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Smart Homes and Their Users

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Smart Homes and Their Users

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Preface

Smart home technologies promise to transform domestic comfort, convenience, security and leisure while also reducing energy use. But delivering on these potentially conflicting promises depends on how they are adopted and used in homes. This book is one of the first attempts to explore systematically how and why people use smart home technologies, and what impact this has on different aspects of domestic life. The book starts by developing a new analytical framework for understanding smart homes and their users. Drawing on a range of new empirical research combining both qualitative and quantitative data, the book then explores how smart home technologies are perceived by potential users, how they can be used to link domestic energy use to common daily activities, how they may (or may not) be integrated into everyday life by actual users and how they serve to change the nature of control within households and the home. The book concludes by synthesising a range of evidence-based insights, and posing a series of challenges for industry, policy and research that need addressing if a smart home future is to be realised.

This book should appeal to an audience of researchers, policymakers and practitioners including smart home technology developers, designers, manufacturers and retailers. For researchers, the book is targeted at those with interest in the areas of energy social science, human–computer interaction and user-centred design. The book demonstrates the value of cross-cutting, integrative research questions and approaches across these disciplines. For policymakers and practitioners, the book is targeted at those with interest in the development and diffusion of smart home technologies, including those focused on the potential contribution of smart homes to a smarter, more efficient energy system.

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We acknowledge the many fruitful discussions and collaborations with REFIT project colleagues. We are also greatly indebted to the sustained efforts of the Loughborough team in setting up and running a field trial of smart home technologies, and leading the in situ data collection efforts. The Principal Investigator of the REFIT project was Steven Firth at Loughborough University. The full REFIT project team comprised the following (listed alphabetically by institution):

- *Loughborough University (School of Civil and Building Engineering)*: Michael Coleman, Vanda Dimitriou, Steven Firth, Farid Fouchal, Tarek Hassan, Tom Kane, Lynda Webb.
- *Loughborough University (Design School)*: Stuart Cockbill, Andrew May, Val Mitchell, Luis Carlos Rubino de Oliveira, Chris Parker.
- *University of Strathclyde*: Jing Liao, David Murray, Amar Seeam, Lina Stankovic, Vladimir Stankovic.
- *University of East Anglia*: Tom Hargreaves, Richard Hauxwell-Baldwin, Charlie Wilson.

We also acknowledge all the householders for participating in the field trial and sharing their experiences with the research team.

Further details on the many different strands of research within the REFIT project, including datasets, publications and the final project report, can be found at https://teddinet.org/project.php?s=refit.

Contents

Abbreviations

IAMs	Individual appliance monitors
ICTs	Information and communication technologies
NILM	Non-intrusive appliance load monitoring
SHTs	Smart home technologies

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Chapter 1
Introduction: Smart Homes and Their Users

Abstract This chapter introduces the book, its rationale and objectives, and the new data sources on which much of the analysis is based. Smart home technologies (SHTs) are now commercially available amid the promise of a smart home future. But there is a dearth of informed research on the users and use of SHTs in real domestic settings. This book is one of the first attempts to explore systematically how and why people use SHTs, and what impact this has on different aspects of everyday domestic life. A field trial of 20 households using commercially-available SHTs provides new data on in situ usage. This household-level data is contextualised by national-level market studies using both surveys and content analysis of industry marketing material. These new datasets are used throughout the empirical and analytical chapters of the book.

1.1 The Smart Home Promise

Smart technologies are pervasive. Embedding information and communication technologies (ICTs) in consumer appliances like phones and TVs and in infrastructures like cities and grids promises enhanced functionality, connectivity, and controllability. Major technology developers, service providers and energy utilities are lining up to extend smartness beyond specific devices to the home as a whole, and link these smart homes into the meters, wires and pipes of the utility networks. The advent of smart homes may ensure smart technologies become a commonplace feature of people's lives, whether they are wanted or not (Haines et al. 2007).

Throughout this book, we use the term 'smart homes' as a generic descriptor for the introduction of enhanced monitoring and control functionality into homes. In essence, a smart home collects and analyses data on the domestic environment, relays information to users (and service providers), and enhances the potential for managing different domestic systems (e.g., heating, lighting, entertainment) (Firth et al. 2013). We use 'smart home technologies' or SHTs as a collective term for the many different hardware and software components of a smart home. Smart home technologies (SHTs) comprise sensors, monitors, interfaces, appliances and devices

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networked together to enable automation as well as localised and remote control of the domestic environment (Cook 2012). Controllable appliances and devices include heating and hot water systems (boilers, radiators), lighting, windows, curtains, garage doors, fridges, TVs, and washing machines (Robles and Kim 2010). Sensors and monitors detect environmental factors including temperature, light, motion, and humidity. Control functionality is provided by software on computing devices (smartphones, tablets, laptops, PCs) or through dedicated hardware interfaces (e.g., wall-mounted controls). These different SHTs are networked, usually wirelessly, using standardised communication protocols. The diversity of available SHTs means the smart home has many possible configurations and, by implication, many different kinds of 'smartness' (Aldrich 2003).

