessons and insight into other similar studies, but will not be able to directly provide definitive findings that are transferable across different study contexts. This is because knowledge is compiled through common themes that emerge from context-specific individual constructions (Table 3.1).

This process of context-specific knowledge creation contributes to constructivism complementing practice theory approaches and thus also the focus of this thesis. Practices have very strong synergies socially (hence across specific studies/contexts of how a practice is performed), yet there are clear differences in individual performances of those same practices across those studies/contexts. Therefore individuals are doing roughly the same activities to meet roughly the same ends, but in a very local and contextual way. Therefore, what is ultimately integral to theories of practice and constructivism (and thus this thesis' approach) is the prominent role afforded to context. To further emphasise the complementarity between an everyday practices approach and constructivism, as Flick (2009) highlights, I note that parts of the constructivist literature have been built on past research regarding socially derived conventions and shared knowledges in everyday life (e.g. Schütz, 1962; Berger and Luckmann, 1966).

How research is actually carried out in situ is part of the context that shapes how a study's reality is constructed. Whilst constructivist studies do tend to be qualitative rather than quantitative, there is nothing implicit to its thinking (or indeed the qualitative or quantitative data) that dictates this should be the case. This is important when thinking back to this thesis' aims, in considering suitable methodological approaches. I argue that one is able to use the quantitative methods that are more traditionally associated with positivism (e.g. building monitoring; life cycle assessment), providing that the context underlying the data's construction is given due consideration. Such due consideration is especially complementary to this thesis since its research questions and aims are inherently focused upon investigating contextual influences.

All stages of the research shape how the study's reality is finally constructed. For instance, initial planning may shape which method(s) is chosen, which is significant

because each method produces very different types of data. Furthermore, the process of data collection also shapes the final construction. For example, findings from interviews could depend upon the specific questions asked as well as more generally the interviewer-interviewee relationship. The researcher is therefore participating in the research process and directly influencing the study and its findings, and as such researchers need to be reflexive about their role in constructing knowledge (discussed more in *Subsection 3.4.3*). Similarly, decisions made by the researcher during study analyses and dissemination also contribute to a very particular construction of knowledge (e.g. choice of units; identification of qualitative themes; design of a figure or table; how findings are explained in written form in-text).

Consequently, it is difficult to buy into the positivist notion that a researcher can be objective throughout the research process and remain independent of the reality which he/she is studying. This is fundamental to constructivism, and thus humans (as I see it, whether they are those studying or those being studied) are actually ‘observers, participants, and agents who actively generate and transform the patterns through which they construct the realities that fit them’ (Reich, 2009, p. 40).

To summarise: positivism essentially relies on the principles of natural science to understand the social world, in that what is observable is reality. Critical realism acknowledges that this is not always the case, but does not go far enough in fully relinquishing the shackles of a reality that is external to those being researched and those researching a specific phenomenon. In contrast constructivism – the philosophy adopted within this thesis – acknowledges the contextual nature of knowledge: there are no facts, only interpretations that are based on contextual constructions. This philosophy of science is best suited to my research questions since they have been derived from a (practices) literature whereby local context is also paramount. Basing one’s research on constructivist principles has implications for how data is collected and analysed, and this is implicit to much of the following sections.

3.3 Advocating a case study research design

This section begins by outlining what exactly a case study is, before advocating its use in this thesis and discussing the contextual insights it can facilitate.

Different rationales for undertaking case study research have led to differences in how a case study is defined (e.g. Verschuren, 2003; Gerring, 2004). However Simons (2009) argues that what unites different case study approaches is their in-depth exploration of real life context, which, I would argue, is essential if we are to understand performances of everyday practice. Nonetheless, following a review of case study definitions, Thomas settled on the following:

‘Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame—an object—within which the study is conducted and which the case illuminates and explicates.’

(Thomas, 2011, p. 513)

This thesis employs a single case study approach to answer its research questions. As I have previously emphasised, context is vitally important to both theories of practice and constructivism, and it is the attention that a single case study approach gives to context (Stake, 1995) that led to a case study approach being adopted here. Indeed, Yin (2009, p. 4) contends that ‘the distinctive need for case studies arises out of the desire to understand complex social phenomena’. Through the ‘force of example’ (Flyvbjerg, 2006, p. 228), case studies have the capacity to provide considerable detail and depth on specific phenomena. Case studies are thus particularly well suited to exploratory research, which focuses on the *how* and *why* (as per this thesis’ research questions) in addition to the more descriptive *what*. As such, case studies are uniquely positioned to help investigate the ‘little things’ (Flyvbjerg, 2006, p. 238) associated with everyday life. These insights would not be attainable if using more reductive methodological approaches, such as large-scale quantitative surveys, which are unable to sufficiently account for context. Put simply, a single case study approach allows me to know a lot more about one specific

context, as opposed to not very much about numerous contexts. Case study approaches therefore better understand local and contextual performances of practices, and thereby are more likely to equip me with the knowledge required to answer this thesis' central research questions and subsequent aims.

Despite the insights that case studies are capable of providing, case study approaches often receive undue criticism. A key proponent of the case study approach, Flyvbjerg, presents five of these said criticisms and terms them as 'misunderstandings' (Flyvbjerg, 2006, p. 219). He strongly advocates the use of case studies, which he makes clear by rebutting each of these five misunderstandings. His astute arguments are presented in Table 3.2, which makes clear that the majority of misunderstandings can be linked (in)directly to the positivist paradigm and the desire of many researchers to find generalisable conclusions. However, as Flyvbjerg's rebuttals reiterate, there is real value in gaining more context-specific knowledge. Indeed, constructivist thinking would emphasise that this deeper contextual knowledge is essential to fully understand the nuanced themes that cut across different constructions of similar or even different contexts. It is the emergence of such nuanced themes that I see as integral to theoretical progression; as Walton (1992, p. 129) comments, 'case studies are likely to produce the best theory'.

No.	Misunderstanding	Rebuttal
1	‘General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge.’ (Flyvbjerg, 2006, p. 221)	As my previous discussion of constructivism supports (<i>Sections 3.1-3.2</i>), Flyvbjerg argues that universal predictive theories do not exist in the social sciences. Thus context-dependent knowledge is much more valuable than searching in vain for context-independent, generalisable theories. Moreover, the closeness to real-life context-dependent situations provides a nuanced view of reality.
2	‘One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development.’ (Flyvbjerg, 2006, p. 221)	As Rebuttal 1 indicates, searching for generalisable social theories is futile. Nevertheless, Flyvbjerg does argue that generalisations are possible for a specific context, and, as such, case studies can still significantly contribute to scientific and theoretical development. For example investigating ‘critical cases’ (Flyvbjerg, 2006, p. 230) would allow one to deduce whether a theory was applicable to all (or no) other cases on the basis of it (not) being valid for the case under investigation.
3	‘The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypotheses testing and theory building.’ (Flyvbjerg, 2006, p. 221)	As can be inferred from the latter end of Rebuttal 2 (regarding critical cases), case study research can both test and build theories. Case selection is a pivotal factor in ensuring theoretical contributions, which very often involves avoiding a representative or random case sample. As Flyvbjerg (2006, p. 229) explains, ‘atypical or extreme cases often reveal more information because they activate more actors and more basic mechanisms in the situation studied’, as well as increase the generalizability of the case study’s findings (as per the critical case).
4	‘The case study contains a bias toward verification, that is, a tendency to confirm the researcher’s preconceived notions.’ (Flyvbjerg, 2006, p. 221)	Case study approaches are no more biased toward verification than any other method of inquiry. Indeed project experiences indicate that case studies are actually more biased towards falsification of preconceived ideas.
5	‘It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.’ (Flyvbjerg, 2006, p. 221)	Case studies can indeed be difficult to summarise, but this should not nevertheless be shied away from because it is that detail and depth that is a primary strength of case study research. Flyvbjerg goes on to argue that difficulties in summarising case studies are more often due to the properties of the reality being investigated, rather than the case study methodology itself.

Table 3.2 - Rebutting the five misunderstandings of case study research design (produced using Flyvbjerg, 2006)

I finish this section by emphasising that the important empirical, methodological and theoretical contributions of this thesis would not be possible without solely studying a single case. This thesis would look very different if a case study research design was not

adopted, and I would undoubtedly struggle to reach the same level of contextual understanding required to answer this thesis' central research questions.

3.4 Methods of data collection and analysis

This section discusses the data collection methods and analysis. Specific details of the methods (e.g. dates; frequency; specific themes investigated) are not provided in this section. These will be addressed for each thesis aim in each of their respective paper-based results and analysis chapters (*Chapters 5-8*). This section instead more generally critiques the adopted methods, discusses how such data could be interpreted, and briefly outlines how the methods were broadly used for this thesis.

Whilst the section is structured in two distinct subsections – qualitative (3.4.1) and quantitative (3.4.2) data – it will become clear that a mixed methods approach was used. Significant effort was expended on integrating data across the qualitative-quantitative divide so as to mutually inform and guide the process of inquiry.

An overview of all the empirical research conducted during the study is also presented in Table 3.3.

	Household interviews	Building construction data collection	Focused participant observation (key events)	Building monitoring	Household appliance audits	Professional interviews (post- embodied energy analysis)
Apr 2011						
May 2011						
Jun 2011						
Jul 2011						
Aug 2011						
Sep 2011						
Oct 2011						
Nov 2011						
Dec 2011						
Jan 2012						
Feb 2012						
Mar 2012						
Apr 2012						
May 2012						
Jun 2012						
Jul 2012						
Aug 2012						
Sep 2012						
Oct 2012						
Nov 2012						
Dec 2012						
Jan 2013						
Feb 2013						
Mar 2013						

Table 3.3 – Overview of empirical research

3.4.1 Qualitative data

This subsection gives a general overview of the qualitative inquiry used to ‘enhance the data, to increase its bulk, density and complexity’ (Gibbs, 2007, p. 4). This detail gives a richness to the qualitative data that the (usually more reductive) quantitative data is unable to provide, and was essential in understanding how practices were performed in the everyday. Thus the rich qualitative data in large part provided the foundations to the research, which the quantitative data (presented in the *Subsection 3.4.2*) built upon.

3.4.1.1 *Semi-structured interviews*

Interviews formed a key part of this thesis' data collection. Hitchings (2012) demonstrates the value of using interviews to investigate mundane aspects of everyday life, insisting that 'people can talk about their practices'. Hitchings (2012, p. 61) argues against those who believe that interviews, as a product of being retrospective, 'can only ever provide an unsatisfactorily washed out account of what previously took place' (c.f. Thrift and Dewsbury, 2000). By drawing upon two interview projects that investigated thermal comfort related practices in city offices and older person households, he shows how study participants were,

'entirely able to talk about relatively mundane actions, such as continuing to sit in the office or putting blankets over knees at home, that may, in some part, usually be performed unthinkingly. Indeed doing so [talking to people] provided various insights regarding the ease with which routine practices become entrenched and how doing differently could be encouraged.'

(Hitchings, 2012, p. 65)

Despite being a relatively recent paper, others have already come out in support of Hitchings' arguments (e.g. de Vet, 2013). Interviews therefore form a fundamental part of my mixed methods approach.

All interviews, whatever their format, had a pre-organised interview schedule which loosely framed the direction of discussion. This semi-structured nature enabled the interview to unfold in accordance with the interview schedule's key questions and topics of focus, yet in a relatively informal and conversational manner that afforded study participants with the opportunity and flexibility to explore issues they regarded as important (Longhurst, 2010). Please consult *Appendices 1-4* for the interview schedules used for this thesis. The order of the interview schedule was not rigidly followed, yet all of its questions or topics were usually always covered, be it directly or indirectly. The interviews were recorded using a dictaphone, and then transcribed. Please see *Appendix 5* for an extract of an interview transcription.

I was keen for the interviews to be relatively interactive by basing the discussion on or around something, be it embodied energy data, building monitoring outputs, or the appliance audit (discussed more in *Subsection 3.4.2*). Indeed one round of the household interviews was recorded whilst moving around their home. This type of interview format is often referred to as the audio tour or ethnographic interview, and has successfully been used by others researching everyday life (e.g. Bakardjieva and Smith, 2001; Powell, 2009; Pierce *et al.*, 2010; Macrorie, 2012). The purpose was to make the discussion more tangible with residents explaining how they use certain technologies (e.g. MVHR control panel; boiler controls; solar gain blinds; appliances) in the very locations that they use them. As Hinton notes, in relation to using the said interview method in researching the performance of thermal comfort related practices in the home,

‘through focusing questions on these [thermal comfort related] practices in the particular places that the practices occur we should be better able to understand the ways that individuals exert agency in their interactions with related socio-technical systems, and the ways that these systems constrain and enable particular forms of practice and particular experiences’

(Hinton, 2010, p. 35)

This shift towards more interactivity provided prompts and a basis for discussion, as memories of performing practices came to the fore. At times it even resulted in the interviewees enacting how a practice was performed, which provided data beyond that of merely talking about what they did.

3.4.1.2 Participant observation and field diary notes

It was crucial that qualitative data was not only limited to ‘wordy worlds’ (Crang, 2003, p. 501), as the audio tours described above started to do. Data collection and analysis needed to go further than post-hoc accounts of how practices are performed. However, as it was not practical to live with the households and participate in their day-to-day life, I was unable to directly observe how practices were performed. Likewise, observing designing and constructing practices in situ could not be organised due to the scheme’s timescales conflicting with my own research timeline. Therefore no complete

participation was undertaken (see Bryman (2012) for the spectrum of field roles and participation in ethnographic research). Instead I participated in as many housing association organised events as possible. These included being involved or present during construction site visits, pre-move-in information sessions, move-in day handover procedures, technology tours and explanations, de-snagging (when *snags* [problems; predominantly technological faults] are reported by residents), official opening day, and project review meetings. Therefore data was predominantly collected through *focused participant observation* that concentrated on 'significant moments' (Styaert and Bouwen, 1994, p. 137). I also crossed paths with several residents (e.g. as they were walking their dogs) when I was attending nearby meetings or interviewing other residents, and these sorts of opportunistic interactions also proved fruitful.

All of these experiences were noted in a field diary. There is no agreed definition or approach to producing a field diary (Emerson *et al.*, 2011), which Sanjek (1990) found could consist of a range of different written forms (e.g. headnotes, scratch notes, fieldnotes). Nevertheless, I feel the overarching purpose of making such notes is nicely captured by Emerson *et al.*:

'Fieldnotes are a form of representation, that is, a way of reducing just-observed events, persons and places to written accounts. And in reducing the welter and confusion of the social world to written words, fieldnotes (re)constitute that world in preserved forms that can be reviewed, studied and thought about time and time again.'

(Emerson *et al.*, 2001, p. 353)

Whilst my field diary primarily noted participant observation related activities, diary entries were also made for the interviews (see *Appendix 6* for an extract). Short-hand entries and key words were noted in a notebook as close to the actual moments of interest taking place. However this was not always possible, particularly when sharing lifts with other members of the scheme's project team. Nevertheless whatever state my initial short-hand notes were in, I was always sure to type them up into a narrative as soon as practically possible (usually upon my return home that same day). It was important that the final long-hand version was produced as soon as possible because otherwise details may have been lost, which could have been especially detrimental to data collection and

analysis since, as Emerson *et al.* (2001, p. 353) note above, it is only in the written form that these details are preserved for future review, study and thought.

Writing the field diary was an evolving process. My first field diary entry was from the pre-move-in information evening, at which I first presented my research, listened to presentations from the design team, met the residents, visited the construction site with the residents, and addressed (with the housing association) resident queries regarding Passivhaus and moving more generally. Although the whole event only last around two and half hours, I felt I had a lot to write about. I was interested in the order of events, presentation content, Passivhaus explanations, resident queries, exchanges and interactions, impressions and feelings, ideas for future notetaking and analysis, methodological observations, as well as every other relevant thought that crossed my mind. Nevertheless as I became more involved and, crucially, learnt more from my ongoing data analysis, I became more adept with my field diary entries, both when doing the final write up and when considering what was noteworthy when out in the field. Therefore the initial, and indeed, intentionally, open frame gradually closed and became more focused.

3were analysed. Following a relatively quick read through to refresh myself and begin the process of immersing myself in the data, I used NVivo software to systematically code the data. Whilst I acknowledge that the decision to use electronic, over manual, methods of coding depends upon the context of each research project (Basil, 2003), I personally found the electronic approach (using NVivo version 9) to be more time efficient when dealing with large amounts of data.

In line with constructivist thinking that data and theory are constructed by the researcher's interactions in the field, I begun by letting the transcripts and diary lead the analysis. Statements of varying length (from phrases to sentences to paragraphs) were assigned codes according to their meaning and content. A code is:

‘most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data.’

(Saldaña, 2013, p. 3)

I coded the data using a broad guiding focus: *everyday life and interacting with technologies*. As part of this approach, I undertook coding without using theory for direct guidance, instead basing it on the data (see *Appendix 7* for the results of initial coding, and *Appendix 8* for an extract from a coded interview transcription). However after doing this for each of the four thesis aims, it became clear that the emergent themes were often bundling around the elements of practice (see *Subsection 2.5.2* for background). If a theme could not be hierarchically ordered under the elements, then it could usually be shown to be a product of how the elements were configured. It is for these reasons that the elements of practice feature heavily in the results and analysis chapters (5-8). My view is that whilst it was vital that my particular construction of the data guided analysis and research outputs, interpretation could nevertheless benefit from the knowledge of past theoretical debate, without the assertion that those theories offer a generalisable solution to my own research's context and particular construction. As such, my analysis was in part inductive and deductive.

In addition to these more formal coding efforts, I also found myself constantly analysing and digesting the data in a much less formal manner. Sometimes this was conscious, other times not, and could be in response to: notemaking, transcribing, receiving feedback from colleagues, reading more into the theory, writing up my findings, or even waking up in the middle of the night with an idea. The findings and their analysis were very often all absorbing. This process actually helped to inform and offer critique throughout data collection, and thereby iteratively evolve my approach, gradually narrow my methodological frame and focus my efforts more efficiently – it thus also contributed to a blurring of the boundary between data collection and data analysis.

Throughout my research, I tried to remain mindful that my role as a researcher was considerably influencing how the data was collected, analysed and presented (and thus constructed as a whole; see *Section 3.2* for more). With this acknowledgement, it was essential that I was reflexive with regard to how my own positionality implicated constructions of everyday life:

'reflexivity is self-critical sympathetic introspection and the self-conscious analytical scrutiny of the self as researcher. Indeed reflexivity is critical to the conduct of fieldwork; it induces self-discovery and can lead to insights and new hypotheses about the research questions. A more reflexive and flexible approach to fieldwork allows the researcher to be more open to any challenges to their theoretical position that fieldwork almost inevitably raises.'

(England, 1994, p. 244)

Participant observation and interviews, as indeed were the quantitative methods undertaken, are active performances (Denzin, 2001) which I participated in and thereby influenced. Such influences include, for example: which questions I posed and how I delivered them, my presence more generally, as well as the relationship and rapport (or potentially lack thereof) between the study participant and I.

3.4.2 Quantitative data

This subsection demonstrates how the quantitative data provide an additional dimension that builds on the qualitative inquiry. Firstly, I take the approach of interpreting the quantitative data as records, traces, by-products, or artefacts (or indeed however one may wish to term them) of performing everyday practices. Without qualitative data there would be insufficient understanding of these performances; the quantitative data thereby help to enhance interpretation of the qualitative data. Secondly, the quantitative data were used as discussion points with study participants so as to aid understanding of quantitative trends and generate further qualitative data. I hope thus to make clear in this subsection that the quantitative inquiry forms part of a wider integrated and mixed methods approach. The quantitative data are hence not merely an output of the methods, but also a means for generating new interdisciplinary output.

To reiterate, the diversification of methods was to gain further perspective through (and to mutually inform and critique) different constructions of how everyday life was performed in relation to new technologies offered by the Passivhaus development. The mixed methods were not part of an attempt to triangulate (double/triple check) data so as to produce a one clear and definitive truth (c.f. Denzin, 1978).

3.4.2.1 Building monitoring

The building monitoring data collected include indoor temperature, humidity and carbon dioxide levels in addition to sub-metered energy consumption (see *Appendix 9* for the full list of monitoring variables and for an extract from the monitoring records). I have approximately 16 months' worth of building monitoring data, collected at (at least) five minute intervals. Problems with the sensors (e.g. calibrated or installed incorrectly) and internet connection (e.g. Wi-Fi router breaking; residents turning the Wi-Fi off; super insulation interrupting the Wi-Fi signal; power cuts) led to a few minor omissions within dataset.

How such data fit theoretically with theories of social practice is the subject of the targeted literature which addresses thesis aim 2 in *Chapter 6*. Nevertheless, to briefly summarise, these data can be taken as proxies of practices being performed. Technological interactions are part of performing practices, and that is what building monitoring can provide insight on. These insights can be contrasted against and/or used to enhance findings from qualitative inquiry.

Building monitoring is also used as a basis for discussion during one of the rounds of resident interviews. This was to give them something tangible to hang our discussion on. Reflections on this process are also provided in *Chapter 6*.

3.4.2.2 Appliance audits

Domestic electrical appliances are used to sustain various domestic everyday practices. By undertaking an audit of the appliances (e.g. noting the specification; type; number of appliances), one can thus gain insight into the sorts of technologies that influence and are influenced by practices (see *Appendix 10* for a blank copy of the appliance audit). Therefore conducting an appliance audit before and after move-in (one per household) enabled consideration of how specific appliances changed, in response to practices changing as a consequence of moving into a Passivhaus dwelling. The pre- and post-

move-in comparisons provide insight into how technological provision (in this case, Passivhaus design) shaped what other everyday technologies (appliances) were used as part of everyday life.

The appliance audits were also used as discussion pieces as part of one pre-move-in and post-move-in interview. It was this broader discussion that led me to significantly annotate the appliance audits, so as to not miss out on the additional detail. This was anticipated prior to the interviews, and, as such, meant that I did not get too caught up in how best to construct the appliance audits. Instead, I acknowledged that a questionnaire-based audit form would struggle to meaningfully collect data on why new appliances were purchased and old appliances disposed of, particularly with regard to deeper (unconscious) social influences. Furthermore, even answering a question as simple as ‘when was the appliance purchased?’ could often be couched in uncertainty and/or with numerous caveats associated with that particular household’s context. In addition to this, evidence indicates that significant limitations exist in taking a reductive questionnaire approach when trying to understand a notion as fluid and dynamic as everyday life (Burgess *et al.*, 2003). I therefore designed the appliance audit forms on the basis that they were simple and accessible, with adequate space for significant annotation. It was crucial, again, that this more quantitative method was not the final output, but instead a platform for further qualitative investigation that could get closer to the influences of changes in practice (and appliance-related requirements). This flexible approach was made possible because I led the completion of the audit forms – instead of the residents completing it by themselves – meaning that I could respond to any queries they had, lead discussion when relevant, and even ignore the structure of the questionnaire when appropriate.

When carrying out the appliance audits, photographs were also taken of key common appliances (specifically: television, washing machine, tumble dryer, dishwasher, oven, microwave, refrigerator, freezer). These photographs acted as a record of each appliance’s positioning in their respective rooms and dwellings, in addition to providing information that helped to guide research into each appliance’s specification (e.g. energy efficiency, age). See *Appendix 11* for two examples of such photographs.

Whilst the broader findings of the appliance audit-related data collection were utilised in all of the household-focused papers (*Chapters 5-7*), explicit reference is made to them when investigating appliance ownership changes in *Chapter 7*.

3.4.2.3 Building construction data

The vision of the designer was given a physical and tangible place in the world by constructors. Insights into the practices of designing and constructing can thus be gleaned from examining building construction data, which can thereby be taken as proxies of practice. The construction data collected for this thesis included: onsite energy consumption; material and components constituting the building itself; construction waste; and transportation (see *Appendix 12* for extracts of the raw data used).

These by-products of performing practices come with energy and carbon consequences, which can be quantified in terms of the amount embodied in the construction. By considering these data in terms of energy and/or carbon, the wider implications of the way designing and constructing practices are performed can be considered. Such implications are of huge importance if, like Passivhaus, the key driver behind the design and construction of the building(s) is to save energy/carbon.

The energy and carbon implications of the development's construction materials were calculated using a range of conversion factors, which formed the basis for a tailor-made spreadsheet that led the analysis. The analytical process is discussed in more detail in *Chapter 8*.

3.5 Ethical research principles

In maintaining a high ethical standard, the UK Economic and Social Research Council (ESRC, 2012), UK Research Integrity Office (UKRIO, 2009) and University of East Anglia

(UEA, 2012a, 2012b) ethical codes of practice were adhered to throughout the research process (i.e. from initial research design to project finish). This section discusses what this involved, and the sorts of considerations and contingencies that were specifically put in place. Specific attention is given to issues of informed consent, confidentiality and professionalism.

The UEA Research Ethics Policy defines informed consent as,

‘the process whereby a prospective participant, prior to participating in research, is fully informed about all aspects of the research project which might influence their willingness to participate, in a language which the participant understands. In addition, the researcher should normally explain all other aspects of the research about which the prospective participants enquire. The basis of this is to provide free and voluntary consent.’

(UEA, 2012a, p. 6)

In ensuring that study participants had informed consent, the following steps were taken:

- a pre-move-in presentation outlining my research was given to all households and project management team;
- the purpose of my research was briefly reiterated when arranging interviews over the telephone;
- the research was explained in detail upon arrival and before officially commencing an interview;
- a project information sheet accompanied the research study’s consent form (see *Appendices 13-14*), with the consent form including a tick box stating that they understood and were happy with information sheet’s contents (e.g. that I would also collect data through participant observation);
- as soon as the dictaphone began recording, study participants were asked once again (on the record) whether they were happy to be recorded;
- after the interview had finished, I reiterated the key issues to the interviewees as well as emphasised that they were entitled to contact me should they want to strike something off the record;

- after data collection had finished, a feedback meeting was held in a local village hall to present key findings and interpretations to the residents and project team.

Throughout all of these stages, I was sure to not rush the study participants and always insist that there was time for me to address any queries that they may have had.

Further, as one of the ESRC's key principles of ethical research notes,

'the confidentiality of information supplied by research participants and the anonymity of respondents must be respected.'

(ESRC, 2012, p. 3)

To protect the identity of study participants, all interview recordings and transcripts were labelled with a randomly assigned code; they were not connected, for example, to the order in which they undertaken, household characteristics or house number.

Care needed to be taken when writing up and presenting the research, as a consequence of the in depth knowledge I had acquired of household everyday life. For instance, it would be inappropriate to give a level of detail whereby it was clear (to neighbours and landlords) which households performed practices in socially undesirable ways that conflicted with social conventions (e.g. rarely showered or bathed). I was particularly mindful of this when analysing building monitoring data because the data could provide insight on household everyday life (e.g. when they showered; whether they cooked with microwave; how often they had friends visits), even if the household had not wanted to divulge that information themselves during the interviews.

Additional steps were needed to ensure anonymity of study participants since there are so few Passivhaus developments in the UK. Indeed protecting the identity of the Passivhaus scheme was part of the agreement struck with the housing association when I was initially afforded access. Effort was therefore made to protect the identity of the scheme, so as to ensure the identity of the study participants was also protected.

In addition to being responsible for the interests of the study participants, researchers also have a duty to report study findings honestly and accurately. Indeed as a UK Research Council funded researcher, I am,

‘expected to observe the highest standards of integrity, honesty and professionalism and to embed good practice in every aspect.’

(RCUK, 2013, p. 3)

Maintaining the researcher-participant boundaries that come with professionalism was something that I was frequently mindful of. At times it was somewhat of a balancing act because, for example, on the one hand I met the participants regularly (through interviews and informal interaction) with the intention of trying to develop a relationship and build trust, yet the more I got to know them, the more vulnerable I became to internal politics (e.g. neighbourly disagreements regarding noise or leaving the communal door open). In such situations it was crucial that I was not seen to become involved or pass judgement.

Furthermore, in accordance with a professional approach, the post-data-collection feedback meeting provided an opportunity to: present the study findings back to the study participants; hear their views on the study findings (e.g. correct interpretation of what they had said); detail what was being and what will be done with these findings (e.g. conference presentations; publications; reports in the mainstream media); and answer any final queries that they may have. The meeting also provided a chance to give something back to the study participants, since without them the research would not have been possible. For the housing development’s project team, they were grateful for evidence on how (in)effective the design was and of household experiences in general. For the households, customised (on a per household basis) recommendation reports were produced, so as to help them improve indoor air quality and/or save energy. These reports also included building monitoring figures and tables, which the households were keen to see.

Chapter 4 – Passivhaus

This chapter introduces the Passivhaus building standard so as to give detailed background context on the case study itself. Therefore, by its very nature, this chapter is predominantly descriptive. It begins by defining Passivhaus and what exactly Passivhaus certification requires, before discussing common design characteristics. History of the Passivhaus standard and how it has been utilised in policy circles (as a technological fix) is then discussed, prior to finishing the chapter with a brief review of Passivhaus research to date and how adopting a Passivhaus case study complements this thesis' research questions and subsequent aims.

It is important to emphasise that I consciously make reference to Passivhaus, as opposed to the English translation, Passive House or (the less commonly referred to, but accurate) Passive Building. This is a topic that has received a lot of debate in the Passivhaus as well as broader energy and buildings community (e.g. Antonelli, 2013). I regard Passivhaus as an approach in itself, which can only be achieved through meeting several very specific criteria that have been approved by the Passivhaus (or as they usually present themselves, Passive House) Institute. To call it Passive House, as many do, I see as potentially confusing. For example, Passivhaus buildings are certainly not passively ventilated since they rely on an active ventilation system. In addition, Schiano-Phan *et al.* (2008, p. 2) highlight further ambiguity in that in southern Europe (e.g. Spain, Italy, Portugal, Greece) a 'passive house generally means any house constructed in line with the principles of passive solar design', yet Passivhaus do not only rely on passive solar gain for achieving heating fuel reductions. Furthermore, the Passivhaus standard is used in commercial contexts; thus are not only houses.

Passivhaus is therefore a specific brand, and, as such, requires a certain way of designing and constructing which in turn produces very similar technological configurations that make up the building one is occupying. It is the use of this specific brand, as a technological solution to reducing energy and carbon emissions, that is investigated in answering this thesis' research questions.

4.1 What is the Passivhaus standard?

Passivhaus is a voluntary standard for building energy efficiency, which originated in Germany in the early 1990s but has since been utilised internationally. Although mainly applied to new buildings, it has also been used in refurbishments to a lesser degree. The Passivhaus standard is not solely for the residential sector, with commercial buildings such as offices, schools, and shops also being constructed to meet the standard. To officially meet the Passivhaus standard, a dwelling must be officially certified by the Passive House Institute based in Darmstadt, Germany.

A Passivhaus building, as defined by Passive House Institute, is as follows:

‘A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air.’

(International Passive House Association, 2013a)

This definition is largely associated with, and as I see it is only part of, what the Passivhaus end product entails. To fully understand what a Passivhaus building encompasses, one must go further and consider the specific criteria required for Passivhaus certification. Passivhaus buildings achieve energy reductions because of the demands inherent to these very criteria, primarily through how the need for space heating or cooling is minimised. Indeed buildings stay warm passively from people, solar gain and appliances, meaning for example, that one could heat their house with a hair dryer or even a small number of candles. Figure 4.1 details the modelling expectations for the heat loss and gains of a typical Passivhaus dwelling.

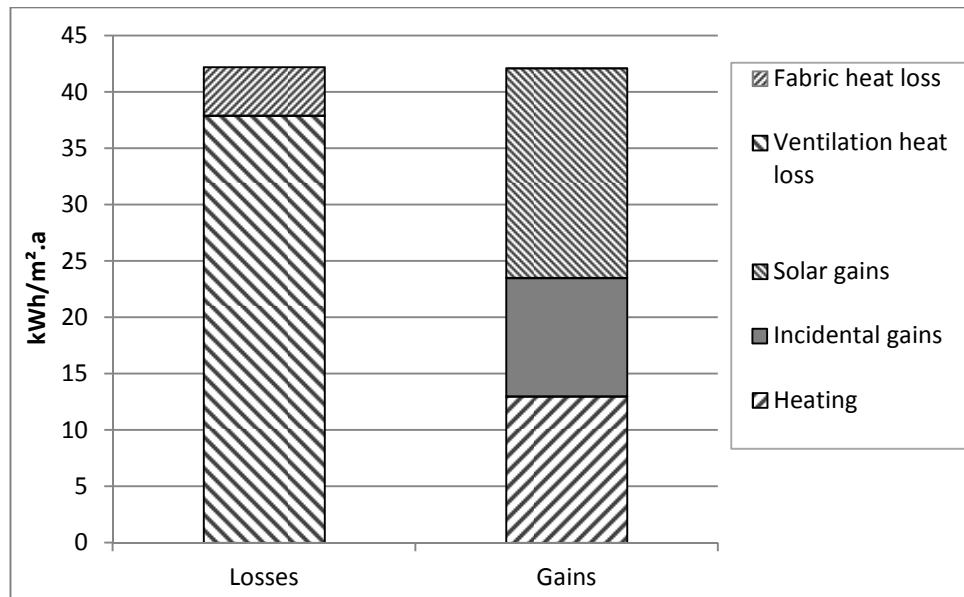


Figure 4.1 - Heat energy losses and gains in a typical Passivhaus. Source: Feist *et al.* (2005, p. 1187).

The balance between heat energy losses (fabric, ventilation) and passive heat gains (solar, incidental, heating) is achieved because of the stringent and relatively innovative requirements of the Passivhaus standard. These minimum energy efficiency requirements are (Cotterell and Dadeby, 2012; International Passive House Association, 2013b; Passivhaus Trust, 2013a):

A(i). Space heating/cooling demand $\leq 15 \text{ kWh/m}^2 \cdot \text{a}$

As with all these requirements, they do not change depending on geography or context. Therefore this energy demand (of regulating indoor temperatures) must be adhered to whether, for instance, the Passivhaus building is in a tropical or colder climate (Passive House Institute, 2012). Indeed this is why both heating and cooling are explicitly included.

Or instead of A(i), adhering to A(ii) is an accepted alternative.

A(ii). Heating load $\leq 10 \text{ W/m}^2$

The specific heating load is essentially the peak power of heating the building at one given moment in time (not over a period of time, as the space heating/cooling

demand [A(i)] addresses). This peak power is calculated in terms of maintaining 20°C internally when it is -10°C externally.

B. *Annual primary energy demand $\leq 120 \text{ kWh/m}^2 \cdot \text{a}$*

This includes all building applications, and thereby covers all the energy demands of the building. Note that there is an explicit focus on primary energy (i.e. the amount of energy produced at the point of generation [e.g. fossil fuel power station], prior to transmission), rather than delivered energy (i.e. the amount of energy used at the point of consumption [e.g. in the home]).

C. *Airtightness $< 0.6 \text{ ac/h}$ at a pressure difference of 50Pa*

Natural ventilation must be reduced to less than 0.6 air changes per hour (ac/h), so as to reduce ventilation heat losses to a level that does not inhibit the heating load reductions detailed in A(i) and A(ii). Since 0 ac/h is not targeted, describing Passivhaus buildings as 'airtight', as indeed many do, is not actually accurate. Passivhaus buildings are merely relatively airtight compared to more conventional builds. A typical dwelling in the UK building stock has around 12-14 ac/h (Schnieders and Hermelink, 2006). Both current and previous UK Building Regulations ask for new dwellings to be designed to an air permeability of 10 m³/(h.m²) (HM Government, 2006, 2010), which is around 6 ac/h at 50Pa.

D. *Excessive temperature frequency ($> 25^\circ\text{C}$ for $\leq 10\%$ of the year)*

Passive heat gains (solar and occupant-related) are so effective at reducing the heating load that efforts are needed to ensure that overheating does not occur and thermal comfort is maintained.

All of these requirements are only met, and thus Passivhaus certification awarded, through the Passivhaus Planning Package (PHPP) excel-based assessment software. This is important to remember when considering, for instance, how much energy is actually consumed or the risk of overheating ($> 25^\circ\text{C}$ for $\leq 10\%$ of the year) from appliances.

4.2 Common design characteristics

Whilst the following are not part of the Passivhaus assessment criteria, they are almost always adopted either in a bid to achieve or as a consequence of achieving the Passivhaus requirements which were set out in the previous section (Cotterell and Dadeby, 2012; International Passive House Association, 2013b; Passivhaus Trust, 2013a):

A. *Super insulation*

Insulation plays an important role in reducing fabric heat losses, and, as such, it is common for additional external insulation and triple glazing to be installed in addition to loft insulation being around 500mm thick. There is no one way to insulate a Passivhaus building because it depends on the broader construction approach taken – again, what is essential is that the assessment criteria (previously presented) are achieved.

B. *Minimising thermal bridges*

This super insulation needs to wrap continuously around the building, and in doing so leave no gaps, between the building elements (e.g. walls, floors, roofs). Otherwise, if high conductivity materials infiltrate the insulation layers, then there will be a path whereby heat can be lost through bypassing the low conductivity materials (insulation). A commonly described analogy here is that of the tea pot (the building) and tea cosy (insulation). Any sort of hole (thermal bridge) in the tea cosy will provide a means for the heat to flood out. It is thus vital that thermal bridges, or cold bridges as they are often known, are minimised through design and construction.

C. *Mechanical ventilation with heat recovery (MVHR)*

As a consequence of relative airtightness being reached, mechanical ventilation is needed to ensure adequate air quality for health purposes. In addition, heat recovery is needed to make this process energy efficient and the whole airtightness approach essentially worthwhile. A ventilation system's heat recovery unit has a heat exchanger within it, which typically ensures 80-90% of the heat in

the outgoing air is transferred to the incoming air. Without this, potentially vast amounts of heat energy could be pumped out as a by-product of adequately ventilating the building.

D. *Passive solar gain*

Buildings often have large south-facing windows. To accompany these, much smaller north-facing windows are typical because obviously there would be no direct sunlight and the glazing would have higher fabric heat loss rates than external walls. Moreover, such is the effectiveness of being south-facing, that solar shading (e.g. brise soleil, internal solar blinds) is commonly installed to inhibit overheating. Whilst facing south is the ideal scenario, buildings can still be Passivhaus-certified if east/west-facing; it merely requires a slight change in design. This is important to note since site-related restrictions for new builds and, in particular, retrofitting projects may not give one the luxury of facing south.

E. *Low energy appliances*

Low energy consuming appliances are needed to meet the low primary energy demand (which covers all building applications). The benefit of this is that efficient appliances consume relatively less energy, generating less heat inside the dwelling, and thereby inhibiting overheating. Indeed, it is usually recommended that energy efficient appliances are pre-installed and sold with the dwelling itself (e.g. as part of a fitted kitchen), so as to minimise the chance of residents bringing in their own, perhaps inefficient, appliances from their previous home. However appliances may not necessarily be provided if landlords are not keen to take on their associated maintenance responsibility (as was the situation for this thesis' case study).

F. *Hot water supply uses renewable technologies*

Whilst assessment criteria A (i and ii, on pages 86-87) focuses solely on space heating, attention to the primary energy demand of all building applications (assessment criteria B) broadens the focus and, thus, also encompasses water heating. Energy efficiency measures can only go so far in achieving this lower

primary energy demand, leading one to consider renewable supplies of energy. Renewables are particularly complementary with Passivhaus because the enhanced airtightness removes the need for heating system temperatures higher than 50°C (Badescu and Sicre, 2003a, 2003b). It is common for solar thermal systems to be installed, the exact details of which vary from project to project.

The requirements and common design characteristics implicitly make clear that constructing to the Passivhaus standard (e.g. airtightness, super insulation, minimal thermal bridges, MVHR) establishes a clear internal-external divide. This essentially creates a fairly isolated internal environment which maintains relatively constant conditions relative to outside variations. For example, internal temperatures remain relatively constant over night and day, as well as between summer and winter. This internal-external barrier is central to how households living in Passivhaus dwellings usually consume less energy than those living in more conventional UK dwellings. The barrier allows for heat to be, in part, passively generated through everyday life – this is in contrast to the passively heated buildings of the past which relied almost solely on south-facing solar gain (with some minimal heating), as well as current low energy buildings which predominantly rely on renewable energy generation for electricity and hot water.

4.3 History of Passivhaus

The underlying concepts of Passivhaus were founded by Wolfgang Feist (Institute for Housing and the Environment, Germany) and Bo Adamson (Lund University, Sweden) who had both been working and publishing extensively on low energy dwelling design. They applied the Passivhaus design approach to a new build development in Darmstadt-Kranichstein in 1990, with residents occupying the four terrace houses the next year. Energy consumption was measured and, relative to the wider German housing stock, savings in the region of 85-90% were consistently achieved year after year.

The Passipedia website – an online Passivhaus encyclopaedia, provided by the International Passive House Association (iPHA) – accredits Amory Lovins, a leading US

energy efficiency figure, with a role in moving Passivhaus from this demonstration phase to a formal standard. Lovins visited the Darmstadt project in 1995 and is quoted as saying:

‘No, this is not just a scientific experiment. This is the solution. You will just have to redesign the details in order to reduce the additional costs - and that will be possible, I am convinced.’

(International Passive House Association, 2013g)

This sort of encouragement in tandem with proven energy savings, following a second development in Groß-Umstadt in 1995, led to Feist codifying the design approach into the Passivhaus standard. The Passive House Institute was founded in September 1996 to both further the energy efficient Passivhaus building standard and act as a body for certification. I would speculate that the development of the Passive House Institute was significantly shaped by a deep-rooted confidence that an energy saving, in Lovin’s words, ‘solution’ can come from technological intervention (Passivhaus) alone.

Following the construction of the first Passivhaus dwelling in Darmstadt in 1991 (Figure 4.2), expansion initially occurred relatively gradually, with Austria’s first houses in 2000, Sweden in 2001, Italy 2002, US 2003, Ireland 2005, and the UK in 2010 (Cox, 2005; Green Building Store, 2012). The majority of Passivhaus buildings have been built in Germany and Austria. Geographic differences, in terms of Passivhaus expansion, are considered in the following section.



Figure 4.2 – The first Passivhaus building, Darmstadt-Kranichstein, Germany. Source: Wolfgang Feist (International Passive House Association, 2013g).

4.4 Application of the Passivhaus concept

4.4.1 An international focus

As of 2012, there were over 37,000 Passivhaus buildings in use worldwide. Most of these Passivhaus buildings can be found in Europe, with 20,000 in Germany alone (Cutland, 2012). Such has been the momentum that Passivhaus gathered in central Europe that a (failed) 2008 European Parliament Resolution proposed that all new EU buildings should reach Passivhaus or equivalent standards (Official Journal of the European Union, 2008). Projects outside Europe have also demonstrated that buildings can be constructed to Passivhaus across a number of international and climatic contexts, such as Mexico (International Passive House Association, 2013d), the United States (Parker, 2009), and New Zealand (Grove-Smith and Schnieders, 2011).

Around 25 million inhabitants live across, as the International Passive House Association call them, 27 EU Passivhaus 'hot spots' (Mekjian, 2011). These hot spots have Passivhaus embedded in the specific area's planning policies and/or building regulations as a minimum requirement. The majority of these hot spots are in Germany, and Table 4.1 details their specific legislative requirements. The two other significant hot spots are in Belgium. First, in June 2013 the province of Antwerp became committed to all new buildings and complete renovations in the public sector being Passivhaus. Second, is the capital region of Brussels, which goes even further by demanding that all new buildings and retrofits, whatever the sector, will have to be Passivhaus from January 2015 onwards (International Passive House Association, 2013e). Therefore policy-makers are beginning to publicly commit legislation to the Passivhaus brand, making it a clear contributor to Europe's future dwelling stock.

Location	Description
States:	
Bavaria	All public new builds will be built to Passivhaus standard. Agreed by council ministers on 19 July 2011.
Hesse	All public new builds, as of September 2012, must be of Passivhaus standard.
Rhineland-Palatinate	All public new build and retrofit projects must be reviewed to determine whether the buildings can feasibly meet the Passivhaus standard. This was from 2010 onwards, in response to the target of becoming a carbon neutral state administration.
Saarland	All new public buildings must be Passivhaus, in addition to it being a central guideline for the retrofitting of all public buildings.
Cities:	
Bremen	In response to the city's target of 50% lower CO ₂ emissions from public buildings, all new public buildings will be built to Passivhaus. Agreed on 25 August 2009, coming into force on 1 January 2010.
Frankfurt	All new public buildings, in addition to any other buildings built as part of the public-private partnership model, must meet the Passivhaus standard. Originated from a 6 September 2007 resolution.
Freiburg	All new dwellings had to meet the Passivhaus standard from 2011 onwards. Originated from a 22 July 2008 resolution.
Hamburg	Municipal funding for new housing was, from 2012 onwards, only available to projects meeting the Passivhaus standard.
Cologne	As of 26 April 2008, all buildings built in the city must be Passivhaus.
Leipzig	All new public buildings and buildings built through public-private partnerships must be Passivhaus. Originated from a 19 March 2008 resolution.
Leverkusen	As of 16 February 2009, all new buildings must be Passivhaus. In addition, a target of retrofitting 50% of existing buildings to Passivhaus standard was also put in place.
Nuremberg	All new buildings must be Passivhaus.
Walldorf	All new buildings built for and by the municipality must be Passivhaus. Originally passed on 20 July 2010.
Districts:	
Darmstadt-Dieburg	All new schools, managed by Da Di-Werk, are to be Passivhaus.

Table 4.1 – Summary of mandatory Passivhaus building regulation requirements in Germany (Produced using information collated by the International Passive House Association (2013e); see this source for links to each respective legislation document).

Other countries have been significantly influenced by the Passivhaus standard, or at least the debate it has triggered around constructing super insulated and airtight buildings. The building regulations and planning guidelines of these countries may not require that the Passivhaus brand, as per the Passive House Institute in Darmstadt, be met as a minimum.