Irrespective of the particular technological configuration of a smart home, its purpose—according to technology developers—is "to improve the living experience" at home in some way (Gračanin et al. 2011; McLean 2011). This may be through new functionality such as remote control and automation of appliances, through enhancement of existing functionality such as heating management, through improved security (e.g., simulating occupancy when the home is empty), or through the provision of assisted living services by monitoring, alerting, and detecting health incidents (Orpwood et al. 2005). Smart homes are also the end-use node of a smart energy system that allows utilities to respond to real-time flows of information on energy demand from millions of homes. This also opens up the possibility of homes responding to utilities' needs for demand to be curtailed or shifted when supply networks are constrained (Darby 2010).

SHTs are increasingly on sale both off-the-shelf and with professional installation. Examples available in the UK include British Gas' Hive system for controlling heating and hot water systems, and RWE's SmartHome system for heating, appliances and lighting. The global market for smart homes and appliances (including fridges, washing machines, tumble dryers, dishwashers and ovens) is projected to grow at a 15% compound annual rate from $24 bn in 2016 to over $50 bn by 2022 (Zion 2017). Other market forecasters put the numbers still higher: $138 bn by 2023 (M&M 2017). Global consumer research carried out in seven countries worldwide, including the UK and Germany, suggests a high level of market support (GfK 2015). Over half the consumers surveyed expressed a general interest in smart homes, and 50% believe SHTs will have an impact on their lives over the next few years (GfK 2016). Over half a million households in Germany will have smart appliances or devices by 2019, driven by widespread adoption of smart phones (Harms 2015). However, actual levels of uptake of SHTs are still low, and smart product sales are dominated by internet-connected TVs (Harms 2015).

Smart homes have increasingly important public policy implications. Progress with smart grids and smart metering has helped integrate heterogeneous and distributed renewable energy sources, and improve energy efficiency in commercial buildings. However, less success has been achieved in homes even though the residential sector accounts for around one third of total energy consumption (Covrig et al. 2014). This helps explain why smart homes are one of the EU's 10 priority action areas in its Strategic Energy Technology Plan: “Create technologies and services for smart homes that provide smart solutions to energy consumers”. Behind this strategic policy objective lies “the Commission’s vision for the electricity market [which] aims to deliver a new deal for consumers, smart homes and network, data management and protection” (EC 2015). A wide range of publicly-funded projects across the EU are designed to engage consumers in this vision (Gangale et al. 2013). Underlying the EU’s strategic goals for a smart home future are clear assumptions that households seek a more active role in the energy system. The Commission argues that “communities and individual citizens are eager to manage energy consumption…” (EC 2015; EESC 2015). From this policy perspective, smart homes are enabling technologies to meet a latent demand by households for home energy control and management. Smart homes are seen as an integral part of a smart and efficient energy system, helping to reduce overall demand and alleviate supply constraints during periods of peak load (Firth et al. 2013; Lewis 2012). Widespread diffusion of smart homes in the UK has long been anticipated in policy documents (DECC 2009; HMG 2009) and is seen as an important ‘building block’ of the smart grid (DECC-OFGEM 2011). Smart home experts agree that “climate change and energy policy will drive UK smart home market development” (Balta-Ozkan et al. 2013a).

1.2 What About the Users of Smart Home Technologies?

Scientific research on smart homes is burgeoning alongside a proliferation of technology development and commercial applications. Behind both the technology developers and researchers advancing applied knowledge in this field is a clear sense of purpose: smart homes will “undoubtedly make our lives much more comfortable than ever” (Lin et al. 2002). But will they?

A growing number of social science researchers are asking: Who are the users of smart homes, and why do they want or need them? Will the technological promise of “customized, automated support that is so gracefully integrated with our lives that it disappears” be fulfilled (Cook 2012)? Might there be unexpected or perverse consequences? Are smart homes an inevitability or a choice? And how will smart home technologies actually be used in practice?

Despite the broad range of potential and assumed benefits of SHTs, a clear user-centric vision is currently missing from a field being overwhelmingly ‘pushed’ by technology developers (Rohracher 2003; Solaimani et al. 2011). Existing research on SHTs has focussed on the technological challenges involved in delivering smart domestic environments (Cook 2012). Much of this work has given no consideration to smart home users at all (Wilson et al. 2015). This is a critical oversight because the overall success of SHTs depends on their adoption and use by real people in the context of their everyday domestic lives.