For instance, from 2015 Finnish dwellings must meet the Finland's own 'Passive House' definition (again, emphasising the need for differentiation from the Passivhaus brand), which is similarly based on achieving high energy reductions through super insulation and airtightness (GBPN, 2013). Atanasiu *et al.* (2011) provide evidence showing how national building policies across Europe, and specifically how these policies define a zero energy house, have been inspired by Passivhaus.

The Passivhaus standard is thus making waves in energy and building policies across Europe, which is in turn beginning to attract further attention globally. It is internationally regarded as a solution to reducing energy consumption in the built environment.

4.4.2 UK focus

The first Passivhaus-certified building in the UK was a multi-purpose office building in Machynlleth, Wales (Figure 4.3). It was completed in August 2008, and was occupied in January 2009. Table 4.2 provides background information on the first new build Passivhaus dwelling, office building and educational building in the UK.



Figure 4.3 – The UK's first certified Passivhaus building: A multi-occupancy office building (Canolfan Hyddgen [the Stag Centre]) in Machynlleth, Wales. Source: Passivhaus Trust (2013b).

The first Passivhaus-certified...	Location	Completion date (month, year)	Project	For more information:
...dwelling	Wales, and the UK	Winter 2009 [*]	Y Foel, Machynlleth	Tiramani (2013)
	England	August 2010	Underhill House, Moreton-in-Marsh	Passivhaus Trust (2013b)
	Scotland	April 2010	Tigh-Na-Cladach, Dunoon	Ford and Hill (2011)
...office building	Wales, and the UK	August 2008	Canolfan Hyddgen, Machynlleth	Passivhaus Trust (2013c)
	England	February 2010	Centre for Disability Studies, Essex	Simmonds.Mills (2010)
...educational building	England, and the UK	February 2010	Hadlow College, Kent	Passivhaus Trust (2012a)

Table 4.2 – Background information on the first Passivhaus-certified new builds in the UK

^{*} Unable to determine specific month of completion. Winter has been assumed here because the client's online diary (Tiramani, 2010) refers to receiving the completion certificate in January 2010, but only after months of struggles. This is supported by Passive Trust (2013d) literature which states that completion was in 2009, thus in the months prior to them receiving the certificate itself.

There are currently 271 Passivhaus units in the Great Britain, where both one dwelling and 100m² of treated commercial floor area equals one unit (International Passive House Association, 2013f). However, primarily because of the cost associated with certification (in addition to Passivhaus construction already being more expensive), many project managers are deciding not to officially certify their units. Instead, designers and constructors may have to prove in other ways (to the client) that the standard has been reached, without having it officially rubber stamped by the Institute itself. For example, the project in Tigh-Na-Cladach only had one of its 10 units officially certified (Passivhaus Trust, 2013e). Therefore it is likely that the figure of 271 Passivhaus units may be a slightly conservative figure, if searching for a figure of how many households or sets of commercial occupants have been exposed to Passivhaus technological surroundings. Either way, relatively few Passivhaus buildings exist in the UK.

The number of Passivhaus-certified new build construction projects being completed year on year is increasing (Figure 4.4). Nevertheless, as the total number of Passivhaus units indicates, whilst Passivhaus is gathering momentum it still remains a relatively niche building standard in the UK. Indeed, such is the state of knowledge in the UK Passivhaus

community, that frequent attempts are made to learn from German counterparts who have already successfully transitioned Passivhaus from a niche to a mainstream construction approach (e.g. Cutland, 2012). One could therefore speculate that the UK public is not only likely to be unfamiliar with Passivhaus technologies, but also unaware of Passivhaus as a concept more generally.

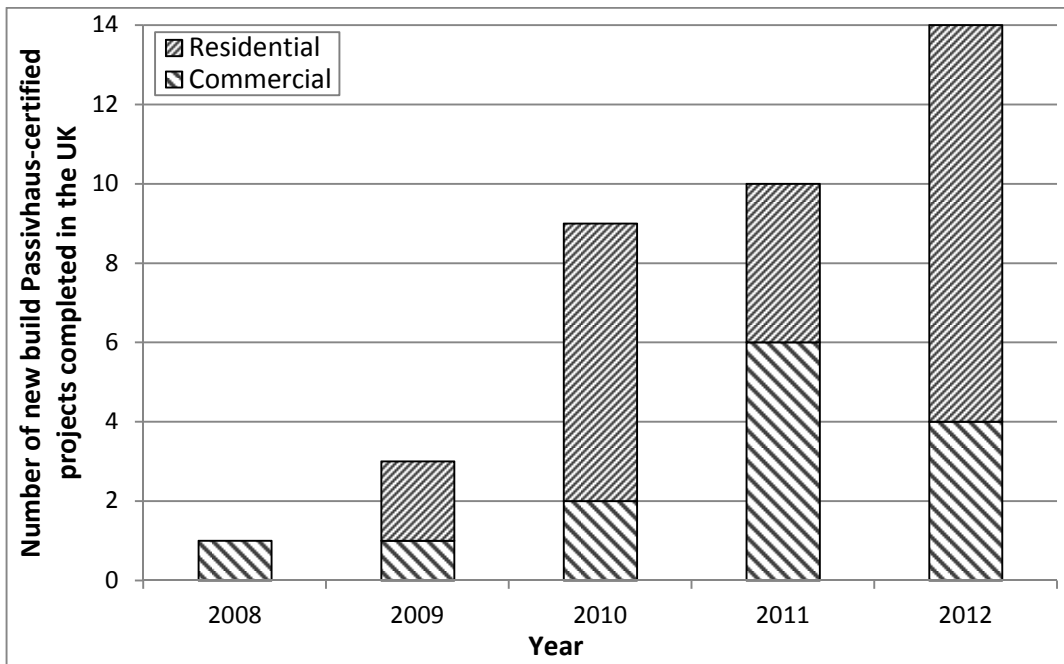


Figure 4.4 – Annual completion rates for new build Passivhaus-certified construction projects in the UK (2008-12). Produced using information from Passivhaus Trust (2013e).

It is anticipated by many that Passivhaus will increasingly become standard practice over the next decade (e.g. Boardman, 2012; Feist in McCabe, 2012). Mainstream UK media have also reported on the Passivhaus standard in recent years (e.g. McGhie, 2008; Anderson, 2013; Earley, 2013; Krestovnikoff and Poyntz-Roberts, 2013), with one headline asking whether Passivhaus is ‘the housing standard of the future?’ (Jenkinson, 2010). Such articles have predominantly been complimentary to the standard. Media interest was perhaps initially sparked by Channel 4’s popular *Grand Designs* television programme, which had an episode dedicated to the design and construction of the Underhill House Passivhaus project (Tebbutt, 2010). Looking towards prominent politicians: Chris Huhne, during his reign of UK Secretary of State for Energy and Climate, stated in October 2010 that he ‘would like to see every new home in the UK reach the

[Passivhaus] standard' (DECC, 2010c). However all of these words of support have never materialised in a policy that advocates Passivhaus.

Despite calls from the Passivhaus community, the UK has no current plans to make the Passivhaus standard mandatory for all new buildings, whether on a national or area-specific basis as Germany have done (Table 4.1). It is unlikely that this will happen, in the short-term at least, primarily because the energy standards of the UK's Building Regulations, Code for Sustainable Homes initiative (now voluntary, but did previously direct building regulations), and Standard Assessment Procedure (SAP) software have explicit carbon dioxide targets, whereas Passivhaus focuses on energy efficiency (*Sections 4.1-4.2*). This inherent difference means that SAP does not realistically reward Passivhaus' energy savings. In addition, critics argue that SAP has numerous underlying assumptions that make Passivhaus design less attractive (Reason and Clarke, 2008). SAP was developed in the 1980s from studying dwellings with poor insulation and high heat loss, hence it rewards buildings that have renewables yet are 'leaky' and have relatively higher heat loss (i.e. enables prioritisation of energy supply over energy demand in decarbonisation). Unsurprisingly the Passivhaus Planning Package (PHPP), being Passivhaus' certification tool, does reward designs that prioritise the reduction of energy demand.

Unless there is a shift in what UK building regulations state (e.g. demanding Passivhaus) and/or how they are assessed (e.g. moving away from the dated SAP), I would speculate that the likelihood of Passivhaus becoming more mainstream for the time being remains low. Therefore adhering to the Passivhaus standard will remain voluntary in the UK, and thereby will most likely continue to rely on designers, constructors and their clients having confidence that the Passivhaus standard will save energy and/or provide occupants with a comfortable living environment. For instance, Hastoe Housing Association has made a commitment for 20% of its new developments to be Passivhaus, as has been demonstrated by two recent 14-dwelling developments in Tye Green Wimbish, Essex (Passivhaus Trust, 2012b) and Ditchingham, Norfolk (Passivhaus Trust, 2013f).

4.5 Passivhaus research to date

4.5.1 Passivhaus as a techno-economic solution

Policies or research that fall within the techno-economic paradigm (see *Section 2.2* for more details), would usually assume that well-designed technologies will linearly save energy, or indeed achieve whatever its design objective is. In drawing on literature from the Passivhaus community, I briefly illustrate how the origins of the Passivhaus concept, intentions that underlie its recent development and relevant research are fundamentally techno-economic.

The following quotation from Passivhaus co-founder and current director of the Passive House Institute, Professor Wolfgang Feist, is frequently used in pro-Passivhaus commentary. It illustrates how the origins of Passivhaus are embedded in the assumption that the failure of one technology can be wholly fixed by another (better-designed) technology.

‘I was working as a physicist. I read that the construction industry had experimented with adding insulation to new buildings and that energy consumption had failed to reduce. This offended me – it was counter to the basic laws of physics. I knew that they must be doing something wrong. So I made it my mission to find out what, and to establish what was needed to do it right.’

(Feist, in Reason and Clarke, 2008, p. 2)

Professor Feist was thus very confident that technologies, which were designed in a way that took advantage of ‘the basic laws of physics’, would be enough in themselves to save energy. Deeply entrenched assumptions thereby also exist with regard to how those same technologies are used by those occupying the Passivhaus buildings, in particular that the technologies are used as the designers had envisaged with the occupants having little influence on energy performance. Passivhaus was therefore developed on the assumption that technologies are the dominant force in decision-making. As I mentioned in *Chapter 2*, it is in this way that the *techno* component of the techno-economic

paradigm has some similarities with structural perspectives, such technological ‘scripts’ (Jelsma, 2003, p. 106).

I would argue that, 22 years on from the first Passivhaus building, Professor Feist (and thus the Passive House Institute itself) still holds true to this technological fix mentality. Such a mentality is emphasised by the following short excerpt from a recent Passivhaus lecture by Professor Feist.

‘We have learnt all the time that it’s no use to try to educate people how to live in a building. People don’t want to change their habits. You have to build buildings in a way that the occupants can handle them without an education programme, and this is exactly what we do with a Passivhaus: in order to use wall insulation, you don’t need any education. In order to use the window properly, you don’t need any education...It has to be the design of a building. The design of a building has to be done so that a normal person can use the building, so that it is difficult to do something wrong, with it more difficult to do that than do it in the right way.’

(Feist, 2013)

Therefore it would seem that, after briefly toying with the information-deficit model¹ (or as Feist puts it, ‘education’), Passivhaus’ technological fix origins were only reaffirmed. It is perhaps unsurprising then that the research focus of much of the Passivhaus community has thus centred upon technical performance, as that would allow one to perfect technological provision (the ‘fix’).

For example, significant attention has been given to the technical performance of Passivhaus buildings, in accordance with the pursuit of technological improvements. Specifically, there has been a significant focus on either modelling building performance (e.g. Thiers and Peuportier, 2008; Badescu *et al.*, 2011; Ferreira and Pinheiro, 2011), measuring building performance (e.g. Parker, 2009; Eicker, 2010; Guerra-Santin *et al.*,

¹ The model suggests the presence of ‘a deficit in public knowledge and understanding of environmental issues which needs to be “filled” by expert knowledge...before individuals will accept their own responsibilities and acknowledge the need to change aspects of their lifestyles’ (Burgess *et al.*, 1998, p. 1446).

2013; Siddall *et al.*, 2013), or a comparison between the two (e.g. De Meulenaer *et al.*, 2005; Badescu and Staicovici, 2006).

The dominance of these technical performance studies in the general Passivhaus literature has often contributed to social science research being bolted on, as part of a wider project. These bolt-ons commonly have a very similar purpose: to understand performance and identify ways to improve it. Much of this sort of research in the UK Passivhaus context has been through Building Performance Evaluations (BPEs) and their accompanying Post-Occupancy Evaluations (POEs). These Passivhaus POEs have been mostly framed around feeding back potential technological improvements as well as some wider project management issues, so as to improve energy performance (e.g. Palmer, 2012; Ingham, 2013). Such approaches are gathering quite a following in UK energy and buildings circles, in part due to the Technology Strategy Board's (2010) funding calls, with the research of Bordass, Leaman and Stevenson commonly cited (e.g. Bordass *et al.*, 2006; Leaman *et al.*, 2010; Stevenson *et al.*, 2013). These approaches demonstrate the linear techno-economic assumption that optimising how technologies are designed and/or presented to the occupant will lead to energy savings.

The following quotation, taken from a POE-related study of the first Passivhaus-certified Danish dwellings, emphasises exactly this. The authors blame poor technological design as well as 'wrong' user behaviour (based on a lack of knowledge) for summer overheating:

'The occupants have to know how to handle the system or understand the strategy to perform "correctly". It is believed that both the combination of "wrong" occupant behaviour and poor design is responsible for the lack of thermal comfort in the summer in all these three cases.'

(Larsen *et al.*, 2011, pp. 7–8)

These Passivhaus researchers would thereby assume that more knowledge (e.g. through information provision that reveals the potential for monetary savings) on how to use better designed technologies, will be rationally processed and acted upon by individuals and so ensure 'correct' usage. Such a view complements the principles of the technology

transfer model, which would indicate that obstacles inhibiting the performance of technologies can be identified and overcome.

Some Passivhaus studies have broadened out the focus, away from operational performance, to the embodied and life cycle performance associated with energy and carbon (e.g. Feist, 1997; Thormark, 2002; Dadoo *et al.*, 2010; Dahlstrøm *et al.*, 2012; Thiers and Peuportier, 2012). Whilst the focus differs from studies on operational performance, both sets of studies predominantly investigate ways to improve the performance (be it life cycle or operational) of technologies.

As a consequence of all of this research into the design and technical performance of Passivhaus buildings, further confidence seems to be generated as to its capacity to reduce energy consumption. From this position, a challenge that techno-economic approaches (such as Passivhaus) must then address is how to ensure widespread uptake of the technologies.

The International Passive House Association – a central organisation in the international Passivhaus community – has a section on its Passipedia (online encyclopaedic) resource called ‘Passive House in use’, which argues for more Passivhaus buildings based on the benefits it gives its occupants. The Association’s argument centres on a series of quotations it has selected from occupants of various Passivhaus buildings (International Passive House Association, 2013h). In addition, there is a discussion not of how occupants behave in a Passivhaus context, but instead of how people can (or maybe even should) behave (e.g. window opening myth-busting) (International Passive House Association, 2013i). The Association’s arguments implicitly highlight the assumption that a discussion based around monitoring evidence would be enough to convince ‘every property developer, architect, building constructor or investor’ (*ibid.*) that they can and should build to Passivhaus standard. Yet as I argue throughout this thesis, individuals – whether in industry and considering Passivhaus as an option, or in a household interpreting and using Passivhaus technologies – are not wholly rational and do not make decisions solely based on the potential for maximum utility.

Perhaps as a signal that individual rationality will only be able to achieve a certain (limited) degree of uptake, the Passivhaus standard is increasingly being incorporated into local and regional building regulations (as was demonstrated by Table 4.1). This mandatory requirement has been justified on the basis that the dwelling technologies that enable Passivhaus certification will ensure optimal energy performance.

In summary, the Passivhaus concept represents a good example of a fairly normative techno-economic solution. The rhetoric surrounding Passivhaus emphasises the belief that external (be they social or technical) factors can be identified and played upon so as to linearly change user-technology interactions and reduce energy consumption accordingly.

4.5.2 Other social science related research

Whilst technical performance related research dominates (with social science sometimes being bolted on), there are an increasing number of studies that are focusing explicitly on the social implications of Passivhaus and the set of technologies that the standard usually represents. However, perhaps as a product of its technical roots, a significant proportion of this literature does not adequately delve into the deeper social dynamics that underpin everyday life. Examples include occupant satisfaction questionnaires that cover factors such as noise, humidity, indoor air temperature, sanitary well-being, and ventilation (Schnieders and Hermelink, 2006), and modelling behaviour for its impact on the energy performance gap (Blight and Colely, 2013).

Müller and Berker (2013) discuss how the growing international success of the Passivhaus standard, as a technological innovation, can be attributed to wholly non-technological influences. Indeed there is a small, but growing, area within the Passivhaus literature that shares this sentiment; the examination of something technological, need not mean that the line of inquiry be dominated by the technologies themselves. This has been evidenced within the Passivhaus context by numerous pieces of research that are more explorative in their nature, rather than following the Passivhaus traditions of being more descriptive.

Examples include: the role of intermediary organisations (Ornetzeder and Rohrer, 2009); social learning and the importance of participatory design (Rohrer and Ornetzeder, 2002); an analytical ('energy orders') model regarding how activities and appliances come together through routinised behaviour (Karresand, 2012); leading design and construction projects with little relevant experience (Janson, 2008); domestication of technologies (Isaksson, 2011); and the sociology of everyday life (Brunsgaard *et al.*, 2012).

Most of these papers approach the Passivhaus standard in a very similar way to how I do within this thesis, in that the standard is utilised as a case study for exploring wider sociotechnical phenomena. Opportunities clearly exist to make theoretical advances as well as Passivhaus-specific empirical advances. Indeed, particularly as an emerging research area, a wealth of potential exists for theoretical application and exploration since to date research in the Passivhaus context has been so hugely dominated by technical lines of inquiry. In addition, although most of these papers share a broadly similar perspective with regard to knowledge and the sociotechnical construction of everyday life, none of these papers are in the UK context nor adopt a practices lens of inquiry.

4.6 Passivhaus summary

Passivhaus is a building energy efficiency standard, originating from Germany in the early 1990s. Since that time the standard has gathered increasing support, with over 37,000 Passivhaus-certified buildings in existence (20,000 in Germany) and calls for it to be mandatory as part of building regulations. In the UK, there are less 300 Passivhaus buildings and the first was only completed in 2008.

Passivhaus research has mostly been concerned with technical performance, as part of a wider techno-economic approach that aims to optimise technological design as the primary means to save energy. Inherent to this, much of the research consistently seems to miss the point: it is technological design that needs to be integrated into people's

everyday life, rather than the other way around. This chapter's brief review also found such principles to reflect the foundations that the Passivhaus standard was built upon.

A Passivhaus housing development is seen as a suitable case study to base this thesis upon because it is a techno-economic solution in itself that, whilst becoming relatively established internationally (as a technological 'fix' to save energy), is still new to the UK public and industry. Therefore the potential exists for the unfamiliar Passivhaus technologies to disrupt or at the very least perturb everyday practices. In addition, the lack of sociotechnical research in the Passivhaus context provides the opportunity for new theoretical and empirical insights.

4.7 Background context on the adopted Passivhaus case study

Having decided that a single case study approach was most appropriate for this thesis, but before settling on a Passivhaus case study, I investigated numerous case study opportunities. Examples include: the UK's first zero carbon affordable housing; a development built using modern methods of construction (offsite); and a development using hempcrete (to sequester carbon) as its primary construction material. Despite all being inherently techno-economic (for more see *Section 2.2* and *Subsection 4.5.1*) which would have been hugely complementary to this thesis' central research questions, these opportunities were not explored any further because they were not innovative enough. These examples tended to be designed around the Code for Sustainable Homes (CfSH) legislation (for more see DCLG, 2010a), which is essentially based on extending the current UK building regulations. As is usually symptomatic of CfSH projects, the housing developments typically attempted to lower net energy consumption through decarbonising the energy supply (e.g. solar thermal or photovoltaic panels) rather than by significantly raising dwelling energy efficiency (e.g. super insulation; airtightness). Consequently, households were more likely to have relevant past technological experience, in addition to the low carbon energy supply still enabling the same patterns of unsustainable consumption that existed in their previous (non-low carbon) homes. In contrast, by using relatively unfamiliar technologies, Passivhaus represented a

significantly different point of departure in terms of design (by striving for energy efficiency), making it more likely for technological provision to challenge and disrupt household everyday life. Since these were the sorts of issues that I had hoped to address within this thesis, I opted for a Passivhaus case study.

I now present background context on the UK Passivhaus case study, upon which this thesis is based. However, in protecting the identity of the development – and its residents and project team – only limited details can be provided. It can be confirmed, however, that it is a small to medium-sized affordable housing development built in the summer of 2011. For more information on the Passivhaus standard and the sorts of technologies it encompasses, please re-visit *Sections 4.1-4.4*.

Figure 4.5 provides an overview of the household and dwelling characteristics of the Passivhaus development. The development is made of up a range of one-bedroom flats (42.86%), in addition to two- (35.71%) and three-bedroom (21.43%) houses, all of which were built using a masonry (concrete block) approach that achieved low heat loss rates (as shown by the very low air leakage rates and u -values). These dwellings have been occupied by relatively young households, with no elderly present and young families common. The occupations of the adults in the households predominantly fell into the skilled or semi-skilled sectors.

Percentage of shared ownership dwellings (%):	28.57
Percentage of socially rented dwellings (%):	71.43
Average household size (persons):	2.50
Average adult resident age (over 18yrs) (years):	36
Average child resident age (under 18yrs) (years):	6
Age range (years):	0-53
Adult : child ratio (persons):	11 : 5
Occupation types include:	Electrician; builder; teaching assistant; administrator; retail assistant; cook's assistant; production line worker; care worker; personal trainer; stay-at-home mum; unemployed
Percentage of each dwelling type	
<i>one-bedroom flat:</i>	42.86
<i>two-bedroom house:</i>	35.71
<i>three-bedroom house:</i>	21.43
Rural/urban:	Rural
Total gross internal floor area (excluding party walls) (m ²):	950.00
Total treated (heated) floor area (m ²):	881.29
Total footprint area (m ²):	656.89
Total opening area (m ²):	239.46
Total roof area (m ²):	1,496.32
Total external wall area (m ²):	1,163.52
External wall width (m):	0.50
Framework:	Masonry
Air leakage at 50Pa (air changes/h):	0.60
External fabric <i>u</i> -values (W/m ² .k)	
<i>external wall:</i>	0.09
<i>floor:</i>	0.07
<i>roof:</i>	0.08
<i>windows:</i>	0.79

Figure 4.5 – Selected Passivhaus case study: Household and dwelling characteristics

In addition, Figure 4.5 also reveals how a large proportion (71.43%) of the development's households are renting (be it with financial support or not) the dwelling from the housing association. The remainder (28.57%) are classified as shared ownership (i.e. part occupier owned and part housing association owned). Shared owners have different entitlements

(e.g. maintenance responsibilities; access to handover information) in comparison to the social renters who had considerably more support, and this is a subject of discussion in the results and analysis chapters.

To enable the development to be constructed in a rural area where house building is usually prohibited (e.g. due to green belt restrictions), the local planning authority granted planning permission under a *rural exception* policy in order to meet a local housing need. This meant that all new residents needed, and will continue to need across the lifetime of the development, to have a local connection to the village (e.g. they or their family live there already). Residents were exclusively selected by the area's local authority on this basis since relatively few interested parties had local connections. This was instead of assessing their environmental credentials which is typical in social housing projects so as to ensure success. The households are therefore not a sample of environmentalists or Passivhaus enthusiasts.

PART III.

Results, analysis and discussion

Chapter 5 – Living with Passivhaus technologies: An everyday practices perspective

Abstract

This chapter uses social practice theory to explore the implications of new low carbon dwellings upon energy consuming practices. The handover period for a small to medium sized UK Passivhaus development was investigated, predominantly using interviews as well as informal observation and participation at key events (e.g. move-in day technology tours, information sessions, post-move-in landlord visits). Evidence showed the introduction of technology could provide scope for certain performances, but did not linearly result in energy savings, as per design intent. The Passivhaus technological configuration contributed to a pronounced nonlinearity and unpredictability due to a messy integration of practices surrounding heating and ventilation energy services – the focus of much of my discussion.

Residents primarily showed a willingness, conscious or not, to refine heating and ventilation related practices either to ease worry of unfamiliar technologies and/or to yield the broader social benefits offered by their new residence. Practical understanding seemed pivotal in learning new skills and adapting practices, partly due to minimal and relatively mistrusted institutional guidance.

The dominance of learning by doing in shaping and holding practices together meant misinterpretation was common since understanding was reliant on past technological experience. ‘Misuse’, as a product of past practice trajectories, could be mitigated against through a combination of technological design that aligns with earlier generations of technologies and expert guidance that is empathetic to the role of know-how and embodied habits (e.g. active participation, regular household contact, seasonal sensitivity). Appreciation of such influences is essential to ensure handover support and technological design enables energy savings and helps fulfil policy ambitions.

5.1 Introduction

The culture of the UK building industry favours refurbishment over demolition and building new, contributing to one of the oldest building stocks in Europe. Of UK dwellings, 39% were built before 1945 and 23% before 1919 (DCLG, 2010b). Therefore current decisions concerning the design of new housing will have a bearing on households' technological configurations for decades, potentially centuries, to come. There is a pressing need for more research on the implications of tying future generations to the design strategies produced on the basis of designers' preconceptions of (fictive rational) users (c.f. Jelsma, 2003). Evidence is needed regarding the actual interpretation and use of new low carbon housing, the building of which government policies target to lower emissions. The UK domestic sector is responsible for 25% of emissions and 40% of final energy use (HM Government, 2011).

Relatively little work has been conducted on obtaining this evidence because most policies and domestic energy research inherently assume technological provision will linearly reduce emissions. A social practices approach helps fill this neglected void, and is thus being increasingly used to examine residential energy consumption (e.g. Strengers, 2010; Bartiaux *et al.*, 2011). Existing research has largely focused on the elements that shape domestic energy consuming practices (e.g. Gram-Hanssen, 2010b), and less on the actual performance of these practices and its implications on everyday life. More research is needed to delve further into how applying practice theory can aid learning about the failings and successes of government strategies that hinge on everyday life.

Few studies have explicitly examined the transitional period where a property is handed over to new residents (e.g. Stevenson and Rijal, 2010; Egginton, 2011), none of which adopt the practices lens that this study does. The handover period considered here includes approximately the time between 2 months before and 12 months after the move-in date. The handover period is insightful when examining the impact of changing domestic technological configurations, which are targeted by international policy agendas, since this is exactly when residents are first exposed to that change.

The aim of this chapter is to investigate the influence of a new and very unfamiliar domestic technological configuration on residents and the performance of their energy consuming practices. Through a practice theory lens, the implications of moving into a contrasting (low energy new build) dwelling upon energy consuming practices are explored. The empirical basis is the resident handover period for a Passivhaus-certified UK affordable housing development, with the focus largely on the initial destabilisation and transformation of practices. This builds on the work of other researchers who have examined Passivhaus occupant experiences through a similarly sociotechnical lens (e.g. Rohrer and Ornetzeder, 2002; Isaksson, 2011; Brunsgaard *et al.*, 2012; Thomsen *et al.*, 2013).

This chapter begins by critiquing the dominant techno-economic approach and outlining how practice theory can be utilised to understand household energy usage. Following an explanation of the methods employed, resident interpretations and experiences of the handover are explored. Findings focus on why and how practices are changed, the role technology plays within that, and the complex interconnections between the elements that shape practices – particularly in the context of how new skills are acquired as residents adapt to new technologies and different ways of heating and ventilating their home. How past technological experience directs the performance of heating and ventilation practices is given explicit attention. A discussion section then brings out the cross-cutting themes before I conclude by reflecting on possible improvements to the handover process and wider policy initiatives, in addition to considering the broader implications of applying social practice theory to similar domestic energy studies.

5.2 Theoretical context

The majority of policy-making and indeed mainstream research within the household energy arena can be classified under the ‘techno-economic paradigm’ (Guy and Shove, 2000). Techno-economic policies focus on technical and economic considerations, typically assuming individuals to be profit-maximisers who rationally make decisions (Guy, 2006). The paradigm therefore assumes building research knowledge is incorporated into

lifestyles and actual action through technology transfer which enables users to take action, or through information provision which demonstrates that the use of that technology can provide a net benefit (Shove, 1998). The assumption is that a technological fix can provide a magic bullet solution. The consequence is that policy can assume technology will solve the problem. This can be illustrated by numerous recent UK policies, including: Building Regulations (zero carbon home standard), the Green Deal (loan system to enable energy efficiency projects in existing homes), Carbon Emissions Reduction Target (subsidised insulation for existing homes), and Feed-In Tariffs (pays householders for microgeneration).

Lutzenhiser and Shove (1999) argued that the techno-economic paradigm had been widely adopted internationally by energy researchers, contributing to a shared techno-economic perception of how best to tackle as well as define energy-related (e.g. domestic energy consumption) problems. Despite such critique arising in the late 1990s, I believe very little theoretical progression has since occurred within the mainstream policy agenda. In addition to the dominance of the techno-economic paradigm, there has been a move towards behaviour change approaches that attempt to reduce domestic energy consumption through targeting the psychology of individuals (e.g. Poortinga *et al.*, 2004; Whitmarsh, 2009; Thompson *et al.*, 2011). These psychological approaches are inherently similar to the economic thinking embedded in the techno-economic paradigm because they both focus on understanding how individuals make decisions (with the psychological approach essentially including a greater number of variables). Both economic and psychological approaches thus share a linearity because each regard behaviour change to be possible through changing the variables (e.g. removing the barriers) that affect individual decision-making.

Social practice theorists adopt a completely different point of departure (Shove, 2010; Shove *et al.*, 2012). Instead of focusing on the technology (e.g. dwellings) or the individual (e.g. dwelling occupant), they focus on practices (e.g. showering, cooking, cleaning, hosting guests), the performance of which can require energy to be consumed. Gram-Hanssen (2008) argues that a priority for the development of policy, information campaigns and technological design is the investigation of components pulling practices

in (un)sustainable directions. By helping practices to be less energy consuming, it is exactly this sort of analysis that can help identify either the most appropriate technologies or approaches that go beyond technologies altogether.

A practice is a habitual and ‘a routinized way in which bodies are moved, objects are handled, subjects are treated, things are described and the world is understood’ (Reckwitz, 2002, p. 250). A practice is a rather dynamic concept in that one can occur within and across other practices of different temporal and spatial scales and contexts. Theories of social practice has its roots in the work of Bourdieu (1977, 1984) and Giddens (1979, 1984), being developed more recently by Schatzki (1996, 2002), Reckwitz (2002), Shove (see Shove and Pantzar, 2005; Shove *et al.*, 2012), Warde (2005), and Gram-Hanssen (2010a, 2010b). No single agreed practice theory exists, with practices remaining a topic of continued debate. For instance the role of materiality within practice theory is not agreed upon (Gram-Hanssen, 2011a), although its inclusion has increasingly become the norm after the work of Reckwitz (2002).

The following framework suggested by Gram-Hanssen (2010a, 2010b, 2011a) is adopted within the core of this chapter:

- *Technology* – anthropogenic infrastructure and physical environment.
- *Engagements* – associated meanings which provide motivation, consciously or not, to take action or not, i.e. why is it a good idea to undertake that practice? Why should a practice change on the basis of new experience and/or information?
- *Know-how and embodied habits* – practical understanding acquired through experience, which is unconsciously embodied in physical everyday habits.
- *Institutionalised knowledge and explicit rules* – less intuitive, explicit ‘rule-based’ information, e.g. expert guidance, instruction manuals.

The changing of an element, such as a new technology, is a way of ‘puncturing practice’ (Hitchings, 2011, p. 2838) which can potentially destabilise, destroy, or create practices. Using Schatzki's (1996) terminology, such frameworks offer a basis for lessons from

empirical studies focusing on ‘practices-as-performances’ (how practices are undertaken in reality) to provide insight into how we view ‘practices-as-entities’ (social organisation of a practice).

The salient feature of social practice theory is in putting practices at the core of understanding the social. By moving conceptually from individuals and technology to technology-in-practice, I argue that the ‘invisible’ (Burgess and Nye, 2008, p. 4454) energy usage which is tied to practices should start to come to the fore. Part of such a transition demands that individuals are regarded as those who ‘carry’ (Reckwitz, 2002, p. 256) social practices. Practices are collective and historic realisations, developing over time through the sociotechnical interaction of groups of individuals who perform (and thus ‘carry’) practices. Scope therefore exists to investigate the individual differences of how a practice is performed on a day-to-day basis (Gram-Hanssen, 2008). Moreover, Gram-Hanssen also notes practice theory’s use in investigating why changes, such as technological provision, do not have the anticipated effect on everyday life:

‘Practice theory does not have an individualized approach to practices, though it is open for understanding how changes in practices may start in the everyday life of individuals, following from both change in engagement and from the introduction of new knowledge or new technologies. The theory can thus also be useful in describing why changes do not always appear even though authorities or organizations try to introduce them into people’s everyday life’.

(Gram-Hanssen, 2011a, pp. 76–77)

By concentrating on practices the broader social dynamics that guide technological interpretation and use, which individualistic approaches would largely ignore, are given more credence. Practice-based studies that focus on performances may engender better representations of what actually happens in an individual or household’s everyday life. A practices perspective is thus used here to examine the implementation of Passivhaus standards (and its associated technologies) on bundles of domestic everyday practices.

5.3 Methodology

The case studied is a small to medium sized UK Passivhaus social housing development. Passivhaus is a voluntary German standard for building energy efficiency and comfort (Feist *et al.* 2005). It has been applied to all tenures and building types, although most have been new build owner-occupied houses to date. The main purpose is to minimise the need for space heating/cooling, thus energy consumption during operation. Passivhaus homes stay warm *passively* from people, solar gain and appliances, as well as often rely on renewables and mechanical ventilation with heat recovery (MVHR) systems. Practices themselves are thus a main source of heating, contributing to a different way of living. Passivhaus is therefore an interesting case study because it provides a radically different technological configuration relative to conventional UK housing.

The development's dwellings are a mix of one-bedroom flats, two-bedroom houses, and three-bedroom houses. Of these dwellings, 29% are shared ownership tenure, with the other 71% being socially rented. Of the households, 43% are single occupancy (all flats), 14% are dual occupancy, and the remaining 43% are (predominantly young) families. There are no elderly individuals living at the development, with the average adult age being 36 years (range: 18-53). The majority of employed adults have partly skilled (e.g. agricultural worker) or skilled (e.g. electrician) occupations, whilst only 8% are in professional (e.g. accountant) employment. Anonymity agreements prohibit me from stating the number of households or dwellings that constitute the development, but I can state that resident interviews involved 28 participants (1-3 members of each household were interviewed, usually altogether).

The technical specification of all dwellings is the same. Conventional gas boilers, supplemented by solar thermal systems, are coupled to large thermal stores. The stores supply hot water and feed top-up heat into the air supplied by the MVHR system. This is a very different setup, in particular with regard to the MVHR, compared to the rest of the UK housing stock: the recent English Housing Survey showed 90.1% of dwellings to have a conventional central heating system, 7.0% to use storage heaters, and 2.9% to have fixed room/portable heaters (DCLG, 2013).

The methodological focus is on how changing the technological configuration of one's home affects domestic energy consuming practices in general, particularly through how it can lead to a 'puncturing' (Hitchings, 2011, p. 2838) of practice and its other three elements of practice (engagements; institutionalised knowledge and explicit rules; know-how and embodied habits). In realising this, empirical attention is given to the performances of practices. Passivhaus and non-Passivhaus dwellings are not directly compared (e.g. with two samples), though by having a longitudinal approach which focuses on the trajectory of practices from 2 months before to 12 months after move-in, investigation of such technological differences is inevitably implicit.

Institutionalised knowledge was mainly provided by what I refer to as resident 'support institutions' which advised residents on various issues, and these will be specifically explored within this element. Support institutions primarily included (1) the housing association which, as landlords to the non-shared ownership residents, provided ongoing support and pre-move-in information evenings, and (2) the construction company which contractual obligations included leading the handover day tour of technologies, producing simplified paper-based guides, and fixing any technological faults.

Pre-move-in interviews were conducted with at least one member of each household to introduce the research project, get to know the participants, explore how they used their previous technological setting, and gauge prior expectations of Passivhaus (for interview schedule see *Appendix 1*). Although interviews can be very useful in researching practices (Hitchings, 2012; de Vet, 2013), the first round's purpose was predominantly supporting and contextual, laying the foundations for the research described below.

In reference to researching practices, 'there is no alternative to hanging out with, joining in with, talking to and watching, and getting together the people concerned' (Schatzki, 2012, p. 25). Practice-oriented research should involve the researcher getting to know participants on a day-to-day, and perhaps a resulting informal, basis. Observation and in some instances participation was thus undertaken at key events including information sessions, construction site tour, move-in day tour of technologies, visitor days, 2 week post-move 'de-snap' visit (which solely focuses on mitigating early problems, or 'snags'),

and 6 week post-move-in resident meeting. In addition, informal and ad-hoc contact was maintained, largely stimulated by operational problems occurring.

Around 9-12 months after move-in, 64% of households (due to dropout) were involved in a second round of interviews (for interview schedule see *Appendix 2*). In addition to allowing residents to comment directly on the handover process (e.g. asked for recommendations for future handovers), they were given the time and space to reflect more generally on living in their new homes as part of a walkthrough interview. This more interactive interview situated the discussion of use exactly where that use, and thus performance of relevant practices, occurred.

The identities of the residents and support institutions are protected. Quotations in this chapter are referenced using, for example, '1A', whereby 1 represents a randomly assigned resident number for one of the 28 residents that were contacted during the study, and A represents the method of data collection (A = pre-move-in interview; B = walkthrough interview; C = informal interaction), thus 1A and 1C quotations refer to the same individual.

5.4 Findings

This section loosely uses Gram-Hanssen's (2010a, 2010b, 2011a) interconnected elements of practice as a structure. The role of new technologies is more generally discussed first, regarding technology's role in directing energy consuming practices. On the basis of technological change, the remainder of this section addresses the other elements largely in the context of heating and ventilation related practices – the rationale for such a focus is explained. The section finishes in discussing how the know-how and embodied habits element significantly shaped how the performance of everyday domestic practices changed in response to new and unfamiliar (Passivhaus) technologies.

5.4.1 Technologies: its role in changing practices

Moving into a new dwelling provides residents with a very different materiality to their previous residence. Such differences have the potential to change how energy consuming practices are performed. Whilst the influence of technologies on everyday living is neither always linear nor guaranteed, Table 5.1 does detail some examples (raised independently by residents) of how technologies provided opportunity and scope to perform practices in new ways, which residents could choose to exploit or not. Table 5.1 also helps to emphasise how technologies take the role of a steer, not dictator, through the options it facilitates.

<i>New technology</i>	<i>Influence on energy consuming practices</i>
No external outlet for a (non-condensing) tumble dryer's vent hose due to airtightness concerns	<i>Laundrying</i> : can only use a condensing tumble dryer. Thus households can either stop using a dryer altogether or buy a new condensing dryer.
Garden washing line	<i>Laundrying</i> : the opportunity now exists to hang one's laundry outside, instead of using a tumble dryer or drying inside.
No kitchen gas connection	<i>Cooking</i> : only electric cooking is possible.
Limited kitchen space (especially in the flats)	<i>Cooking, cleaning, laundrying, homemaking</i> : had to prioritise certain white goods leading to few householders using dishwashers.
Bath with shower attachment	<i>Showering, bathing</i> : allowed those who could previously only shower to bath, and vice versa.
Plug socket and light switch locations	<i>Appliance-using practices</i> : more convenient plug sockets made it easier to turn electrical devices off standby. Some poorly placed light switches increased the effort required to switch lights off.
Smaller garden	<i>Gardening</i> : now less hassle to mow the lawn. Indeed one household disposed of their electric lawn mower, mowing manually instead.

Table 5.1 – How introducing different technologies as part of a new domestic setting can constrain or enable certain ways of performing practices

It clearly is not as simple as introducing a technology to alter one's daily living. For example, almost all residents independently acknowledged that free hot water would be available from the solar thermal system after the sun had been out for a few hours, yet no-one changed when they showered or bathed. Residents do not necessarily perform

practices on the basis of what the designers would deem to be rational, with technologies very often not used as the designers would have intended. For instance, would the designer approve that the airtight dwelling's front door was kept open continuously to allow access for a cat? The impact of residents potentially choosing to not purchase the expensive (Passive House Institute approved) cat flap, yet still own a cat, was seemingly not given enough consideration. Looking after a cat was non-negotiable for some households as they sought to make their house a home. It is thus a good example of how technological interventions can be ineffective. Indeed a robust practice (e.g. homemaking) can have considerable flexibility in how it is performed (e.g. how technologies are used) so as to meet a particular desire or need (e.g. owning a cat).

In contrast, the performances of some practices were very readily changed when new technologies were complementary to certain modes of previously unachieved energy services. Technological configurations can inhibit one undertaking a practice in a certain way to utilise a specific energy service. Therefore for most residents, moving into a Passivhaus dwelling gave them scope for new performances. Many of these were not necessarily anticipated or Passivhaus-related. For example, one household bought a deep fat fryer because the boost function of the MVHR (if used like an extractor fan) would prevent "stinking out their house" (22B) as occurred in the past. Moreover, the spray and aerator functions of water saving taps were said to "give better [more] bubbles" (10B), leading to 14% of households having considerably more baths. Perhaps most unexpectedly is how one household turned on their water heating as part of making homemade bread: the bread is placed on top of boiler for 45 minutes since the heat it gives off helps to give the bread "just the right texture" (25B). Therefore practices changed when new technologies aligned with previously unachieved energy services or changes that they were already keen to make, often contributing to technologies being used in unexpected ways.

The reason behind these unexpected uses is practices; further investigation is needed into how technologies interact with engagements, institutionalised knowledge and explicit rules, and know-how and embodied habits in shaping and holding practices together. The remainder of this section (7.4) attempts to tease out these complexities

with a focus on practices that link to the energy services of heating and, to a lesser extent, ventilation. These practices are discussed because the residents were clearly disconcerted about heating and ventilation, raising it most frequently prior to move-in. Furthermore, although an open investigative frame (targeting energy consuming practices in general) was initially adopted, both these services emerged as recurrent linchpins that entwined almost every domestic practice. This high degree of overlap and integration (through heating and ventilation services) means that to a certain degree generalisation across this context's practices and its elements is enabled (e.g. engagements are widely applicable to almost all domestic practices), despite an elements framework typically being used to detail what holds one discrete practice together (e.g. turning electrical appliances off standby (Gram-Hanssen, 2010a); Nordic walking (Pantzar and Shove, 2010); car driving (Shove *et al.*, 2012)).

5.4.2 Engagements: why learn new skills and consider changing domestic practices?

This subsection discusses how the engagements element of practice was shown to influence changes to the performance of domestic everyday practices, as a consequence of moving into new Passivhaus dwellings.

Environmentally-related engagements (e.g. associated with saving energy) were not prominent in the practices of the development's households. Around 4% of residents had heard of Passivhaus (from television), but that was limited to only recognising the name as a low energy building initiative. The key reason for applying for the move was therefore not Passivhaus-related, with only 7% of households having at least one resident that could be described as environmentally conscious.

The reasons for wanting to move home were significant in providing a willingness, conscious or not, to perform domestic practices in new ways. Households were eager to move to the Passivhaus development, not because it was Passivhaus, but because of an array of other social benefits. Most residents spoke with excitement about how their new

homes would, to name a few examples, provide a: safer environment for their children; rurality; more convenient location for socialising with friends or family; shorter commute to work; separate rooms for each of their children; independence from parents; improved aesthetics (internally and externally) compared to their older and apparently outdated previous dwelling; security and support offered by social housing; and/or an opportunity to own (in part) their first property. These were linked (as part of homemaking and hosting practices) to aspirations and social expectations of what a good home encompasses, how one's home can help demonstrate that one lives a good life, and how one can be a good parent and provider for one's family. This list also highlights engagements of practices that were performed outside of home (e.g. socialising; working; driving). All of these engagements were important because, as I now go on to explain, it was the fear of losing these social benefits that engaged households enough for them to incorporate new skills and new technologies into new ways of performing domestic practices. In addition, it is because of this that numerous domestic (as well as non-domestic) practices shared, to a surprising extent, these same engagements.

From talking to the residents, many seemed to implicitly (and not necessarily consciously) assume that if they did not try to use the Passivhaus technologies (through changing practices) as the support institutions had intended for them to, then there was a real danger of being evicted from the house. This is a reflection of the institutional guidance that the residents were given, which reiterated how lucky they were to be living in these dwellings and employed an authoritative rhetoric (e.g. "if you are to live in these dwellings you must use the ventilation system in a certain way"). Therefore, although the guidance's (deemed) orders were not necessarily followed perfectly, the wrongly assumed underlying message that one would not get their new home unless they were seen to be following orders did seem to prevail. This seemed to be especially prominent, perhaps compared to moving into other dwellings, because the Passivhaus development was the only social housing available at that location with very limited alternatives elsewhere. Thus, the deemed risk of losing the social benefits associated with not being able to perform an array of practices in certain ways, was not regarded to be substitutable by other local housing alternatives.

The homely vision that was an engagement (of hosting and homemaking) within the above discussion also contributed to a small number of households readily changing how they performed practices. These households did not want to be confused upon entering a new home and did not want their homely vision to be disrupted. When discussing this issue, it was clear that this was both personal (i.e. how they viewed themselves in their new home) and social (i.e. how others viewed them in their new home). These households were genuinely worried by the unfamiliar Passivhaus technologies, in particular the “really complicated” (11A) MVHR, and this seemed to contribute to an early willingness to learn about and interact with the new technologies. Consequently, these few households experienced the fewest problems and technological misinterpretations (discussed more in *Subsection 5.4.4*), as they more readily adapted to how practices were performed. For these households, fears of everyday life being halted or disrupted in some way (e.g. not being able to meet social and cultural expectations of homemaking and hosting practices) therefore featured fairly strongly in shaping and holding together new or amended domestic practices.

In contrast, some households did not even entertain the prospect of having to change their everyday life, and thus for these households engagements were not spearheading (initially, at least) practice-related changes. There was a blind faith that the status quo would be maintained because the housing association “wouldn’t give it [Passivhaus technologies] to us if it didn’t work” (6A), and was not “easy to use” (1A) or “low maintenance” (20A), particularly since those in continental Europe had proved it suitable (“tried and tested” (5C)) for their use. However, engagements did begin to influence practice-related changes after residents had actually experienced the technologies and witnessed for themselves (the dominance of experience and know-how is discussed in more detail in *Subsection 7.4.4*) that the practices may need to change if performances were still to meet the social expectations, aspirations, ideas and symbolic meanings that were attached to respective practices. For example, for the practice of hosting guests, heating-related technologies needed to be used in a very different way (compared to their previous homes) if relevant thermal comfort expectations were to be met.

The potential for saving money through saving energy could also have been an additional engagement for almost every practice performed in the home. Whilst the idea of bill savings certainly seemed to enthuse residents, with most raising it in their interviews, whether this actually translated to practices being changed could not be determined. Interestingly, whilst every household commented on how moving into Passivhaus dwellings would provide bills savings, most did not appreciate the extent of the likely savings. For example, one six-person household set aside £50/month (around half of previous bills) for gas payments, but their actual bill for six months (July-January) was £30.

5.4.3 Institutionalised knowledge and explicit rules: inhibited by innovation

Residents spoke fairly positively about their rapport with the housing association (landlords), explaining how the landlords were “trying their hardest” (25B) and “really want[ed] this to work” (16B). Yet despite this, the provision of institutionalised knowledge was relatively ineffective in facilitating changes to how practices were performed in response to new domestic technologies. Some of the reasons that underlie this ineffectiveness are now presented. I begin by discussing how the lack of trust in the support institutions, and thereby the guidance they were providing, contributed to a relatively minimal role of institutionalised knowledge and explicit rules in adjusting how practices were performed in their new homes.

Every household acknowledged how the support institutions severely lacked the Passivhaus knowledge required to help them with any problems they encountered. A commonly occurring story, for instance, was of no-one at the housing association knowing what Passivhaus was when telephoning for assistance. Other common complaints relate to outsourced workers from the wider industry struggling with the Passivhaus concept. For example, one household talked of a plumber visiting who had no idea how the plant room worked, so after asking the resident for help and then telephoning a German contact, he left without rectifying the problem. Another resident, who had similar experiences, compared this to “going into a secondary school to teach French, when you don’t know French” (11B). Indeed another resident was similarly critical

regarding the construction company's lack of knowledge: "I'm not a builder, I just assume that they know what they are doing. They know their job, I know my job. I do what I'm supposed to do" (10B). Such experiences were particularly frustrating for residents who repeatedly booked time off work only for the problem not to be rectified. All this, combined with the very fact that problems (predominantly technical faults) were even occurring, meant that the expertise of the support institutions was in doubt, and thus the advice they provided was treated with a certain degree of caution and mistrust.

The relationship between those receiving and those providing information influenced how information was (un)consciously assimilated in relation to establishing new performances of practices. Evidence showed the likeability of key individuals within the support institutions to significantly influence their trustworthiness as an information source, shaping how residents would use the information afforded to them or even whether they would take notice of the information at all. Numerous tales of "rudeness" (1C) were described, such as specially booking the day off work only for the builders not to show. Indeed one household took a particular dislike to one individual from a central support institution, who was described as "a pain" (26B) and would just "turn up on the doorstep and say "I need to get in" as it was almost sort of his right...but on a technical side he clearly knew his stuff" (25B). For this household, as they seemed to openly admit, his technical expertise did not particularly matter because they were not giving him (and his advice) much attention simply because they did not like him. In this way, the social relationships influencing how information was provided were therefore shown to be more important than the quality of information itself.

Contradictory advice was given both across and within support institutions, which only further reinforced the mistrust that already existed. Indeed I witnessed one expert tell one household to open their windows when they wished, and then later in that same visit also tell that same household that it would be best for them to not open their windows (e.g. use the MVHR for cooling). Other examples I encountered included how to use the MVHR, water heating controls and solar gain blinds. It was therefore "less hassle" (8C) for residents to "work it out by ourselves" (20C) based on their limited knowledge than overcome significant obstacles by increasing their (existing, but minimal) interaction with

informal (e.g. neighbours, friends) or formal (e.g. housing association) institutions for additional guidance. Whilst emphasising how habits are not necessarily changed solely through individual self-reflexivity, this also reveals how institutions of whatever form were only consulted in light of problems. Building trust and the foundations for regular interaction was shown to be especially challenging if the few moments of contact consist of resident frustration and support institutions struggling to answer queries. Indeed if institutionalised knowledge is primarily sought by the residents in moments of frustration, its relationship with knowledge is likely to be fraught with difficulties.

I now switch the focus away from issues of trust towards issues of delivery. Whilst evidence in the broader literature has shown attempts to use information provision (so as to fill a deficit in knowledge) as an ineffective means to change one's view and/or behaviour (e.g. Burgess *et al.*, 1998; Sturgis and Allum, 2004), information provision can still be regarded as an intervention in practice and, as such, can be critiqued on the basis of practice-related principles. Moreover, given that changes in practices can come about through conscious reflection (Gram-Hanssen, 2011a), I would infer that information provision does still have a role to play. Therefore I now consider how certain aspects of the delivery of the support institution's formal guidance could have contributed to institutionalised knowledge and explicit rules largely failing to aid the transition to living in Passivhaus dwellings.

In this case study information provision almost always targeted only one individual within a household, as opposed to setting it in a broader household context as Hargreaves *et al.* (2010) recommend. For example, the move-in day technology tour of the dwelling involved only one adult householder rather than the whole of the household. Such approaches fail to consider how individuals within the same household can differ in their responses to formal advice and in the way that they domesticate new technologies, as a consequence of the sociotechnical context in which each individual performs their practices. It is because of such intra-household differences that no-one in the same household was seen to change their domestic practices in the same way. Moreover, these differences formed the basis of negotiations amongst household members with regard to how a practice could be performed (e.g. husband-wife power struggles over thermostat

settings). Often roles or responsibilities were shared across the household, all of which were essential to each individual performance of a practice. For example, showering in one household relied on one technically-minded individual who “sorts out the hot water controls because I haven’t got a clue” (8B). Therefore setting information provision in a household context could help it to reach all those negotiating and shaping domestic practices, which could ultimately help to give its central message more traction.

How the information was delivered also lacked an appreciation of temporal (in particular, seasonal) context. This longitudinal study consistently highlighted how heating and ventilation related practices were performed changed throughout the year (e.g. solar gain blinds may be down in the summer, but up in the winter). As one resident remarked:

“It would have been much better if they [the support institutions] had said that in the summer these hints may be helpful for you, and in the winter use these set of rules. I was not interested in how to heat my house [at move-in, in summer]; it was really hot in here. All I wanted to know was how to keep it cool. And I knew that come the winter I was not going to remember anything that he’d said anyway.”

(10B)

The support institutions seemed eager to give households the attention they felt that they deserved and, as such, this resulted in an overly comprehensive approach. This is emphasised by the support institutions telling the residents, in detail including demonstrations, how to use the heating and ventilation technologies in both the summer and winter months. However, “overloading” (23C) the residents on move-in day with detailed information was shown to be ineffective since the residents had other priorities. Specifically in this case, households were especially concerned with performing (or at the very least preparing for later performances of) homemaking practices. The tendency to prioritise homemaking practices, over the gathering of knowledge for new heating and ventilation practices that were to be performed later in the year, was made stronger due to completion occurring on the move-in day itself (construction was delayed because of its innovative nature). One resident outlines the situation as they saw it:

“The problem was that you’re so excited that you’re moving house and you’re flapping because everything’s trying to get done, and we had the carpet fitter in on the same day we moved because you wanted the carpet in first before the furniture that you don’t pay too much attention...So much is going on, removal vans all over the place. It wasn’t actually finished because they were still putting up the sheds and laying our grass. So then you worry: don’t leave without leaving our grass, don’t leave without putting the shed up properly.”

(21B)

Institutionalised knowledge was not drip-fed to households across several visits over the course of several months. Instead residents were bombarded with guidance on move-in day, seemingly making an already stressful day even more stressful. This further undermined the implicit assumption of the support institutions that to provide the information once (regardless of timing or context) would be sufficient in equipping households with the knowledge required to adjust their practices to new Passivhaus surroundings.

Whilst this subsection has reiterated the minimal role of institutionalised knowledge in transitioning practice to a new (Passivhaus) materiality, there were two notable exceptions. First, one resident commented how her household could not remember how and when the MVHR filters were changed (maintenance practices), but was sure that “what we are doing must be right as that is what the information said” (25C). A second household was still unsure 10 months after move-in whether pictures could be hung on internal walls due to the fear of “damaging the thermal seal” (14B). They had incorrectly scaled up a passing comment (which I was witness to) by the housing association at a pre-move-in information session about not damaging the wall insulation. This second household did not challenge this position nor did they consult the resident handbook which would have clarified the situation. Both households were open about why they relied upon institutional guidance: lack of experience with Passivhaus technologies led to a lack of confidence in their own intuition, so they set about to fill their gap in knowledge by drawing on formal guidance. The second household was a relatively extreme example of this since their lack of experience and confidence led to an overreliance on formal guidance, causing them to misinterpret passing comments, which they opted not to challenge (despite being unhappy with not being able to hang anything on their internal

walls). However, this situation was rare with evidence only for these two instances. Tacit know-how, the topic of the next section, thus played a greater role than institutionalised knowledge in shaping how practices changed.

5.4.4 Know-how and embodied habits: experience matters

This subsection further discusses how different types of knowledges (specifically, tacitly learnt know-how and the formal provision of institutionalised knowledge) relate to one another. The trade-offs between these two knowledges are made clear, in particular that the previously discussed failings of the institutionalised knowledge have led to a significant reliance on know-how and embodied habits in transitioning domestic practices.

The dominance of know-how and embodied habits, rather than institutionalised knowledge and explicit rules, in adapting practices was clear when considering how the practices of the shared ownership households had changed. In comparison to the tenants who were renting their homes, the shared ownership households received much less institutional guidance at move-in and interacted much less with the support institutions post-move-in, yet they showed no less competency through the practices that they performed. I would argue that this is because the skills required to adapt practices to Passivhaus surroundings were largely acquired through experience.

Active learning seemed to be in many of the residents' mindsets prior to move-in in that every resident who had prior concerns about Passivhaus thought that confidence would be gained through experience and "actually living it" (6A; 19A). An acknowledgement beforehand perhaps that a setting so different would eventually fade into the background and embed its position within the norm. The novelty of the development only made learning by doing more inevitable because the lack of resident knowledge could not be adequately compensated by institutionalised knowledge. Even those residents who had general building-related technical knowledge were resigned to tinkering with the controls and making mistakes (e.g. overheating) which were then embodied into daily habits,

although they were somewhat more comfortable doing this than the less technically minded residents.

Most residents, usually unwittingly, therefore attained competency through trial and error with domestic practices refined until optimal conditions were achieved and/or services obtained. Residents adapted how practices were performed based on how their own contextual situation sat within the Passivhaus materiality. For example, one household that washed clothes every day began switching when they used their tumble dryer, from the middle of the day (which had been routine for years) to the evening, so that the heat it gave off would help heat the house. When discussing this change, the resident spoke largely of experiences (demonstrating know-how) explaining that in the evening there is no heat gain from the sun, the “children are in bed so they aren’t running around, and cooking is over” (21C). More hands-on involvement, of which there was little, during the handover day technology tour could provide residents with early experience of using Passivhaus technologies so as to help them learn how to adjust practices sooner.

Know-how seemed to develop much more quickly, consequently changing practices more readily, when interacting with institutionalised knowledge and explicit rules, or engagements. In this case, engagements were shown to significantly help embed know-how in everyday habits. For instance, the aim of being a good host was enough of an engagement to spearhead a tacit understanding of altering the ventilation controls to mitigate higher temperatures and “that stuffy, uncomfortable feeling” (16C). Being proud of one’s home was a recurrent theme that aligned with escalating know-how. One household talked of how they “want a house that looks like the owners care about living in it” (13C). Such sentiments seemed interlocked with others’ perceived sensory readings of one’s home, beyond just visual appearance (e.g. the MVHR system stops it “smell[ing] of boy” (2B)). Therefore whilst being tidy was essential to most, the even more essential cleanliness requirement included evading the feel and smell of hot and/or humid conditions. Social expectations dictated what constituted a welcoming environment, and as the residents reflected on their time in their homes it was clear that experiencing what they deemed social awkwardness once was enough, and this manifested itself in unwitting changes to their practices.

It was through the build-up of know-how and its infiltration into habits over time that the entanglement of practices became increasingly clear. Residents had to reorganise bundles of practices, rather than just one practice in isolation, to obtain their desired heating and ventilation levels. For example, one household learnt through experience not to cook any meal that used the oven for long periods on warmer days as the house got too hot. However on the days that were not as warm or if they really wanted a certain meal, they began to strategically change when they watched their large LCD television or did physical activity (e.g. children running around; playing on the Wii; cleaning). Further, almost every household referred to experiencing higher temperatures because of vacuuming and as a result many now never vacuum when the oven is on. In preparation for hosting guests, residents similarly had to think more carefully about when to vacuum to combat the common complaint of temperatures being too high when guests arrive, having usually only vacuumed minutes before arrival. Residents have therefore seen a domino effect across practices. The gradual evolution of assemblages of practices were in part a consequence of not learning (by doing) to use the MVHR as designers had envisaged, making altering the performance of various practices the primary means of temperature regulation.

This subsection has so far shown how know-how has been a significant influence in helping practices adjust to Passivhaus technologies. However, relying so much on previous experience as the knowledge base for performing new or changing existing practices can result in misinterpretation of unfamiliar technologies. Indeed, despite being fundamentally different, frequent attempts were made by households to normalise newly encountered technologies through parallels with their previous home's technologies. The remainder of this subsection is dedicated to detailing five examples that illustrate how domesticating new technologies on the basis of past technological experiences can cause misunderstanding and misuse, relative to design intent:

1. *Warmth without radiators:*

A common concern prior to move-in was "how can I stay warm without radiators?" (19A). Most previous homes had been heated by central heating and

radiators, whilst those 'off-gas' used electric storage heaters. There had always been a visually distinct object that one could also feel as a heat source. Such was the worry this created that, as far as I could see, the support institutions' most consistent and clearly communicated message – a Passivhaus home will maintain a warm temperature throughout the day and seasons – was ineffective in countering the dominance of past know-how.

2. *Controlling the MVHR:*

Several residents compared the MVHR controls to their boiler controls, describing how radiators are warmed by turning the thermostat up. The rationale was then that to heat one's home, one puts the ventilation system on a higher setting ("turn it up" (7C)). However a higher MVHR setting increases the rate at which (warm) internal air is removed. A lower setting, and lower removal rate, ensures temperatures would rise as there is a greater accumulation of heat passively generated through performing practices. Interestingly one resident made a parallel to a cooling fan, saying that you turn it up to cool and down to warm. This was probably stimulated by the guides constantly referring to the MVHR as "a fan", in a bid to use less intimidating and more familiar terminology. Yet previous technological encounters indicated something similar to a cooling fan, or for others, an air conditioning unit. Therefore terminology that support staff often took for granted was frequently misinterpreted by residents on the basis of past experience.

3. *Regulating summer temperatures:*

Past experience told the residents to open windows for cooling during hot spells. However this was not on the basis of a building that was designed to establish a clear internal-external divide. Thus if it is warm inside, but even warmer outside, opening the windows would allow warmer air to enter and the limited throughflow of air could increase temperatures, particularly if windows are then shut (e.g. at night). In addition, external blinds were provided to help control the amount of solar gain, yet several residents initially considered their presence primarily for privacy purposes, as that was the context in which blinds had always

been used previously. Indeed half the households still do not have curtains one year on, using the blinds as a direct substitute. Residents should instead be inhibiting overheating during prolonged hot spells through opening the windows at night to allow cooler air to enter and using the blinds for shading during the day. Complicating matters further, this strategy need not be employed during typical summer days when window opening, for example, would have little impact on internal temperatures (i.e. practices can align more with their previous home). These nuances only emphasise the difficulty of relying on past experiences for new technological encounters.

4. *Drying plaster in airtight dwellings:*

As a consequence of high humidity, a few dwellings initially had signs of mould growth, particularly in enclosed spaces such as cupboards. Residents lacked the knowledge that a dwelling built using a *wet trades* approach (i.e. using wet plaster as the internal air leakage seal) with extremely little natural ventilation requires higher than usual mechanical ventilation to aid drying out. The relevant support institutions were also unaware of this to an extent, even after mould growth on the construction site, emphasising how innovative constructions require the development of skills from those other than the occupants. For instance, if construction practices were to ensure a well-ventilated construction site then the ventilation burden placed on the household practices may be lessened.

5. *The rate of internal temperature change:*

Since the MVHR only needs to input a small amount of heat into the incoming air because of the system's high heat recovery and dwelling's low heat loss rates, attempts to control temperature usually took longer to come to fruition. This slow change, sometimes taking several hours, was not anticipated by residents as it is a stark contrast to the previously used thermostat and radiators that provide immediate feedback. Residents were informed of this prior to moving in, but very few incorporated it into their heating practices until they actually experienced it. In addition, I note that the housing association did not follow the logic of its own guidance when conducting its only winter handover, leading to new residents

using portable heaters for two days. This was commented on by one neighbouring household: “they [the housing association and new residents] were expecting that when you put the heating on it would be red hot in an hour like a conventional house. But you’ve got to get your head round that it’s not like that. Ideally what you [the housing association] should do is put the heating on a couple days before move-in, so that when you [new residents] move in it is warm enough” (26B).

Therefore interpreting and using new technologies on the basis of old can contribute to further confusion and result in numerous unintended consequences. Indeed many of the examples presented illustrate how using heating or ventilation technologies so as to improve thermal comfort or air quality can actually have the opposite effect if performing practices on the basis of outdated knowledge. This has the potential to adversely affect how one adapts to a new environment, and thus it is perhaps unsurprisingly to note that, as time went on, residents began to realise that learning often had to start afresh.

5.5 Discussion

In reflecting upon on the previous findings section, I now discuss four crossing-cutting themes: (1) the difficulties of reconfiguring the elements of practice through innovation, (2) practices represent a source of heating, (3) the interconnectedness between practices, and (4) the interconnectedness between the elements of practice.

The results indicate that reconfiguring the elements of practice to save energy, whether intentional or not, through technological innovation can be fraught with difficulties. Despite technological progression being vital in facilitating new (less energy consuming) ways of performing practices (as *Subsection 5.4.1* indicated), that same progression can ironically be its downfall. This is highlighted by the households’ lack of Passivhaus know-how. Indeed it was the support institutions’ lack of Passivhaus know-how that led to institutionalised knowledge being treated with caution by the residents, since the support institutions simply lacked experience in delivering Passivhaus projects. It is an unfortunate consequence of being innovative, and from moving a concept from the niche to the

mainstream, that one may have to significantly stray from a current practice-related trajectory. In this instance, a leap was required for the know-how trajectory (relating to past experience), creating problems both for the support institutions and the households themselves. I would suggest that more research is needed to help limit, or at the very least plan relevant contingencies for, such problems.

The Passivhaus technologies contributed to practices becoming a source of heating. This was evidenced through resident stories of how cooking, laundering, hosting and cleaning, amongst others, changed how thermally comfortable the household felt. Indeed, whilst this is never talked about in terms of practices, the Passivhaus standard has undoubtedly been developed on the premise that the everyday life of building occupants will help to successfully lower (heating) energy consumption. Since, as I have argued previously (see *Subsection 4.5.1*), Passivhaus is a techno-economic policy that assumes technologies represent a magic bullet solution, it is somewhat counterintuitive and certainly ironic that a linear technological solution depends on something as messy as practices.

The multiplicity of practices was clear in that residents often had to alter several interconnected practices, rather than changing just one practice. Thus changes to one practice had implications for other practices. I would argue that the scale and extent of such knock-on influences was greatly enhanced with practices becoming a source of heating. The heating, and to a lesser degree the ventilation, technologies helped to establish more horizontal links between practices and thereby strengthen the interconnectedness of practices. Therefore, using Shove's terminology (see Shove *et al.*, 2012, p. 17), Passivhaus technologies have transformed many *bundles of practices* ('loose-knit patterns based on co-location and co-existence') into *complexes of practices* ('representing stickier and more integrated arrangements including co-dependent forms of sequence and synchronization'). In large part, more complexes have now formed due to the heat by-products of various practices jointly implicating thermal comfort; hence the performance of one practice is more likely to depend upon whether another practice is being performed, which was not the case within a more loosely knitted bundle of practices.

The interconnectedness was also evident between each of the elements of practice. For example, the interconnectedness between the forms of knowledge that make up the elements of practice was made clear: how one is configured can significantly influence how another is configured. This was demonstrated by households relying on know-how, as opposed to institutionalised knowledge due to issues of trust and poor delivery, in changing how they performed practices in response to new technologies. Indeed such was the interconnectedness of the elements, that it presented challenges in structuring a chapter around each of the elements, as can be inferred from me going slightly off topic at times in discussing how the configuration of one element translates to another element changing.

All four cross-cutting themes emphasise how technologies do not always produce linear consequences, and I would speculate that the Passive House Institute is beginning to acknowledge this. For example, as can be inferred from this discussion so far, it is particularly difficult for Passivhaus technologies to guarantee that building occupants will be thermally comfortable, since it depends on how they live their lives. Perhaps this has been realised to some degree by the Passive House Institute because its most up-to-date Passivhaus definition, which states that thermal comfort ‘can be achieved’ (International Passive House Association, 2013a), replaces a very similar definition that said Passivhaus ‘guarantees thermal comfort’ (Feist, 2007).

5.6 Conclusions

This chapter investigates the influence of new and unfamiliar technologies on the performance of energy consuming practices in the home. It is clear that changing practices to save energy are unlikely to be stimulated by introducing technology alone. Technological provision does not guarantee predictable outcomes on one’s everyday life, nevertheless Reckwitz (2002) and others were right to include technologies as an element that shapes a practice. A significant change to the technologies element (moving into a Passivhaus dwelling) altered the inter-element relationships that bind everyday practices together. The technological change also served to establish deeper horizontal linkages

across practices through the energy services of heating and ventilation, indicating that the already messy integration of practices is made even messier in low energy homes that employ super insulation and high airtightness, whether Passivhaus-certified or not. Since international policy agendas and building codes are targeting these new build design approaches, such deep-rooted integrations mean that actual outcomes are even more unpredictable and nonlinear than in the past. Therefore a salient consequence of significantly lowering domestic heating and cooling energy consumption is that almost every aspect of domestic everyday life (practices) implicates heating and/or ventilation, potentially having major repercussions for how households live their lives.

The willingness to use (and indeed the wider benefits of) a technology was not associated with a technology itself, but instead with how a technology is practically used through existing practices. Residents were primarily willing to learn new skills and disrupt existing practices because it minimised their apprehension regarding the new Passivhaus setting, or it was deemed necessary in order to obtain their new home and the wider social benefits which accompanied it. Based on these engagements, residents mainly adopted a trial and error approach where everyday know-how was altered and embodied in a new set of domestic practices. In part because the institutionalised knowledge was at times contradictory and limited (due to the development's innovative nature), the reliance of the residents on their previous technological know-how became increasingly dominant, hindering how practices adapted to the new dwelling. Residents interpreted and used new technologies through the lens of past experience. To enable low carbon living further the need thus exists for more intuitive design whereby new and old technologies are analogous, especially but not limited to instances where institutional guidance may be lacking. Where technologies are incomparable, hands-on experience under the mentorship of an expert (e.g. during the move-in day tour) or exposure to new learning experiences could help equip households with practical knowledge. It is important that residents gather as much experience as soon and as quickly as possible.

Dependence on experience emphasises how practices have evolving trajectories. Very rarely is there an instantaneous switch to new habits and routines (e.g. through an elemental change) since continual adjustments are typically made as practices are

(re)performed in reality. To increase residents' confidence with new, and perhaps daunting, technological configurations they are encountering for the first time during the handover period, continual support and regular interaction is vital to help them find their way through experiencing the technology. This also provides the support institutions with the opportunity to learn more from the residents, facilitating improvement to future handovers and thereby lessening know-how's dominance (and its interpretative pitfalls) in shaping new practices. This is especially crucial to social housing where there can be a high resident turnover. Improved knowledge should be provided to the residents at a household-level taking into consideration their previous know-how, thereby helping to avoid misunderstanding. In conjunction with this, and although only subtly different, buy-in should be sought by emphasising the benefits of residents *adapting* their practices and *learning* new skills, and not simply the benefits of *living* in a Passivhaus dwelling as that creates the assumption that the benefits are attached to the technology, not its practical use.

These insights into how everyday life is rarely pushed and pulled at the mercy of information and new technologies were made possible through a practices approach. By going beyond the restrictive and narrow-sighted techno-economic paradigm I could delve deeper into what the often irrational (or rather, *practically* rational) and abstract reality of everyday life actually involved. Adopting the elements framework presented by Gram-Hanssen (2010a, 2010b, 2011a) helped structure an investigation into the mechanics underlying practices that are influenced by an elemental (in this case, technological) change. The framework's distinction between *institutionalised knowledge and explicit rules* and *know-how and embodied habits* also proved crucial, emphasising the need to appreciate and research how experience shapes practice trajectories, whether Gram-Hanssen's framework is adopted or not.

More work is needed on trajectories and how practices are, and thus perhaps can, be steered in certain directions. The tracking of performance trajectories is essential. By taking a longer study period we could see to what degree practices are in flux or settle as residents become used to their new homes. In light of future climate change predictions, trajectory investigations into how experience of seasonal extremes shape practices in

Passivhaus dwellings will also be vital. For instance, will adapting to a prolonged heat wave induce zero to minimal, clear but temporary, or salient step changes to everyday domestic practices? Will the residents resent making changes, such as reorganising timings, to existing practices? Understanding how households change how practices are performed in response to future climates, or indeed any elemental perturbation caused by certain policies and designs, is critical in anticipating and preparing for ground-level impacts on everyday life.

Chapter 6 – Investigating the performance of everyday domestic practices using building monitoring

Abstract

Building monitoring can enhance our understanding of everyday life, yet has sparsely been used in social practices research. Monitoring usually provides context (e.g. differences in performing practices) for more prominent qualitative inquiry, and is rarely centrally integrated methodologically. This chapter aims to investigate the potential usefulness of utilising, and integrating more centrally, building monitoring to study the performance of domestic practices.

Since the practice theory literature shows no theoretical incompatibility with monitoring, a UK Passivhaus development is examined in considering applicability further. Monitoring data include temperature, humidity, carbon dioxide, and electricity sub-metering. These data are records of interactions with the material world, and, as such, are shown to be a particularly good basis for investigating how technologies relate to the other elements (influences) of practice in shaping everyday life. Reflections regarding the benefits and limitations of integrating monitoring with qualitative data are also shared (e.g. resident enthusiasm for co-investigating monitoring data; monitoring data having insufficient richness without accompanying qualitative data).

Monitoring and qualitative data are shown to be complementary, and capable of producing insights beyond those of non-integrated approaches. I advocate using building monitoring more in researching practices, particularly when considering the everyday implications of technological changes.

6.1 Introduction

The climate change and sustainable energy consumption agendas have created an upswell in research attempting to understand everyday life (e.g. Shove *et al.*, 2012), with the domestic setting receiving significant attention. From understanding what exactly constitutes as well as influences everyday life, many have become interested in how best to intervene and govern everyday activities and in doing so, for instance, reduce energy consumption (e.g. Shove, 2012). A diverse range of approaches exist as to how best this understanding could be deepened (Wilson and Chatterton, 2011), within and across disciplines. However there has been relatively little methodological integration across disciplines. Relevant social and technical research methods have developed in isolation, with the technical sciences largely dominating attempts to understand how buildings are used.

Technical disciplinarians have mainly used building monitoring in a very technologically focused manner to descriptively detail the performance of innovative buildings (e.g. Bordass *et al.*, 2001). In furthering notions of individual behaviours, monitoring data have largely been used to either stimulate behaviour change (e.g. Studley *et al.* (2011), or consult Darby (2006) for a review of energy consumption feedback studies) or directly inform behavioural models (e.g. Reinhart, 2004; Rijal *et al.*, 2007). In broadening the search for factors which shape dwelling performance and individual behaviours, more exploratory ‘user-centred’ case study research has tended to couple monitoring techniques with psychological and/or economic approaches to consumption (e.g. Gill *et al.*, 2010; Gupta and Chandiwalla, 2010; Stevenson and Rijal, 2010; Stevenson *et al.*, 2013).

However, critiques show the practice ‘turn’ (Schatzki *et al.*, 2001) in broader social studies to provide a more meaningful representation of everyday life (Shove, 2010; Shove *et al.*, 2012). Theories of social practice place practices (e.g. cooking, driving, hosting guests, washing) at the centre of its research, acknowledging how practices construct, uphold and structure everyday life. Similarly to the research on individual behaviours, in the past monitoring has been used and explored as an intervention to change practices (e.g. visible energy monitors: Strengers, 2011b; Hargreaves *et al.*, 2013). Of the practices

studies that have used monitoring data as an investigative method rather than for targeted intervention, they have largely centred around qualitative data with monitoring used to descriptively highlight that differences do exist in performing practices (e.g. Morley and Hazas, 2011). Studies tend not to give monitoring data too greater a prominence, such as using it to explain or enhance qualitative interpretations rather than the other way round.

Potential therefore exists to deepen our understanding of how building technologies are operated by analysing building monitoring data through, and in conjunction with methods associated with, a social practices lens. Different approaches create different insights, and as such integrating methods can enhance our understanding of how best to develop the theories of social practice literature. Continuing on this premise, the capacity exists for an improved interdisciplinary understanding of domestic everyday life and how households interact with their surrounding technologies (e.g. Morley and Hazas, 2011; Bates *et al.*, 2012). I believe that innovating methods in such a way can also demonstrate a feasible course of action as to how technical and social disciplines can work together holistically, from which a transition may be aided to a more widely shared research agenda that better reflects how consumption takes place in the everyday.

The aim of this chapter is to investigate the potential utility of using theories of social practice in conjunction with building monitoring to further our understanding of how everyday practices are performed in dwellings or, indeed, any built environment. This will be achieved through the completion of three objectives:

1. Review the literature to examine, from a largely theoretical perspective, how compatible building monitoring data are with a practices lens;
2. Reflect upon and discuss experiences of using building monitoring with qualitative approaches (traditionally associated with practices studies) for one specific residential case study;
3. Present findings obtained from using such mixed methods to investigate the elements (i.e. underlying influences) of everyday domestic practices, in relation

to this same case study. Broadly focus on how technological change influences practices in general, rather than a specific practice (e.g. cooking).

The case study is a small to medium sized UK affordable housing development built to Passivhaus standard. The super insulated and airtight Passivhaus dwellings provide a radically different domestic technological configuration, and thus is a good basis for considering how building monitoring can help us understand technological interactions as part of performing everyday life.

This chapter is structured around the three objectives. I begin by introducing theories of social practice (*Section 6.2*). Following this the case study is presented, before reflecting on building monitoring's complementarity with qualitative methods (*Section 6.3*). A final illustrative discussion relating to the elements that shape practices is then provided in the context of technological change (*Section 6.4*). I conclude with how building monitoring can facilitate an improved understanding of practices (*Section 6.5*).

6.2 Theoretical context

6.2.1 Individuals and their behaviours

I begin by discussing two disciplinary categories – economic and psychological – and the types of theories which are inherent to those. The economic perspective regards individuals as utility-maximisers who make rational choices based on available information. Its research often focuses on the role of information (e.g. Ueno *et al.*, 2006) or pricing (e.g. Narayan *et al.*, 2007). A standard critique is that the economic perspective ignores the attitudes and values of the individual. These are central to the psychological perspective which introduces further rationalities and environmental cues that are not solely economic (e.g. associated with attitudes and values, as Brandon and Lewis (1999) and Gill *et al.* (2010) do). However, both psychological and economic perspectives employ individuals as the central unit of analyses, whose behaviour is subject to external

pressures. More sophisticated analyses usually involve identifying and applying more external pressures. Research therefore frequently searches for the most acceptable or satisfactory conditions that would trigger or at least ‘nudge’ (Thaler and Sunstein, 2008) individuals towards, for instance, less energy intensive choices. These cause-and-effect relationships fundamentally create more of a linear and simplistic problem framing (Shove, 2010; Shove *et al.*, 2012), yet have largely been used when attempting to make sense of how people behave from building monitoring data.

I advocate theories within the anthropological and sociological literatures which appreciate the social and cultural dynamics that are at play in everyday life. By acknowledging the somewhat messy worlds of consumption, one can begin to engage ‘with the whole process of sociotechnical change and with living systems of knowledge, practice and experience, in all their complexity’ (Shove, 1998, p. 1111). Specifically the notion of social practices provides an insightful lens for analysing everyday life. Such theories provide a means for considering the practical and institutionalised knowledge, skills and competences, and meanings that individualistic lens largely bypass.

Such critiques of individualistic perspectives remain whatever the type of data under consideration, and are thus just as valid when examining building monitoring data. What is important is how the data are interpreted, hence why the theoretical foundations of analyses come into question. These questions are hugely important if theoretical progression is to be adequately mirrored by (meaningful) methodological progression, as Crosbie (2006) highlights as not having happened in the household energy studies literature over recent decades.

6.2.2 Moving towards a theories of social practice approach

Studies drawing on theories of social practice focus on the practices themselves rather than individuals. In reinforcing the arguments of Schatzki (1996), Warde (2005, p. 136) emphasises how ‘practice theories are neither individualist nor holist; they portray social organization as something other than individuals making contracts, yet are not

dependent on a holistic notion of culture or societal totality'. Practices analyses do consider individuals but only in relation to how they carry a practice and sustain its existence through individual performance.

A practice is essentially a set of routinised behaviours, forming the building blocks of everyday life. Therefore individuals associate themselves as *doers* of practices (i.e. practitioners) such as cooks, drivers, cyclists, hosts, washers, cleaners, and all manner of other identities that are created by the specific undertaking of a practice. Consumption is a by-product of undertaking such practices and thus, in the words of Warde (2005, p. 137), is 'a moment in almost every practice'.

A practice is a 'routinized type of behaviour' (Reckwitz, 2002, p. 249) representing a sequence of often unique single actions. These are made up of the largely unconscious 'doings' (bodily behaviours) and 'sayings' (expressive doings that do not change the physical environment) (Schatzki, 2002), which are routinised as part of an overarching practice. Providing the onus is on practices, scope exists to investigate the variety of performing practices and constituent doings and sayings, so as to better understand how practices influence the everyday life of its individual carriers (Gram-Hanssen, 2008).

6.2.3 Elements of practice

Investigating the elements that other studies and practice theorists have found to shape practices can be useful. However there is no agreement on one single formulation of social practice theory, with there being considerable discussion regarding the different directions the theory could take. More recent proponents, each with slightly different propositions regarding the elements, include Schatzki (1996, 2002), Reckwitz (2002), Shove (e.g. Shove and Pantzar, 2005; Shove *et al.*, 2012), and Gram-Hanssen (2010b).

The framework suggested through empirical investigations of household energy consumption, by Gram-Hanssen (2010a, 2010b, 2011a), is utilised later in this chapter (*Section 6.4*). Changes to the four elements, and crucially the interrelationships, can

shape (e.g. transform, destroy, create) a practice. Whilst all elements are required for a practice to be undertaken, their presence does not guarantee that a practice will actually be undertaken. Table 6.1 summarises Gram-Hanssen's elements, using cooking as an illustrative practice.

Element	Description	Cooking example
Technologies	The tangible physical environment that makes up the world in which we live	Oven; hobs; microwave; saucepans; energy; energy supply infrastructure; oven gloves; apron
Engagements	Social significance of participating in a practice: norms; aspirations; attachments; motivations; ideas; symbolic meanings	Being healthy; worldly; part of a family unit; sustainable; a good host; affectionate; nationalistic; a shrewd cost saver
Know-how and embodied habits	Practical understanding gathered through experience, which is (usually unwittingly) embodied into everyday habitual life	Sense of smell/taste; managing the hottest part of the oven; how to react to it all going wrong; complementary dishes/ingredients
Institutionalised knowledge and explicit rules	Sourced from those ('experts') who know more than you: less intuitive, explicitly spoken information; cultural myths; recommendations for using technologies	Recipes; appliance manuals; energy efficiency advice; dietary advice; weights and measures; serving suggestions

Table 6.1 – Introducing the elements of practice (produced using Gram-Hanssen, 2010a, 2010b, 2011a)

6.2.4 Practices as entities and performances

Schatzki (1996) introduces two notions of practices: (1) as a co-ordinated entity, and (2) as a performance. The first focuses on a 'practice as a temporally unfolding and spatially dispersed nexus of doings and sayings' (Schatzki, 1996, p. 89), and has received more attention to date with the elements of practice being explored. However since practices consist of doings and sayings, there is an implicit indication that investigations into practices must address how these are undertaken in actuality. Indeed it is the (re)performing of these doings and sayings which ensures a practice persists. Practices are co-ordinated entities that need to be performed to exist, thus transitioning to a low carbon society, for instance, demands a transition in the reproduction of practices (Shove and Walker, 2010).

When the turnover of individuals performing a practice in a certain way (i.e. carriers) slows or stops then the prominence of a practice or practice element lessens (e.g. quill technology in the practice of writing). Certain traits of a practice's elements can undergo 'fossilisation' in that they may be left behind as a performance of a practice stops or changes (Shove and Pantzar, 2006, p. 59). If one or more of the four practice elements (know-how and embodied habits; institutionalised knowledge and explicit rules; engagements; technologies) were to change, new inter-element relationships could change the practice itself (Pantzar and Shove, 2006).

The literature has predominantly had an entities focus perhaps because that creates and maintains a more distinct separation from economic and psychological literatures. By empirically focusing on performances the divide between literatures becomes less distinct since one is more likely to be drawn towards discussing the doings and sayings of individuals. This research gap needs to be filled if we are to develop our understanding of how everyday life is actually carried out over time and space. It is particularly important when reviewing past and examining prospective (even if potentially inadvertent) efforts to reconfigure the elements of practices; for example, attempting to lower domestic energy consumption by moving households into Passivhaus dwellings (the subject of *Section 6.4*).

6.2.5 Monitoring performances of practices

Building monitoring data tells us about the consumption of a technology, providing an access point for investigating the interconnections between technology and the other elements of practice. Through examining technological usage, monitoring provides a measure of performance and thus serves as a proxy for practices. It is not the practice that is measured, but the by-products of a household or individual performing that practice. This is perhaps most easily recognised in the context of energy consumption whereby building energy data is simply a record of energy consumption, which has come about through performing practices. This is fundamental to Gram-Hanssen's (2011b) analysis which used space heating and appliance energy usage data to reveal the

importance of practices (relative to improving technological efficiency) in lowering domestic energy demand. These principles still remain for more sophisticated monitoring methods. For example, changing the control settings of a ventilation system can be observed by changes in system electricity usage and temperature flows, as well as indoor humidity, carbon dioxide and temperature levels. However since practices are the central unit of analysis, observations such as these would need to be attributed to a practice(s) rather than describing the action(s) in isolation.

As a consequence of practices being so heavily integrated with one another, it can be difficult to obtain suitable proxies for one specific practice. For instance, using the ventilation example again, control changes could be attributed to hosting guests (to improve air quality), thermal comfort (to change temperature), cooking (to eliminate odours), or washing (to remove steam) practices, amongst others. The reality is that all of these practices are co-evolving alongside each other, all shaping how we perform our everyday life. Therefore the rigid differentiations between each building monitoring dataset cannot be directly translated into different factors that shape everyday life. Theories of practice do not sit well with linear cause-effect relationships (i.e. searching for factors), instead regarding everyday life to be a much more messy and non-linear affair (i.e. searching for influences). Indeed, household practices are also influenced by the designing, constructing, manufacturing and maintenance practices of industry, which only adds further layers of complexity. Interpretation of monitoring data also requires qualitative data that have the richness needed to search for such messy influences, which is discussed more in *Section 6.3*.

Some studies have already used building monitoring data as part of investigations into everyday practices. Gram-Hanssen (2010b) used heating-related energy consumption totals and internal room temperatures across her sample of five identically designed dwellings to help qualitatively address the everyday changes that underlie wide differences in the quantitative data. Morley and Hazas (2011) employ daily electricity consumption profiles for households to similarly demonstrate the link between practices and inter-household variations. Monitoring efforts to date have largely centred on energy

consumption data, often in isolation, to examine energy consuming domestic practices. A gap thus exists around the use of other building data in such endeavours.

Morley and Hazas (2011, p. 2046) call for more detailed (micro-level) monitoring, reflecting on how 'average consumption values fail to represent highly diverse groupings, and they obscure detail from our understanding of energy demand, which for example might help identify particularly intensive varieties of practice'. Aggregated and average data provide little insight into what is actually happening on an everyday basis, even though many behavioural studies may use such values as headline findings (e.g. McCalley and Midden, 2002; Benders *et al.*, 2006). For instance, a stated (e.g. 10%) reduction in energy consumption does not reveal changes to the performance of everyday domestic practices (e.g. should we thereby assume: 10% shorter shower times? 10% more devices off standby?). Disaggregated monitoring data can give more detail as to how practices interact with material surroundings (e.g. sub metering of plug sockets disaggregates practices involving specific appliance usage from overall electricity consumption). Bates *et al.* (2012) disaggregated total energy consumption by end-use demand to determine the role of specific domestic energy services (e.g. lighting, refrigeration), the characteristics of which were considered qualitatively in the implicit context of practices-as-performances. Although an insightful study, the default position of primarily using qualitative inquiry to explain variations in quantitative monitoring (energy usage) data is adopted, rather than integrating to the degree that both are used to explain or support each other.

Building monitoring has been underutilised in the social practices literature, despite there being nothing implicit within the data that dictates alignment with a particular discipline and/or analytical framework. Indeed utilising such data is less about the data itself and more about the lens of inquiry and theoretical basis in which it is applied and interpreted. Researchers investigating practices within built environment domains are therefore encouraged to go beyond current descriptive applications of monitoring data and use it for more exploratory purposes; for example, use monitoring data to examine how the elements of practice influence its performance. The wider fringes of potential are indicated by how Shove and Pantzar (2005) consulted quantitative sales and market share information on Nordic walking sticks in detailing the status, diffusion, and underlying

influences of Nordic walking as a practice. Considerable potential hence exists to more generally broaden, develop and transfer methodological approaches across disciplines to further the practices literature, in particular the under researched aspects of practices-as-performances. Therefore this chapter addresses this knowledge gap by investigating the potential utility of the more technical and traditionally behavioural building monitoring methods in researching mundane practices.

6.3 Methodological reflections: integrating building monitoring and qualitative methods as part of a practice-oriented approach

To empirically investigate how theories of practice could work with monitoring, a case study research design was used which provided the depth required to suitably reflect on data collection, theoretical application and analysis related issues. For more on the further merits of case study research design, consult the work of Flyvbjerg (2006). This section presents the case study and the mixed methods approach adopted (*Subsection 6.3.1*) and illustrates how building monitoring and qualitative data can complement one another in developing an understanding of how practices are performed in a built environment (*Subsection 6.3.2* and *6.3.3*).

6.3.1 Case study and data collection

Monitoring data were available for a small to medium sized UK Passivhaus affordable housing development, for 16 months post-occupancy after move-in in July 2011. The dwellings shared the same design characteristics, excluding floor area and in part layout. Passivhaus dwellings use high levels of insulation and airtightness to maintain warmth passively through body warmth, appliance usage and solar gain. For this housing development, a mechanical ventilation with heat recovery (MVHR) system was used to ensure fresh air while minimising energy losses from doing so. Minimal space heating, in addition to water heating, was provided through a solar thermal system and a gas-fired boiler. A small heating load was achieved because Passivhaus dwellings are purposely

designed for incidental gains from general living to assist in heating one's home (Feist *et al.*, 2005). Almost all domestic practices fundamentally generate heat; whether it is cleaning, washing, cooking or simply relaxing in your home, heat is generated through, for example, body warmth and electrical device usage. Investigating methodological innovations through monitoring Passivhaus dwellings is thus a particularly useful case study because temperature data can show how practices are performed in a way that monitoring data of more conventional dwellings cannot.

The monitoring of all dwellings include measurements at five minute intervals for lounge humidity and temperature as well as electricity meters (dwelling total) and sub-meters (kitchen, plant room (including solar thermal, boiler and ventilation systems), plug wall sockets). Three dwellings have more detailed monitoring, additionally including master bedroom, kitchen and hall (outside bathroom) humidity and temperature sensors in addition to lounge and bedroom carbon dioxide (as a proxy for air quality) sensors. The monitoring strategy therefore goes beyond that of other domestic energy studies which have adopted a practices lens. Going beyond just measuring energy consumption by examining temperature, humidity and carbon dioxide is new in the practices literature. Plans had been made to monitor gas and water usage in detail, but initial installation problems meant data was not available at the time of writing. For a detailed summary of the monitoring data collected and for an extract of the building monitoring records that were kept see *Appendix 9*.

From a constructivist perspective, these monitoring data provide a *construction* of reality depending upon the context in which data collection occurs (consult Halkier and Jensen (2011) for more on qualitative data through a social constructivist practices lens). Of course, decisions taken regarding which and how monitoring data are collected shapes that construction, but beyond that monitoring data are only capable of capturing certain aspects of everyday life, thereby missing others. For example, monitoring can reliably and precisely show that a meal has been cooked, but has no way to differentiate between different meanings of a meal which could be experienced in very different ways by the household (e.g. exactly the same meal could be eaten in haste before rushing out for the evening, or for enjoyment over a dinner party with friends). Similarly qualitative data

construct realities, but in different ways which could, for instance, begin to answer some questions that monitoring cannot answer (e.g. regarding tacit learning, emotions, aspirations). Such methods aim to uncover completely different forms of knowledge. Monitoring is very reliable and precise with regard to the extent and timing of changes to energy consumption, temperature and the like, but needs the richness offered by qualitative data to find out what those measurements actually mean. In contrast positivist perspectives, which have largely dominated interpretation of building monitoring data, are likely to unrealistically regard monitoring data not as a construction of reality (findings limited to a given context) but as a representation of one true reality (findings transferable across all contexts).

A mixed methods approach is therefore adopted, with qualitative data also sought. During the total 19 month study period (of which monitoring covers 16 months), planned observation and participation was undertaken at key events (e.g. resident information sessions; move-in day tour of technologies; visitor days; landlord meetings), as well as more informal interaction with the residents being maintained (e.g. emails; ad-hoc discussions when visiting the site for other reasons). In addition, households were interviewed over three semi-structured rounds, all of which took place in the home:

- A. *April-May 2011*: first round involved interviewing all households prior to move-in, the purpose being to introduce the research project and get to know them as practitioners. An average first interview was 46 minutes in length (range: 36-63 minutes). For the interview schedule see *Appendix 1*.
- B. *March-June 2012*: the second round (64% of households interviewed due to dropout) was after they had lived in their new homes for one heating and cooling season. It predominantly consisted of the resident(s) leading a walkthrough of their home, explaining and enacting how they use their home's spaces and technologies, ultimately talking about their practices where those practices were actually performed. An average second interview was 52 minutes in length (range: 27-74 minutes). For the interview schedule see *Appendix 2*.
- C. *October-November 2012*: final round (86% of households, including 22% that were re-recruited after dropping out in the second round) predominantly involved the presentation of monitoring data to the households themselves, the substance of

which is discussed in more detail in *Section 6.3.3*. An average final interview was 58 minutes in length (range: 30-87 minutes). For the interview schedule see *Appendix 3*.

Across the development, 43% of households are single occupancy, 14% are dual occupancy, and 43% are (predominantly young) families. There are no elderly residents, with adults averaging 36 years in age (range: 18-53). The majority of employed adults work in the partly skilled (e.g. agricultural worker) or skilled (e.g. electrician) sectors, whilst only 8% work in the professional (e.g. accountant) sector.

Data collection involved contact with 28 individuals. Quotations in this chapter are referenced using '1A', whereby '1' represents the individual and 'A' represents the method (A = pre-move-in interview; B = walkthrough interview; C = monitoring data interview; D = participant, observation and informal discussions). The interviews were transcribed and coded on the basis of emergent practice-related themes.

6.3.2 Monitoring data as performance artefacts: comparing versions of doings

Building monitoring data are records of technological usage (e.g. through consumption), thus are proxies for performing practices. A mixed methods approach is essential in this analytical process because qualitative data is central to understanding what the monitoring data means and what practices it could represent. Yet, as this subsection discusses, that same qualitative data can require critical examination which the monitoring data can assist with. More integrated approaches are needed so that these traditionally separate methods can mutually inform one another – each has their own restrictions depending on how they construct reality.

Whilst researchers should not 'adopt a naively "optimistic" view that the aggregation of data from different sources will unproblematically add up to produce a more complete picture' (Hammersley and Atkinson, 2007, p. 184), monitoring does provide an opportunity to examine how practices are undertaken within buildings. Indeed 14% of

households were so shocked at the accuracy and effectiveness of interpreting monitoring data that it unearthed some social awkwardness when discussing the data because, as they saw it, I would be able to “see when and where we [the residents] have sex” (19C). They saw this as a possibility because of how successful the mixed methods approach had been in deducing mundane everyday performances. Resident agreement with most of my interpretations of the monitoring data did therefore endorse the integrated methodology adopted.

Households were asked to discuss their everyday life as part of qualitative inquiries, but there were mismatches between what they said they did and what they actually did. This requires revisiting some of *Chapter 5*’s findings: it was indicated that many residents wanted to live in their homes to obtain broader social benefits (e.g. new home, more bedrooms, nearer family, rural location) and that they were willing to alter existing practices largely because they thought that if they did not then they may lose their new homes. Alongside this, despite trying to remain impartial with no allegiance to the housing association, residents saw me (the researcher) as a key part of the institutional system with all the power they saw it to encompass (e.g. asked to fix broken taps; postponed a pre-arranged interview until the builders fixed their front door). It would seem that some residents sometimes said what they thought they wanted me to hear to reinforce the fact that they were using their home correctly (so ‘we’, the institutions, did not take it away from them). Whatever the underlying reasoning, versions of activities were not always supported between different qualitative datasets (e.g. saying they turn appliances off standby when not in use, despite visits suggesting they do not). Analysis of quantitative monitoring data served to highlight these disparities further.

In reference to frequent visits at monthly visitor days, one resident talked of how they “had got better at answering questions” (21D). Whilst this could be due to establishing more confidence in unfamiliar situations, I would have to employ a degree of hesitancy. Indeed social pressures (in this instance, to impress visitors) most likely led to this resident telling visitors that tumble dryer usage had been moved from early afternoon to mid-evening to help heat the house. However when investigating this claim with building

monitoring data, it was not wholly supported: evidence shows that this part of their laundering practice was often undertaken in the afternoon.

Similar social influences shaped how another household talked about how the MVHR was used. They seemingly knew the best practice answers, but yet these were not followed through when actually performing. It was only through consulting monitoring data that this mismatch was realised, specifically that the home was mainly ventilated through window opening rather than the MVHR settings. With this knowledge, one could set about subtly probing and finding out how the household actually uses the dwelling. It soon became clear that household practitioners were merely repeating what deemed 'experts' (be it housing association staff, the construction company, or interested visitors) had been saying.

As Strengers (2010) notes, whilst some may attribute these mismatches to the 'Hawthorne Effect' (where individuals behave differently in response to being involved in an experiment (Benson, 2004, p. 427)), practice theory would regard this as a change to the engagements element (Table 6.1). A change to the engagement element, in turn, changes the willingness to perform, or even be seen to perform in this case, practices in certain ways.

It is difficult to know how common this mismatch (between stated practices and monitoring) is because the monitoring dataset is so sizeable that it would be too time consuming to manually check all aspects of how practices are performed. Indeed most of these mismatches were only identified opportunistically or because of large anomalies being found. Further, mismatches rarely occurred for those aspects that could be easily checked (e.g. time of cooking; bedtimes; occupancy hours). What this subsection demonstrates, however, is that significant mismatches can occur, often in response to wider social pressures, and monitoring can offer a way to highlight and critically examine these.

6.3.3 Co-investigation: presenting monitoring results back to residents

This subsection continues discussing how quantitative monitoring methods have helped enhance qualitative means of inquiry. This discussion is in specific relation to household interviews which used monitoring results (e.g. printed graphs, tables) as central discussion pieces.

Even after getting to know the households, some trends in the monitoring data could not be easily explained without resident assistance and specific discussion about a period of time. For example, for two weeks around Christmas 2011, one household had a 15kWh/day increase in electricity consumed through kitchen plug sockets, as well as experiencing 18.6% higher internal temperatures (peaking at over 33°C) and a fall in average relative humidity from 56.1% to 33.6%. Without speaking to the household, I would not have known that a flood had led to a dehumidifier being used constantly for two weeks. Similarly, another household's MVHR system did not work for one month, contributing to 12.6% higher relative humidity. This was only clarified through speaking to the household and realising that they had not, for example, temporarily changed practices involving window opening. These were temporary disruptions to practices, caused in both cases by technological breakdowns, the headline quantitative findings of which would not be representative of any regularly performed social practice. Attempting to reach conclusions without resident assistance is fraught with risks of misinterpretation. For instance, monitoring data could have been used to (wrongly) justify that households are performing energy consuming practices that produce or even directly encompass certain comfort levels, ventilation regimes, or use of electrical gadgets.

Discussing the monitoring data directly with the households helped uncover more abstract facets of domestic practices in ways that the previous two interviews failed to do. More tangible methods, from the resident perspective, helped to hook the mundane, yet complex, everyday dynamics into the dialogue. For instance, one household spoke enthusiastically of how there was a clear drop in several monitoring data trends (e.g. energy use, temperature, carbon dioxide) at the same time each night because that was when their favourite television programme finished and they went to bed. Another

resident laughed at the significant rise in temperature every Sunday afternoon when she ironed close to the temperature sensor. The targeted nature of the results seemed to make it more real than simply talking about everyday life more generally, helping to bring everyday rhythms to the fore. Having said all this, there are many valuable methodological ‘hooks’ available and it is not for this chapter (or thesis) to argue which is best, only merely to emphasise the untapped potential of building monitoring (and other technical data) data which have traditionally been confined to researchers’ desks for analysis.

Households had tolerated “a horribly ugly box” (8B) (the monitoring equipment) on the wall of either their lounge or hallway for over year which, although it had largely “faded into the background” (15D), they were keen to learn more about the purpose of. Nevertheless even with initial interest, it was still surprising how interested most residents were in the data, specifically how accurately it could identify technological usage:

“Wow, that’s so cool [how monitoring can show what we’re doing].”
(10C)

“That’s so weird though [that the monitoring showed we left our windows open], oh my God!”
(11C)

“That’s really, really interesting [that the monitoring showed how our routine had changed for a week], absolutely incredible.”
(19C)

Such was their enthusiasm that most took it upon themselves to check personal diaries and calendars for what exactly they were doing during the periods of time that the graphs and tables covered. These graphs and tables were nearly always kept so they could “show them to friends and family” (8C) or to “spend my evenings trying to figure what I did” (1C). Several households asked for more specific information (e.g. effect on monitoring data when a boyfriend moved in) with one household going so far as to offer to experiment with their practices for measurement purposes. The development-wide enthusiasm underlined the possibility of using monitoring data to incentivise participation and enrolment.

Much of the success of this approach, and thus how monitoring data enhanced existing and created new qualitative lines of inquiry, was due to good relationships being built with the households over the previous 19 months. This meant that by the time of the final interview, there was a more relaxed feel to our discussions which crucially provided an environment where I felt comfortable enough to challenge one another. It is difficult to speculate over how successful co-investigating the monitoring data would have been earlier in the study period, prior to such a relationship developing.

6.4 Investigating the elements of practice

Continuing on from theoretical and methodological discussions, this section briefly discusses findings obtained through the Passivhaus case study and mixed method approach. Findings are presented in relation to Gram-Hanssen's (2010b) elements which shape the performance of a practice. The four elements are technologies, institutionalised knowledge and explicit rules, know-how and embodied habits, and engagements (Table 6.1). Particular attention is given to how moving into a new Passivhaus dwelling, with its unfamiliar technologies, transformed practices (as was the focus of *Chapter 5*). An open frame thus focuses on domestic practices (influenced by this technological change) more generally and not a specific practice (e.g. cooking; laundering); although Passivhaus technologies do tend to pull discussion towards practices connected to heating/cooling and ventilation energy services.

6.4.1 Technologies: accessing the inter-element relationships

A much looser and more flexible approach is needed than is typical for building monitoring studies. This closing illustrative discussion is largely related to technological usage because monitoring data are generated through practice-related interactions with the material world. If one is to use building monitoring to explore why practices are performed in certain ways, then the technology element becomes the gateway for

accessing the other elements of practice. Making technology the focal point also provides an insightful means for examining the everyday impacts of technological provision and innovation (e.g. Passivhaus). However, it is not the technology itself that is really being examined; instead it is the inter-element relationships between technology and the other elements of practice. Specifically, it is not even the relationship that is being measured, for such associations cannot be so rigidly captured. Measurements taken through building monitoring only represent performance by-products, thus, through using qualitative data to aid interpretation, the influence of such relationships upon performances can be explored.

If using monitoring to examine technology in isolation, most findings will only ever be descriptive. For instance, energy itself is material and its usage can easily be quantified to show how much energy is consumed in the home (e.g. average dwelling energy usage: 77kWh/a.m²). Sub-metered energy usage can indicate which, when and to some extent how technologies are used to yield certain energy services (e.g. plug socket electricity usage peaks in the evenings between 1900-2200). However, monitoring data are largely limited to showing technological use, and not the (practice-related) reasons behind its use; hence cannot fully explain how and can rarely say much (in isolation) on why technologies are used.

Technological monitoring-only analyses struggle to explore the underlying reasons behind why this material situation exists and has evolved. Using technologies depends on attached meanings and competences which need to persist to be able to perform a practice. Ultimately, monitoring does not get to the heart of practices, leaving researchers with somewhat impoverished findings. Investigating the inter-element relationships can provide researchers with exploratory findings, and this can be enabled by using technologies as the reference point. The following subsections do exactly this, with each element being discussed in relation to how technological usage has changed in response to new Passivhaus surroundings, helping to put the spotlight on the sorts of findings that building monitoring can enable.

6.4.2 Institutionalised knowledge and explicit rules

The influence of institutionalised knowledge and explicit rules, in relation to technology, can be indicated through monitoring around the times of ‘expert’ intervention and involvement. Through participating and observing the move-in day technology tours, it was clear that information provision lacked impact. This was largely because of the language used (e.g. too technical) and sheer quantity of information provided (e.g. most tours lasted ~1 hour), as well as it being inappropriately timed (e.g. more worried about positioning belongings) contributing to residents paying little attention. When discussed further in interviews, this was only reinforced: “there was just too much information being thrown at me, I didn’t take any of it in” (3C), in addition to the instruction manual being “impossible to understand” (9C; 19D). Nevertheless, even if the process of information provision was optimised, it is unlikely that it would have been enough to change practices (Hargreaves *et al.*, 2010).

However this element is not solely about knowledge provision, it formulates rule-based structures that contribute to shared practices. As a consequence of the housing association and builders sometimes contradicting each other (e.g. regarding the use of windows, water heating controls, the MVHR, and appointment times), the rules and knowledge associated with these deemed experts were accompanied by a certain degree of mistrust. This in combination with the relative ineffectiveness of information provision meant that, even with semi-interactive participation (e.g. on the move-in day technology tour), institutionalised knowledge and explicit rules played only a minor role in residents learning how best to interact with their new homes. This was evidenced by key events specifically designed to help residents adapt to their new technological surroundings (e.g. six week early tenancy visit by the housing association; revisit by the expert who gave the move-in day tour) having no noticeable immediate or delayed effect on monitoring data trends and how technologies were used.

The institutions that households therefore attempted to rely on were more informal (i.e. friends and family, rather than formal expert advice) but, due to the rarity of UK Passivhaus dwellings, these informal institutions lacked the knowledge to aid the

transition to living in a Passivhaus. Consequently, Passivhaus-related skills were primarily learnt through experience, as is the subject of the following subsection. For more information on the minimal role of institutionalised knowledge and explicit rules, consult *Chapter 5* (in particular, *Subsection 5.4.3*).

This also emphasises the restrictions on the type of data that monitoring generates. Monitoring is particularly good at identifying changes in the performances of practices. In this case, no changes could be attributed to institutionalised knowledge and explicit rules because it played only a minor role in adapting practices to the new technological (Passivhaus) setting. However this is not to say though that it did not play a role. Its role was important to the performance of practices more widely – through the prior (non-Passivhaus) skills it equipped individuals with, to the language it provided when talking about everyday life and/or Passivhaus – and thus, whilst influencing practices, did not directly shape changes to practices in response to the unfamiliar Passivhaus technologies.

6.4.3 Know-how and embodied habits

Learning by doing and experiential learning influenced how practices were performed, particularly in the unfamiliar Passivhaus context, and hence how technologies were used. For example, substantial changes to how one household ventilated their dwelling were clearly apparent through monitoring internal humidity levels. According to European recommendations for office buildings (European Committee for Standardization, 1998), internal relative humidity should remain between 30% and 70%. Mould growth and respiratory problems can occur at around 70% and above, making living conditions damp and uncomfortable for occupants, particularly after a prolonged period. Through experiencing high humidity levels, and most likely not enjoying it, the effect of adjustments to ventilation controls is likely to be noticed (un)consciously, especially when conditions become more preferable. This build-up of tacit knowledge (know-how) can become unwittingly embodied in habits so as to prevent a re-emergence of undesirable and uncomfortable humidity levels.

This is supported by one target household which had their ventilation system on too lower setting (Figure 6.1: red dashed line) contributing to considerably higher humidity than the other dwellings (Figure 6.1: black solid line). Once trial and error had yielded a lower humidity, such conditions were maintained across the longer-term. In fact that particular household consistently now has one of the lowest humidity levels, all because of what experience had taught them and how it shaped engagements in ventilation-related practices (e.g. including hosting and homemaking practices). The change in the performance of the practice marks a new configuration of elements of practice and, in particular, how know-how and embodied habits relates to the other elements. This analysis is reaffirmed by qualitative evidence showing that humid (or, as many described it, “muggy” (17C; 25C; 27D)) conditions offer an unwelcome environment which good hosting and homemaking should prohibit because of the discomfort that all households agreed it would provide.

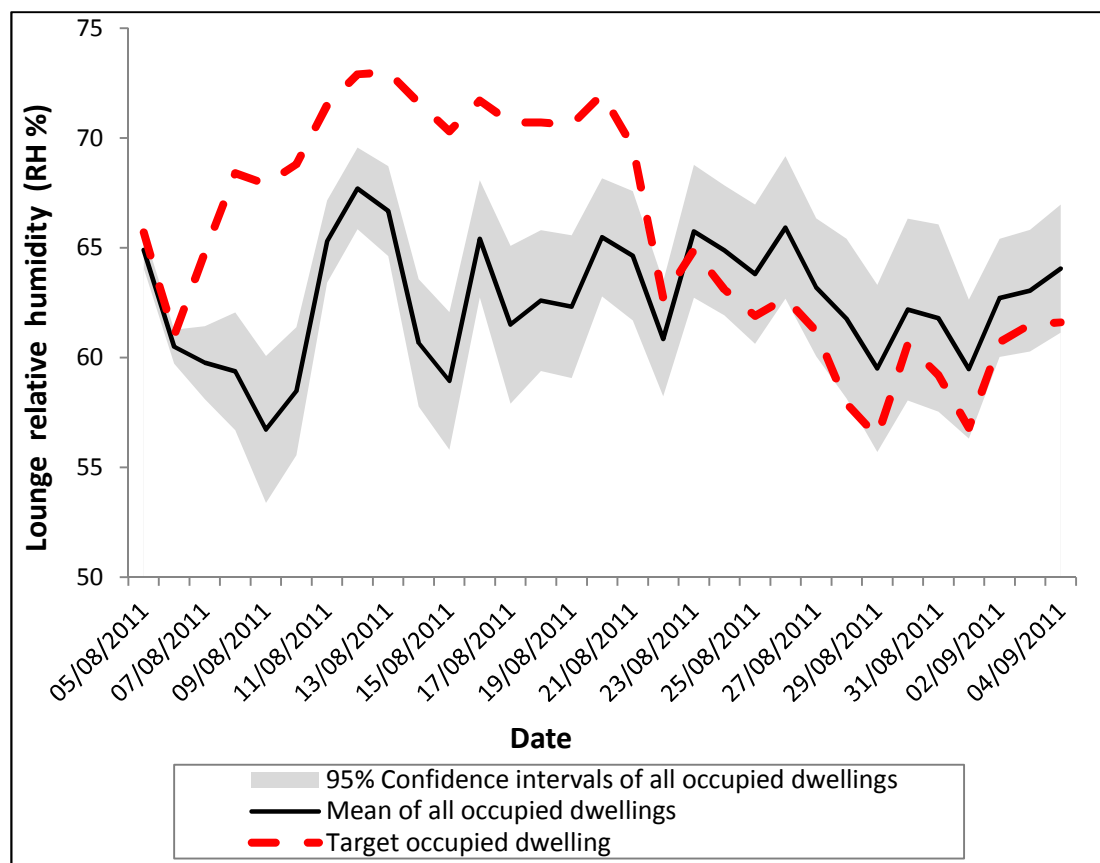


Figure 6.1 – Comparison of the daily average lounge humidity in one target dwelling (which temporarily had its MVHR on a lower setting) with the average (95% Confidence Intervals) of all dwellings, 05/08/2011-04/09/2011 inclusive^a

^a 46.2% of the development’s dwelling lounge humidity sensors were not enabled until 15/08/2011

6.4.4 Engagements

The performance of a practice can be influenced, though not exclusively, by rational cost concerns. Economic pressures can directly influence everyday life, and I now present one notable example: circumstances meant that one household was desperately keen to minimise expenditure, directly influencing how practices were performed in yielding specific energy services (e.g. cooking predominantly used the microwave because it was seen as the cheapest option). Their very considered purchasing choices indirectly shaped practices through how it configured their technological surroundings which (1) made it more difficult to perform certain practices (e.g. purchasing a small television was prioritised over seating for hosting guests), or (2) led to a limited range of technologies which could be used through certain practices (e.g. nominal number of electrical appliances could be afforded). The make-up of their practices were thus starkly different to other households, as is evidenced by internal temperatures being on average 3.3°C cooler (Figure 6.2: blue dotted line) than the mean of other occupied dwellings (Figure 6.2: black solid line). Such was the influence of cost engagements that their lounge temperatures were more similar to an unoccupied dwelling which obviously had no household performing practices within it and was 4.1°C cooler as a consequence (Figure 6.2: red dashed line).

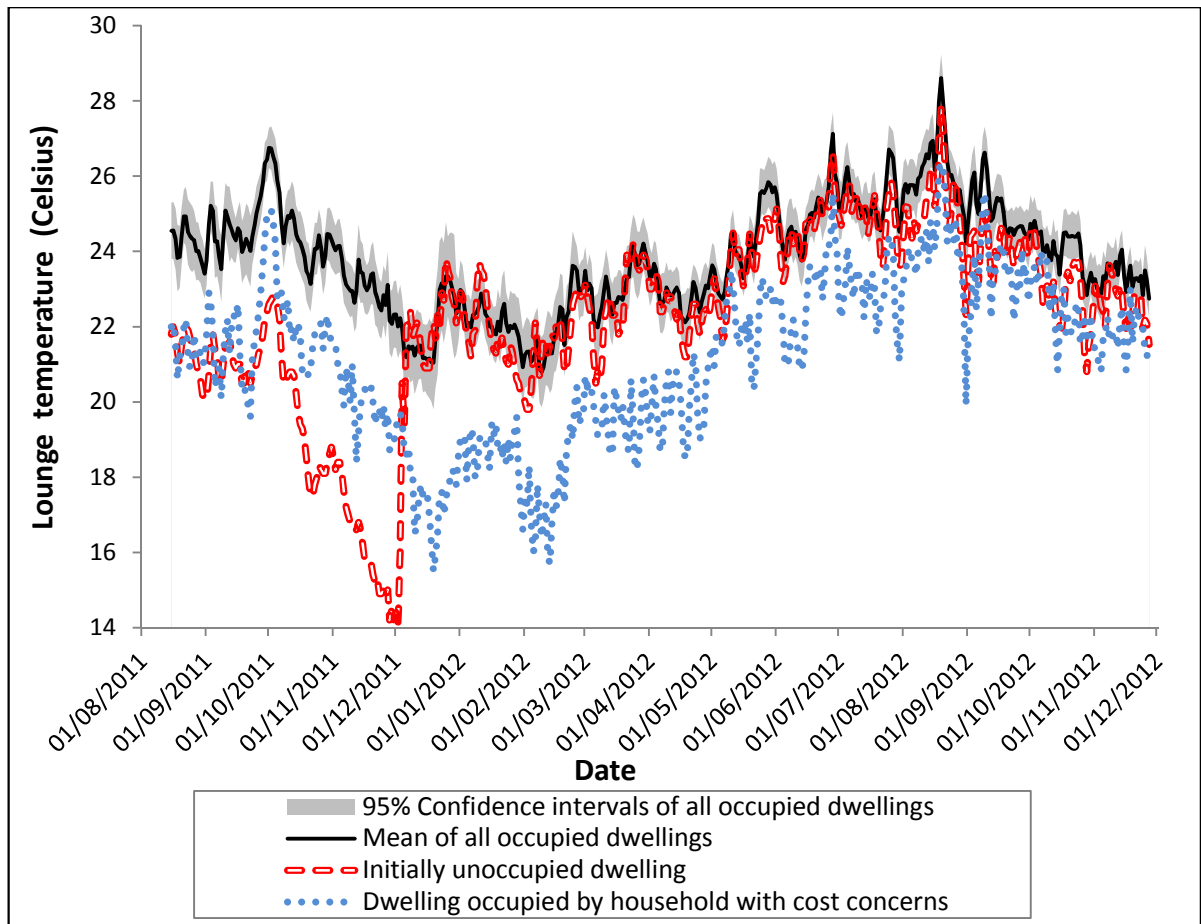


Figure 6.2 – Comparison of daily average lounge temperatures for one initially unoccupied dwelling, one dwelling with financial worries, and all occupied dwellings (15/08/2011-27/11/2012 inclusive)^a

^a 7% of the development's dwelling lounge temperature sensors were not enabled until 23/09/2011

However the money conscious household's temperature was not lower solely because of practices generating less heat. Although the energy bills for Passivhaus dwellings are already very low, the money conscious household were keen to reduce bills even further by turning the MVHR off for most of the day and opting to naturally ventilate the dwelling by opening windows. The household had no idea if it was actually saving any money at all, but monitoring shows running the MVHR is likely to cost only £40 per year. Despite this, turning the MVHR on/off ironically contributed to higher gas consumption (and also lower internal temperatures) because of heat loss through the open windows. The engagement that it could be saving money seemed enough to influence an array of domestic practices, thereby producing different heating/cooling and ventilation related practices which, combined with their sporadic performance, led to relatively more fluctuations in internal temperatures as well as increased gas bills.

However finance was not a strongly recurrent engagement across all practices and all households, largely being limited to the practices performed by this one money conscious household. This is especially noteworthy since in *Chapter 5 (Subsection 5.4.2)* I found that most households said they were motivated by monetary savings, yet I was unable to determine whether such views actually translated into action. Therefore this chapter's mixed methods were able to uncover something that my earlier qualitative-only methods (*Chapter 5*) could not, in addition to emphasising that offhand comments made in interviews do not always linearly translate into action.

Hosting guests and homemaking (creating and maintaining a homely environment for the household themselves) practices have clear engagements associated with societal expectations of what is regarded as (e.g. thermally) comfortable (consult Shove (2003) for more on social constructions of normality). Building monitoring highlighted that performing these practices unexpectedly affected indoor temperatures. In addition to thermal comfort, social expectations demanded that a good host and homemaker ventilate their dwelling with 'fresh' air as well as maintain a tidy appearance. To many households the former conflicted with having to use a MVHR, which was deemed to not provide fresh air despite its fine filters ("well that's [still] mechanical air isn't it?...it breeds germs" (1A)), thus most households left several windows open (albeit, a crack) almost permanently. In terms of tidiness, the "ugly" (16D) remote thermostat (which controlled space heating through the MVHR) was seen as clutter that needed to be hidden away, leading to many positioning it on an out-of-sight windows sill. However with the window being open, the air temperature around the thermostat was lower, causing the MVHR to heat incoming night air. This was unnecessarily heating the dwelling during summer nights (typically between 0000-0700) because the system was taking the thermostat's cooler temperature as being representative of the whole dwelling. Therefore the combination of these engagements – the need to provide others and the household themselves with a clutter-free and freshly ventilated home – ironically countered those same hosting and homemaking practices which also sought to maintain comfortable temperatures and avoid overheating.

Misconceptions thus exist, as was the case with the money conscious household previously, only highlighting the messiness of performing practices. Although only identified for two households, resident discussions regarding window opening and thermostat positioning indicated that up to half of households may have encountered a similar problem. This could not be confirmed by monitoring data because the MVHR air flow temperatures were only recorded for three dwellings. Anomalies within the monitoring prompted this investigation; without such prompts numerous technological interactions could remain unrevealed because of the residents being completely unaware of such issues. Lastly on this subject, residents were told during the move-in technology tour to turn their heating system off at the programmer (but keep their hot water on) over the summer months which would have avoided this problem altogether, further emphasising the minimal role of expert advice in shaping practices.

6.5 Conclusions

The aim of this chapter is to investigate the potential usefulness of using building monitoring techniques with theories of social practice as a means of understanding how everyday life is performed within the built environment and, specifically in this case, dwellings. A novel methodological approach to studying everyday practices was thus discussed in reference to a UK Passivhaus residential case study, which integrated building monitoring (e.g. temperature, humidity, energy, carbon dioxide levels) with qualitative (largely interview) data.

Although a research gap clearly exists in the use of monitoring data to investigate how practices are performed, there is little theoretical rationale behind this. The use of theories of social practice provided technical data with a theoretical backbone in its application (e.g. as artefacts of performing practices), allowing for complementary integration with qualitative data. Reflecting on using this mixed method showed that these (often deemed incommensurate) data types can actually mutually guide, inform, critique and create opportunities for one another. Ultimately, integrating monitoring and qualitative data can produce something that is more than simply the sum of its parts. This

is demonstrated further by *Section 6.4*, as structured by Gram-Hanssen's (2010a, 2010b, 2011a) elements of practice, which yielded findings that monitoring-only or qualitative-only approaches would miss.

Building monitoring can be very insightful in investigating practices, but only if utilised as part of a broader approach. It is clear that without the input of qualitative evidence, even the most sophisticated monitoring would struggle to capture any meaningful social or cultural components of everyday life. Artefacts of performing practices are not always tangible, let alone quantifiable, making the role of qualitative evidence so vital. I advocate that those with expertise in building monitoring not only consider widening their methodological approach, but importantly begin to seek answers to some of the broader social questions posed by the practices literature (e.g. associated with the elements of practice). Equally, I hope that by forwarding the limited empirical application of practices and monitoring, social practice theorists can be encouraged to broaden out their repertoire of tools and break down qualitative-quantitative boundaries in search for a better understanding of practices-as-performances. Building monitoring can help enhance our understanding of temporal and spatial changes to the distribution of practices, material by-products of practices, and the multiplicity of practices, to name but a few potential contributions. More studies are needed to see how, and to what extent, understanding of everyday life can be enhanced through approaches utilising building monitoring, or indeed any other methodological innovation – it is through illustrating and debating such innovations that understanding can be developed and applications across contexts recognised.

Although monitoring can provide useful insights on changes to the elements of practice, its inherent focus on technological usage makes it particularly useful in examining how interventions (whether intentional or not) change the technology element of a practice and hence practice-related performances. Monitoring can also reliably and precisely record internal conditions in relation to time, and since a practice changes over time and space as its trajectory evolves, monitoring could assist in tracking the implications of changes in trajectory. Taking the Passivhaus example whereby practices help heat one's home, for instance, monitoring could help investigate whether seasonality influences

when certain practices are performed or, looking to the longer-term, if societal notions of comfort change in response to Passivhaus technologies being mainstreamed. How technological changes are influencing the other elements of practice and the resulting performance of practice needs further study if we are to understand the everyday implications of a policy landscape that commonly targets technological ‘improvements’ (e.g. low energy new builds), and building monitoring provides an innovative means to do so. Indeed, in light of climate change and sustainable energy concerns, it is essential that more research is conducted on the construction, maintenance and transformation of practices, so as to better understand how to potentially guide performances in certain (e.g. less energy intensive) directions.

Chapter 7 – Turning houses into homes: Investigating how everyday practices influence appliance ownership

Abstract

Low carbon dwellings shift the focus to electricity consumption and appliances by significantly lowering space heating energy consumption. This chapter investigates how different dwelling technologies can change the appliance requirements of appliance-using practices. A UK Passivhaus case study is explored primarily using interviews and pre/post-move-in appliance audits.

Appliance ownership differences were due to differences in how practices (e.g. cooking, laundering) were performed in response to a new technological configuration (e.g. dwelling layout, super insulation). Appliances were purchased or disposed of to enable certain ways of performing practices. Appliances either complemented or conflicted with a new technological configuration depending on whether the social meanings of practices could be met. This was evident, when moving home more generally, by households buying new modern appliances and managing spatial constraints. More specifically, regarding Passivhaus, performing hosting and homemaking practices in ways that met thermal comfort expectations contributed to purchasing energy efficient appliances which generated less heat. Whilst skills and competences were needed to perform appliance-using practices, these were less prominent in influencing appliance ownership changes.

Appliances are integral to domestic practices, and indeed vice versa, due to a deep relationship between *having* and *doing*. Consequently, any policy-making or research targeting appliance ownership should account for practices, instead of focusing on individuals and/or appliances in isolation.

7.1 Introduction

Appliance ownership has been consistently increasing year on year, with the total number of UK domestic electrical appliances having grown by 27% over 1996-2011 and showing little sign of relenting (DECC, 2012d). The appliances included in the scope of the DECC ownership survey² are mainly the traditionally high electricity consuming white goods, with all home computing and consumer electronics (e.g. television, laptops, games consoles) and many cooking (e.g. microwave, kettle) appliances excluded, despite calls to give these more attention (e.g. Owen, 2007). This research takes appliances to be electricity-consuming devices, only excluding lighting devices which play a largely unique role in everyday life.

In light of climate change concerns, there is a pressing need to reduce domestic energy consumption which in 2012 accounted for 29.12% of final energy usage (DECC, 2013f). Appliance usage, excluding lighting, is responsible for 18% of the carbon emissions attributed to UK households (calculated using UK Department of Energy and Climate Change (2012d) and Energy Saving Trust (2011) figures). UK domestic energy policy focuses more on improving dwelling fabric and thermal efficiency (e.g. 2016 zero carbon homes definition does not account for appliances (McLeod *et al.*, 2012)); therefore the proportion of appliances-related consumption will only increase as space heating demands lessen, and that is before even accounting for rises in ownership. The emphasis should not be put on the house, but instead the home, so that research and policy considers how we live our everyday lives within the walls of our houses. How we go about making a house a home needs further research since it shapes which appliances we choose to surround ourselves with.

Most appliances research has focused on identifying various external economic (e.g. cost, information, technology) and/or psychological (e.g. attitudes, values) factors, which affect an individual's decision-making regarding appliance ownership and use (e.g. Mansouri *et*

² DECC survey data is somewhat conservative in that it only includes chest freezers, upright freezers, fridge-freezers, refrigerators, washing machines, tumble dryers, dishwashers, electric ovens, and electric hobs.

al., 1996; Efstathiou *et al.*, 2004; O'Doherty *et al.*, 2008; Leahy and Lyons, 2010; Zimmermann *et al.*, 2012). Direct cause-effect relationships are thus typically sought. However, if we want to understand why new appliances are purchased and used as part of everyday life, these cause-effect viewpoints are too simplistic. Its linearity usually fails to capture the social influences that underpin practices (e.g. cooking, hosting, washing) which have been shown to often produce a markedly nonlinearity from intervention to outcome(s). Critiques have hence advocated focusing on the performance of everyday practices (e.g. Gram-Hanssen, 2010a; Shove, 2010; Hargreaves, 2011; Shove *et al.*, 2012). Switching the focus from individuals to the actual doings and sayings (practices) of everyday life is vital because these practices push/pull individuals in certain directions (e.g. regarding appliance disposal and purchasing).

In addition to furthering the empirical application of theories of social practice in domestic appliances research, other knowledge gaps also exist. Whilst it is hugely important that detailed discussion is given to key appliances separately, so as to be able to appreciate the historic role of specific appliances in trajectories of social practices, few studies have broadened out the scope to include all appliances (e.g. freezer focus: Shove and Southerton, 2000; Hand and Shove, 2007) or the whole dwelling (e.g. kitchen focus: Shove and Hand, 2000; Southerton, 2001; Hand and Shove, 2004). It is the wider technological configuration (i.e. how appliances relate to one another as well as the dwelling) that in part provides opportunities for performing practices. There has been little research into how significant changes to the wider technological configuration – such as moving home – change the appliances-related requirements of practices. Wilhite (2012, p. 96) stated that moving home often stimulates ‘the purchase of new appliances and changes in practices in the new home’. I argue that, in this quotation, ‘and’ should actually be ‘due to’ because practices drive our appliance demands. More research is needed to understand how moving home can influence appliance-using practices and so shape appliance ownership. It would be particularly interesting to explore changes associated with moving into a low carbon dwelling because it would provide insight into how the next generation of (unfamiliar) building technologies could shape our everyday lives.

This chapter aims to investigate how appliance-using practices, and thereby appliance ownership levels, respond to new technological surroundings. This will be achieved through the following four objectives:

1. Quantify differences in appliance ownership between pre-move-in and post-move-in, and consider in the context of energy consumption changes;
2. Provide illustrative examples of how technologies can complement and conflict with appliances, showing how that can shape appliance ownership;
3. Consider dwelling-level technologies associated with the Passivhaus (building energy efficiency) standard and discuss how that influences appliance ownership. Specifically focus on the heating role that appliances acquire in Passivhaus settings;
4. Broaden the focus by identifying and exploring key issues associated with how moving homes can more generally influence appliance ownership.

These involve investigating how appliance-using practices are performed and how they can change as a result of moving home, encountering different technologies, and inter-appliance relationships. The wider technological configuration is given explicit consideration, with attention given to what appliances households choose (consciously or not) to own as they appropriate a new material environment. This chapter does not serve to provide an exhaustive list of all potential influences, instead detailing salient influences and everyday examples found in one UK affordable housing case study.

The case study is a small to medium-sized Passivhaus development, which provides energy efficiency through airtightness, super insulation, and mechanical ventilation with heat recovery (MVHR), in addition to a low carbon energy source through solar thermal technology. This German design standard represents a radically different technological configuration compared to that of conventional UK dwellings, hence is a sufficient contrast to where households would have previously been using appliances.

I begin by introducing theories of practice and summarising what it can offer analyses such as this (7.2). More detail is then provided on the case study employed and the

methods adopted (7.3). The core of the chapter is structured around presenting (7.4) and discussing (7.5) findings associated with the four objectives. Conclusions are then presented regarding implications for future research and governance (7.6).

7.2 Theoretical context

Theories of social practice draw on disciplinary literatures that have pulled away from the traditionally dominating individualistic approaches. These individualistic theories, be they rooted in more rational economics or the psychological perspective, typically model a number of factors (or contextual cues) which cause individuals to behave in certain ways. Individuals are therefore the primary change agent, as they respond to various contexts. This usually creates a theoretical linearity because individual behaviours are products of rigid cause-effect relationships. For example, the Habit-Discontinuity hypothesis (Verplanken *et al.*, 2008) posits that there are key ‘moments of change’ (Thompson *et al.*, 2011, p. 1) – such as moving home – when behaviour is more deliberately considered, making us more prone to other behavioural changes (e.g. living with different appliances). Such theoretical perspectives miss out on broader social dynamics and the often unanticipated consequences of major life changes, which can be captured by using practices as the central unit of analysis, as opposed to individuals. For instance moving home, to name a few influences, could involve: new technological surroundings; exposure to different institutions; aspirations of how to occupy that home according to societal expectations; and this all interpreted through a lens based on past experience. These influences interact, somewhat unpredictably, in establishing new performances of everyday practices. Therefore, in many ways, moving home is actually a ‘moment of change’ – indeed this is fundamental to this chapter (and indeed the broader thesis) – but the difference is that I regard moving as an intervention in practice and not a change in contextual factors that individuals linearly respond to.

A practice is a ‘routinized type of behaviour’ (Reckwitz, 2002, p. 249) which are the constituents of everyday life. Practices range from flying, driving and playing football to hosting guests, homemaking, cooking, and showering. A ‘practical rationality’ (Sandberg

and Haridimos, 2011) exists in that individuals and households make decisions, consciously or not, in accordance with the practices they undertake. Practices-related research demands examination of broader social processes, which do not simply treat practices as additional contextual variables which individuals are subjected to. The onus needs to be on practices and how they are performed (by individuals and households being practitioners), instead of individual energy consumers or appliance users. As McMeekin and Southerton reflect:

‘Conceptualising consumption in this way moves analytic attention away from specific goods and services and from individual expressions of preferences, towards an understanding of how products are appropriated as a consequence of the ways in which practices are socially ordered. In making such a conceptual shift, notions of demand, need and want are re-cast as the consequence of the ‘doings’ (or practices) through which daily lives consist: as Warde (Warde, 2005) puts it, “activity generates wants, rather than vice versa”.’

(McMeekin and Southerton, 2012, p. 350)

This shifts the attention away from individual preferences and/or specific appliances in themselves, to appliance-using practices which over time create and maintain the need for specific appliances (e.g. laundering: washing machine, tumble dryer; cooking: oven, hobs, microwave). Such practices amass certain requirements as they are performed, be they technological or not, which in turn sustain further performances.

What these social practices require and how they are influenced has provided much debate amongst prominent social practice theorists. The foundations of the practices literature can, in part, be found in the work of Bourdieu (1984) and Giddens (1984) who interestingly barely mention technologies, instead opting for almost wholly ‘social’ theories. However in recent years there has been an increasing acknowledgment that ‘practices are intrinsically connected to and interwoven with objects’ (Schatzki, 2002, p. 106), which demonstrates a material turn within a wider ‘practice turn’ (Schatzki *et al.*, 2001) in contemporary social theory. Consequently recent discussions into the influences (or elements) of practices account for the material world; specifically, this includes the work of Shove (in Shove *et al.*, 2012: ‘material’), Gram-Hanssen (2010a: ‘technologies and

material structure'), and Reckwitz (2002: 'things'). Indeed, the theories of practice literature now largely regard materiality as a key element of practice (Røpke, 2009).

Technology, materiality, or however it is termed, is constantly evolving and interrelated within itself. It is not one manageable coherent entity that can be targeted independently and manipulated at will so as to push or pull practices in desired directions. For instance, domestic appliances would offer nothing without the wider infrastructure of power stations and transmission lines that enable it. Appliance ownership and usage also depend on other technologies situated within the home, such as plug sockets or other appliances that already provide opportunities for practices. Appliances thus form part of a wider technological configuration.

Whilst technological configurations are the predominant focus of this chapter, and has thus received the most introduction, it is only one of the elements shaping practices. Indeed all the aforementioned theorists who tout technology as a key influence all agree that practices are constructed and organised in very complex ways. Practices are not only dependent on technologies relating to one another, but also how that technological configuration relates to the configuration of the other practice elements across a range of different practices. For example, on the basis of her domestic energy research, Gram-Hanssen (2010a) proposes the following four elements:

- *Technologies*: surrounding physical environment;
- *Engagements*: aspirations, expectations, motivations, and the social significance associated with performing a practice;
- *Institutionalised knowledge and explicit rules*: explicit expert advice and rules of thumb;
- *Know-how and embodied habits*: tacit knowledge gained through practical experience.

These elements emphasise the complexity of practices and that studies of technology-in-practice should investigate how technologies relate to various modes of competences (be

it expert or tacitly derived) and meanings. Understanding the nuances of practice organisation is important here because households only own appliances because of the practices that utilise them.

The literature emphasises that practices, and by extension the appliances that assist them, depend on messy relationships (e.g. between practices; between the elements). Through a practices lens, I investigate the underlying influences that underpin these messy relationships and thereby shape appliance ownership. This chapter empirically furthers discussions on how appliances shape and in turn are shaped by domestic everyday practices.

7.3 Methodology

As part of adopting a constructivist perspective, there is an inherent relativist acknowledgement that situatedness shapes the construction of objects, whether they are knowledge claims or technologies. Indeed I see local and specific context as shaping how a reality (study findings) is constructed. As such, it is essential that a methodology is employed which enables as an informed reality as possible. A single case study approach is thus adopted to provide a deeper focus. From this, theories can be generated so as to aid the understanding of other constructions of realities in other studies.

In achieving this deeper understanding, the richness of qualitative data is central. Whilst a mixed methods approach is adopted, quantitative energy and appliance ownership data are largely only used for contextual purposes which the qualitative inquiry can then draw upon when exploring underlying influences.

A small to medium-sized UK Passivhaus affordable housing development was adopted as the case study. Passivhaus is a German energy efficiency building standard, which aims to achieve significant energy consumption savings through its super insulation and relative airtightness that lowers heat loss rates (Feist *et al.*, 2005). Airtightness levels require the installation of mechanical ventilation with heat recovery (MVHR) systems for air quality

purposes. Solar thermal and gas-fired boiler systems provide space heating through the MVHR (no radiators) and water heating. The very low heat loss rates mean that these systems provide very little space heating in actuality because heat is *passively* obtained through everyday life (e.g. appliance usage) and solar gain. As such, part of becoming Passivhaus-certified usually involves providing energy efficient appliances, so as to mitigate overheating risks. However for the development studied, as with most UK social housing projects, no appliances were provided because that would require maintenance responsibilities. The consequence was that the residents brought all their own appliances.

The households' previous dwellings had been, contrastingly, more typical of the wide ranging UK housing stock. Housing type covered semi-detached, detached, mid-terrace, end-terrace, and flats. Housing age was similarly diverse, ranging from construction in the late 1800s to 2008. All dwellings had a central heating system with radiators, but the constituent boilers had different fuel supplies (e.g. gas, oil, wood, coal).

Around 29% of the new homes are shared ownership (i.e. part housing association and part householder owned), with the remaining 71% social tenants. The new occupants of the shared ownership homes were moving largely as part of making their first property investment. The social tenants were moving because of various different circumstances, including: their previous socially rented dwelling was too small/large; they had lost their job and/or home; were keen to move away from their parents; wanted to live in a rural location; or were unhappy in their previous home (e.g. due to damp or safety concerns).

Two appliance audits were undertaken for each household, one around two months before move-in (April-May 2011) and the other around 16 months after move-in (October-November 2012). The audit involved recording the existence of every appliance, the specification of larger appliances (e.g. white goods), the approximate purchase date of each appliance, and whether it was second-hand. Ownership included appliances that were regularly used, but not owned, by the household (e.g. loans) as well as those that were owned by household members. For a blank copy of the appliance audit see *Appendix 10*.

The primary purpose of the appliance audits was as a basis for the semi-structured interviews that explored ownership changes. A (two months) pre-move-in interview accompanied the first appliance audit, providing an opportunity to immediately discuss how and why appliances were owned and used in certain ways in their previous technological surroundings (for the interview schedule see *Appendix 1*). The second appliance audit was undertaken in the weeks before discussing it in and/or during the final interview (16 months post-move-in; for the interview schedule see *Appendix 3*). Additional context was gleaned from informal discussions, participant observation (e.g. resident information evenings) and a further, third, round of (walkthrough) interviews which took place in between the other two rounds at around 11 months post-move-in (March-June 2012). These additional methods were undertaken as part of wider research on this case study, and whilst it had little explicit discussion of appliance ownership, it did help provide the foundations for interview discussions and later analysis.

Energy consumption data was also gathered to examine whether energy usage had changed by moving home. Pre-move-in energy data was collected through past bills (proportionally scaled up/down to find annual estimates), whereas manual gas and electricity meter readings (taken a year apart) were used for the post-move-in comparison. Floor plan information enabled energy consumption to be normalised on a per m² basis. Each household's energy use was summed under either electricity or heating fuel (e.g. coal, wood, oil, gas); this distinction was aided by the fact that no dwellings were electrically heated.

All these activities involved speaking to 28 individuals. Quotations in this chapter are referenced using '1A', whereby '1' represents the individual and 'A' represents the method (A = pre-move-in interview with first appliance audit reflections; B = interim walkthrough interview; C = final interview and second appliance audit reflections; D = participant observation and informal discussions). Pseudonyms are used when appropriate.

7.4 Findings

7.4.1 Appliances ownership levels

A marked reduction in space and water heating fuel consumption was achieved when moving from conventional to Passivhaus dwellings (Figure 7.1). The mean annual heating fuel consumption, on a per annum (a) and metre squared (m^2) basis, dropped by over 85% from 219kWh/a.m^2 (min-max: $141\text{-}284\text{kWh/a.m}^2$) to 32kWh/a.m^2 (min-max: $20\text{-}61\text{kWh/a.m}^2$). These findings reflect a wider trend in thermal efficiency improvements which, whilst lowering heating fuel usage, increases electricity's proportion of total energy usage and thereby redirects attention from heating to practices that consume electricity (Monahan and Powell, 2011a).

Many dwelling-level technologies (e.g. solar thermal, boiler, airtightness, insulation) directly shape how much heating fuel is used, and thus the practices which are inherent to this. In contrast, practices that consume electricity generally use smaller-scale technologies that the households bring with them (e.g. appliances), as part of how they occupy and appropriate their new homes. On the surface this may seem to fit well with Figure 7.1 since it reveals how electricity consumption in their previous conventional dwelling (mean: 47kWh/a.m^2 ; min-max: $22\text{-}67\text{kWh/a.m}^2$) and new Passivhaus dwelling (mean: 45kWh/a.m^2 ; min-max: $25\text{-}64\text{kWh/a.m}^2$) are very similar. One may infer that similar electricity consumption is a consequence of using the same electrical appliances.

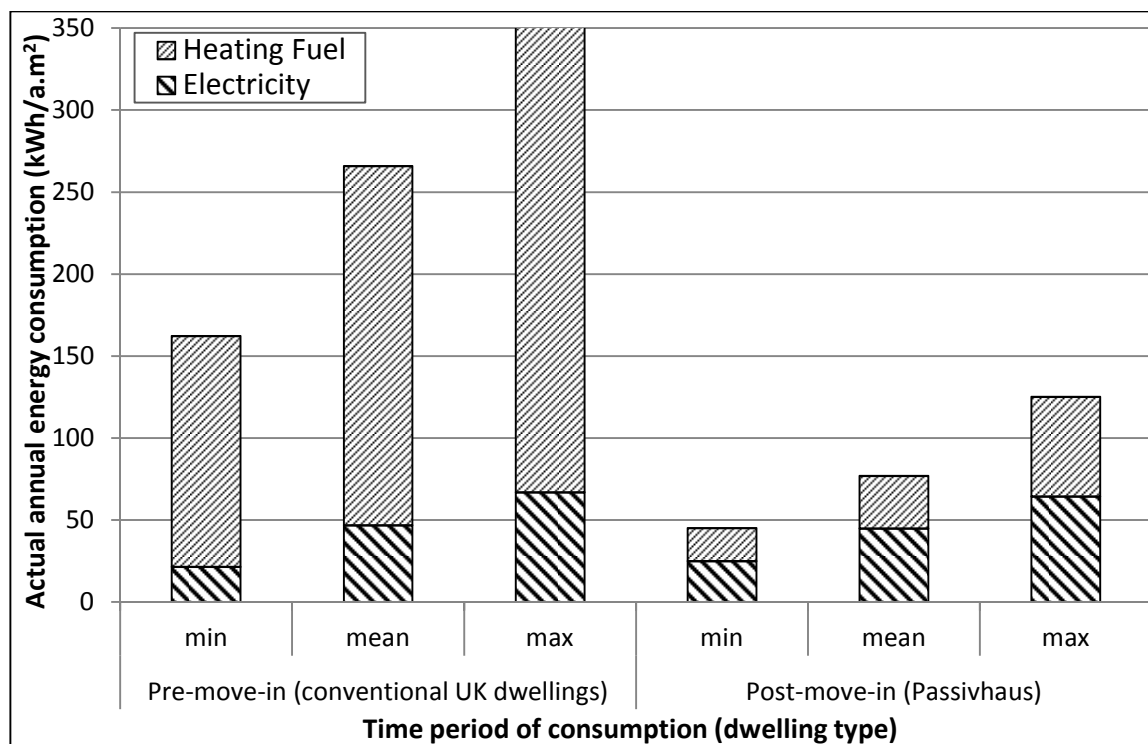


Figure 7.1 – Comparing actual energy consumption: Conventional versus Passivhaus homes

The total number of appliances owned by households dropped by 5% to a mean average of 25 (min-max: 13-34) appliances post-move-in. A 2010-11 study of 251 English households showed average ownership to be 41 (min-max: 13-85) appliances (Owen, 2012), suggesting that this study's households use relatively fewer appliances in their practices. However such averages do not convey the full story because practices give appliances very different meanings with, for instance, owning and using a kettle constituting something very different to owning and using a washing machine. Complicating matters further, as these practices evolve over time so too do the appliances, and the associated engagements and the competences required to use them. This dynamism contributed to no household keeping all the same appliances between pre- and post-move-in. Ownership changes ranged considerably, from a decrease of 33% to an increase of 47%. Drilling down further, around 39% of the larger (and more electricity consuming) appliances were replaced. Almost 80% of cookers were replaced, in addition to both 50% of washing machines and cold appliances with freezer capabilities.

In purchasing replacements, considerably more of the larger appliances were bought new, compared to the very few households that purchased second-hand equivalents, which

contributed to higher energy efficiency ratings. The majority of these replacements occurred in the weeks surrounding move-in itself. If I was to discount this round of move-in replacements, major appliances (as per Table 7.1) were on average last purchased four years and five months before move-in. The qualitative evidence presented later, in conjunction with Objectives 2-4, explores why after all that time replacement became a priority around move-in.

Table 7.1 also serves to show how appliances are relied upon for domestic practices, in both previous and new homes, and that this is representative of the wider UK trend. Indeed ownership levels remained high and largely unchanged. The proportion of households owning at least one of specific appliance types only fell for the tumble dryer, microwave oven and dishwasher, largely because of spatial constraints contributing to prioritisation (discussed in *Section 7.4.4.1*). The only other appliance type to fall in ownership was the washing machine but, unlike with the aforementioned appliances, practices were not performed without this specific appliance. All households unwaveringly used washing machines when laundering clothes, with no alternative ever considered. The drop in washing machines was therefore due to residents lacking the required skills, having moved away from their parents for the first time, hence it was their parents' washing machine (and skills) that were utilised by their laundering practice. Every household owned a cooker, television and appliances with refrigeration and freezing capabilities, and thus these were seemingly a non-negotiable component of everyday life. Such was the intimate association between appliances and everyday life that multiple appliance ownership was very common for certain devices (e.g. most households owned a second laptop/computer/tablet, with many owning three or more).

Appliance	Ownership (% of households with ≥ 1 appliance)			Replaced post-move-in (% of total households)	
	2 month pre-move-in (May 2011)	16 month post-move-in (Sept. 2012)	UK household mean average (2010) ^a	with new equivalent	with second-hand equivalent
Cooker	100 ^b	100	-	50	29
Washing machine/ Washer-dryer	100	93	96	43	7
Tumble dryer/ Washer-dryer	71	50	57	21	0
Refrigerator/ Fridge-freezer	100	100	-	43	7
Freezer/ Fridge-freezer	100	100	-	36	7
Dishwasher	21	7	40	0	0
Microwave oven	93	86	92	36	7
Laptop/ Desktop computer / Tablet	86	86	77	29	0
Television	100	100	97	29	7
mean average:	85	79	77	32	7

Table 7.1 – Appliance ownership changes: Comparing households’ pre-move-in to post-move-in stock of key domestic appliances

^a Source: DECC (2012d). Ownership mean percentages are based on 2010 surveys.

^b This total includes gas cookers (oven and hobs) as well as electric equivalents.

Domestic (appliance-using) practices have become increasingly dependent on plug sockets. The provision of plug sockets was an institutional expectation, with the housing association stipulating the number of plug sockets (on a per room basis) in the original brief. Each 1-bedroom flat had 30 plug sockets, and the 2-bedroom and 3-bedroom houses had 40 and 44 plug sockets respectively (excluding fused spurs). This is consistent with English households’ mean appliance ownership being 41 (Owen, 2012). It is interesting to reflect upon the past trajectory of domestic practices and how plug socket provision has changed in accordance with practices becoming more reliant on appliances. For instance, the number of plug sockets in a new build 3-bedroom house, as recommended by the UK National House Building Council, has risen from 17 plugs in 1977, to 21 in 2000 and 38 in 2007 (CDA, 2000; Lane, 2007). It is perhaps unsurprising then that other surveys indicate a lack of plug sockets to be a real cause of resident dissatisfaction (CDA, 2000), as it is likely to be inhibiting desired performances.

7.4.2 Complementary and conflicting technological configurations

What makes an appliance complementary or conflicting to other technologies is how the technologies come together to form a technological configuration that services the requirements of a specific performance of a practice. Analysis shows that many appliance ownership changes have come about through individuals and households attempting to enable a preferred (and very often sustain an existing) way of performing a practice. In considering this, one is then drawn towards why individuals and households would want to perform practices in certain ways, leading onto associated social meanings and expectations.

Table 7.2 presents 10 examples of how appliance ownership was found to be influenced by a different domestic technological configuration (i.e. connected to moving into a new dwelling). These examples are linked to the predominant practice(s) that uses the appliance(s) in question, before showing how that practice's associated engagements helped shape the change in appliance ownership. Table 7.2 thus indicates that simply attempting to design and provide the right technologies may not achieve design intentions (whether energy-related or not) because everyday life hinges on the complex social dynamics of practice.

Table 7.2 – Illustrations of the interconnectedness, through practices, of the wider domestic technological configuration to domestic appliances

Wider domestic technological configuration	Observed change in domestic appliance ownership	Relating practices to appliance ownership changes		
		<i>Predominant appliance-using domestic practice(s)</i>	<i>Relevant engagements of performing practice</i>	<i>Comments on performing the practice(s) without making these appliance ownership changes</i>
Lounge window fitted with the wrong hinges, thus could not be opened	Cooling fan bought for the lounge during summer months	Hosting, homemaking, ventilating	Being welcoming, healthy, able to relax	Not purchasing a cooling fan could have meant that at times during the summer the household and guests were not thermally comfortable in the lounge.
Recently bought a surround-sound system	Bought a new television that was compatible with it	Hosting, homemaking	Being modern, stylish, proud of one's home	Not purchasing a new television could contribute to less desirable television viewing experiences as part of general living and hosting guests.
No radiators (excluding a heated bathroom towel rail)	Some who previously dried laundry on radiators bought tumble dryers	Laundrying, working, socialising	Being clean, stylish, convenient	Unwilling for clothes (e.g. for work and socialising) to dry slowly. Tumble dryers provide rapid and convenient drying, substituting the instant heat from radiators.
Large south-facing windows providing heat through solar gain	Good space for drying clothes quickly, which led to disposing of their tumble dryer	Laundrying, working, socialising	Being clean, stylish	For those in less of a rush, but still unwilling for clothes to dry naturally more slowly, their solar gain spaces substituted a tumble dryer.
No external outlet for a (non-condensing) tumble dryer due to airtightness	Condensing tumble dryers were bought to replace non-condensing equivalents	Laundrying, working, socialising	Being clean, stylish	As non-condensing tumble dryers were not allowed to be used (landlord rules), without a new purchase households would have to dry clothes naturally throughout the year.
No kitchen gas supply	Replace gas with electric ovens and hobs	Cooking, hosting	Being healthy, a good parent/friend, skilled, worldly, welcoming	Without an electric oven/hobs, cooking would largely use the microwave. This did not provide the variety needed for everyday meals and when cooking for guests.
Gaps under internal doors to facilitate air circulation by MVHR	Less powerful hi-fi speakers purchased to minimise noise disruption	Homemaking, hosting	Being polite, a good household member	It was regarded as pointless to replace an old hi-fi with similarly powerful speakers: utilising their full capability may create an unhomely and unwelcome environment.
Passivhaus' need for airtightness strongly discourages drilling through external walls	Appliance purchases restricted by number, location and specifications of plug, telephone line, and aerial sockets	Communicating, hosting, homemaking	Being modern, connected, proud of one's home, stylish, wealthy	This cap on communications appliances was frustrating for some because it restricted homemaking and hosting performances (e.g. children could not watch satellite television channels in their bedrooms with friends).
MVHR system enables healthy air quality and humidity levels	Disposed of the de-humidifiers, used in previous dwellings to inhibit damp and mould growth	Hosting, homemaking	Being clean, healthy, a good parent	MVHR contributed to an internal environment that is more synonymous with being a good host/homemaker, which de-humidifiers would otherwise provide.
Size of mugs	Eco-kettle (max. capacity: half a pint) replaced with a new one so that more than one cup of tea could be made at the same time	Hosting	Being polite, welcoming, time efficient	Without a new kettle guests would either get their tea one at a time or not be offered it; both did not meet what households regarded as being a good host.

In considering how practices shape appliance ownership, Table 7.2 largely focuses on meanings, aspirations, ideas, attachments and motivations (the *engagements* element of practice). However, skills, knowledges and competences are also shown to be a key influencing element of social practice (as discussed in *Section 7.2*). It is thus worth briefly reflecting on this here with regard to appliance ownership changes. There were a few one-off examples of appliances being bought because the household did not understand how to use the Passivhaus technologies. For example, those who really struggled to understand how the external blinds, windows, MVHR, remote thermostat and heated towel rail could help keep the house cool in the summer usually owned a cooling fan. However more generally, skills, of whatever form, were very rarely a barrier to a household changing appliances. Indeed, when skills were raised in interviews, residents commonly laughed it off by commenting on how most appliances are based on similar principles which they have learnt through past experience. Therefore, whilst skills and knowledges are essential to operating appliances and hence performing appliance-using practices, they had very little influence on the household changing which appliances they owned. Whereas meanings and expectations which ‘engaged’ (c.f. Gram-Hanssen, 2011a) individuals in specific ways of performing a practice dominated ownership changes – this will continue to be apparent through the rest of this chapter’s findings and discussion, which largely focuses on technologies and engagements of everyday practices.

7.4.3 New dwelling technologies changing the role of appliances: The thermal role of appliances in Passivhaus dwellings

Passivhaus technologies – specifically those that provide airtightness and super insulation – significantly minimise heat loss. Heat provided by the occupant’s own body warmth and, crucially for this discussion, the use of electrical appliances therefore helps heat one’s home. Figure 7.1’s rigid distinction between electricity and heating fuel is therefore blurred. Whilst the vacuum cleaner was the most commonly referred to device for generating heat, every household told stories of how almost every appliance heated the home. Indeed, often too much heat was generated with, for instance, the remote thermostat “display[ing] at least 27 degrees when the TV is switched on” (2B). Passivhaus

construction has thus imposed upon appliances the additional role of being heaters. One resident spoke of a laptop not as a communications device but as a heater for her daughter's bedroom, mainly because it remained powered on all of the time. Unsurprisingly, residents also commented on how they could "feel a change [in temperature] when more than one [appliance] is used at any one time" (11C). Practices which encompass appliances in certain ways have hence gained new engagements (i.e. relating to temperature regulation) in addition to more established and conventional engagements (e.g. of a television providing a reference point for relaxation and hosting). The shift in emphasis was demonstrated by some residents pre-empting any concerns (they deemed I would have) regarding electricity consumption, by explaining in the interviews how usage was essential in maintaining comfortable temperatures.

The implications of this additional (thermal) role in domestic appliance-using practices were evident upon appliance ownership. However, each household was influenced in a different way because the thermal impact of an appliance depended upon how that appliance was used when performing practices. For instance, one household that watched a lot of television found their high electricity consuming plasma screen to be overheating their home frequently during summer months, whereas a household with a similarly inefficient screen who watched much less television reported no such problems. Interestingly, all members of the overheated household recalled conversations with each other about buying an LCD television which would use less electricity and thus affect temperatures less. Passivhaus technologies had for many therefore brought energy efficiency to the fore in the purchasing of appliances, not for environmental or monetary benefits, but because thermal comfort expectations had become more relevant for domestic practices.

Passivhaus buildings were rarely too cool, and, as such, over half of the households disposed of plug-in heaters around move-in. In part this was because the appliances helped to fill that heating need, but it is more related to the significantly lower heat loss rates that Passivhaus design ensured. Despite residents being told by the housing association at pre-move-in information sessions that they would not need plug-in heaters, residents only disposed of any heaters they owned after experiencing it for themselves

post-occupancy. Tacit learning was shaping practices, and thus in part appliance ownership. The situation regarding ownership of electric cooling fans was slightly different in that a few households disposed of their fans before moving home, rather than in response to experience. Nevertheless, because of post-occupancy experience, all of these same households regretted disposal with each buying a new fan to alleviate the higher than expected summer indoor temperatures – specific examples included needing a cooling fan when watching television, vacuuming, or cooking on warmer days.

There were some one-off examples of replacing or throwing away appliances because of their effect on temperature (e.g. replacing an old CRT television in a south-facing bedroom), but on the whole very few appliances were disposed of. Again, this relates to the fact that appliances are deeply embedded in the performance of domestic practices. In response to appliances' new thermal role, residents consciously or not typically made changes to *how* and *when* rather than *what* and *which* appliances were used. In this way appliance-using practices only needed to be slightly adjusted to achieve the same ends within this new Passivhaus setting. Changes to the *how* largely centred on juggling performances of multiple practices alongside each other. Passivhaus technologies seemed to establish closer associations across domestic everyday practices because they could all influence and be influenced by thermal comfort. The consequence was that adjustments to both appliance- and non-appliance-using practices were needed to accommodate for there being little flexibility in the types of appliances being used (e.g. clothing: never vacuuming with a jumper on; cooking: summer meal choices ensure the oven is used less). By extension, this also led to many households multi-tasking less during the summer (e.g. not vacuuming when cooking), which discussion of daily routines in the pre-move-in interviews showed to be common. Changes to the *when* included a temporal stretching of some practices so that the cumulative heating effect was more sparsely distributed (e.g. laundering: not using the tumble dryer immediately after washing). Therefore if thermal comfort – or, as many residents described it, “cosiness” (11A; 19A; 2C; 13C; 14C) – was to be maintained, other adjustments to *how* and *when* practices were performed (away from *what* and *which* appliances) had to be made.

7.4.4 How moving home can in itself influence appliance ownership

7.4.4.1 Spaces: constraining and enabling practices

Technological design and layout can both impose spatial constraints and provide opportunities for conducting certain practices in certain ways. Although this subsection is largely couched in the context of dwelling space and how appliances fit within that, consideration is also given to the capacity of appliances (e.g. refrigerator/freezers being large enough).

During most resident discussions, if there was one issue that would spark a passionate response, it was space. However, whilst the most important issue for many, space rather was a non-issue for others. Whether a dwelling provides adequate space very much depends upon the practices being undertaken within it. It is exactly for this reason that one resident explained how initial worries of downsizing from a three-bedroom to a one-bedroom dwelling were unwarranted because everyday life had changed her space demands, now she was living on her own.

Looking at one particular element of space – specifically, the capacity of certain appliances – further demonstrates how practices are shaping appliance ownership. One household that grew by one adult halfway through the study considered buying a larger fridge-freezer as essential, not because of there simply being one extra person, but because of the change in household practices that the larger fridge-freezer was capable of facilitating. For example, a larger fridge-freezer allowed for more storage as more food needed to be cooked and the likelihood of guests visiting for dinner increased. The foundations of such deliberations can be found in how cooking practices have developed over time, to the point where they considerably rely on cold appliances for food storage. Otherwise, a smaller fridge-freezer or indeed no fridge-freezer could have been adequate.

Shove and Southerton (2000) also explore space in terms of cold appliances, discussing how practices and arrangements associated with the development of supermarkets,

frozen food, the microwave and kitchen design approaches have normalised freezer ownership. Indeed, every household in this study owned a freezer (Table 7.1), which is perhaps unsurprising considering how cold chain technology ‘has made itself indispensable’ (Garnett, 2007, p. 5) in everyday life. Moreover, Shove and Southerton (2000, p. 315) argue that the freezer can currently be seen as a ‘time machine’, in that it helps ‘manage the otherwise intolerable demands of scheduling, ordering and co-ordination’. Most households were keen to utilise the time efficient shortcuts that greater freezer capacity provides:

“I’m one of those people that can always fill the freezer up! I could always do with more space! It just speeds up cooking meals. Plus, I can store more, so don’t have to shop as much. But this [freezer capacity] is adequate, I suppose.”
(25C)

Many households would have preferred scope for more or larger freezers, often only being limited by spatial restrictions set by the kitchen design. One such household talked of how they considered buying a chest freezer, but had thought it an inefficient use of space because it uses too much floor space for the amount of freezer capacity it provides, instead buying a freezer and fridge-freezer. Juggling the need for adequate freezer capacity within the dwelling’s own spatial constraints also posed a challenge, hence most households owned a fridge-freezer due to its efficient use of space – meaning that households did not have to choose between having a refrigerator or freezer.

The space created by dwelling design can make households re-negotiate previously non-negotiable ways of performing a practice. In reference to moving to a dwelling with different (often smaller) spaces, residents commonly spoke of how it made them “more ruthless in throwing things [appliances] out” (9C). Whilst moving home was associated with meanings and expectations of what a new home is meant to entail (as *Subsection 7.4.4.2* furthers), there was evidence to suggest that the moving of possessions to a new dwelling (with its associated spatial characteristics) contributed to a prioritisation of appliances. This was particularly salient regarding fitted kitchens which imposed certain spaces upon the household to fill with kitchen appliances. In the most basic sense, the limited space led households to prioritise appliances (e.g. not having a

dishwasher) and by extension certain ways of performing a practice (e.g. washing up dirty dishes instead). For instance, the cooker, refrigerator, freezer (central to cooking) and washing machine (laundry) technologies were given prime locations. When discussing this in interviews, it became apparent that these prioritisations were being shaped by the social expectations of not only performing certain domestic practices (e.g. cooking, laundering), but performing them in rather specific ways (e.g. with specific appliances).

Some appliances that were previously in prime positions could now only be accommodated in less preferable “empty spaces” (1C) “because there was nowhere else to put them” (4B). This spillover into non-ideal spaces provided a buffer for appliance ownership, helping the continuation of a practice in as near to its previous form as possible. I would infer that years of reperforming the same practice with the same appliances had reinforced that construction of everyday life, making it difficult for households to imagine life without those appliances. This meant that some households would do whatever they could – sometimes consciously, sometimes not – to not throw away appliances that had been regularly used previously. Interestingly, those same households began to normalise their new technological interactions as time went by, emphasising that lowering appliance ownership is likely to be met with household disapproval potentially only in the short-term:

“I did move the tumble dryer to my bedroom, but it hasn’t been used all the time I’ve been here. I could run a lead through, but I’m not too happy about that idea! My clothes dry just as well on a clothes-horse in the plant room. It is handy having the dryer, but I don’t feel there is all that much space for it, so it’s ended up in the shed, just in case I need it at some point in the future.”

(3C)

Whilst most spoke very positively about having no radiators which had previously restricted how objects were organised in a room, those residents who relied on radiators for energy services beyond that of simply keeping warm spoke about it much more negatively. For example, laundering in one household had always relied on the radiators for drying clothes quickly, which was essential for work purposes and a young child who was “always getting dirty” (27D). Not having adequate space for a tumble dryer in addition to, as they saw it, no suitable place for drying clothes only compounded this

problem further. They bought a (high electricity consuming) washer-dryer so that changes to their laundering practice (e.g. using a washer-dryer) would not change their clothing practice (e.g. still did not have to wear clothes more than once before laundering, as dictated by social notions of cleanliness). A lower electricity consuming alternative to maintaining their current clothing practice could be the provision of a designated clothes drying area (e.g. a small cupboard connected to the MVHR), as has been purposively designed into other Passivhaus developments.

Marked spatial differences, relative to one's previous home, can also create opportunities for performing existing practices, or even establishing new practices, in previously sought after ways. This was largely only the case for a few households who had previously been living in much smaller dwellings. As one resident explained, "with having more space, sometimes I see things that I've always wanted, and now I've got room to put it" (25C). One household had always dreamed of having an outdoor hot tub to host friends and relax in during the summer, but they had not had a garden for the previous 10 years. They still talk of even having that possibility very fondly and, needless to say, within a month of moving in they bought a hot tub saying to one another, "well, we've got a garden now, this will be great!" (26C). Spatial constraints, as determined by their technological surroundings, was therefore the key inhibitor stopping them from purchasing this (high electricity consuming) appliance. These sorts of tales were not uncommon, contributing to a shared 'if you've got the space, fill it' mentality.

7.4.4.2 New appliances for a new home: Keeping up appearances

Moving home in itself involved the re-evaluation of appliances, with a few households hiring a skip for disposal of various items prior to moving. For some this was simply because there was no "point [in] moving things to a new house that I won't use again" (12C), but for most moving home represented a "good time to start afresh" (14C). It is what this fresh start means to individuals and households that this subsection explores, in relation to what appliances were deemed suitable. The situation is complex, going far beyond issues of functionality; otherwise why would many households have each bought

a new microwave with an almost identical specification (e.g. wattage) to replace older microwaves which, according to the households, were still in working order?

For many, new appliances were essential for a new home, particularly as their new homes were new build properties. There was a need for “more modern items for such a nice, new house” (13C). It was very common to delay purchasing new appliances (“making it last” (25C)) in the lead up to moving home, so that the enjoyment of having something new could be reaped, and presumably enhanced, by their “lovely new home” (8C). Discussions with the residents indicated that the meanings and expectations of performing practices with these newer appliances were to convey social status, wealth, the ability to provide for one’s family, modernity, stylishness, and that the new home was not regarded as out of one’s reach. This was particularly evident for hosting and homemaking practices. Consequently, when reviewing the market for appliances for their fresh start, second-hand items were not considered appropriate by most households:

“It didn’t even occur to us to get second-hand [appliances] for this house [despite always doing so previously]. You’ve got a new house, a new kitchen, and you just want it all new!”

(24C)

“You don’t want to fill your new house with rubbish [i.e. second-hand appliances]. You want to start as you mean to go on, so only good stuff [i.e. new appliances].”

(26C)

Aesthetics were intrinsic to these engagements surrounding ‘keeping up appearances’. Having appliances which matched each other and the general decor was commonly discussed across most interviews, thus in many cases non-matching appliances either had been or were planning to be disposed of. One resident spoke proudly of how her recently bought kitchen items had been carefully co-ordinated:

“Have you seen that all my red things match? They are all the same make. The microwave, the [storage] pots, the kettle, the toaster. They have to match! We didn’t have them when we moved in here. Once we bought one, we had to buy all the others so they were co-ordinated!”

(19B)

Another household talked of how future purchases of brand new matching appliances had already been planned out for first few years of living in the property. Their older appliances from their previous home were being treated as a stop-gap prior to buying the ones they really wanted. Savings schedules had effectively been drawn up to replace old appliances with equivalents that better suited the images and meanings of their new home (and thus the engagements of homemaking practices).

When questioned more generally about kitchen layout and appliances, several residents independently raised the issue of gaps in between appliances and the fitted kitchen's work surfaces. It was usually raised to either criticise neighbours who had gaps or, in one case, to pre-empt any concerns others may have about their own gaps. This was in part aesthetic, but seemed largely rooted in conventions of cleanliness in that gaps would attract dirt, dust and food waste which could not be easily accessed and removed. This conflicted with the homely conditions that a good host or homemaker were expected to provide. Some residents therefore criticised other residents' general competence in buying kitchen appliances because they did not understand the importance of dimensions when ordering. Indeed, one resident critically remarked, "our cooker fits in perfect [sic], but Susan's over there, she didn't check her measurements before she ordered her oven, so she has gaps!" (21C). Another resident was disappointed that "it never occurred to me I would need a washing machine that would fit exactly" (10C). Social expectations of how to interact with the material world (e.g. a fitted kitchen), as determined by practices (e.g. hosting, homemaking), therefore influences the specification of purchased appliances (e.g. size, thus usually electricity consumption).

The practices of every shared owner were to some extent influenced by these social expectations of how best to create, maintain and present their new home. Whilst some tenants were similarly influenced, some explicitly discussed how they were not worried about making the 'perfect home'. In general, the shared owners seemed to have more of an emotional attachment and sense of pride relating to their dwelling. This may in part be influenced by investing money and time into purchasing (part of) the dwelling, but the purchase also represented a commitment to living in their new home for longer. The shared owner households hence aspired to future visions of living in their new home for

years to come, which consequently influenced appliance choice. This was made especially clear by one household who made a distinction between what appliances were suitable for her new home and all her previous homes which had only been occupied for a few months at a time.

7.4.4.3 Maintaining practices and avoiding disruption: Breakdown contingencies

If appliances were to break then the practices themselves would have to change, even if it only temporarily until technologies were repaired or replaced. Fear of disruption was implicit to many resident discussions, with it clearly influencing appliance ownership.

There was safety in purchasing new appliances because of the reliability offered and, in the deemed unlikely event of a malfunction, repairs could be quickly organised through the product's warranty. Second-hand appliances were often deemed to not provide that reliability and thus the surety that everyday life would be protected. Interestingly, not one resident talked of insurances which could also provide protection, instead focusing on the appliances themselves, perhaps because replacement of broken old appliances was deemed a burden on everyday life regardless of who was paying. Such was the importance of reliability that one household did happily buy a second-hand refrigerator, but only because the manufacturer was regarded as reputable, and they resolutely refused "to ever buy washing machines or hoovers [vacuums] second-hand as [family (relative 'experts') had insisted that] they probably wouldn't work" (11C).

The wider technological configuration in which the appliances sat also influenced these notions of reliability. This in turn influenced appliance-related choices because using certain appliances could act as a contingency in case of other technologies breaking down. Many households were genuinely concerned by the unfamiliar Passivhaus technologies because they had very few relevant skills and competences that could deal with the breakdown of the MVHR and solar thermal systems. The few households that did suffer breakdowns thus kept fan heaters, despite never using them, just in case a problem with heating was to arise again. In many ways this was about the residents not placing

sufficient trust in the Passivhaus technologies. Keeping certain appliances, such as a fan heater, therefore provided a safety net in case another breakdown was to occur. Such appliances were consequently kept in reserve and not used simply because they were available.

Appliances are so embedded within domestic practices that when certain appliances failed – in particular the larger items and white goods – replacement as soon as possible was seen as essential. Such breakdowns occurred for a few households when moving the appliances from their old to new home. When talking about these past breakdowns, the panic it caused was clear to see, particularly due to its timing. The frustration of having to replace appliances at an already expensive time was not ideal, but the residents talk as if they had no choice but to buy them. Domestic practices (e.g. cooking, laundering) rely on washing machines, refrigerators, cookers and the like. They were unwilling to either stop performing these practices or significantly adjust their performances to cope without an appliance, the reasons of which link back to a practice's social expectations. Since buying a replacement appliance was therefore seen as an urgent but costly need, the same few households had to (in the interim at least) source replacements from friends and family or potentially buy the cheapest second-hand equivalent available. In these instances, older energy inefficient appliances were typically acquired which, whilst cheaper or more convenient, could be detrimental to longer-term thermal comfort (as was explored further in *Subsection 7.4.3*).

7.5 Discussion

This section discusses four cross-cutting themes. First, appliances are essential to domestic practices. Certain appliances were commonly referred to as a *need*. This was reflected by many appliance types (e.g. cooker, television, refrigerator, freezer) being owned by every household both before and after moving home. Certain appliances were non-negotiable, and even those appliances that were not owned by every household were still usually described as *essential* or a *need* to that specific household's everyday life. Indeed appliances were so integral to everyday life that fear of breakdown, which

could disrupt the convenience or even possibility of performing a practice, strongly influenced appliance purchases (e.g. reason for replacements, not buying second-hand, and/or having an alternative appliance option available).

Second, appliances are relational, thus the wider technological configuration that the appliance(s) fits within needs consideration; specifically, how the configuration influences the practices that use it. For instance, dwelling-level materiality was shown to clearly influence the appliances that households used in appropriating their dwellings, both more generally with spatial constraints leading to prioritisation of appliances, and more specifically through Passivhaus technologies giving appliances a heating role. By giving practices the spotlight, the importance of inter-technological relationships became particularly apparent because of how practices bind technologies together in respective configurations. Practices connect and make technologies relevant.

Third, changes to appliance ownership are largely attributed to the 'engagements' (per Gram-Hanssen, 2010a) of everyday practices. The expectations, aspirations and symbolic associations attached to performing domestic appliance-using practices in certain ways dominated the influences underlying appliance ownership changes. The engagements element of practice therefore played a more prominent role in shaping the technologies element (appliances), in comparisons to two skills-related elements which relatively rarely came to the fore. Whilst skills are needed to be able to perform a practice, they were only a small influence in changing appliance ownership. More generally, the dominance of engagements was illustrated by numerous examples in Table 7.2.

Moreover, the desire to keep up appearances (e.g. co-ordinated, clutter-free, modern) in the households' hosting and homemaking practices further emphasises the significant influence of engagements. Even though spatial constraints and contingency planning may seem to have been the initial stimulus for some appliance ownership changes, these only occurred so as to serve certain performances of practices which upholds certain associated engagements. For instance, and more specifically related to the case studied, appliances also being heating devices led to new associations between appliances and thermal comfort social expectations (e.g. in turn leading to greater consideration of

energy efficient appliances that generate less heat). Whilst there is no single linear solution to transform appliance-using practices and thus appliance ownership, targeting the social significance and symbolic meanings associated with appliances-using practices in new homes would certainly aid the transition.

Fourth, variety in the individual performances of practices led to each household owning different appliances. Throughout this chapter, I have emphasised the embeddedness, stability and non-negotiability of practices and the technologies that utilise them. Indeed, a social practice is usually performed through roughly similar means to achieve roughly similar ends. In actuality this, only rough, similarity means differences exist in how the same social practices are individually performed. These performance differences can contribute to different (perhaps unanticipated) appliances becoming firmly embedded in an individual household's everyday practices. Unintended consequences are a common product of practices and part of what makes them so very difficult to govern.

These four themes implicitly reinforce the conclusions of Shove *et al.* (2007, p. 141), regarding their research on the practical usage of everyday objects, who emphasise that 'things are acquired, discarded and re-designed with reference to culturally specific expectations of doing *and* of having – not of having alone'. As they simply put it, 'doing matters for having and having matters for doing' (Shove *et al.*, 2007, p. 142). Therefore in researching technological ownership (*having*) – in this case, of appliances – one is unable to separate it from the performance of practices (*doing*).

7.6 Conclusions

This chapter aims to investigate how moving into a dwelling which uses different technologies influences appliance-using practices and thereby appliance ownership levels. A Passivhaus development was used as a case study. The electricity consumed by these households in their previous dwellings was very similar to the amount consumed in their new Passivhaus dwelling. Yet despite this, changes in appliance ownership were evident for every household, both with regard to the total number and individual specifications of

each appliance type. The extent and type of ownership changes varied markedly across households. Ultimately, these ownership differences can be attributed to differences in how appliance-using practices are performed, in particular how practices were adjusted to new technological surroundings.

It is clear that practices need to be the focus, as opposed to individuals or appliances which are actually guided by practices themselves. I support the arguments of Reckwitz (2002), and other practice theorists who developed his propositions further, regarding the inclusion of technologies as a central element influencing and being influenced by practices. Indeed, in this chapter, appliance-using practices (*doing*) influenced and were influenced by appliance ownership (*having*). This chapter also supports the prominence of social expectations, ideas, aspirations and the like in much of the recent elements of practice research work. Admittedly, by focusing solely on change (e.g. appliance ownership changes in the context of moving home), this study struggles to capture many of the subtleties that maintain and hold together practices in the everyday. Further work on this would help highlight the importance of skills, competences and tacit knowledges in appliance-using practices. Beyond appliances, it would be interesting to investigate when a lack of skills can be a barrier for choosing to incorporate new technologies into existing practices. This is because, in the context of this study at least, households rarely felt that they lacked the skills to sufficiently operate mundane domestic appliances which, in part, led to much of this chapter focusing on the engagements of practices.

When considering how practices change, or indeed how they could be encouraged to change, researchers and policy makers need to recognise that technological ownership is not solely rooted in functionality. The benefits of technologies are not merely associated with the technologies themselves, but instead how the technologies are used within the performance of practices. This chapter has reiterated how the engagements of performing practices in certain ways are of great significance in shaping appliance usage (e.g. in maintaining thermal comfort). Moreover, changing dwelling technologies (e.g. airtightness, super insulation) were shown to shape new and existing practices (e.g. through heat generated by appliances) which in turn could shape purchasing preferences (e.g. towards energy efficiency). Therefore whatever interventions are taken in targeting

Chapter 7

product purchasing and ownership, institutions should ensure that the doings of everyday life are at the heart of prospective initiatives.

Chapter 8 – Investigating how designing and constructing practices influence embodied energy and carbon

Abstract

A rise in operationally low energy dwellings is shifting attention towards the amount of energy and carbon embodied in dwellings. This chapter aims to investigate how the embodied energy and carbon of dwellings are influenced by designing and constructing practices. The embodied energy and carbon of a new build Passivhaus development (UK) is quantified; the practice-related influences of which are explored through qualitative methods (e.g. interviews, internal audit document, and field diary).

The designers and constructors were keen to build in the way that they did because of a variety of engagements (e.g. professionalism; desire to learn; expectations of what a new dwelling entails) that put the emphasis on achieving Passivhaus. Being Passivhaus-certified required considerably more insulation, contributing to a relatively high proportion of the development's embodied carbon being attributed to plastics. Whilst past experience did shape designing and constructing, expert-derived guidance was particularly essential in achieving the challenging Passivhaus performance, and consequently played a greater role in shaping the development's embodied energy and carbon.

This qualitative interpretation of the life cycle data demonstrates how focusing on social practices can provide insight on underlying influences, highlighting the complexity and potential difficulty of reducing embodied emissions.

8.1. Introduction

Climate change concerns have grown considerably in recent years, and, as a consequence, so have calls for society to lower energy consumption and its resulting carbon emissions (e.g. UNEP, 2009). The increase in designing and constructing low energy (in operational terms) buildings is contributing to a shift in emphasis away from operational to the life cycle energy consumption. Therefore action is needed to tackle the influences underlying life cycle emissions (CCC, 2013; HM Government, 2013).

Most building-related studies that embraced this shift (towards the life cycle, instead of operation) have predominantly aimed to quantify the energy or carbon *embodied* in a certain building or building product. In this way, studies have tended to be more descriptive. The more exploratory components of embodied energy or carbon studies are often associated with sensitivity analyses which experiment with the effect of different contextual changes (e.g. Upton *et al.*, 2008; Gustavsson and Joelsson, 2010; Himpe *et al.*, 2013). More investigation is needed into why buildings are being designed and constructed in the way that they are (e.g. materials used; sources of materials; methods of transportation; energy used on site; waste management) and how that influences embodied energy and carbon. Despite research emphasising how decisions made across the life cycle, by key participants in the supply chain, can significantly influence life cycle environmental impacts (Thormark, 2006; Brunklaus *et al.*, 2010; Dahlstrøm *et al.*, 2012), there have been few studies that have attempted to explore, perhaps qualitatively, these deeper underlying influences further (e.g. Davies *et al.* (2013) investigated how organisation within a construction company affects on-site energy consumption). In investigating how the actions of such participants influence the embodied carbon of buildings, the focus has traditionally been on individuals and how they interact with technologies (e.g. Hernandez and Kenny (2010) explored embodied energy in relation to occupant preferences). However, this chapter advocates a different point of departure that focuses on practices (seen here as routinised activities), such as designing and constructing.

Whilst practices have formed the basis, even if just implicitly rather than explicitly, of some more technical based building research (e.g. Gram-Hanssen *et al.*, 2012; Galvin, 2013), practices are yet to be considered in the context of life cycle assessment. Typically, practices-related research focuses on the everyday practices during the occupation or operation phase of a technology (e.g. showering, cooking, driving), but the same theoretical and analytical frameworks can also be applied to understanding how practices over the rest of the life cycle can influence energy consumption and carbon emissions. The potential is indicated by research investigating practices in the workplace more generally (e.g. Hitchings, 2010; Hargreaves, 2011), and the construction industry more specifically (e.g. Pink *et al.*, 2010; Tutt *et al.*, 2013). This has direct relevance to the embodied carbon literature because designing (regarded here as planning the form and structure of a building(s)) and constructing (regarded here as erecting a building(s)) buildings are practices. Designing and constructing both requires specific skills and the use of certain technologies, in addition to sufficient meaning being attached to the practices (e.g. to the extent that individuals can associate themselves as being ‘designers’ or ‘constructors’).

This chapter aims to investigate how the embodied energy and carbon of a housing development is influenced by designing and constructing practices. Since meeting the Passivhaus building energy efficiency standard requires a shift in designing and constructing, a UK Passivhaus case study is employed to investigate this aim. This shift is particularly true for the UK where there have been fewer Passivhaus projects, particularly relative to other parts of Western Europe.

I begin by briefly outlining the Passivhaus standard and the practices framework employed (8.2), before describing the adopted methods (8.3). The findings, analysis and discussion are then split between quantifying the embodied energy and carbon attributed to this one housing development (8.4), and considering how the designing and constructing practices shaped this (8.5). The discussion (8.6) explores how designing and constructing dwellings were shown to influence a development’s embodied energy and carbon, in addition to considering how practices analyses could be further applied in this research area. This chapter then finishes with some conclusions (8.7).

8.2. Background

8.2.1 The Passivhaus standard

Passivhaus is a building standard providing high levels of energy efficiency, primarily through airtightness and super insulation (Feist *et al.*, 2005). The standard assists in achieving significantly lower operational energy consumption which, if searching for ways to minimise life cycle energy and carbon, inherently shifts the focus onto embodied energy. As operational carbon is significantly lower in low energy homes, the proportional contribution of a dwelling's embodied carbon to the total life cycle emissions (i.e. net emissions from construction, operation, maintenance, demolition, disposal/ recycling) of a dwelling will increase even if embodied energy was to remain at the same levels. Past studies quantifying the life cycle energy and carbon of Passivhaus buildings are summarised in Table 8.1.

Source	Study object	Location	LCA boundaries	Completion year of building(s)	Study object floor area (m ²)	GJ/m ²	kgCO ₂ e/m ²
Thormark (2002)*	20 apartments in 4 two-storey rows	Gothenburg, Sweden	Cradle-to-grave	2000	2,400.0	9.63	-
Feist (1997)*	1 mid-terrace house	Darmstadt, Germany	Cradle-to-construction	1991	156	5.01	-
Dahlstrøm (2012) [#]	1 two-storey residence (4 different heating systems modelled)	Stord, Norway	Cradle-to-grave	-	93.5	35.90-44.00	1,193-1,342

Table 8.1 – Past studies quantifying the embodied energy or carbon of new Passivhaus buildings

* based on actual data [#] based on modelled data

Passivhaus is often touted as the future for residential and commercial buildings, particularly because research suggests that the operational energy savings significantly outweigh any additional embodied energy associated with construction (Sartori and Hestnes, 2007). However, a recent review of delivering two UK Passivhaus dwellings

‘suggested that achieving such a high level of performance was not easy due to problems in the construction process, and required exceptional vigilance and scrutiny from the design team’ (Guerra-Santin *et al.*, 2013, p. 40). A change to practices within industry would therefore seem to be required, relating in particular to the way buildings are designed and constructed. Indeed evidence from an Austrian case study showed that adhering to the Passivhaus standard ‘has the potential and currently seems to set out to profoundly transform dominant construction practices of buildings’ (Ornetzeder and Rohrer, 2009, p. 1538).

The likelihood of potentially rapid evolution to designing and constructing practices is emphasised in a 2012 interview with, Passivhaus co-founder, Professor Wolfgang Feist:

‘I think in 10 years, that’s 2022, all the things we are discussing now: triple glazing, airtight window frames, airtight construction, good insulation, ventilation with heat recovery. All these things will be just normal, just what you do.’

(McCabe, 2012)

Professor Brenda Boardman recently made a similar assumption regarding UK buildings:

‘Beyond 2025, the need for any space heating will disappear as properties are made low-energy or brought up to Passivhaus standard.’

(Boardman, 2012, p. vi)

The following section goes on to briefly outline how prospective changes in designing and constructing practices could be constituted by changes to certain elements of practice.

8.2.2 The elements of practice

Table 8.2 provides a description of four elements (influences) of practice – technologies, engagements, know-how and embodied habits, and institutionalised knowledge and explicit rules (Gram-Hanssen, 2011a) – as well as illustrating their distinctions by applying the framework to designing and constructing practices. Not all of these examples relate directly to embodied carbon, but they do serve to illustrate the differences between the

elements that influence what people do. For more on the background of social practices and its relevance to policy, please consult the work of Shove (e.g. 2012).

Element	Description	Illustrative practices	
		<i>Designing</i>	<i>Constructing</i>
Technologies	Anything tangible that constitutes our surrounding physical environment	Computers; drawing boards; plans; building material catalogues; offices; tape measures; energy	Building materials; waste skips; hard hats; work clothes; machinery; site office; energy
Engagements	Aspirations; expectations; ideas; motivations; norms; associated meanings	Being good at one's job; sustainability; stylish; innovative; value for money; able to create a welcoming/ attractive building for its occupants	Reliability; high quality workmanship; value for money; sustainability; capable of enacting the designer's vision
Know-how and embodied habits	Tacit knowledge developed through experience (e.g. apprenticeships) which becomes habitual	Timekeeping; understanding client needs; adopting design strategies based on past success/shortcomings; learning what looks good post-construction	Timekeeping; ordering of tasks; sensual interpretation (e.g. look and feel of finishes); how and which other contractors to liaise with
Institutionalised knowledge and explicit rules	Explicitly stated knowledge from a source that knows more than you do ('expert')	Planning laws; Building Regulations; energy efficiency standards/ targets; client specification; guidance from specialist groups (e.g. Royal Town Planning Institute); line manager advice	Installation manuals; Building Regulations; guidance from specialist groups (e.g. Chartered Institute of Building); line manager advice

Table 8.2 – The elements of practice (description distinctions sourced from: Gram-Hanssen, 2011a)

8.3. Methodology

8.3.1 Case study information

The case study is a small to medium sized UK affordable Passivhaus development, built during 2010-11. Details of specific dwellings cannot be provided due to privacy agreements. Therefore this chapter focuses on the development as a whole, from which embodied energy and carbon values are provided on a per m² basis.

Table 8.3 details the design parameters of the development's dwellings and Figure 8.1 shows the external wall and floor composition. The development includes 3-bedroom and 2-bedroom houses (both with two floors) in addition to 1-bedroom flats (one floor).

Design parameter	Specification
Total gross internal floor area (m ²)*	950.00
Total treated (heated) floor area (m ²)	881.29
Total footprint area (m ²)	656.89
Total openings area (m ²)	239.46
Total roof area (m ²)	1,496.32
Total external wall area (m ²)	1,163.52
External wall width (m)	0.50
Framework	Masonry
Air leakage at 50Pa (air changes/h)	0.60
External fabric <i>u</i> -values (W/m ² .k):	
<i>external wall</i>	0.09
<i>Floor</i>	0.07
<i>Roof</i>	0.08
<i>windows</i>	0.79

Table 8.3 – Design parameters of the whole case study development

* excludes party walls between dwellings

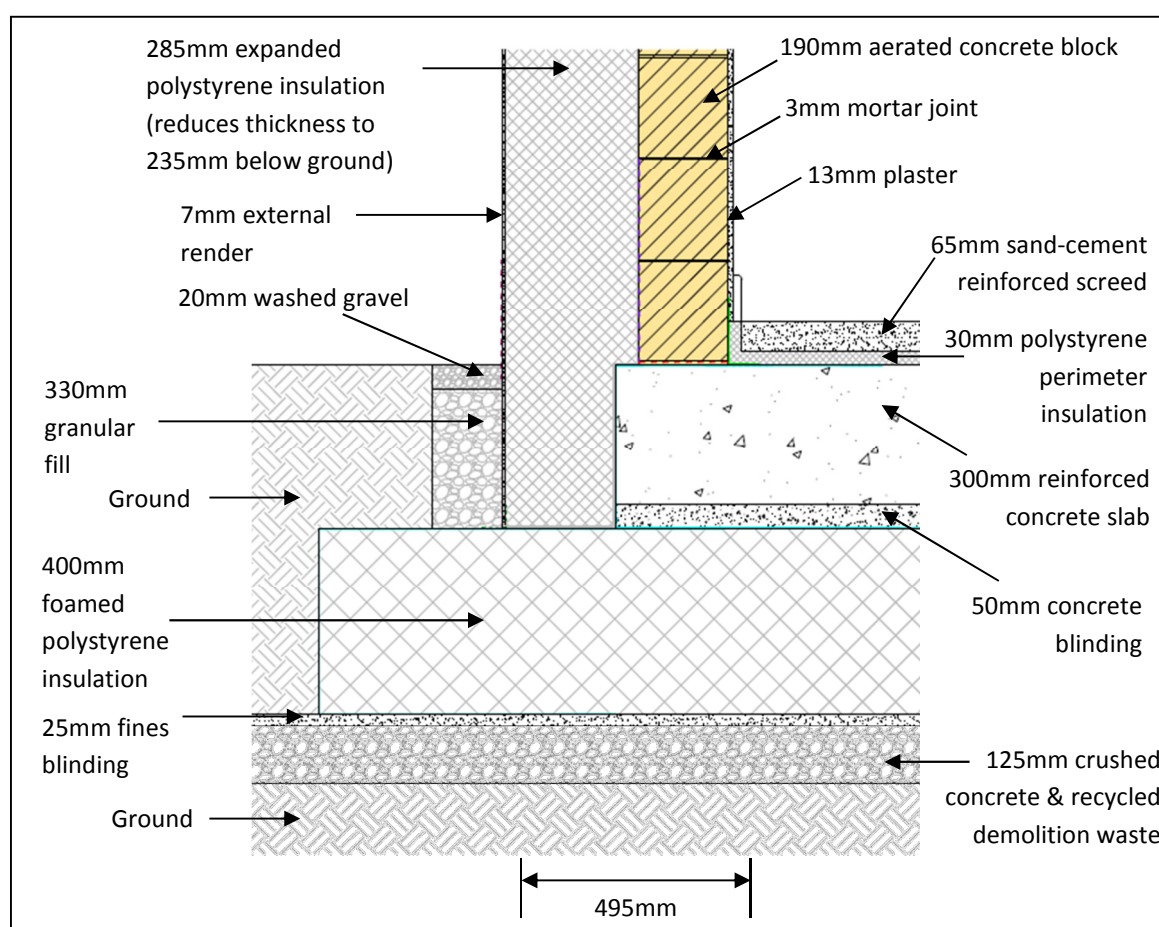


Figure 8.1 – Simplified cross-sectional sketch of the external wall and floor components

8.3.2 Life cycle assessment (LCA) framework

The LCA framework provides a basis for evaluating the environmental impact (e.g. energy, carbon) of a service or product (e.g. a dwelling). According to International Standards (ISO 14040, 2006), there are four main stages to the LCA framework:

1. Goal, scope and definition;
2. Inventory analysis;
3. Impact assessment; and
4. Interpretation.

Stage 1, which involves defining the assessment's scope and boundaries, is the topic of the *Subsections 8.3.2.1-8.3.2.2*. Data sources for the Inventory itself are then discussed in *Subsection 8.3.2.3*, before presenting the Inventory's findings in *Section 8.4*. This study does partially evaluate the environmental impact (Stage 3: Impact assessment) through its quantification of CO₂e emissions, which is also in *Section 8.4*, but it goes no further. Indeed, these findings are not used to explicitly provide policy recommendations (Stage 4: Interpretation) because the focus is essentially on the underlying influences of the Inventory's, and in part Impact assessment's, findings.

8.3.2.1 Goal of study

In quantifying the embodied carbon of the Passivhaus development, this study conducts a partial LCA using the LCA framework. Emissions are quantified from cradle to Passivhaus dwelling construction. An inventory of materials and energy used is compiled and analysed, in calculating the primary energy and associated embodied carbon emissions of the dwellings' construction. This part of the chapter, that employs the LCA approach, explicitly aims to investigate the embodied carbon implications of designing and constructing Passivhaus dwellings.

8.3.2.2 Case study boundaries

There is a dual scope focus to this study: primary energy demand and its associated carbon dioxide equivalent (CO_2e) emissions. No other environmental impacts are investigated. This is because the Passivhaus concept is commonly justified on the basis that it saves energy and carbon, and I am interested in examining how the undertaking of designing and constructing practices influence this – such as, whether there are any unintended consequences that may, for instance, not lead to energy and carbon savings.

The cradle to construction energy and emissions cover (Figure 8.2):

- materials, components and technologies used as part of construction
- transportation of these materials to the construction site
- transportation of the waste materials generated on site to disposal
- disposal of the waste materials
- energy used on site during construction

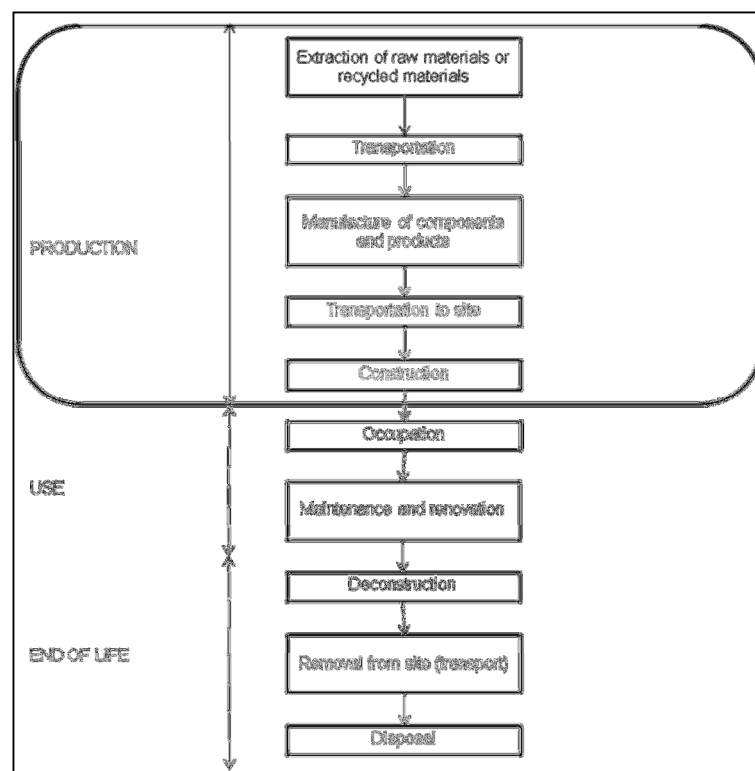


Figure 8.2 – Simplified life cycle process flow chart: Case study boundaries (Source: Monahan and Powell, 2011b).

All other emissions connected to the construction of the dwellings are excluded. These include the energy required for workman to commute to the construction site, the provision of infrastructure (e.g. roads, factories), and the installation of internal finishes and fittings. These activities were excluded primarily because this study is investigating how embodied energy and carbon are influenced by different ways of performing designing and constructing practices. Whilst these activities form part of how the studied housing development was designed and constructed, they would also form part of how other (e.g. not Passivhaus or low energy) dwellings are designed and constructed. Data were thus omitted because they did not provide an adequate enough link from the embodied energy and carbon data, to the differences in how designing and constructing were practiced.

Although aggregated data (i.e. data collected for the development project as a whole) were used, efforts were made to exclude resource consumption attributed to non-dwelling related construction activities (e.g. garages for other nearby residents that were reconstructed to make space for these new dwellings; landscaping).

8.3.2.3 *Inventory and data sources*

The quantities of materials were calculated using information from quantity surveyors, architects, contractors and others involved in the supply chain. The architects provided detailed site plans, which helped to determine building dimensions. The waste management company kept collection records regarding the tonnage of each waste stream, categorised under the following: packaging, wood, plastics, metals and inert. For an extract of these raw data see *Appendix 12*.

Fossil fuel energy consumption data were obtained through site meter readings (grid electricity, gas) and bills (diesel, petrol). Site-level energy data were only available, thus disaggregation and attribution of data to specific activities was not possible.

Energy and carbon emissions factors were utilised for both energy production of different fuel types and for specific processes and services (using other cases as proxies). There was an effort to make it UK-relevant wherever possible or, if produced or manufactured elsewhere, for that specific country of origin:

- UK Government carbon emissions conversion factors (DEFRA / DECC, 2012)
- The Inventory of Carbon and Energy (ICE), version 2.0 (January 2011 update) (Hammond and Jones, 2011)
- Other published LCA research for a minimal number of specific components and technologies (e.g. Ardente *et al.*, 2005; Hernandez and Kenny, 2009; Atkinson, 2010; Dahlstrøm, 2010)

Despite 58% of the development's external doors being fully glazed, the embodied energy and carbon calculation assumed that 100% were fully glazed. This was due to there being no available conversion factor for highly insulated and airtight unglazed external doors (u -value: $2\text{W}/(\text{m}^2.\text{K})$), with insufficient resources available to quantify it within this case's specific context. This was deemed acceptable because the primary purpose of this study is to use the embodied carbon analysis as an indication of the consequences of designing and constructing buildings in certain ways.

8.3.3 Accompanying qualitative data collection

A field diary was kept around the time of construction site visits which significantly informed the analysis (see *Appendix 6* for an extract of the field diary more generally). The field diary covered three construction site visits (from six months before completion onwards) as well as attendance at key site events (e.g. official opening; open days; project evaluation meetings).

A confidential internal document, which audited the design and construction process, was also used to develop an understanding of designing and constructing practices.

Two semi-structured interviews were undertaken to support this line of inquiry. One was with the designer of the development and the other with the author of the confidential design and construction audit. Within these interviews, the Inventory and its key findings were used as the basis for discussion. Tables and graphs were used as a reference point throughout, and the pre-prepared interview schedule (used to guide the line of questioning; see *Appendix 4*) was produced using the analysis' findings. This was to ensure that discussion remained connected to (the by-products of) how the development was designed and constructed in its own context-specific way, be it if that contributed to high/low resource use, energy consumption, and/or emissions.

The purpose of these qualitative methods was to explore the underlying influences behind the Inventory itself. For instance, why were certain materials and product types used more than others? Why did certain processes contribute to a greater/lesser proportion of the dwelling's embodied carbon? How and why does this Inventory differ from other ways of designing and constructing? In considering such issues, the practices of designing and constructing are given explicit attention, particularly in relation to the elements of practice (Table 8.2). The Inventory is treated as a record of the by-products of designing and constructing.

When referencing the quotations from these qualitative methods in this chapter, the following system was used: (A) field diary quotation, (B1) quotations from the interview with the designer, and (B2) quotations from the interview with the design and construction auditor.

8.4. Inventory analysis: Quantifying the embodied carbon

8.4.1 Inventory summary

Table 8.4 provides a summary of the LCA Inventory, normalised to the functional unit of treated internal floor area (m²). The case study Passivhaus development required a total

of 7,345.56MJ/m² for construction, which consequently had 533.17kgCO₂e/m² embodied in the development. The largest proportion of embodied carbon can be attributed to using minerals as a construction material in the development, summing 39.52% (Figure 8.3).

Category	Description	Quantity (kg/m ²)	Primary energy (MJ/m ²)	Emissions (kgCO ₂ e/m ²)	% of total emissions
Metals	Aluminium	3.87	663.75	38.49	7.22
	Steel	3.15	68.19	4.95	0.93
Minerals	Autoclaved Aerated Concrete (ACC) blocks	188.13	658.47	57.85	10.85
	Other concrete	876.21	767.18	117.64	22.06
	Cement	135.62	195.08	32.12	6.02
	Gypsum plaster products	12.89	35.63	2.33	0.44
	Aggregate	154.20	4.67	0.79	0.15
	Bitumen	0.01	0.73	0.01	0.00
Openings	Windows and external doors	-	526.83	22.96	4.31
Plastics	Polystyrene insulation	17.73	1,935.65	77.82	14.60
	Phenolic insulation	0.53	23.82	0.98	0.18
	Fibreglass insulation	9.01	252.35	12.17	2.28
	Polyurethane insulation	0.92	93.29	3.92	0.74
	Polyvinylchloride (PVC)	1.13	107.58	3.73	0.70
	Polyethylene	0.00	0.04	0.00	0.00
Timber	Composite board products	4.21	46.39	3.11	0.58
	Engineering timber	32.98	343.01	28.69	5.38
	Softwood	19.75	146.14	11.65	2.19
	Plywood	2.59	38.80	2.85	0.53
Heating & ventilation systems	Mechanical ventilation with heat recovery (MVHR) system	-	190.63	27.78	5.21
	Solar thermal system	-	139.17	11.45	2.15
	Gas-fired boiler	-	133.54	19.46	3.65
Fuel	UK grid electricity (kWh/m ²)	0.67	2.40	0.35	0.07
	Mains gas (kWh/m ²)	3.09	11.12	0.57	0.11
	Diesel (kWh/m ²)	39.42	141.92	9.47	1.78
	Petrol (kWh/m ²)	1.60	5.76	0.39	0.07
Transportation	Factory gate to construction site (km/m ²)	13.41	227.90	15.93	2.99
	Site to waste transfer (km/m ²)	51.62	227.04	15.87	2.98
	Waste transfer to waste treatment (km/m ²)	85.87	98.09	6.86	1.29
Waste	Treatment	105.07	260.39	2.98	0.56
Total:		-	7,345.56	533.17	100

Table 8.4 – Summarised inventory for the construction of this Passivhaus development, normalised on a per m² basis: Quantity, primary energy, embodied emissions of materials, fuels, transportation and waste

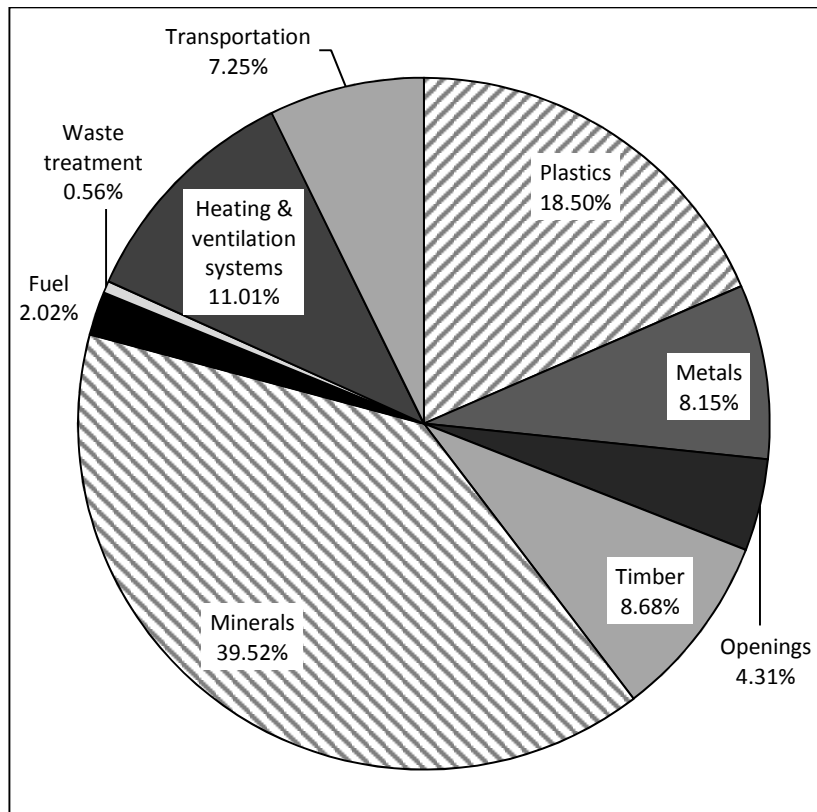


Figure 8.3 – Categorical breakdown of embodied carbon attributed to this Passivhaus development. Total embodied carbon: 533.17kgCO₂e/m².

The remaining subsections of *Section 8.4* probe further into each category – materials, fuels, technologies, transportation, and waste treatment – by detailing more specifically which were the relatively largest or smallest contributors to embodied carbon. This provides context for *Section 8.5* which qualitatively explores how a specific way of performing designing and constructing practices may have led to this embodied carbon breakdown.

8.4.2 Materials

Relating back to Table 8.4's categories, materials include: plastics (e.g. insulation), metals (e.g. steel, aluminium), minerals (e.g. concrete, aggregate), openings (e.g. windows, doors), and timber (e.g. plywood, composite boards, engineering timber). Altogether these account for 79.16% (422.06kgCO₂e/m²) of carbon embodied in the construction of the development. It is common for the materials to dominate the categorical breakdown

of embodied carbon (e.g. Thormark, 2002; Cuéllar-Franca and Azapagic, 2012; Amiri *et al.*, 2013). Figure 8.4 details the breakdown across these different types of materials used.

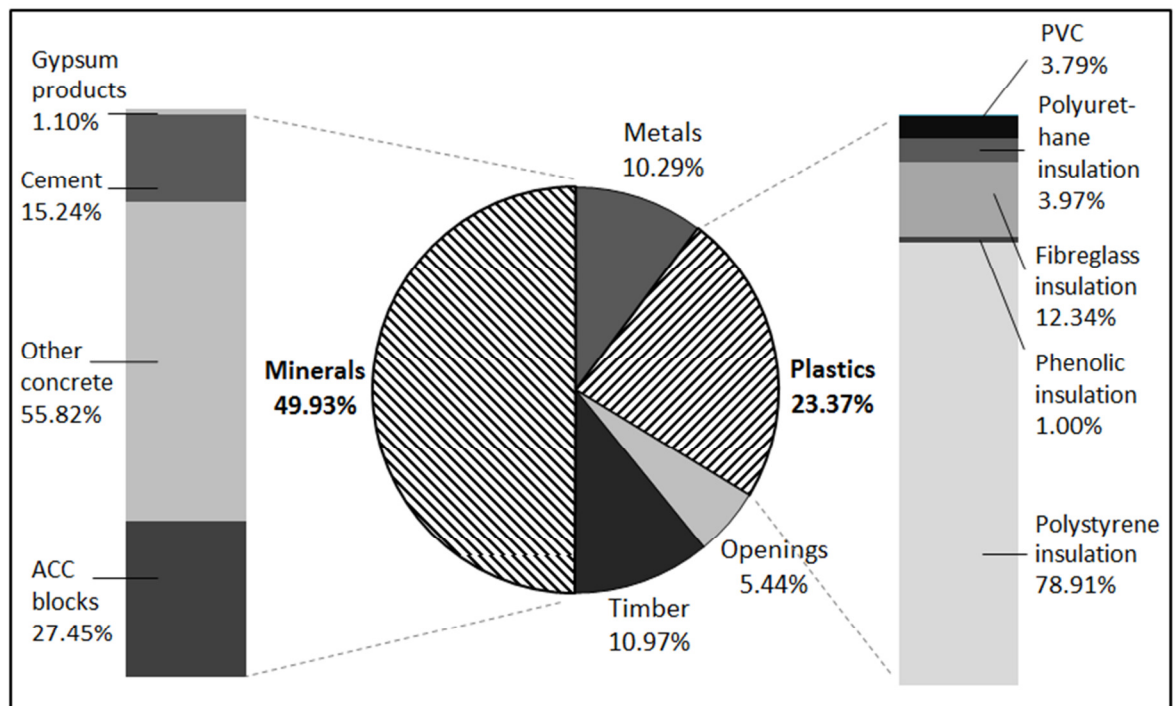


Figure 8.4 – Proportion of embodied carbon attributed to the materials of this Passivhaus development (thereby excludes technologies, fuel, transportation and waste). Total embodied carbon of materials: 422.06kgCO₂e/m².

Across the building materials, minerals are the largest embodied carbon contributor (49.93%; 210.73kgCO₂e/m²). This is largely because of the carbon intensive nature of concrete. For instance, the Autoclaved Aerated Concrete (AAC) block, which is the main structural constituent of the case's external walls (Figure 8.1), requires 3.50MJ and emits around 0.31CO₂e in the production of one kg (Hammond and Jones, 2011). 'Other concrete' includes roof tiles, as well as (in the substructure and foundations) a reinforced slab, blinding, and crushed concrete waste (Figure 8.1) – the cumulative energy demands of which contributed to 55.82% of minerals' embodied carbon.

Plastics account for 23.37% (98.62kgCO₂e/m²) of the embodied carbon attributed to materials. Of this plastics total, 78.91% (77.82kgCO₂e/m²) can be attributed to polystyrene insulation alone. There is up to 285mm of polystyrene insulating external walls, as well as 30mm below the ground floor and 400mm in the substructure (Figure

8.1). It requires 88.60MJ to produce one kg of expanded polystyrene, embodying 3.29CO₂e per kg in the process (Hammond and Jones, 2011). Fibreglass is responsible for 12.34% of the carbon embodied in the development's plastics, and this is due to there being 500mm in every loft in between the joists.

The relatively higher proportion of embodied carbon attributed to plastics is a salient feature of this analysis and, as such, was the reason for Figure 8.4 having a specific plastics breakdown, in addition to the minerals equivalent. Indeed it is fairly common for minerals, again because of concrete related emissions, to hold a greater share of the embodied carbon, but it is rarer for plastics to be as high (c.f. Adalberth, 1997a; Asif *et al.*, 2007). Compared to other design and construction approaches, meeting the Passivhaus standard requires a significant amount of insulation.

The amount of carbon embodied in metals is also interesting to reflect upon (10.29% of the embodied carbon attributed to materials). Whilst steel was required for structural purposes, it is the emissions relating to the use of aluminium that stood out. As has just been discussed, Passivhaus requires a significant amount of insulation to reduce heat loss. However this, in conjunction with Passivhaus' airtightness, would cause buildings to overheat unless some sort of solar shading technologies were used. For the case in question, aluminium internal solar blinds and an external brise soleil were installed, which accounted for 88.60% (38.49kgCO₂e/m²) of the metals-related embodied carbon (remaining 11.40% attributed to steel). According to the ICE database (Hammond and Jones, 2011), one kg of aluminium sourced in the UK requires on average 155MJ of energy and emits 9.16 of kgCO₂e.

The remaining 16.41% of materials-related embodied carbon was attributable to timber (10.97%) and openings (5.44%). Since this was a masonry build, rather than being timber-framed, there were no noteworthy timber related embodied emissions. In addition, whilst the embodied carbon of the 0.80W/(m².K) uPVC/aluminium triple glazed windows was higher on a per window basis (compared to less energy efficient alternatives), it did not lead to a higher proportion of the total embodied carbon being attributed to openings (c.f. Asif *et al.*, 2007; Monahan and Powell, 2011b).

8.4.3 Heating and ventilation systems

Heating and ventilation summed 11.01% of the development's total embodied carbon. For this case, these systems include the mechanical ventilation with heat recovery (MVHR), solar thermal and gas-fired boiler systems. The MVHR is required to maintain good air quality in Passivhaus buildings, as a consequence of the Passivhaus standard demanding a comparatively airtight building fabric. The solar thermal system works in conjunction with the gas-fired boiler to provide water heating and space heating (through the MVHR and one towel rack).

The breakdown across these heating and ventilation systems is as follows: MVHR (47.33%), solar thermal (19.51%), and gas-fired boiler (33.16%).

8.4.4 Transportation

Transportation from factories, through relevant distribution networks, to the construction site sums 11,343.70km (2.99% of total embodied carbon). This was very similar to other Passivhaus studies; for example, Thormark (2002) found transport to construction site to sum 2.57% of total embodied energy (assuming that the same boundaries as in this chapter are adopted). In sourcing Passivhaus-certified products and indeed other materials and components that would help achieve the required airtightness and *u*-value levels, UK manufacturers were seemingly able to provide most of the materials. Nevertheless certain products (e.g. airtight loft hatch; triple glazed windows; solar gain blinds and brise soleil package) had to be sourced from international suppliers (e.g. in Austria) because no UK alternative existed at the time.

Transportation of the raw materials to factories is not detailed separately (here or in Table 8.4) because this is included in the material (MJ/kg; kgCO₂e/kg) conversion factors. These spanned the cradle to gate boundaries of the life cycle.

Transportation of construction site waste contributed to 92,507.14km being travelled. Most of this (77,249.11km) can be attributed to transporting waste metals from the waste transfer site to the remelting plant in China. A waste management company was employed to collect the waste from the construction site and transport it to their sorting facility (using skip lorries), prior to each waste type (packaging, wood, plastics, metals, inert) being transported to respective treatment facilities (primarily using articulating lorries).

8.4.5 Onsite fuel consumption

Onsite fuel consumption contributed to 2.02% of the development's total embodied carbon. Of the fuel used in the construction of the development, 87.85% can be attributed to diesel, which was primarily used for the operation of the onsite welfare unit, forklift trucks, and excavators. Petrol was consumed by site generators and cutters (3.65% of fuel used), with electricity used for other site equipment (3.24%), and gas predominantly for heating and hot water in the dwellings as the development neared completion but were still being used by the construction team (5.26%).

8.4.6 Waste treatment

Waste treatment contributed only 0.56% of the development's total embodied carbon. No waste was landfilled because the central waste management contractor, which collected the waste and transported to others for treatment, was committed to "recycling or recovering 100% of its waste" (A). Records show that 97.47kg of waste was produced for each m² of floor area.

Table 8.5 details the embodied energy and carbon implications of treating the construction site's waste. Packaging and plastics waste formed part of the same stream, with both waste types treated by the same treatment company.

Waste type	Waste treatment	Treatment location ^a	Quantity (kg/m ²)	Embodied energy (MJ/m ²)	Embodied carbon (kgCO ₂ e/m ²)
Packaging	25% MBT ^b ; 75% Incineration	London, UK	41.64	55.88	0.87
Wood	Chipped	Devon, UK	29.22	39.21	0.39
Plastics	25% MBT ^b ; 75% Incineration	London, UK	0.71	3.42	0.01
Metals	Remelted	Shanghai, China	1.21	5.83	1.67
Inert	Reuse	Essex, UK	32.30	156.06	0.03
Total:			105.07	260.39	2.98

Table 8.5 – Summarised embodied energy and carbon implications of treating the waste produced at this UK Passivhaus development

^a Specific locations could not be provided due to confidentiality agreements with participants.

^b Mechanical Biological Treatment.

Whilst inert waste accounted for 30.74% of waste weight produced, it only accounted for 1.08% of embodied carbon because of its reuse (e.g. crushed concrete) using considerably less energy than the other waste treatments. In contrast, treatment of metal waste (1.15% of waste weight produced) accounted for 55.86% of treatment emissions. Bearing in mind that the production of metal is also very energy intensive (Table 8.3), the inclusion of metals in the design of buildings does come with a very significant embodied carbon burden.

8.5. Exploring how the elements of practice influence embodied carbon

The embodied carbon data set out in the previous section are seen as by-products of practices, predominantly the designing and constructing of buildings. Specifically, these data are the by-products of the context-specific performances of the studied housing development's designers and constructors. The underlying influences of how designing and constructing practices implicate embodied carbon are discussed in this section, by drawing upon accompanying qualitative inquiry.

Practices are upheld and shaped by the elements of practice, and thus the underlying influences to these embodied carbon findings are discussed with regard to the elements of practice (technologies; institutionalised knowledge and explicit rules; know-how and embodied habits; engagements). The four elements are now discussed more generally in relation to what upholds the designing and constructing practices, with a focus on how the elements implicate certain ways of consuming resources and, consequently, embodying energy and carbon into the dwellings.

8.5.1 Technologies

Since the purpose of *Section 8.5* is to discuss the technological choices (which are embodied with various amounts of energy/carbon) that came about because of the relationships between the elements of practice, the technologies element is implicitly considered when discussing how the other elements shape designing and constructing (*Subsections 8.5.3-8.5.2*). Using Table 8.2's elements of practice distinctions, energy, as something tangible in the physical environment, is considered to be a technology. Therefore when discussing embodied energy or carbon through the elements framework, the fundamental focus is on the relationships between technologies and other elements of practice.

This subsection thus leaves discussing how each of the other elements of practice relate to which and how much of a certain technology (be they minerals, timber, openings, metals, etc) is used in construction to *Subsections 8.5.2-8.5.4*. In light of *Section 8.4* providing an overview of the technologies that were opted for through design and construction, this subsection briefly discusses some of the salient intra-element (technologies element) relationships that influence which technologies could be employed. Specifically, (1) how choosing one technology can commit you to another, and (2) the availability of technologies in supply chains.

First, technologies do not work in isolation; they form part of a broader package of technologies that interact with one another. Therefore, opting for one technology within

the design has knock-on effects when considering other technologies. For example, having larger windows for solar gain help achieve a high operational energy performance, but is burdened with the requirement of solar gain blinds and/or brise soleil to prevent overheating. This case study showed 7.29% of the development's total embodied carbon was attributed to such aluminium shading technologies (Table 8.4). Similarly, constructing to a relatively high airtightness (e.g. external letter box instead of an opening in the front door) requires designers to have a ventilation strategy. A MVHR system was adopted here (5.26% of total embodied carbon), and indeed is typical of Passivhaus design, to ensure efficient ventilation and adequate air quality.

Second, the availability of Passivhaus components was limited in the UK due to an underdeveloped supply chain. For example, during initial design there were only two window options that were deemed suitable, whereas now there are over 50 UK-sourced windows available. Whilst supply chain difficulties was one of the most frequently raised issues (in interviews and field diary), the need to source components from outside of the UK did not contribute to considerably higher transportation emissions. Of the development's total embodied carbon, 3.02% was attributed to transportation of building technologies from the factory gate to construction site (Table 8.4), thus was similarly as low as other studies (e.g. Adalberth, 1997b; Monahan and Powell, 2011b).

8.5.2 Engagements

In the earliest stages of the project, prior to design even beginning, it was understood that the development would be Passivhaus. However, as the designer pointed out, "it was clear to us that it [achieving Passivhaus] wasn't a given" (B1). Consequently,

"Performance of the materials became paramount because we weren't sure that we could even achieve the standard. So whenever there was a decision about which material we might want to use, we always took the safe route in terms of performance, against any other factor."

(B1)

Performance therefore became the driving influence behind how the dwellings were designed and constructed. Moreover, achieving high (Passivhaus) performance was especially challenging because they “had to deliver Passivhaus at a sensible cost, whereas a lot of the early adopters were pioneers that just wanted to achieve it” (B1).

Achieving high performance (but at an affordable cost) thus drove technological design, with embodied energy and/or carbon not considered in either design or construction (as some projects are starting to do now; e.g. Passivhaus Trust (2013g) and Green Building Press (2013)). This was openly acknowledged by the project team. For instance, initial design drawings included a timber brise soleil, but its higher financial cost led to an aluminium alternative being used. This is despite the materials that constitute a timber brise soleil (8.66MJ/m^2 ; $0.31\text{kgCO}_2\text{e/m}^2$) having a considerably lower embodied energy and carbon than the installed aluminium alternative (531.39MJ/m^2 ; $30.81\text{kgCO}_2\text{e/m}^2$).

To understand the engagements that underlie why designers and constructors were eager (consciously or not) to design and construct in the specific way that they did, and indeed understand why building performance became such a focal point, then one must look deeper. Of course, there was a contractual commitment to meet the Passivhaus standard and a commercial desire to turn a profit, but I now consider and discuss the deeper influences that were more associated with the aspirations and expectations of their involvement in the housing development.

Aspirations of being an industry frontrunner were a key engagement underlying why the development was designed and constructed in the way that it was. Being directly involved in and responsible for innovation was an exciting opportunity. Indeed there was a definite desire to learn more through participating in the project. This was particularly clear when discussing my research findings with the project team, who were largely very keen for constructive feedback. Members of the project team were thereby keen to participate in the project and, in particular, achieve the energy performance required for Passivhaus certification.

In addition, the designers and constructors wanted to have a positive influence on the lives of the occupants. In this way, the designer's vision reflects some of the hopes and expectations of prospective households. On a basic level this encompasses the technological arrangements of standard dwelling design (e.g. no cross-household communal facilities; always have a lounge for the household to congregate in or to host guests), but also includes broader social expectations as to what constitutes a new home (e.g. modernity; aesthetics). For instance, the designer made a passing reference in the interview to "bad design" (B1), which related to the timber materials on the external face not being quite as co-ordinated as they could be. Taking pride in one's work, particularly because that work will become someone's new home, was hence shown to shape technological design. Indeed the duty felt by the project team to design and construct the dwellings in accordance with the households' best interests was fundamental to the whole project: the housing association commissioned the Passivhaus project to help alleviate fuel poverty, thereby putting the focus on energy performance from the outset.

Therefore there were a range of engagements – relating to professional integrity, an eagerness to learn, a duty to do right by the households, and expectations of what constitutes a new home – which shaped designing and constructing practices. There were certainly no broader regulatory or social expectations of the wider industry meeting the Passivhaus standard, but these engagements reinforced the willingness (conscious or not) of the project's designers and constructors to meet it nevertheless. This put the onus on performance, which seemed to influence the embodied energy and carbon come what may.

8.5.3 Institutionalised knowledge and explicit rules

The emphasis on performance, and the "fear" (B1; B2) of not reaching the Passivhaus standard, resulted in the project team focusing on knowledge from the Passivhaus community. I now discuss how such expert-derived explicit knowledge influenced designing and constructing practices, and thus in turn technological choices, resource consumption and embodied energy/carbon.

The Passivhaus Planning Package (PHPP) is an institutional resource that significantly shaped design and construction. PHPP is a building performance model, produced by the Passive House Institute, which assesses whether a building can be Passivhaus-certified or not. The concern that performance may not meet the onerous Passivhaus standard led to the PHPP being used as a reference point for almost every decision during design and then again during construction (should the design need to be changed):

“Every time someone wants to make a [technological design] change you need to go and plug that back into PHPP to check that doesn’t have an adverse [building] performance implication.”

(B1)

An ‘adverse performance implication’ was essentially sub-text for keeping heating load and energy consumption estimates within the acceptable limits demanded by the Passivhaus standard, as per the PHPP. This in fact captures the Passivhaus way of designing and constructing, in that heat loss rates are given considerable attention both with regard to ventilation and building fabric losses. Consequently the dwellings were constructed with a significant amount of insulation (e.g. 500mm of loft insulation; 285mm of external wall insulation; 400mm of foundational insulation), so as to establish a thermally efficient internal-external barrier. Plastics constitute 17.67% of the development’s total embodied carbon, which is greater than other low energy dwellings (e.g. Monahan and Powell, 2011b) and considerably greater than more traditional builds (e.g. Adalberth, 1997a). Of this plastics total, 96.21% can be attributed to insulation provision more generally and 78.91% to polystyrene insulation more specifically. The need for insulation provision is embedded within the Passivhaus standard and constantly reiterated through its community’s performance literature.

It was acknowledged that the wider design and construction literature was at times directly instructing the design and construction of the studied development. The foundations are a good example of this. Institutional knowledge was central in conceiving how the concrete slab and insulation could come together to produce an innovative thermal-bridge-free foundation. Indeed, whilst a few amendments were made due to this

development's specific context, there are intentionally significant similarities with certain industry recommended approaches to achieving a high energy performance (specifically: Pokorny *et al.* (2009) and AECB (2009)). The embodied carbon of the construction materials used below ground-level contributed to 69.87% of the development's total embodied carbon. This proportion is so high mainly because of the 300mm reinforced concrete slab and 400mm foamed polystyrene insulation installed below ground (Figure 8.1), which was a direct consequence of industry recommendations.

In addition, there was a tendency to design and construct using formally approved product listings. For example, product selection was usually (particularly initially) based on officially certified building components. Whilst Passivhaus-certified components need not necessarily be used for a building to be Passivhaus-certified, the certified components were seen as offering a guarantee of performance. Therefore when Passivhaus components were available, alternative options were rarely chosen.

8.5.4 Know-how and embodied habits

Know-how is accumulated through past experience and is habitually embodied into designing and constructing practices. It is thus significant that none of the project team (e.g. client, designer, constructor) for the studied development had any prior experience in Passivhaus projects. In reference to this, I now develop two points of discussion: (1) the more exposure the project team had to Passivhaus, the more they began to rely on intuition and knowledge they had learnt along the way rather than institutionalised knowledge, and (2) designing and constructing experiences associated with past (non-Passivhaus) projects still shaped the approach adopted for this development, despite the dominance of institutionalised knowledge more generally.

First, experiential learning during the course of the project influenced how the dwellings were designed and constructed. For instance, returning to the previous section's discussion regarding the reliance on Passivhaus-certified components; other options were more seriously considered as confidence grew in accordance with supply chain know-how

also growing. Indeed all the windows at the development were not Passivhaus-certified, hence their performance was independently tested and verified in the absence of Passivhaus certification. Undergoing a process such as this was not even considered when beginning the project; instead it came with time as knowledge of the sector developed (the decision regarding window suppliers was relatively last in the project's timeline).

Second, an effort was made during design to ensure that the know-how of the constructors was complemented:

“They didn’t want to pose too much of a challenge to the construction industry, I think they knew that the airtightness alone would be challenging enough to deal with, let alone then having to deal with a totally novel construction approach.”

(B2)

The main consequence of this was that aerated concrete blocks were used to structure the dwellings, instead of factory-made timber panels for instance (hence timber only constituted 8.68% of total embodied carbon). Having a block design made it easier for conventional bricklayers:

“Using blocks was something that they [constructors] would be used to doing and they would know what to do.”

(B2)

Over time the constructors had developed a working knowledge of constructing brick or block (using mortar) external walls. This working knowledge includes numerous sensory judgements (e.g. mortar consistency; wall stability; whether the blocks are level; aesthetics), which cannot easily be learnt from explicit guidance, be it in the form of an instruction manual or expert advice – hence why the block design was regarded as less challenging.

However the decision to base the design around concrete blocks – contributing to 10.86% of the development's total embodied carbon, or 21.76% if one includes all the external wall materials – was not solely due to the constructors' know-how. Indeed the designers

had accumulated expertise through their experiences in a number of successful low energy housing projects, most of which had been constructed using externally insulated concrete blocks. Therefore continuing with the block approach meant that both the designers and constructors could take what they “were already doing and tweak it so as to get the extra performance” (B1) that Passivhaus certification required.

8.6. Discussion

In designing and constructing the Passivhaus development, skills were drawn upon through both tacit learning (know-how and embodied habits) as well as more formal expert-derived and often rule-based knowledge (institutionalised knowledge and explicit rules). Whilst know-how was accumulated as a consequence of participating in the project, it had relatively less influence on the formulation of the initial design, which was obviously produced prior to the project team gaining any experience of Passivhaus. Nevertheless, aspects of the design did have synergies with previous (non-Passivhaus) design and construction, but only when the approach could be a direct *evolution* of their previous work. However since constructing to the Passivhaus standard requires an approach that goes beyond more conventional approaches (particularly regarding airtightness and insulation provision), previous experience was insufficient in guiding a more *revolutionary* approach. This contributed to the designers and constructors harnessing knowledge from the existing, and albeit relatively small, Passivhaus community. For instance, the designers and constructors utilised Passive House Institute guidelines in a bid to secure Passivhaus certification. Moreover the willingness, conscious or not, to design and construct in the way that they did (engagements) centred on becoming Passivhaus-certified, and it was this desire for high build quality and energy performance that contributed to the project team pulling on the sources of knowledge that they did – in particular, formal advice from experts provided a mode of information that would seemingly guarantee innovation.

The story behind design and construction is important if one is to understand the influences that underlie the embodied energy and carbon of the development. Whilst the

LCA data provides insight into how the dwellings were designed and constructed, alone it offers very little insight on why this was the case. By acknowledging that the LCA data are by-products of how designing and constructing practices are performed, attention is shifted away from only asking *what* and towards practices and the question of *why*.

It is therefore the context-specific way in which designing and constructing practices are performed that explains the differences in embodied energy and carbon across different studies, be they investigating Passivhaus new builds (Table 8.1) or otherwise (see in-text comparisons in *Section 8.4*). Indeed this is why it is unsurprising that Himpe *et al.* (2013, p. 447) found Passivhaus life cycle emissions as ‘not substantially different’ in comparison to a standard zero-energy house – it is not the energy efficiency standard that makes the difference or that one should even be comparing, but instead the practices that surround it.

8.7. Conclusions

This chapter aims to investigate how the embodied energy and carbon of a Passivhaus housing development was influenced by its designing and constructing practices. Following the quantification of embodied energy and carbon using a life cycle assessment approach, this was further explored using qualitative inquiry and Gram-Hanssen’s (2011a) four elements of practice: technologies, engagements, institutionalised knowledge and explicit rules, and know-how and embodied habits.

Exploring the influences that underlie the embodied energy and carbon of a new build project through a discussion of these elements provides insight and a richness that was beyond what quantitative alternatives (e.g. sensitivity analyses) or indeed the LCA alone could offer. This case study indicates that the provision of magic bullet technologies or design strategies which target lower operational emissions (e.g. Passivhaus) is shaped by the relationships between technologies and the other three elements of practice. As such, the original energy saving intent behind technological provision has the potential to be negated to some degree over the rest of a technology’s life cycle. If the embodied energy

and carbon of buildings is to be reduced, the way designing and constructing practices are performed needs to change. However this chapter demonstrates the complexity that underlies designing and constructing, and, as such, suggests that reducing embodied energy and carbon is a challenging task which is more to do with what designers and constructors *do* than the actual energy and carbon itself.

Indeed, the distinct focus on embodied carbon or energy need not be the sole analytical focus or output of one's inquiry. Although the life cycle approach does span systems (e.g. energy, transport, waste) to a certain degree, its focus on quantifying the amount of energy or carbon (or perhaps even water, for instance) does inevitably create a relatively tightly bound point of inquiry. I contend that in understanding the underlying influences of embodied energy/carbon, the researcher should think more broadly and look beyond these rigid divides (e.g. set out by kWh or tCO₂e) in exploring why industry professionals do what they do. I argue that researching practices could help fill such a void. Practices go across the traditional systems thinking that would focus on energy, transport, and waste separately. Indeed, this is why much of this chapter's discussion not only spans, but also integrates across, such distinctions.

More research is needed into the practices that shape life cycle energy consumption and consequently emissions. Since practices are fundamentally interrelated in their nature – as can be inferred from this chapter investigating designing and constructing in conjunction with one another – it would be really interesting to explore how the relationships between practices across a building's life cycle influences its life cycle resource usage. For example, how do designing and constructing practices shape practices associated with building maintenance (e.g. including MVHR filter changes and external insulation repair) or end-of-life disposal/recycling? Alternatively, instead of focusing on practices connected to the life cycle of technologies and design approaches, the potential exists to switch it around and focus on the life cycle energy usage and emissions of a particular practice. For instance, one could quantify the embodied energy and carbon of the technologies required to cook, launder, or shower. Whilst such an approach would create a much more technical framing, it could complement the more focused and interpretative lines of inquiry that discuss in depth, for instance, cooking,

Chapter 8

laundrying or showering. But whatever approach is taken, hopefully this chapter has demonstrated the merits of crossing literatures and disciplinary divides in trying to understand the influences behind embodied energy and carbon.

PART IV.

Conclusions

Chapter 9 – Conclusions

This thesis began by outlining why it is a priority for domestic energy consumption to be reduced, covering issues of climate change, energy security, and fuel poverty. However, a debate exists over how exactly this challenge should be approached. As I set out in *Chapter 2*, the starting point of this thesis is in questioning the assumption, which has traditionally dominated domestic energy research and policy-making to date, that technological provision will linearly reduce energy consumption and its associated carbon emissions. In questioning this techno-economic linearity and considering alternatives for domestic energy research and policy-making, my theoretical and policy review took me through other individualistic (e.g. associated with psychological perspectives) as well as structural approaches. The individualistic approaches typically shared the linearity of the techno-economic paradigm and lack an appreciation of broader social and cultural processes, as a consequence of searching for cause-effect relationships that impact an individual's decision-making. Structural approaches instead usually focus on social structures that are responsible for pushing and pulling the actions of individuals, but fail to appreciate an individual's free will. On the basis of this critique, I opted to explore theories of practice further. Approaches that focused on the doings and sayings (practices) of everyday life provided me with a middle ground between individualistic and social structural approaches, with the literature suggesting it to be a potentially insightful basis for investigating the influences of energy consumption.

To challenge the well-established technical approaches that seek to linearly change behaviour, in addition to help critique, operationalize and develop the relatively young practices approach, the following central research questions were adopted by this thesis:

QUESTION 1: *What are the consequences on practices of advancing dwelling design to reduce residential energy consumption and carbon emissions?*

QUESTION 2: *Can a practices approach help to understand these consequences? And if so how?*

A UK Passivhaus case study was used to explore this further. Passivhaus is a building energy standard that has increasingly gained support internationally within both policy and research agendas, yet few buildings have been built to the Passivhaus standard in UK. Therefore, even though households and industry have only minimal experience of Passivhaus technologies, it is widely deemed to be a relatively reliable 'advancement' in dwelling design to reducing residential energy consumption and carbon emissions.

The two central research questions were investigated through four separate thesis aims, which formed the basis for *Chapters 5-8*:

AIM 1: Investigate the influence of a new and very unfamiliar domestic technological configuration on residents and the performance of their energy consuming practices.

Addressed in Chapter 5.

AIM 2: Investigate the potential utility of using theories of social practice in conjunction with building monitoring to further our understanding of how everyday practices are performed in dwellings or, indeed, any built environment.

Addressed in Chapter 6.

AIM 3: Investigate how appliance-using practices, and thereby appliance ownership levels, respond to new technological surroundings.

Addressed in Chapter 7.

AIM 4: Investigate how the embodied energy and carbon of a housing development is influenced by designing and constructing practices.

Addressed in Chapter 8.

9.1 Summary of findings

This section begins with a summary of the main findings and conclusions with regard to each of the four thesis aims, which were used to focus the discussion in *Chapters 5-8*. Following this, I return to the central research questions in drawing out meta-level conclusions that transcend my findings from each of the thesis aims, in addition to highlighting the key empirical, methodological and theoretical contributions of this thesis.

9.1.1 The thesis aims: Summarising each results chapter

9.1.1.1 *The influence of unfamiliar technologies on practices*

In *Chapter 5*, the post-occupancy experiences of the households living at the Passivhaus development were investigated with regard to how different and unfamiliar domestic technologies would more generally influence household everyday practices. The handover period (from two months before move-in, to one year after move-in when institutional support largely stops) formed the basis for this chapter, since it was the time period within which residents encountered unfamiliar technologies for the first time.

This research found technological change could change the other elements of practice (institutionalised knowledge and explicit rules; know-how and embodied habits; engagements) as well as changing other practices. In addition, technological changes also changed the connections between each of the elements (both within and across practices) and each of the domestic practices. Indeed, primarily as a consequence of Passivhaus technologies making the performance of practices a source of heating, the ties between practices were strengthened as households sought to meet thermal comfort expectations. This degree of interconnectedness and complexity resulted in new technologies often being used in unexpected ways and potentially having major repercussions for everyday life.

The relationship between different types of knowledges was also a recurring theme. Specifically, trade-offs existed between knowledge that was tacitly acquired through experience and knowledge that was gleaned from an expert explicitly presenting it in some way. To be able to perform practices in new (and crucially, unfamiliar) technological surroundings, individuals began to rely on their past experience of performing practices. However, those performances (and thus the tacit knowledge it created) were on the basis of a very specific sociotechnical context. Consequently, households were misinterpreting and (perhaps in the designer's eyes) misusing these new low carbon technologies, with the design intentions of the technologies very often not mirroring actual usage. The emphasis placed on experience also reiterated the importance of considering path dependency and trajectories of practice (e.g. how a practice's history implicates its current and future).

These findings implicitly undermine any research or policy-making assumptions, which indeed the Passivhaus standard itself is based upon, that deem technological provision will linearly change everyday life and, as a consequence, reduce domestic energy consumption.

9.1.1.2 Using building monitoring to explore the influences of unfamiliar technologies on everyday practices

Chapter 6 was in large part a methodological extension to the first thesis aim since it innovatively combined qualitative inquiry (which was the sole basis for investigating the first aim; *Chapter 5*) with building monitoring data in investigating domestic everyday life.

The main contribution of this chapter was its methodological approach in furthering the practices literature. The mixing of two different sets of methods, each of which produce very different types of data, was shown to be fruitful. Many insights – regarding everyday life in the home and the influence of technological change – were attained that would not have been possible if adopting a monitoring-only or qualitative-only approach. For more

on the novel methodological contributions of this thesis see *Subsection 9.1.4.2*, and for further methodological reflections see *Section 9.3*.

This methodological approach fully supported the conclusions reached in addressing the first aim (in *Chapter 5*). The support institutions were shown to play a limited role in transitioning the performance of domestic practices, from their old to new homes. Evidence showed there to be instances where the experience of using the unfamiliar technologies became unwittingly embodied in household habits, with expert-derived knowledge playing a minimal role in transitioning practices to a new material context. As was a common theme across the whole of this thesis, the engagements surrounding what makes a good homemaker and host were shown to significantly influence how new technologies were incorporated into people's daily lives.

9.1.1.3 *The influence of new technological surroundings on appliances*

Whilst the two previous thesis aims set out with open frames that looked more generally at practices performed in the home, the nature of the Passivhaus technologies (which target heating fuel savings) consequently narrowed the focus onto heating and (to a lesser extent) ventilation related practices. In *Chapter 7*, this third aim intentionally diverted the focus away from heating fuel and onto electricity consumption, and specifically appliance ownership.

Even though Passivhaus technologies were not provided for this purpose, they significantly influenced appliance-using practices and, thus by extension, appliance ownership. For example, performing hosting and homemaking practices in ways that met thermal comfort expectations contributed to the purchasing of energy efficient appliances, which generated less heat. However, moving to a new dwelling (whether it was Passivhaus or not) also more generally influenced appliance ownership. For instance, again with regard to hosting and homemaking practices, households were keen to buy new appliances to meet social expectations of what constitutes a new home. In making

appliances-related changes, engagements (expectations, social meaning, aspirations, etc) were especially important.

This close association between *having* (appliance ownership) and *doing* (practices) emphasises the difficulties of trying to reduce electricity consumption because appliances are so firmly embedded in the way we live our lives. Moreover, whilst low energy technologies usually target a specific energy end-use (e.g. Passivhaus design targets heating), the influences of such technologies are not constrained in any way by end-uses (e.g. appliance usage changes): what matters is how technologies are practically used.

9.1.1.4 *The influence of designing and constructing on embodied energy and carbon*

Chapter 8 addressed the fourth thesis aim which involved investigating how the, usually hidden or ignored, embodied energy and carbon of new low energy technologies (specifically, those relating to Passivhaus) could be influenced by the practices of those designing and constructing the dwellings.

This research highlighted that institutionalised knowledge was heavily relied upon in changing how these industry-based practices were performed (i.e. in a Passivhaus context) because of the designers and constructors' inexperience. The development's project team were unable to (as the households did; *Chapters 5-6*) learn through experience because they could not afford to risk mistakes and not achieve Passivhaus certification. They were contractually bound to deliver Passivhaus-certified dwellings, and their inexperience meant that their professional integrity was in jeopardy. Thus, formal expert-derived knowledge (e.g. books; industry colleagues) was primarily used to equip relevant personnel with the knowledge required to change how practices were performed. Therefore the potential exists for these practices, and the knowledges they draw upon in selecting technologies for design, to undermine the energy saving intention behind a new technology. By focusing so much on successfully delivering new operationally low carbon technologies (e.g. associated with Passivhaus) come what may,

the rest of the building life cycle could hence be neglected by designing and constructing practices.

Methodologically, this chapter also further highlighted the potential and value of crossing disciplinary divides and using quantitative consumption-related data in new ways so as to enhance our understanding of how practices are performed in the everyday.

9.1.2 Understanding the consequences on practices of advancing technological design of dwellings

The summaries of each of the separate results chapters (*Section 9.1.1*) in large part answers this thesis' first research question (regarding the consequences of advancing dwelling technological design). It makes clear that the main consequences of advancing technologies relate to everyday life. Technologies actively constitute and shape everyday life, and, as such, can provide options for or even sometimes increase the likelihood of performing practices in certain ways. Thus the implications of providing energy or carbon saving technologies go far beyond that of energy and carbon, as they can significantly influence everyday life more broadly.

The view that the techno-economic (and indeed the Passivhaus) community holds that technologies can linearly reduce energy and emissions is hence unrealistic. It does not account for the dynamism of everyday life. It is important to note that the argument that technologies do not represent a magic bullet solution to reducing energy consumption is not especially new (e.g. Lutzenhiser, 1992; Rip and Kemp, 1998; Shove, 1998; Suchman *et al.*, 1999). However I would hope that this thesis has supported as well as furthered these arguments through the investigation of a relatively novel sociotechnical context and the consideration of broader (practice-related) influences as part of an in depth mixed methods case study approach. In addition, I hope that this new context and methodological approach will help to open up these arguments regarding everyday life to technical audiences (e.g. the Passivhaus community), in the same way that many of the technical aspects of Passivhaus and technological change could potentially develop the thinking of some practice theorists.

The way in which the provision of technologies shapes everyday life can often lead to unintended consequences as to how everyday life is performed and technologies are actually used. These consequences could result in, for instance, the expected energy and carbon savings not being achieved or just simply the day-to-day lives of building occupants changing in unanticipated ways (potentially for the better or worse). I do not argue that the energy saving technologies will not save energy, rather I emphasise that there are no guarantees.

This thesis provided numerous illustrations of how unintended consequences are characteristic of attempts to meddle with everyday life. For instance, one household's baking practices utilised the top of the boiler to proof their home-baked bread, meaning that the boiler was being used in an unintended way (*Chapter 5*). In addition, the homemaking and hosting practices of many households meant that the unattractive thermostat was positioned out of sight next to a window (usually open because of the deemed requirement of fresh air), resulting in the MVHR system heating incoming air during cooler summer nights (*Chapter 6*). Further, *Chapter 7* showed how the effectiveness of Passivhaus technologies in keeping internal heat gains inside the building changed the meanings attached to appliances, and thus how and why the appliances were used. The surprising way technologies were integrated into practices was a re-occurring theme throughout this thesis, with numerous other salient instances beyond the few detailed here. Specifically, the way a technology came to be used was not necessarily in line with its original purpose (e.g. baking using the boiler; appliances as heaters).

The unintended consequences were not only relevant for the interpretation and appropriation of these technologies during operation (by the households), but also cut across how these technologies were designed and constructed. It was thus clear that delivering low energy buildings or meeting specific building energy standards could also pose challenges to industry. *Chapter 8* focused on the connection between the practices and the embodied energy/carbon of delivering a Passivhaus housing development, and it emphasised that the consumption of resources that occurs during construction is as a

direct consequence of the practices performed by the project team. How these practices are performed depend on past experience, ability to access additional guidance and support, professional integrity, their vision of the occupants, amongst numerous other context-specific sociotechnical influences. All such influences have the potential to uniquely shape how a building is designed and constructed, meaning that the amount of energy and carbon embodied in a development is difficult to control (especially when it is not even considered) and, as such, could undermine the intentions and expectations underlying energy and carbon saving technologies – an unintended consequence, indeed.

On the basis of such examples, one has to wonder what so-called technological advancements are actually advancing. This thesis demonstrates the importance of remaining mindful of the (often unintended) consequences on everyday life that new technologies can bring, which could undermine the very purpose of the technologies being provided. Examples of the unintended consequences coming from the provision of new domestic technologies included: confusion and uncertainty regarding practical use; a dwelling was now heated through living out day-to-day life; other technologies (e.g. appliances) that households brought into their home were influenced by new dwelling-level technologies; new technologies changed how other seemingly unrelated activities in the home (and beyond) were carried out; and levels of embodied carbon was shown to have little to do with the technology itself, and more to do with its provision; to name only a few consequences.

In highlighting the consequences of advancing the technological design of dwellings, many new questions are raised: how do we go about shifting the mindset of researchers and policy-makers that technologies actively influence everyday life and cannot guarantee particular patterns of usage? Are we willing to accept significant changes to everyday life, which could potentially challenge preferred ways of performing practices? Are there better means, be they technological or not, to reduce how much energy is used in buildings? Are there ways in which design, provision or ongoing support could help increase the likelihood of technologies being used as designers would intend and/or mitigate any detrimental influences on everyday life? Are changes to everyday life simply just necessary if energy demand is to be successfully reduced? Whilst it is not for this

thesis to answer these questions, these do serve to emphasise that new questions are needed that begin to address technology-in-practice (further avenues of research are considered in *Section 9.2*), instead of re-hashing past questions regarding advancing technological design. It is the merits of this shift in focus, towards practices, that the next subsection specifically reflects upon.

9.1.3 Reflecting on a practices approach

The previous subsection (9.1.2) implicitly began to answer this thesis' second research question (regarding how useful a practices approach is in understanding these consequences), and demonstrated how adopting a practices approach has helped uncover the practice-related consequences of technological provision. However, I now more explicitly reflect upon the practices approach in answering this second research question, with reference to five items of discussion: (1) elements of practice, (2) trajectories of practice, (3) interconnectedness of practices, (4) classification of practices, and (5) practice theory's middle ground positioning between structure and individual agency.

9.1.3.1 Using the elements of practice

Gram-Hanssen's (2010a, 2010b, 2011a) four elements were drawn upon throughout this thesis: *technologies* (the surrounding physical environment); *engagements* (what shapes the (un)conscious willingness to perform a practice); *institutionalised knowledge and explicit rules* (expert-derived information); and *know-how and embodied habits* (tacitly learnt knowledge).

Firstly, I found these elements to provide a means to successfully analyse and explain the influences of everyday life. Indeed this thesis has shown how discussing the elements can tangibly show the usefulness of a practices approach to policy-makers and those in other research disciplines (e.g. buildings science, which I hope this thesis could appeal to in some modest way) across an array of different practices and contexts (e.g. from designing

to laundering). The potential for practice-based domestic energy interventions is discussed further in *Section 9.2*.

Secondly, the principle that changes to any one of these elements (e.g. to technologies) has the potential to change how practices are performed, is useful in considering the everyday consequences of policy initiatives. Akin to this principle is that each element is just as an important influence than any one of the other elements, and this was emphasised throughout this thesis since non-technological changes to the elements also significantly influenced practices. More specifically, as this thesis emphasises, it is the relationships between the elements that were shown to be particularly important. Therefore how technological change resulted in and related to changes of each of the other three elements led to changes in how practices were performed. For example, *Chapters 5-6* demonstrated the dominance of *know-how and embodied habits* in leading changes to how practices are performed with new heating and ventilation-related technologies (e.g. hosting guests, homemaking, cooking, showering). *Chapter 7* showed *engagements* to lead the transition of appliance-using practices in Passivhaus surroundings. In addition, *Chapter 8* showed *institutionalised knowledge and explicit rules* to significantly shape how designing and constructing practices changed to incorporate the provision of new technologies. Thus how technologies interacted with each of the other elements of practice was shown to be pivotal in the construction of new ways of living.

Thirdly, this thesis demonstrates the importance of the relationships within an element of practice in influencing how practices perform and adjust to (albeit largely technological) changes. Take the technologies element, for example: it is made up of an array of technologies, all of which are linked by their common (in)direct use when performing a practice, thus the success of technological provision was shown to in part depend upon how different technologies related to one another. Indeed the relativity of technologies to their technological surroundings was made clear throughout this thesis. For instance, it was the Passivhaus design that meant using appliances helped heat one's home (*Chapters 5-7*); limited space (in terms of dwelling layout) meant that certain appliances could not

be owned and used (*Chapter 7*); and using a significant amount of super insulation meant that an MVHR system was needed for indoor air quality purposes (*Chapter 8*).

Whilst these three salient points of discussion help to emphasise the value of considering change (as well as attempts to instigate change) on the basis of the elements, I do acknowledge that using elements of practice is only one way of exploring and analysing everyday life. Therefore practices approaches need not always adopt an elements approach. I see nothing wrong with adopting a wider interpretative (and less prescriptive, compared to the elements) approach to researching everyday life that still places practices at the heart of its inquiry (e.g. Pink, 2012). Similarly, I would argue that there is little point in getting lost in a debate about whose proposed elements framework is best. Post-Reckwitz (2002) and his explicit inclusion of technologies as an element, most of the proposed frameworks are largely very similar. I regard each framework as spreading the emphasis slightly differently across different influences. Indeed, it is because this thesis found there to be such a difference between tacit and expert-derived knowledge that I have predominantly referred to Gram-Hanssen's (2010a, 2010b, 2011a) elements framework throughout this thesis, as opposed to Shove's (see Shove *et al.*, 2012) for instance. Whilst this distinction proved very useful when explaining my research findings, those adopting Shove's three elements framework (which does not explicitly make this distinction) would I hope still implicitly consider such influences.

Finally with regard to the elements of practice; concerns could be raised relating to the prescriptive nature of a framework that immediately isolates four areas of focus. Whilst it may not seem like it from how my thesis has been presented (e.g. my literature review advocated the elements very early on), my eventual use of the elements to explain many of my findings was not a product of an early decision to use the elements. Any indication I may have given that I chose to frame my research around the elements early on in my PhD is most likely a product of having to write a coherent well-structured thesis on the backend of an often chaotic and ever-evolving research process. Indeed, I did not deductively conduct my research on the basis of the elements; instead I learnt from the data and only then applied the elements framework in response to what it were telling me. I emphasise this point here because I would potentially find it concerning if

researchers were beginning a research process with the sole intention of basing their work around the elements, unless there was a clear evidential justification for doing so (e.g. previous research on the same case).

9.1.3.2 Considering trajectories of practice

The acknowledgement of the practices literature that a practice has a history and is on a continually evolving trajectory (e.g. Southerton *et al.*, 2012), was useful in considering what was influencing changes to everyday patterns of consumption. For instance, in helping understand why there was evidence for the performance of practices changing during the course of the study period (e.g. as residents gain Passivhaus know-how).

By exploring the potential consequences of the future building stock (which Passivhaus is often touted as being) on everyday life, this thesis considers what exactly future trajectories of practice could encompass. For example, Passivhaus technologies could contribute to changes in thermal comfort conventions as a consequence of mundane practices beginning to actively heat one's home. The following quotation from a Germany household interview supports this thesis' finding that expectations of everyday life (and in the context of this quotation: hosting practices) were thus changing how we use technologies:

'It is very comfortable here and it has made me more sensitive. When I visit friends I am immediately conscious if there is a window behind me, not an open window but a [less thermally inefficient] window. Or when there is a half open door because I immediately notice cold coming in or uncontrolled air-flow. That doesn't happen here.'

(Lynch, 2013, 1min04sec - 1min29sec)

As Shove (2003, p. 194) remarks, in the very similar context of redesigning homes for air-conditioning, 'by building this expectation [here, with regard to thermal comfort] into the fabric of the property itself, consumption of energy was inevitably ratcheted up'. It is through appreciating that everyday practices are dynamic and always in flux, and thus considering where practices have come from and where they may be going, that I was

able to begin to understand the deeper consequences of attempts to reduce consumption (e.g. the ratcheting up of thermal comfort conventions by Passivhaus technologies). Without a practices approach, and its implicit appreciation of trajectories, I suspect insights such as these may have been missed.

9.1.3.3 *The interconnectedness between practices*

In attempting to capture and understand the messy consequences of advancing technological design, themes of interconnectedness proved useful. As such, the interconnectedness between professional and household as well as various household practices are now discussed. This interconnectedness revealed a further layer of complexity that made the technological fix mentality even more ominous.

The practices of the housing development's project team significantly shaped the practices performed by the households occupying the houses. For example, household-landlord interactions led to mistrust being placed in the Passivhaus guidance being provided (*Chapter 5*), and the designers and constructors were directly responsible for providing the technological setting (the dwelling) that the households lived their day-to-day lives in (*Chapter 8*).

However interconnectedness is fundamental to practices more generally, and thus was not only a useful concept when considering the relationships between household practices and those of their support institutions. Indeed changes to one practice performed in the home nearly always had knock-on implications for others. For instance, changes to when certain domestic practices were performed also contributed to the timing of other performances, such as households opting not to clean the house (in particular, vacuum) when cooking (in particular, having the oven on) because it would contribute to uncomfortable indoor temperatures (*Chapters 5 and 7*).

By broadening the focus to include an interconnected web of *doings* and those that *do*, the linear model of technological transfer (*Subsection 2.2.1*) is completely abandoned.

This reiterates that energy saving interventions need to look beyond just individuals or technologies, and should not be expected to provide quick and easy solutions. Practices instead offer a unit of analysis for considering doings and those that do.

9.1.3.4 *The classification of practices*

This thesis has reiterated the difficulties of establishing distinct ontological and methodological boundaries for given practices. As such, attempting to distinguish what exactly practices are can sometimes be difficult, yet is vital since practices approaches demand that a practice is the unit of analysis. Through reflecting upon my findings and analysis, I wonder whether the notion of a ‘compound practice’ (Warde, 2013, p. 25) could help in the drawing of such boundaries, as well as providing a basis for discussing some of connections that exist between practices. Warde describes eating as a ‘compound practice’ because it involves at least four other practices (e.g. associated with food supply, cooking, organising meal occasions, aesthetic judgments of taste). The implication is thus that numerous practices can cluster around (or rather within) another overarching practice, such as eating. Relating this back to the Passivhaus case studied in this thesis, this system of classification could be used to understand heating (or thermal comfort), which became an almost all-encompassing compound household practice under the influence of Passivhaus technologies. Indeed these connections between practices were the reason why practices helped to heat dwellings.

This thesis has highlighted how confusion exists in the literature with regard to how to label practices that consume energy. Many examples exist of researchers referring to energy practices or energy consumption practices (e.g. Schwartz *et al.*, 2010; Liu *et al.*, 2013). I would argue that these labels make it sound like energy consumption in itself is the practice. But as my thesis makes clear, energy consumption is a by-product of practices, which means that their performance has almost nothing to do with energy. Indeed, in my mind, doings that centre on energy saving would only be an indication of energy saving as an *engagement* (as per Gram-Hanssen’s elements) in energy consuming practices, rather than the existence of a distinct energy saving practice. I thus found it

more appropriate to refer to energy consuming practices (i.e. simply practices that consume energy).

9.1.3.5 *Working in the middle ground between structure and agency*

I now discuss how practices approaches regard everyday actions (being within a middle ground between social structure and individual agency), and how I felt that complemented my thesis' findings.

One of the main reasons I was pulled towards using theories of practice was its appreciation of the messiness of everyday life, and how it stepped away from the linear processes (of fixes, for instance) that are inherent to the dominant behaviour change approaches. This was something that I appreciated very early on during data collection. Yet reflecting back, the messiness that I witnessed at that early stage was nothing compared to what I would soon uncover through developing a deeper relationship with those involved in the housing development and from gaining a more nuanced understanding through further analysis. Indeed, at the beginning messiness was largely reflected through design intentions not being achieved, but the more I delved into this the messier everyday life seemed to become (e.g. by uncovering: tacit, sensory and symbolic influences; conscious and unconscious decision-making; connections between practices; connections between elements of practice). Therefore the interpretation of my findings (and its messiness) was facilitated by the everyday practices literature, whether it was situated in the domestic energy context or not. If I had not sought out or been exposed to the practices literatures, then perhaps I would have attempted to rationalise this messiness by generalising at the societal level or by linearizing the messiness in accordance with individualistic cause-effect relationships.

To this end, I finish this subsection by emphasising how practice theory's middle ground positioning complemented my research findings' view of everyday life. In particular, it supported the position that understanding everyday life is much more than understanding either individual decision-making or social structures; practices were guide

individuals and structures as part of guiding everyday life. I appreciated the space that practice theory afforded me in considering the role of individuals within practices, not as 'passive dupes' but as 'skilled agents' (Hargreaves, 2011, p. 83) that are constantly negotiating and performing practices. Indeed this research found that individuals can consciously demonstrate free will, assertiveness and rationality. For example, changes were made to how practices were performed on the basis of cost concerns (*Chapter 6*: by one money conscious household) or new information (*Chapter 8*: by industry learning about Passivhaus). However, it was the practices approach that demonstrated and then helped to explain why this was not the case for every individual in every context. For instance, when the guidance provided by support institutions played a very minimal role in practices adjusting to their new material surroundings (*in Chapters 5-6*).

9.1.4 Key contributions of this thesis

9.1.4.1 Empirical contributions

Using tangible everyday examples, this thesis discusses in depth how technologies, which are intended to reduce energy use in the home, can influence everyday life in very fundamental (and often unintended) ways. Insights are provided on how industry-endorsed cutting-edge technologies are experienced in practice. Adopting a UK Passivhaus case study to explore these issues provided an opportunity to research a relatively unique technological context, especially because so little research has been conducted (internationally, but also particularly in the UK) on how Passivhaus technologies are experienced.

Such evidence is vital if we are to prepare for the wider consequences of energy saving technologies in addition to designing more successful interventions (be they technological or not). In discussing the role of technologies, numerous other everyday influences were also discussed, all of which can assist attempts to mitigate climate change and save energy.

9.1.4.2 *Methodological contributions*

One of the main contributions of this thesis regards how I mixed methods and crossed disciplinary divides as a means to understanding everyday practices. I opted to interpret quantitative consumption-related data as artefacts or traces of performing practices. Only a small number of practices studies have used building monitoring, and these studies were yet to integrate monitoring more centrally within its line of inquiry. Furthermore, before this thesis no-one had combined life cycle assessment approaches with a practices lens. Whilst I would not pretend to have embraced the full (practices-related) potential of either building monitoring or life cycle assessment, I do feel that I have demonstrated the usefulness of and set a precedence for using those methods in the future as well as more generally emphasising the value of spanning disciplinary and/or qualitative-quantitative methodological boundaries.

9.1.4.3 *Theoretical contributions*

This thesis strongly advocates that domestic energy (or indeed wider consumption related) research focuses on the performances of practices, rather than technological performance or individual decision-making. Whilst support is growing for conducting research using social practice theory, it is still a relatively underdeveloped literature. I hope to have emphasised: the usefulness of using the elements of practice for analysing and communicating one's findings; the importance of distinguishing between expert-derived and tacitly learnt knowledge; how a practice can connect seemingly disparate aspects of one's day-to-day life; the link between practices and purchasing or consuming; how governing practices is not easy to do; the policy relevance of practices thinking; and how empirical and methodological progression can be enabled by employing theories of social practice; to name only a few contributions.

9.2 Embedding the principles of practice in domestic energy policy

Building on the lessons learnt in this thesis, I now provide some ideas and recommendations for policy-makers. Specifically, I provide an exploratory discussion as to how domestic energy policies could benefit from adopting a practices approach. This in itself is another clear contribution of this thesis, since practice governance is a relatively new area of focus in the practices literature.

This thesis advocates using practice theory as the basis for interventions. I would hope not to have given the impression, through focusing much of this thesis on the nonlinearity of everyday life, that practice theory advocates a non-interventionist approach. The pivotal role of policy has been consistently emphasised throughout this thesis, in that the technological provision (often underlying energy policy) was shown to inadvertently intervene in energy consuming practices. The challenge is thus how to increase the likelihood of policy interventions (whether technological or not) to more predictably influence everyday life and, by extension, help to achieve the desired energy savings.

I begin by suggesting that policies could focus on the elements of practice. Specifically, I consider how Gram-Hanssen's (2011a) elements of practice (technologies; engagements; institutionalised knowledge and explicit rules; know-how and embodied habits) could be targeted so as to hinder or facilitate certain ways of performing practices. To illustrate what would be involved by policy interventions targeting the elements, I now briefly address each element in turn with some examples of the areas one could focus upon.

Technologies:

Exploit connections between different technologies of different scales. This thesis found the provision of new technologies to enable or constrain other technologies. For instance, *Chapter 7* showed appliance ownership to be influenced by the design and provision of new technologies (e.g. super insulation; dwelling layout; plug sockets).

Specific technologies could be ‘scripted’ (Jelsma, 2003, p. 107) to direct practices in certain (e.g. energy saving) directions. Design could encourage ‘what is acceptable, desirable and comfortable, while counteracting what is strenuous, contemptible and forbidden’ (Jelsma, 2003, p. 107). For example, technologies could provide users with only low energy consuming options (e.g. solar thermal system), thereby designing out the possibility of a higher energy consuming means (e.g. gas fired boiler) to meet those same ends (e.g. hot water for showering). Alternatively, energy consuming doings could simply be made more difficult to perform (e.g. fewer plug sockets for appliance-using practices (*Chapter 7*)). Whilst my earlier theoretical critique (*Section 2.4*) supported a move away from solely employing structural perspectives such as scripting, much of this thesis indicates that technological scripting could prove to be useful if considered in the context of practices and not as an all-governing technological structure.

Technologies could be designed to explicitly link to practices. This thesis has reiterated the importance of this through emphasising that individuals undertake and prioritise their interactions with technologies on the basis of practices. Designing technologies in terms of how they are actually used and experienced could help to minimise resident confusion, which *Chapter 5* showed to be prominent. For example, instead of the MVHR control panel settings primarily being labelled as numbers, the settings could be renamed to suit actual day-to-day usage (e.g. ‘1’ as ‘not home/nighttime’; ‘2’ as ‘daytime’; ‘3’ as ‘hosting guests’; ‘boost’ as ‘cooking/showering’).

Chapter 5 revealed how households can interpret new technologies on the basis of old (deemed) equivalents, particularly when the new technologies are unfamiliar. Therefore technologies could be designed to be more intuitive so that they are more similar to previous technological encounters. This would make the residents’ existing knowledge more transferable, despite it potentially being based on the use of very different technologies. For example, MVHR controls could be made similar to boiler controls so that they help to increase internal

temperatures when they are turned up (mirroring the turning up of the thermostat). At present turning up the MVHR currently helps temperatures to drop, as warm internal air is removed at a quicker rate. This led to the MVHR not being used as it should be (*Chapter 5*).

Engagements:

Pricing structures, in particular for households with relatively little money, would be likely to sometimes influence how practices are performed. *Chapter 6* revealed how a household with financial worries was selective in the practices it performed (e.g. hosted guests less often; fewer appliances purchased). Therefore economic incentives (e.g. grants for energy efficiency improvements) or additional taxes (e.g. to raise cost per kWh) could help slightly in transitioning households to less energy consuming domestic practices. However the situation is far more complex than playing upon rational responses to cost concerns (which the *economic* component of the techno-economic paradigm would have you believe), hence much more is needed.

The social expectations of homemaking and hosting practices should be targeted; for example, through social marketing campaigns that focus upon the meanings behind what we do. Indeed these expectations were shown in this thesis to influence: what sort of appliances complement a new home (*Chapter 7*); how a new home should be presented (e.g. notions of tidiness, cleanliness) (*Chapters 5-7*); what it means to be thermally comfortable at home and/or when hosting (*Chapters 5-7*); and how design and construction aims to complement ideas of what a new home encompasses (*Chapter 8*) – all of which shape how much energy is consumed in the home. Therefore the challenge is to associate the expectations of homemaking and hosting with actions that consume as little energy as possible (e.g. so that new appliances are not expected for new homes, or warmer temperatures are not expected for a home to be deemed as welcoming for its guests).

Engagements to design and construct to the Passivhaus standard included: aspirations as to the sort of designer/constructor that they wanted to be(come); a duty to deliver; identity; professionalism; and a desire to learn (*Chapter 8*). It is perhaps unsurprising then that the *quality* seemingly offered by adhering to the Passivhaus standard was an emergent theme from the professional interviews in *Chapter 8*, since high quality perfectly complemented these engagements. These sorts of engagements could be played upon – through, for instance, emphasising quality or another technological characteristic that could appeal to designers and constructors – to encourage the design and construction, and thus uptake and usage, of certain technologies (be they Passivhaus or not). It is important to enthuse industry not solely on the basis of the energy saving technology itself, but what it can practically do for them (e.g. enhance professional standing).

Energy saving should be more widely promoted because energy saving was not a prominent engagement throughout this thesis. Saving energy did not influence the willingness to participate in a practice. Therefore households did not perform cooking, cleaning, hosting, homemaking, and heating (to name only a few practices) in a way that would save energy (*Chapters 5-7*). Similarly, designers and constructors openly admitted that they did not think about energy saving either (*Chapter 8*). Whilst targeting energy saving as an engagement is important, it may prove more fruitful in the short-term at least to focus on existing engagements (e.g. what makes a good home; professional aspirations).

Institutionalised knowledge and explicit rules:

Organisations need to ensure a good relationship exists between those receiving and those providing advice, otherwise it may be ignored. It is vital that trust exists between and within different communities of practice, as individuals communicate with and search for answers from those who know more than they do about performing a practice in a certain way (e.g. in a Passivhaus context). This thesis demonstrated such a need because of how the lack of trust in the institutions translated into a lack of trust in institutional guidance (*Chapter 5*).

Institutionalised knowledge is inherently a product of the practices that those in formal institutions perform. These practices need explicit attention (e.g. asking why do landlords do what they do?) so as to help understand how they relate to the practice(s) that one is hoping to transform. *Chapter 8's* discussion of designing and constructing practices demonstrated the complexity underlying how and why institutions do what they do.

Language is relative to the practices that people perform, and one must be sensitive to this. As such, there is a risk of institutional jargon being presented to the target audience (e.g. households), which the institutions may understand perfectly but may seem incomprehensible or at least be easily misunderstood by those who it is actually for. For example, many residents compared the MVHR to an air conditioning unit or cooling fan because institutions regularly referred to the MVHR as a “fan”, leading to unintended usage (*Chapter 5*). Language must therefore complement the language that the target audience use or have used previously in reference to specific practices.

Information – of whatever form, be it a technology tour, presentation or instruction manual – should be given at appropriate times. The recipients of the information are constantly negotiating and performing a wide range of practices, which can contribute to other priorities that could otherwise occupy the attention of those that the information is targeting (e.g. homemaking practices meant much of the move-in information was ignored and/or not fully assimilated; *Chapter 5*).

By focusing on practices, guidance could be made more tangible and easier to relate to (e.g. when cooking/hosting/showering in a certain way, use the MVHR and heating system in this specific way). This was something that was not done by the studied support institutions.

Make more detailed information available for those that are particularly interested (e.g. householders who are technophiles) or are required to understand it in more depth (e.g. designers and constructors who are contractually obligated). Detailed information will not be an effective source of knowledge for everyone, but it can be useful for those performing certain practices in certain contexts. For instance, *Chapter 8* showed how industry sought out formal sources of information in acquiring Passivhaus knowledge. Thus, the advice they encounter needs to be the most appropriate advice (e.g. presented in ways that pull on engagements, and is understandable and trustworthy).

Know-how and embodied habits:

Initiatives attempting to influence know-how should consider how their endeavours could be directly and indirectly connected to institutionalised knowledge and explicit rules. This thesis has demonstrated how trade-offs exist between each type of knowledge, in that one is often drawn upon to substitute a deficit in the other (*Chapters 5, 6 and 8*). It would be thus constructive for the two skills-related elements to be both complementarily working towards the same ends. This is just one example of the broader need to more optimally configure the connections between the different elements of practice.

This thesis shows how people learn through experience, and such learning can take very different paths due to people experiencing life in very different ways. It is hence vital that people are exposed to different learning experiences. For instance, establishing more interactive and participatory learning environments could better facilitate learning by doing in accordance with how the each participant performs practices (e.g. a household technology tour involving interacting with technologies, rather than just talking about them).

Similarly, industry training should be focused on gathering experience. There is a need to develop tacit skills that are learnt through spending more time on the

construction site (constructor) or at the drawing board (designer). *Chapters 5, 6 and 8* demonstrated how very often there is no substitute for experiential learning. Through gathering more experience, I believe that industry would be better prepared, not only to lower their own energy consumption (i.e. embodied carbon of a building), but also to help put households in a position to do the same (i.e. operational carbon). Therefore, industry should resist any temptation to meet the growing demand for low carbon housing by quickly training up staff (e.g. to be Passivhaus certifiers) through short intensive courses that only cover forms of institutionalised knowledge. If industry is to successfully manage and contribute to a sustainable transition of practices, training should not be rushed.

Since tacit learning takes time, brief exposures to new learning experiences should not be assumed to significantly influence the performance of practices. This thesis made clear how learning by doing is more likely to influence practices (e.g. in a less energy consuming direction) if a deeper and more concerted effort is made to embed oneself within the desired working culture, rather than being talked at by those from that culture. In this way, short trips to Germany to visit Passivhaus construction sites and meet relevant management teams (as was done by professionals studied in this thesis, and are said to be prevalent more widely) will not enhance know-how. Whilst this could be regarded as gathering experience to enhance know-how, its short duration limits the opportunities for learning by doing. In this way, such trips largely represent innovative means of providing institutionalised knowledge, because any knowledge learnt would most likely require conscious reflection (as opposed to unwittingly being embodied in everyday habits). A direct parallel can be drawn here regarding the limited success of the household's move-in day technology tour (*Chapters 5-6*).

Be empathetic to how the previous performances of practices can lead to misinterpretation or misuse (in the designer's eyes, at least) of technologies and institutionalised knowledge. This could be a consequence of people trying to perform practices in very similar ways to a time when the elements were actually configured very differently (i.e. from when they were in their previous home).

This discussion of the elements is provided to illustrate the types of interventions that could be undertaken, and does by no means represent an exhaustive list. It is only meant to explicitly serve as a flavour of the sorts of policy measures that have been more implicitly supported elsewhere in this thesis.

The practices perspective is relevant for tackling both practices that are performed privately in home (e.g. cooking, showering) as well as those practices that are public and/or professional (e.g. constructing, designing). This is consistent with the situationally-specific (as opposed to all governing, context-free) principles that underpin theories of practice. Therefore the messiness of the practices considered in this thesis also holds true for the practice of policy-making. Indeed, whilst the unintended consequences of attempts to direct practices in highly desirable directions (e.g. technological provision) have emphasised the need for alternative approaches, they also implicitly emphasise the difficulty of changing how policy-makers make policies (and, similarly, how technoeconomists do their research). They simply do what they do, and are bound to that practice trajectory in the same way that a certain configuration of elements binds householders to cook, shower or clean in the way that they do. Therefore, in considering how domestic energy policy could and perhaps should be changed, it is important to be mindful of these constraints and shift our expectations of policy-makers in accordance: practices have histories, they evolve over a time and as a consequences are rarely malleable. Thus, policy-making is much more likely to evolve incrementally, rather than radically transform as part of some sort of policy-making revolution.

9.3 Methodological reflections

9.3.1 What worked well?

I now briefly reflect upon four aspects of my methodology that I feel worked well: (1) treating certain quantitative data as proxies of practices being performed, (2) using interdisciplinarity to demonstrate the value of a practices approach to technical disciplinarians, (3) integrating methods so as to mutually inform and critique, and (4) a longitudinal case study research design.

I found it very insightful to treat certain types of quantitative data as consumptive by-products of performing practices. In this sense, consumption could range from energy usage (and the changes in internal temperature that it could influence) to purchasing data (be it to do with construction materials or household appliances). These consumptive acts can be quantitatively measured, and thus serve to be proxies of practices since those acts only occur because of performing practices in certain ways. I took exactly this approach in *Chapters 6-8* with respect to building monitoring, appliance ownership, and construction data. Whilst these quantitative data were of use, it quickly became clear that the role of qualitative data was absolutely vital in interpreting what the quantitative data actually meant. Quantitative methods only constructed certain types of data and was completely ill-equipped to provide certain insights (e.g. tacit learning; meanings; emotions; the role of the senses), meaning that my approach was predominantly directed by qualitative inquiry. Therefore my thesis' mixed methods approach yielded insights through successfully playing upon the contrasting strengths of the sorts of constructions that each data type could offer.

Despite the challenges I experienced in mixing methods and crossing disciplinary boundaries (e.g. different languages, time pressures, academic homelessness), interdisciplinary methods were shown to provide a means for demonstrating the potential of practice-related thinking to those in technical disciplines. I would argue that if we are to change the way research is conducted (e.g. from techno-economic to practices), then it is not enough to sit back and critique from afar. We need to cross disciplinary

divides and begin to demonstrate the applicability of practices approaches. Otherwise how can practice theorists expect those working in technical disciplines, including those designing technologies, to think more broadly about how technologies have meanings and fit within people's everyday lives. I would hope that by applying practice theory to technical methods (e.g. building monitoring; life cycle assessment), I may help to expose some technical disciplinarians to practice theory. Time will tell whether this is successful or not, but either way I believe it is unrealistic to expect researchers who are firmly embedded in the techno-economic paradigm to change their research approaches without engaging directly with their literatures. Moreover, I would argue that nuanced critiques can only be achieved through a deeper (e.g. working) understanding of the principles that the technical literatures are built upon.

I found it fruitful to not use any one dataset as an end point. Data collection was integrated across methods, hence developments to one dataset (e.g. interview; building monitoring) informed and critiqued another. Indeed the findings from one method were often used as the very basis for another contrasting method. This was particularly evident when building monitoring (*Chapter 6*), appliance audit (*Chapter 7*), and embodied energy and carbon (*Chapter 8*) data were used to direct interview questions, the qualitative findings of which then in turn re-informed my interpretation of these technical quantitative data. This approach consistently yielded findings that isolated methods would not have uncovered.

A single case study research design was found to be appropriate because it allowed me the time and space to focus my efforts more deeply on one specific contextual construction. Indeed I found that researching practices (as a fundamentally complex set of sociotechnical interactions) could be assisted through gaining a deeper understanding of one given context. In this regard, I found achieving adequate depth to be particularly important because I actually had relative breadth to my research due to it focusing upon how technologies changed an array of everyday practices, rather than investigating one practice more specifically (as is often the approach). In addressing the need for depth, the thesis' longitudinal research design was effective at accessing a more nuanced

understanding of one specific context and, in particular, how that context responded to change over time.

9.3.2 What could have been done differently?

I now briefly reflect on what could have been done differently during the research process that underpins this thesis. I single out four methodological points of interest for discussion: (1) accessing sensory and tacit knowledges, (2) the use of household diaries, (3) using experiments in practice, and (4) the trade-offs between depth and breadth.

Whilst I felt I attained good data and useful insights from conducting interviews, other methods did help to uncover tacit and sensory knowledges which were more difficult for study participants to talk about. Although I was able to access these types of knowledges (e.g. through participant observation), upon reflection I think that even more could have been done. For instance, the success of the audio tours in uncovering tacit and, in particular, sensory knowledges made me think that developing this approach further could have been useful (e.g. through videoing the resident as they took me on a tour of their home (for more details see Pink and Leder Mackley, 2012)). In a similar vein, my limited participant observation could have been enhanced considerably. For example, ethnography at the construction site could have provided an opportunity to get to know workers in situ, and thus improve my understanding of constructing practices (for examples of such an approach see Pink *et al.*, 2013). Looking back, it was unfortunate that this could not be organised due to the construction team being so far behind schedule, hence did not seem to have much time for me, in addition to my involvement with the project team only beginning a few months before the construction was finished.

Asking households to record their daily activities in diaries, even if only brief and for a short time, could provide further insights into the studied households' everyday life. In particular, data on how and (perhaps most usefully) when practices were performed could have complemented the building monitoring data (*Chapter 6*). Apart from a few opportunistic encounters that were predominantly linked to technological failures, I was

largely restricted to investigating specific temporal trends using retrospective interview accounts. Even though many residents used their calendars for assistance, they frequently were unable to recall what they were doing and when. Daily diaries would have provided a useful record, as well as provided an opportunity for households to take the reins in communicating their day-to-day priorities and experiences.

As I mention in *Chapter 6*, when presenting the building monitoring data to one household, they offered to experiment with what they did and when they did it for the benefit of the building monitoring. Since it was not in the scope of the study, I declined their offer. Nevertheless it did get me thinking more broadly (beyond the monitoring component of my research) about the sorts of insights one could attain through having households experiment with their practices. In particular, it would be interesting for considering how households respond to changes to practices, and whether or not they are even open to such changes. For example, asking them to perform several practices at the same time so as to discuss its influence on thermal comfort, or to not touch the MVHR controls or open any windows when hosting guests (even if air quality begins to change) and discuss how that made them feel. Such discussions could provide a range of rich data on the stability that practices hold in everyday life.

The thesis' relative breadth inevitably restricted how deep the inquiry was able to go. This is not to say that I feel not enough time or resources were dedicated to reaching an informed understanding of my research questions and aims. Nevertheless, using a narrower set of methods could have helped to delve even deeper into some of empirical, methodological and theoretical issues that certain approaches brought to the fore. However, focusing more on the application of one or a selected combination of methods would have significantly diminished a key contribution of this thesis: the crossing of methodological divides in the study of practices, which was enhanced by the thesis' breadth (e.g. using both LCA and building monitoring methods).

9.4 Further research

Conducting the research that constitutes this thesis has provided me with an abundance of research ideas for the future. To illustrate this I now briefly detail some of the opportunities and ideas that I have identified. The sorts of ideas I provide also demonstrate the applicability of a practices approach across a range of topics, in addition to showcasing a wider research agenda that (as a consequence of this thesis) I endorse the development of.

I begin by summarising some of the opportunities for continuing my longitudinal research with the same case study upon which this thesis is based:

1. Continue *monitoring the performances of practices*:
 - a. Further work on my approach, focusing on the elements of practice.
 - b. Examine the temporal rhythms of everyday life. Thus, instead of time-use data as many use, use building monitoring data to trace performances.
 - c. Cluster analysis of different ways of performing practices (e.g. common characteristics of high energy use) in the low energy home or Passivhaus context (c.f. Browne *et al.*, 2013).
2. *Trajectories of practice* – continuing to investigate how practices change over time, which could include:
 - a. Returning to the development to speak to households still living there, considering questions such as: how has the usage changed? Have routines been normalised? How has know-how, in particular, developed? Reflections on learning and experiences? Memory of moving in? Has (and if so how has) the relationship with the landlords changed, and has that been linked to independent learning by doing?
 - b. Talking with households who have moved away from the development. In reference to their ‘practice memories’ (Maller and Strengers, 2013, p. 243), consider whether synergies exist between households performing practices in their past Passivhaus or new non-Passivhaus home, as well as if

elements of practice have lied or are lying dormant ready to be called upon if required.

- c. It would also be interesting to investigate the practice trajectories of the designers, constructors, and landlords: how have these changed as a consequence of being involved in more Passivhaus projects? For instance, the landlords (housing association) have committed to completing one new Passivhaus development every year. In doing so, how have their practices changed?
3. *Fictive visions* – how are designing and constructing practices influenced by a fictive vision of building occupants? *Chapter 8* showed expectations of household use to influence dwelling design, and these influences could be a source of further investigation. In addition, how close is this fictive vision to reality (or at least the reality constructed through my research)? Was a techno-economic vision, for instance, adopted? How did this fictive vision influence household practices?
 4. *Model critiques* – the understanding I have gained (particularly through *Chapters 5-7*) regarding life in Passivhaus buildings provides a good basis for critiquing the rational occupant assumptions of the Passivhaus Planning Package (PHPP) software. Such research could be especially important because, as *Chapter 8* revealed, the PHPP software is hugely instrumental and highly instructive in the design and construction of Passivhaus buildings.

Although it would lose much of its longitudinal perspective, many of these potential plans could also be used as part of other case studies. As I look beyond the boundaries of this thesis' case study, numerous additional research ideas have been stimulated, some of which are detailed here:

1. *Techno-economic policy review* – this thesis has shown that despite the literature on the paradigm predominantly being published around 15 years ago, its critiques are still very relevant for current research and policy. For instance, the arguments presented in Guy and Shove's (2000) book – 'A Sociology of Energy, Buildings and

the Environment’ – still represent an insightful critique of the dominant policy approaches. Since policy approaches have moved on so little, I believe that an up-to-date review of the relevance of the techno-economic paradigm in current climate change mitigation (and, in particular, energy and buildings) policy would have considerable value.

2. *Inequality and practices* – more work is needed to build upon the small amount of work already conducted in this area (e.g. Walker, 2013). This line of inquiry became particularly apparent during the course of this thesis predominantly because of how new (Passivhaus) technologies were seen to change the number, type and scope of opportunities for performing a practice (*Chapters 5-8*). Moreover, *Chapter 7* reiterated the link between performing practices (doing) and technological ownership (having), and vice versa. These relationships were exacerbated, in part, by the studied development being affordable housing, thus their low levels of wealth were already restricting how and which practices were performed (*Chapter 6*). The potential thus exists to research how interventions (e.g. new technological designs) can be accompanied with justice-related implications for everyday life.
3. *Policy relevance of the practices approach* – I have demonstrated that (particularly in *Section 9.2*), despite not being able to guarantee specific policy outcomes, the practices approach can be policy relevant. I believe that calls for practices thinking to be embedded in policy-making is likely to only gain more traction in policy circles, and indeed amongst many researchers, if further suggestions are provided based on different (and detailed) case studies and contexts.
4. *Struggles of innovating in the design and construction industry* – experience was shown to be a key influence of practices, whether performed by households or industry. A lack of relevant experience (e.g. Passivhaus) could lead to misunderstandings, as parallels are drawn with non-relevant experience (e.g. non-Passivhaus) (*Chapter 5*). My involvement with industry during this research process demonstrated how clear struggles exist in delivering niche-level design

when project partners have little (in this case, no) experience within that particular niche. Although this was touched upon in *Chapter 8*, the LCA focus of the chapter meant I was not able to discuss this in depth. It would be really interesting to explore more deeply how lack of experience can be linked to unintended consequences. Such research could emphasise how unwise it may be to assume energy saving technologies are constructed and/or installed correctly (an implicit techno-economic assumption). As Stevenson and Bordass (2011, p. 109) argue, such research could help inform industry's learning since 'even bad news can be beneficial'.

5. *Connections between practices* – this thesis has found the relationships between practices to influence as well as be influenced by changes to everyday practices. Based on this thesis' findings, I would be especially keen to investigate: how certain interventions (e.g. Passivhaus technologies) can bring more practices (e.g. cooking, hosting, showering) together under one 'compound' (Warde, 2013, p. 25) practice (e.g. heating); how 'bundles' (Shove *et al.*, 2012, p. 17) of practices (loosely connected) can transform into 'complexes' (Shove *et al.*, 2012, p. 17) of practices (more deeply integrated and co-dependent) and vice versa; how such shifts in the ordering of practices influences everyday life; and what increasing complexity (i.e. more compound or complexes of practices) could mean for policy-making and designing interventions in practice.
6. *Talking about practices* – I found audio tours to provide unique insights because of the discussions being situated where practices are actually performed (e.g. surroundings act as a discussion prompt; enable performance re-enactments) and because the occupants take more of lead as a consequence of them showing me round their home (e.g. seemed more confident; less 'dead air' in the recording; provided other non-textual data that was useful with regard to understanding tacit knowledges and engagements). It would be interesting to reflect upon how the data collected from such methods differ from more conventional styles of interviews, which Hitchings (2012) advocates for practices research.

7. *LCA of specific practices* – investigating the embodied energy and carbon (or other environmental impacts, using LCA) of a specific practice, rather than researching practices more generally (as I did in *Chapter 8*). Focusing LCAs in this way may complement other (wholly qualitative) studies which have adopted the same practice as its unit of analysis. Therefore one would be able to discuss in detail the carbon implications (including embodied carbon) of, for example, cooking or showering.
8. *Further ways of utilising practices approaches in other technical literatures* – this thesis' work on LCA and building monitoring have emphasised the value of interpreting technical data through a practices lens. I have shown how interdisciplinary mixed methods offer something different to multidisciplinary conclusions that may be bounded within separate 'technical' (e.g. building monitoring; life cycle assessment) or 'social' (e.g. behaviours; practices) disciplinary research silos. Therefore value exists in broadening the lenses of inquiry (to include practices) within the more technical disciplinary literatures, which have to date been dominated by technological performance and/or linear investigations of individuals.

I am also, more broadly, interested in the processes surrounding being an interdisciplinary researcher, in particular the challenges they face (e.g. sense of homelessness; time pressures; different disciplinary languages; publishing in mono-disciplinary journals). Conducting this thesis' research has reaffirmed to me that despite institutions encouraging researchers to be interdisciplinary, those very same institutions are fundamentally biased towards mono-disciplinary research (Evans and Randalls, 2008; Lyall and Meagher, 2012). I believe that these challenges are enhanced if opting to do interdisciplinary research by one's self, instead of sharing the (interdisciplinary) burden across a team. I think that space is needed for greater reflection on these sorts of issues, largely because I have found interdisciplinarity to be a fruitful and enjoyable basis for inquiry, and thus I would find it a great shame if such obstacles were to inhibit others PhD researchers from effectively crossing diverse disciplines.

9.5 Concluding remarks

Addressing the urgent need to reduce domestic energy consumption and mitigate climate change has predominantly focused upon advancing (although perhaps only in the designers' eyes) the technological design of dwellings. There has been an overwhelming focus on getting the technologies right, with the implicit assumption that residents will use technologies as intended. More recently there has been a slight shift away from technological performance and wholly rational consumers, as part of a bid to include a more sophisticated array of external factors that affect what decisions individuals make (and thus how technologies are used). Yet this thesis has demonstrated that these linear approaches to researching and attempting to reduce energy consumption are way off the mark and are thus likely to be ineffective.

Technologies are experienced in very different ways, depending upon the contextual and social dynamics in which people live their lives and perform practices. As such, technological provision can pose numerous consequences on everyday life that one may struggle to expect, but are usually likely to extend far before the initial intention underlying the technology. This thesis has emphasised how technologies are only one of many agents of change, hence if we are to successfully reduce how much energy we use, then a shift in energy-related (be it domestic or not) policy-making and research is required.

I advocate a new research agenda that steers research and policy-making away from technologies or even what individuals think about technologies, and towards what people actually do (thus technology-in-practice). By approaching this thesis on the basis of exactly this new research agenda, I hope to have demonstrated the potential usefulness of operationalizing theories of practice and specifically focusing on how practices are performed (e.g. through the elements of practice), in a bid to enhance our understanding of the construction, maintenance and malleability of everyday life. In doing this, I hope to have challenged the traditionally dominant paradigms and thus stimulated debate regarding how technologies and individuals are regarded in research and policy. In particular, by drawing on technical methods, I also hope to have opened up the practices

approach not only to a broader audience, but to the same technical audience that has been the basis for much of this thesis' critique. Such interdisciplinarity is imperative if we are to encourage technical disciplinarians to reframe how they define the problem of energy consumption and convince them that technologies only represent part of a package of (potentially effective) solutions.

I finish this thesis by reiterating my call for a contextual and social practice based understanding of how and why energy is consumed, the underlying influences of which should form the sole foundations of any proposed energy saving intervention.

Appendices

Appendix 1 – Interview schedule: First round with households

- Information sheet, consent form (with signature), appliance audit; while they are completing I can copy details from past energy bills.
- Quick tour of the house. Photographs taken (inside & outside) if possible.
- No right or wrong answers. Independent.
- Any specific questions you have about the development, maybe leave to the end.
- I want to listen, not talk – as far as I see it you are the expert.
- Confidentiality again; recording permission – ask again on the record.
- Tell me about yourself... e.g. occupation, age, interests, like to host?, like to cook?, occupancy patterns.
- What do you think are your main energy consuming activities? Electrical end-uses specifically? Use appliance audit as discussion point.
- Who will be living in the new home?
- Describe a typical day for you in your current house? Activities undertaken? When?
- Appliances used? (refer to appliance audit & ask addition Qs as appropriate)
 - Showering/bathing; laundering; cooking (gas/electric); chargers.
- Currently in social housing or privately rented?
- Could you explain the process around how you've been given this house?
- Heard of energy efficient or low carbon housing before? Context? Expectations?
- Heard of Passivhaus before? Purpose of Passivhaus? How does the house work? Why has it come about? Good thing? Any independent research?
- What did you think of the houses when you had a look around? How do they compare?
- Expectations of moving in? Looking forward to anything specific? Unsure of anything?
- Current technological setup; e.g. fuel, heating system & controls, insulation levels.
- How happy are you with your current house?
- Condensation – have to open the windows much? Do you like the fresh air?
- How are your heating controls typically set? How are these decided upon?
- Use any additional heating/cooling equipment (app audit)? Why?
- Energy saving – heating, bulbs, lights off, standby.
- Views on climate change? Involvement in environmental initiatives?
- How would you evaluate your involvement with the Housing Association to date?
- Had a chance to look through the Passivhaus information they gave you yet? Useful?
- Anything that you are confused about regarding the house? e.g. role of MVHR?
- Is there anything I've not asked that you think I may be interested in?
- Do you have any questions for me?

Appendix 2 – Interview schedule: Second round with households

- Information sheet, consent form (with signature), appliance audit?
- I want to listen, not talk – as far as I see it you are the expert.
- Confidentiality; recording permission – ask again on the record.
- No right or wrong answers. Independent.

Audio Tour:

Please show me around your home and talk to me about how and why:

1. You use Passivhaus (e.g. MVHR) & non-Passivhaus (e.g. oven, tv) technologies
2. You use specific spaces and rooms (e.g. for what purpose; when?)
3. These have changed over time (e.g. living there longer; seasons)

Ask if they don't arise during tour:

- When has it been particularly hot/cold?
- What do you do if it is too (1) hot, (2) cold, (3) stuffy/humid/smelly, (4) dry air?
 - Have you got to these points much? Do these extremes happen much?
- MVHR vs. windows?
- MVHR controls – timings? boost? settings used most?
- Scorching smell from MVHR unit?
- Windows – wide/tilted open?
- Blinds – open or closed? Use own curtains instead much?
- Thermostat setting – Alter much? (also note down what it was during the interview)
- Influence of appliances on internal temperatures?
- Need to put a jumper on or use a blanket for warmth in winter? T-shirt? Seasonality?
- Touch anything in the plant room? Changed default settings (e.g. water tank thermostat)?
- Showering/bathing habits and timings [solar thermal influence?]
- Cooking routines

Other questions:

- Do you like living in the house? Why?
- Handover – what worked, what didn't work, suggested improvements
- Is living in a PH different from what you thought it would be?
- Complicated? What was hardest to understand? Still apprehensive about anything?
- How useful did you find the instruction manuals and guides?
- What did you do when you didn't know what to do?
- Have the landlords been quick to problems? (have there been many?)
- Any changes to how you use your home as a consequence of living there for longer?
- Energy bills – amount? How much lower? Electricity/gas? Why do you think?
- Have you changed your routines since moving in? (e.g. timings you do activities)
- Best and worst aspects of living in a PH?
- Health impacts – positive/negative?
- Lights too bright/dim/fine? Any glare from natural sunlight?
- What do you think consumes the most energy in the house?
- Do you think the MVHR consumes much energy?

Appendix 3 – Interview schedule: Third round with households

- Independent. Anonymous and confidential. Paperwork & signatures. Recording.
- Why retain old appliances? Buy new or second hand?
- Anything that you didn't have a need for before, but do now?
- Anything that you are able to own/use as a consequence of moving?
- Anything that you don't need as a consequence of moving?
- Did you feel a need to sort your belongings out around a move?
- New appliances for a new start?

- Have you given any thought to the monitoring while you've been living here?
- Go through each table/graph; explain data – Surprising? Expected? Reasons for trends?

- Best and worst aspects about living in the homes?
- Remember what you thought before you moved in?
- Present them their own expectations (quotations) from the first round of interviews
 - Agree? Disagree? Surprised you said that? Remember when your thoughts changed?

- How are your utility bills?

- Does the ventilation do what you want?
- Do you adjust it, or just leave it on/off all the time? How easy is it to control?
- Have there been any problems? – e.g. faults; or found it draughty/stuffy?

- Have there been any times when you have been uncomfortable? – too hot/cold; too dry/humid?
- Normal summer day:
 - What do you do (if anything) to stay thermally comfortable?
 - How well does it work?

- Really hot day – do you do anything different? (show them the wide variations across dwelling temperatures, as a consequence of households doing things differently)

- Anything else that you would like to comment on? Any additional Qs for me?
- Dates that are available for a resident feedback meeting; topics they are interested in?
- Give them business card; thank them for help across the duration of the project.

Appendix 4 – Interview schedule: Industry (embodied energy)

- Forms; confidentiality; ask on the record if recording is okay.
- Explain research project – field diary and LCA results to have shaped interview Qs.
- Explain LCA boundaries and headline results.
- Prior expectations?
- Immediate thoughts on the pie chart? Surprised?
- Technological availability? Supply chains? Much changed between then and now?
- Certification: which products are needed? Windows/doors? Sources and locations?
- Constraining having to buy certified or approvable products?
- Knock-on effects – having one technology dictates the use of another?
- Experience before the project?
- Why did you want to be involved in the project?
- Was it just the same as all other projects? Important to you to be a frontrunner?
- To what extent was it designed with householders in mind?
- Benefits to households?
- Project rationale: Why did the client want to build it in the first place?
- Supportive local community / parish council?
- How has involvement in the project influenced your reputation? Lead to future work?
- What parts of the design were innovative / conventional?
- What was the rationale behind these?
- How different would you say designing/constructing to Passivhaus is compared to new builds?
- Passivhaus training courses – becoming accredited Passivhaus certifiers – describe.
- Role of myths and recommendations from colleagues and friends in industry?
- How did PHPP influence design and construction?
- Where did you primarily get your design knowledge from when (if indeed) experience did not suffice? Any useful guidance documents relied upon?
- In what ways was the development was similar to past projects?
- Did past experience (or even lack of) lead to any problems?
- Refer back to embodied energy/carbon data and offer my interpretation for what underlies those trends/proportions (on basis of interview discussion). Ask for feedback.
- Explain that I will send quotations for approval and, as a courtesy, also send any outputs that use those quotations.

Appendix 5 – Interview transcription extract

This extract was taken from a second round household interview.

Interviewer: “In general, where would you say it’s been the hottest all the time you’ve lived here?”

Respondent: “It’s hot in the kitchen area when I’m cooking, so I tend to leave the door slightly open. In the lounge it’s quite warm with the TV on as that generates a fair bit of heat. In the summer it was fairly nice and cool. We do try and use things properly so most of the time our blinds are down, unlike most other people’s, in order to use them as intended. During the last really hot summer the temperature panel [thermostatic device which also acted as a thermometer] on the north side of the house was 30 degrees some days, obviously meaning it was hotter on the south side. If Julian’s [husband] asleep we have the blinds closed, as well.”

Interviewer: “Are their curtains up in the bedroom?”

Respondent: “We haven’t gone out of our way to get curtains as we don’t feel that overlooked. Apart from being decorative, we don’t really need them. The [external] blinds go down upstairs during the summer and then in the winter they’re up to draw as much sunlight in as possible.”

Interviewer: “Are the blinds ever pulled down and left open, or fully up?”

Respondent: “We do both. The ones in the spare room are [pulled down but] open to get in as much of the sunlight. In our bedroom, we open them in the morning and shut them again at night. It all depends on how sunny it gets.”

Interviewer: “Do you open the windows much?”

Respondent: “If we want to. When it gets hot I’ll tilt the nearest one to me open, which we do on a regular basis. The window next to the door in the lounge is supposed to be changed soon as they installed the wrong fittings, which means it doesn’t tilt open far enough. Someone was supposed to come out and look in September but to be honest it doesn’t make much difference to us because we’d open another window to get in air anyway.”

Interviewer: “Did the housing association fix the problem with your door that you previously told me about?”

Respondent: “They did, but with a lot of hassle! It was a ‘top priority problem’ that was meant to be sorted within a week but instead took months. We’ve found the housing association to be good; it’s just the contractors [the construction company] whose customer service is pretty terrible.”

Appendix 6 – Field diary extract

This extract was taken from a section of the field notes that focused on a pre-move-in information session for residents. The session culminated in the residents visiting their new Passivhaus homes (that were still being constructed) for the first time, which is what this particular extract refers to.

“There seemed to be a genuine excitement when visiting their (soon-to-be new) homes for the first time. As I was chatting to the housing association staff, one female resident walked past and said “goodbye” on three separate occasions. Each time coming back to just “double check something”. She was at times literally dragging her (I assume) partner back with her. On her final return – when housing association staff were laughing and joking with her about the fact that she kept coming back – she simply said “I’m so excited, it’s like Christmas”.

One resident, in particular, caught my eye because she was one of the only residents who took notes during my earlier presentation to the residents (both, it seemed, with regard to my research and Passivhaus more generally). Her enthusiasm and attention to detail did not seem to stop there. Using a tape measure (with the help of her mother), she measured all of the dimensions of the flat to assist her in drawing a plan (which she told me was for carpets and furniture). Following this exercise she took a video-recorder out of her bag, which she used to film the whole of her flat. Her filming (which included a lot of panning and zooming in/out) also involved a running commentary on what the rooms would be and how she was planning to use them. She even made an attempt to explain how the Passivhaus technologies worked; such as how the ventilation system would move heat from the bathroom to the living room (she did this as she zoomed in on the ventilation inlets/outlets in each room). She also explained to me how this was the first house she was investing in (as a shared owner) and that that made her very excited. There was clearly a significant amount of meaning that had been attached to a home that she had not even moved into yet.

The father of a son who was moving into one of the flats took a real interest in the Passivhaus concept. This became clear during the construction site tour when he initiated a conversation with me about this. He questioned me on similar studies that been conducted elsewhere (particularly Germany, perhaps because the earlier presentations had explained Passivhaus’ German origins), and asked if the need for UK studies existed because of a different climate. He also showed other residents where the MVHR was coming in and out (although this was more as an observation, than as part of an explanation as to how the MVHR worked). During this time, the son (the sole future occupant) did not seem interested. The son looked at his watch several times whilst his father was talking to me, and I suspect that if it had not been for his father’s interest, he may well have left the construction site much earlier. As I type this, I wonder whether it would be a good idea to explore this father-son relationship further, such as the type of knowledge the relationship equips the son with.”

Appendix 7 – Results of initial coding

First round of household interviews:			
Anxiety	Environmentalism	Money	Sunlight
Appliances	Experience	Multiple doings	Systems
Blind faith	Freshness	New beginnings	Temporality – routines
Cleaning	Good family member	Occupancy	Test dummies
Confusion	Guidance	Place	The German way
Contented	Homely	Policy	Thermal comfort
Control	Hosting guests	Privileges	Time
Convenience	Laundering	Radiators	Trust
Cooking	Miscellaneous	Research	Washing
Delays	Misunderstanding	Space	Watching television
Employment	Moisture	Standby	What makes me happy

Second round of household interviews:			
Appliances	Control panel	Laundering	Operation manual
Asking for help	Cooking	Lazy	Place
Bad communication	Design improvements	Learning	Pride
Being comfortable	Disruption	Leaving untouched	Showering
Being uncomfortable	Don't know	Looking back	Smell
Blinds	Experience	Messy	They told me to
Change	Fresh air	Miscellaneous	Touch
Cleaning	Good home	Misunderstanding	Trust
Cleanliness	Habit	Money	Unhappy
Comparing technologies	Health	Move-in day	Windows
Complacency	Honesty	MVHR	
Confused	Hosting guests	Negotiation	
Control	Integrating practices	Neighbours	

Third round of household interviews:			
Access	Experts	Laundering	Space – constraining
Change	Feedback	Miscellaneous	Space – enabling
Cleaning	Future	Misinterpretation	Standby
Cleanliness	Habit	Muggy/stuffy	Surprise
Combining appliances	Health	Neighbours	The good life
Cooking	Hindsight	Norms	Time
Design improvements	Homemaking	Overheating	Trust
Disposal	Hosting guests	Praise	Unanswerable
Disruption – actual	Household discussions	Purchasing	Ventilating
Disruption – fear of	Identity	Seasonality	Watching TV
Energy	Inaccuracy	Second-hand	
Experience	Integration	Showering	

Round of industry interviews:

Aesthetics	Expectations - household	Numbers	Reputation
Airtightness	Experience	On the continent	Research
Aspirations	Fictive	Passive House Institute	Symbolic
Brief	Insulation	PHPP	Thermal comfort
Carbon	Knock-ons	Policy	Time
Change	Leading the pack	Predictions	Training
Constraints	Learning	Previous projects	Uncertainty
Contingencies	Magic bullet	Pride	Unexpected
Cost	Making a difference	Problems	
Energy	Masonry	Professional relationships	
Expectations - client	Miscellaneous	Quality	

Field diary:

Anxiety	Finance	MVHR	Space
Authoritative	Frustration	My influence	Strained relationships
Blind faith	Generalising	Neighbours	Substituting technologies
Breakdown	Good host	Networks	Surprise
Community	Hindsight	Noise	Tacitly learnt
Confused	Homely	Non-negotiable	That's not what I was told
Constraint	Household dynamics	Overheating	Thermal comfort
Contradictory	Housing association support	Performance	Time
Convenience	Indifference	Policy - local	Trust
Daily routines	Instruction manual	Policy - (inter)national	Ventilation
Dreams	It didn't used to be like that	Power	Weather
Enabler	Jargon	Practices beyond the home	What not to do
Energy	Messy	Pride	
Enthusiasm	Miscellaneous	Quality of life	

Appendix 8 – Extract from coded interview transcription

Interviewer:	“What do you think the idea of Passivhaus is to you, is it sort of the same idea as energy efficient housing [relating to the respondent’s earlier reference]?”	
Respondent:	“No, no I think it’s slightly different because obviously energy efficient housing, well the ones I’ve known about before, have just been solar panels in the roof. They haven’t been anything to do with the house itself like the air flow in the house and things like that and the heating systems and stuff.”	<i>Experience; guidance; systems</i>
Interviewer:	“Yeah.”	
Respondent:	“It’s only been, they’ve stuck a couple of solar panels on the roof, whereas now it’s like they’ve looked at everything...”	<i>Guidance; systems</i>
Interviewer:	“Yeah.”	
Respondent:	“Instead of just that, so...”	
Interviewer:	“Yeah that’s good. So with all those things you just mentioned, how do you think that they all combine? How do you think it works?”	
Respondent:	“I don’t know because I haven’t really got my head round that yet because they did say to me, this is one of their quotes, if you get cold you’re supposed to be able to light five candles and it will heat the house up because it will take the heat from the candles and distribute it throughout the house. I thought five candles? Surely that’s not going to be high enough, but they assure you like if for instance if you turn your oven on like I said before the kitchen gets hot if I turn my oven on then that will spread that round the house.”	<i>Confusion; guidance; trust; thermal comfort; cooking; appliances; systems</i>
Interviewer:	“Yeah.”	
Respondent:	“So it makes sense but it will take some getting used to I think because I think you’ll think more about how you could heat up the house and things like that.”	<i>Anxiety; new beginnings; time; thermal comfort</i>
Interviewer:	“Okay.”	
Respondent:	“Rather than just “oh I’ll turn the heating on.””	<i>Control; convenience; thermal comfort</i>
Interviewer:	“Yeah.”	
Respondent:	“Because everybody – everybody I know just if they’re cold they’ll put the heating on, that’s all we’ve known in a house, or that’s all I’ve known anyway.	<i>Experience; thermal comfort</i>
Interviewer:	“Yeah.	
Respondent:	“Whereas now it’s going to be: right if I cook dinner that will turn some heat up and stuff like that, so yeah.	<i>Cooking; multiple practices; thermal comfort</i>

Appendix 9 – Building monitoring data: parameters and record extract

This appendix summarises the parameters of the building monitoring data, before then providing an extract from the building monitoring records that were kept. These are provided to give a flavour for how monitoring data were collected and stored. These also serve to demonstrate the sizeable dataset that I had and how this thesis was only able to touch the surface of its potential, particularly since data were collected over 16 months at (at least) 5 minute intervals. Note that only three dwellings were ‘fully monitored’.

Summary of building monitoring parameters

	Fully monitored houses	Fully monitored flats	Partially monitored houses	Partially monitored flats
Temperature (°C)				
lounge	✓	✗	✓	✗
kitchen	✓	✗	✗	✗
kitchen-lounge area	✗	✓	✗	✓
bedroom	✓	✓	✗	✗
hallway (next to bathroom)	✓	✓	✗	✗
Relative humidity (%)				
lounge	✓	✗	✓	✗
kitchen	✓	✗	✗	✗
kitchen-lounge area	✗	✓	✗	✓
bedroom	✓	✓	✗	✗
hallway (next to bathroom)	✓	✓	✗	✗
Carbon dioxide (air quality) (ppm)				
lounge	✓	✗	✗	✗
kitchen-lounge area	✗	✓	✗	✗
bedroom	✓	✓	✗	✗
Electricity (0.1kWh)				
dwelling total	✓	✓	✓	✓
kitchen	✓	✓	✓	✓
plug sockets	✓	✓	✓	✓
plant equipment	✓	✓	✓	✓
Other utilities (0.1kWh)				
gas dwelling total	✓	✓	✓	✓
External*				
temperature (°C)	✓	✓	✓	✓
relative humidity (%)	✓	✓	✓	✓
solar irradiation (W/m ²)	✓	✓	✓	✓
MVHR				
airflow temperatures (x3) (°C)	✓	✓	✗	✗
electrical load (fans & heater) (0.1kWh)	✓	✓	✗	✗
Thermal system				
heat flows (x5) (°C)	✓	✓	✗	✗
cylinder temperature (°C)	✓	✓	✗	✗
electrical loads (boiler, solar, heating) (0.1kWh)	✓	✓	✗	✗

* For these *external* monitoring data, only one of each is collected for the development as a whole.

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Extract from building monitoring record

Note that data was initially collected at five minutes intervals, but once confidence was established in the reliability of the monitoring equipment, data was collected more frequently (the more frequently data was collected, the shorter duration could be temporarily backed up). This contributed to a very sizeable dataset, thus data were initially analysed on an hourly basis (as per the below table), from which I could drill down further (to more frequently collected data) or aggregate (e.g. for daily, monthly, seasonal, annual averages or totals) as I deemed appropriate.

Date	Time	Temperatures (°C)				Relative humidity (%)			Carbon dioxide (ppm)	
		<i>Kitchen-lounge area</i>	<i>Bedroom</i>	<i>Hallway</i>	<i>Outside</i>	<i>Kitchen-lounge area</i>	<i>Bedroom</i>	<i>Hallway</i>	<i>Kitchen-lounge area</i>	<i>Bedroom</i>
27.03.2012	1900	24.11	23.24	23.23	14.42	39.20	39.46	41.14	483.20	433.40
27.03.2012	2000	24.38	23.40	23.41	11.57	40.66	39.67	42.11	554.20	505.20
27.03.2012	2100	24.28	23.31	23.34	10.05	39.82	38.70	41.03	565.80	509.20
27.03.2012	2200	24.37	23.13	22.96	8.70	39.71	36.40	41.76	610.40	454.40
27.03.2012	2300	24.10	23.13	23.14	7.72	38.20	36.79	39.59	572.00	516.60
27.03.2012	0000	23.93	23.05	23.13	7.12	38.31	35.29	39.34	525.00	606.20
27.03.2012	0100	23.67	22.96	22.97	8.00	38.58	35.01	39.14	504.60	626.60

Appendix 10 – Appliance audit

Name: _____

Date: _____



Q.1a. Large Appliances: Please complete the below table, and start a new row if there are additional items (e.g. another television). Leave rows blank if you do not have the relevant item.

Appliance Type	Bought new?	Approx. date of purchase	Manufacturer	Model name & number	Location?	Average no. of hours used per day?	Left on standby when not in use?	Any additional information? (Perhaps from plate on/in the appliance)
<i>e.g. Washing machine</i>	<i>Yes</i>	<i>2010</i>	<i>Beko</i>	<i>WM5100W</i>	<i>Kitchen</i>	<i>1</i>	<i>Yes</i>	<i>A+ energy rating; 2000W heat, 500W spin, 250W wash; 190kW/year</i>
Fridge-freezer								
Fridge								
Freezer								
Cooker								
Microwave								
Washing machine								
LCD TV (lounge)								
Dishwasher								

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Appliance Type	Bought new?	Approx. date of purchase	Manufacturer	Model name & number	Location?	Average no. of hours used per day?	Left on standby when not in use?	Any additional information? (Perhaps from plate on/in the appliance)

This space is provided just in case there is not enough space in the above table.

Q.1b. Focusing further on your use of washing machines, tumble dryers and dishwashers, please complete the following tables. Leave tables blank if you do not own one. If temperatures do not exactly match, simply pick the nearest one.

If (normal) summer use is different, then please note this.

Dishwasher:

	<i>...at 55°C</i>	<i>...at 65°C</i>
<i>No. of cycles per week</i>		

Washing machine:

	<i>...at 40°C</i>	<i>...at 60°C</i>	<i>...at 90°C</i>
<i>No. of cycles per week</i>			

Tumble dryer:

	<i>...at 40°C</i>	<i>...at 60°C</i>	<i>...at 90°C</i>
<i>No. of cycles per week</i>			

Q.2. Chargers: Complete the below table for all chargers that your household owns, even if everyone doesn't use them very much at present. Fill in additional rows for additional devices (e.g. second phone charger; other chargers that are not listed).

Charger type	How often do you charge the device? (per week)	Each time you charge the device, how many hours is it plugged in?	Is there a 'usual' time that you charge your device?	Do you leave the charger on and plugged in when not connected to the device?	Was this purchased just before or since moving in?
<i>e.g. camera, phone, electric toothbrush</i>	<i>3</i>	<i>8</i>	<i>Overnight</i>	<i>Yes</i>	<i>Yes</i>

Q.3. Small Appliances: Please read through the tables below and give one tick for every appliance owned (e.g. if own 2 = ✓✓). Leave blank if the household doesn't own one. Also note down if you bought the device just before move-in or since being in your new home ('bought new'), as well as indicating how often you use it.

Appliance	No. you own?	Bought for new home?	How many times per week do you use it?	Average no. of hours used each time of use?	Tick if left on standby when not in use
<i>e.g. radio</i>	✓✓	No / Yes	5 / 2	1 / 0.5	✓✓
Kettle					
Iron					
Toaster					
Plug-in grill					
Coffee maker					
Deep fat fryer					
Baby milk steriliser					
Vacuum cleaner					
Electric whisk					
Mini fridge					
Slow cooker					
Steamer					
Blender					
Juicer					
Donut maker					
Popcorn maker					
Ice cream maker					
Bread maker					
Yoghurt maker					
Landline phone					
Separate answering machine					
Broadband box					
Fax machine					
DVD player					
VCR player					
Digital TV box					
TV surround sound system					
Games console					
Desktop computer					
External hard drives					
All-in-one printer-scanner					

Appliance	No. you own?	Bought for new home?	How many times per week do you use it?	Average no. of hours used each time of use?	Tick if left on standby when not in use
Printer					
Scanner					
Laminator					
Electric paper shredder					
CD player					
Hi-fi system					
Electric blanket					
Electric heater (e.g. radiator, fan, fire)					
Gas or LPG heater					
Electric cooling fan					
Patio heater					
Plug-in lamp					
Alarm clock					
Dehumidifier					
Humidifier					
Hair straighteners					
Hair dryer					
Hedge trimmer					
Electric mower					
Pressure washer					
Others? (e.g. kitchen, musical, fitness, gardening, charging devices, etc)					

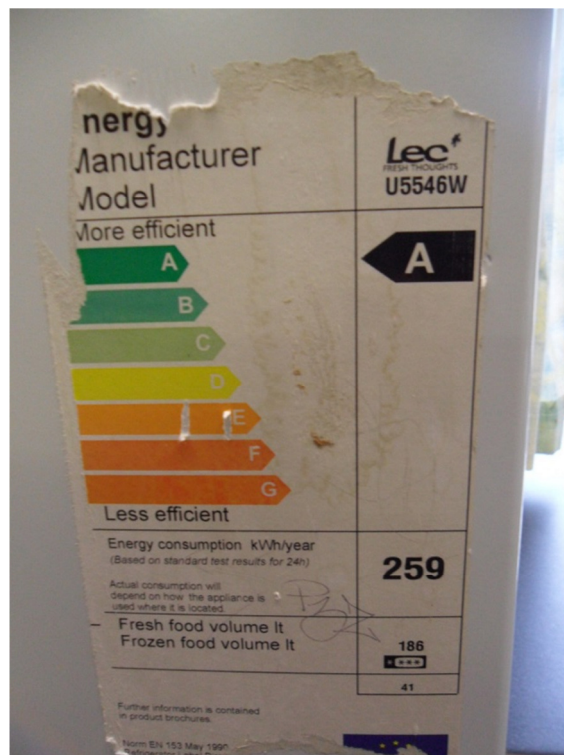
Thank you for taking the time to complete this questionnaire. All the information you have provided will remain confidential and anonymous. Should you have any queries or would prefer to complete this via email, please contact Chris Foulds (c.foulds@uea.ac.uk).

Appendix 11 – Examples of appliance audit photographs

Photographs were used as records of each appliance's positioning in a room:



Photographs were also used to record each appliance's specification:



Appendix 12 – Building construction data extract

These extracts were taken from three of the main sources of data (plans were also used, but cannot be included; manual meter readings were also taken on move-in day) and provided here so as to give a flavour of the raw data's type, form, and mix of relevance/irrelevance.

Extract from bill of quantities

	Quantity	Units
<u>F: MASONRY</u>		
<u>F31 PRECAST CONCRETE SILLS/LINTELS/COPINGS/FEATURES</u>		
<u>Precast concrete; bedding in cement lime mortar (1:1:6)</u>		
<u>Padstones</u>		
215 x 100 x 215 deep	13	number
450 x 100 x 215 deep	6	number
<u>G: STRUCTURAL/CARCASSING METAL/TIMBER</u>		
<u>G12 ISOLATED STRUCTURAL METAL MEMBERS</u>		
<u>Steel; preparation and priming at works</u>		
<u>Beams; SE drawing nr 41296/S/02</u>		
beam B1; slim floor beam SFB64 section; 3000 long	3	number
beam B2; 150 x 75 x 18 PFC section; 2400 long	3	number
beam B3; 150 x 100 x 6.3 RHS section with 15 thick x 310 wide fully welded bottom plate; 2200 long	5	number
<u>Columns; SE drawing nr 41296/S/02</u>		
column C1; 80 x 80 x 5 SHS section; 2600 long	3	number
<u>Galvanised steel</u>		
<u>Columns; drawing nr 2865.36 & 37</u>		
column; 150 x 150 x 6.3 SHS section; 2700 long with 250 x 250 baseplate and 350 x 300 top flange to support sunshades/canopies	23	number
<u>Tie beam/gutter; drawing nr 2865.37</u>		
beam; 100 x 50 x 10 PFC section; 2550 long	0	number
beam; 100 x 50 x 10 PFC section; 2800 long	0	number
beam; 100 x 50 x 10 PFC section; 4150 long	0	number
<u>Fixings</u>		
<u>Anchors; drawing nr 2865.35</u>		
M12/250 long with washer packers; resin fixed in 100 deep mortice in blockwork	3	number
M12/125 long; resin fixed in 125 deep mortice in reinforced concrete floor slab	3	number
<u>M: SURFACE FINISHES</u>		
<u>M60 PAINTING/CLEAR FINISHING</u>		
<u>Preparing; touch up primer and apply two coats bituminous paint on metal surfaces</u>		
<u>General surfaces of structural metalwork</u>		
over 300 girth	7	m2

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Extract from waste management company reports

Period: 1 st September 2010 – 31 st January 2011			
	Number	Bin Size	Tonnage
	2	20 yard	5.52
	3	7 yard	21.31

	Tonnage received	Percentage recycled	Tonnage recycled
Packaging	3.2	100	3.2
Wood	5.6	100	5.6
Plastics	0.0	90	0.0
Metals	0.0	100	0.0
Inert	18.0	100	18.0
Gypsum	0.0	100	0.0
WEEE	0.0	100	0.0

Extract from the catalogue of invoices

	Quantity	Units	Supplier
2440x350x9mm WBP Strips (<i>weather & boil proof</i>)	1	sheets	**supplier names removed for inclusion in the appendix due to confidentiality agreement**
2440x350x9mm WBP Strips (<i>weather & boil proof</i>)	60	sheets	
2440x1220x8mm MR MDF	20	sheets	
47x100 Treated R/Sawn 4.8m	48	metres	
Thomas Armstrong Airtec 140x620x215mm 7.3N Seven	400	m2	
Thomas Armstrong Airtec 100x620x215 7.3N Seven	170	m2	
Thomas Armstrong Airtec 100x620x215 3.6N Standard	600	m2	
Thomas Armstrong Airtec 190x620x215 7.3N Seven	240	m2	
Thomas Armstrong Airtec 190x620x215 3.6N Standard	848	m2	
152x152x23UC Primed Steel 3300mm (site to confirm dimensions)	3	number	
ITW/K-190 2550mm Keystone Lintel	2	number	
ITW/K-190 1050mm Keystone Lintel	22	number	
ITW/K-190 1650mm Keystone Lintel	6	number	
ITW/K-190 1350mm Keystone Lintel	7	number	
ITW/K-190 1800mm Keystone Lintel	25	number	
25kg bags rocksalt	5	number	
25kg hand lay tarmac	8	number	
Aqueous bitumen (Prufit) 5L	5	number	
Rolls thermoboard expansion foam 25mm x 150mm wide	4	number	

Appendix 13 – Consent form

Interview date:

Interview id code:



CONSENT FORM

	Please tick to confirm
I confirm that I have read the information sheet provided to me by the researcher and understood the purpose of the study and the manner in which my personal data will be used.	<input type="checkbox"/>
I agree to participate in an interview.	<input type="checkbox"/>
I agree for the interview to be recorded and for notes and transcriptions to be made from the recording to be used in the research.	<input type="checkbox"/>
I understand that any information which I provide will be treated confidentially and will not be released to persons other than the researcher (specified on the information sheet) except where it is in a completely anonymised form such as the final research report or thesis.	<input type="checkbox"/>
I understand that my participation is voluntary and that I am free to withdraw, without giving any reason. If I decide to withdraw then I understand that the information I provide will not be used in the study if my withdrawal happens within the first 30 days after the interview.	<input type="checkbox"/>
I confirm that I have received a copy of this statement.	<input type="checkbox"/>

I understand that information may have to be given to a 3 rd party in an anonymised form if this research is subject to a Freedom of Information Act request.	Yes <input type="checkbox"/> No <input type="checkbox"/>
--	---

Signature of participant: _____ Date: _____

Signature of researcher: _____ Date: _____

Appendix 14 – Project information sheet

The purpose of this research is to find out how residents use their new Passivhaus homes, ultimately seeing how their daily routines and practices are affected. The design of these homes is important to ensure as much of their predicted energy savings are achieved in reality. It will be used as an example of low energy housing, which the UK Government are aiming to construct more of. The study is for research purposes only, not commercial.

The research is funded by Technology Strategy Board (monitoring) and the Economic and Social Research Council (the researcher) and carried out by the University of East Anglia. Contact details for the researcher involved in this project are included at the end of this document.

The research will be conducted in collaboration with *name removed* (the social housing provider) and *name removed*. The duration of the energy consumption monitoring will be across a 2 year period from the handover, but the interviews will only take place during the first 18 months. The first interviews will be carried out at your previous home (end of May to start of June 2011), and from then in your new homes. You will also be asked to undertake a questionnaire, two appliance audits, and participant observation.

Participation in the research is voluntary and participants will be asked to give written consent to their participation using the accompanying consent form. Should participants change their mind and wish to withdraw their participation they can do so by contacting the researcher and indicating their wish to withdraw within 30 days of the date of being interviewed (contact details below).

The identity of the tenants will be kept confidential and they will not be personally identified in any document produced as a result of the research. Transcripts and notes of interviews will not contain the name of participants. Data will be held securely by the researcher at the University of East Anglia and will only be shared with other researchers or the project funders once it has been entirely anonymised.

The findings will form part of the researcher's PhD work. It will therefore be included within his thesis as a case study as well as potential publications, websites, broadcasts and teaching. As part of the 'Technology Strategy Board's (TSB) Modern Built Environment Knowledge Transfer Network Building Performance Evaluation Competition', some findings will also be fed back to TSB and the Energy Saving Trust, and possibly published accordingly. If you would like copies of the reports produced or interview transcripts, these can be requested by contacting the researcher involved. It is planned that general findings will be relayed to all occupants at future resident meetings.

Contact information for the researcher involved in this project:

Name: Chris Foulds

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Thesis abbreviations, acronyms and units

ABC	Attitude-behaviour-context
BRE	Building Research Establishment
CCC	Committee on Climate Change (UK)
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
DCLG	Department for Communities and Local Government (UK)
DECC	Department of Energy and Climate Change (UK)
DEFRA	Department for Environment, Food and Rural Affairs (UK)
ESRC	Economic and Social Research Council (UK)
EIA	Energy Information Administration (US)
EST	Energy Saving Trust (UK)
GHG	Greenhouse gas
GJ	Gigajoule
iPHA	International Passive House Association
kg	Kilogram
km	Kilometre
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
m ²	Metres squared
m ³	Metres cubed
MJ	Megajoule
MVHR	Mechanical ventilation with heat recovery
Mtoe	Millions tonnes of oil equivalent
°C	Degrees Celsius
PHI	Passive House Institute
PHPP	Passive House Planning Package
POE	Post-Occupancy Evaluation
ppm	Parts per million
SAP	Standard Assessment Procedure
TAM	Technology Acceptance Model
TIB	Theory of Interpersonal Behaviour
TRA	Theory of Reasoned Action
TPB	Theory of Planned Behaviour
TWh	Terawatt-hour
UEA	University of East Anglia
uPVC	Unplasticised Poly Vinyl Chloride
VBN	Value-Belief-Norm

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