SHT developers are already recognising the challenge of gaining the trust and confidence of prospective users (Harms 2015). Market research has found the most significant barrier to adoption is upfront cost, followed by lack of awareness and privacy concerns (GfK 2016). Several studies have examined prospective users' concerns about SHTs in more depth using small samples in technology demonstration labs, deliberative workshops, or focus groups (Balta-Ozkan et al. 2013a, 2014; Paetz et al. 2012). These studies have confirmed interest in the energy-management potential of smart homes, but have also identified market barriers to adoption including cost, privacy, security, reliability, and the interoperability of different technologies. Privacy and trust-related issues have delayed or halted smart-meter rollouts (AlAbdulkarim and Lukszo 2011; Hoenkamp et al. 2011). Similar issues may arise with data collected by internet-enabled SHTs within the home (Balta-Ozkan et al. 2013b; Cavoukian et al. 2010). A wider set of sociotechnical concerns with SHTs includes an increased dependence on technology, electricity networks or outside experts, and the proliferation of non-essential luxuries inducing laziness in domestic life (Balta-Ozkan et al. 2013b).

Summarising this literature, Balta-Ozkan et al. (2013b) define five key design criteria for SHTs to encourage consumer acceptance:

(i) *Fit with users' current and changing lifestyles*: SHTs should be easy to use (Park et al. 2003), 'fit in' with household routines both practically and aesthetically, and should be able to evolve over time (Edwards and Grinter 2001).
(ii) *Administration*: SHTs should not require high levels of user knowledge or the regular intervention of experts for installation, troubleshooting and maintenance (Paetz et al. 2012).
(iii) *Interoperability*: SHTs should be interoperable across manufacturers to enable 'piecemeal' development as new technologies are introduced into evolving home networks (Edwards and Grinter 2001).
(iv) *Reliability*: SHTs should not fail or act unpredictably, but should accurately sense and monitor homes, interpret user requirements and be able to cope with crashes (Friedewald et al. 2005).
(v) *Privacy and security*: SHTs themselves, and the information they gather about users must be private and secure (Cook 2012).

As well as these challenges for SHT design and consumer adoption, there is also a critical need for research on how SHTs are used in situ. Many studies rely on interviews, workshops or focus groups with *prospective* smart home users or experts (e.g., Balta-Ozkan et al. 2013b; Paetz et al. 2012). There is a dearth of research exploring how people *actually* use SHTs and what sorts of challenges emerge from their use. The small number of available studies in this field have focussed on special interest groups such as enthusiasts and hobbyists (e.g., Brush et al. 2011; Mennicken et al. 2014; Mozer et al. 2005) or groups such as Orthodox Jews with very specific reasons for pursuing home automation (Woodruff et al. 2007). These studies also tend to be quite short-term, capturing rich snapshots of how SHTs are used in context but neglecting longer-term trajectories of domestication or rejection.

Two recent review papers clearly identify a wider interest in the use of SHTs in situ or 'in the wild' (Mennicken et al. 2014; Wilson et al. 2015). These reviews raise issues and questions that are more situated and social than the instrumental concerns of consumer acceptance studies. Mennicken et al. (2014), for example, identify three core themes linked to identity and meaning, to the complexity of homes and domestic life, and to control and controllability.

First, SHTs should not merely 'fit in' with current household aesthetics and routines, but need to actively support and augment households' social goals and values. Davidoff et al. (2006), for example, identified the importance to domestic life of 'enrichment activities' such as boosting physical fitness, creative abilities, or teaching social and personal values. Such enrichment activities are vital in helping to create and sustain household identities, but potentially clash with attempts to automate or optimise the domestic environment. For example, it may be easy to automate switching lights off, but this reduces opportunities for parents to teach their children how not to be wasteful. Similar arguments have been made concerning whether and how smart homes support the construction of gender identities (Richardson 2009), create 'homey' homes (Takayama et al. 2012), or are consistent with religious or pro-environmental goals (Woodruff et al. 2007). In short, smart homes should be meaningful as well as functional.

A second theme for research on SHT users is the complexity of homes revealed by in-depth explorations of domestic life. Homes have a plurality of meanings and resonances: security, control, permanence, relationships, activities, status, identity, values (Aune 2007; Despres 1991). Household members have different domestic roles and relationships with technology (Mennicken et al. 2014; Nyborg 2015). Multiple householders must interact and negotiate their potentially conflicting wants and needs in order to achieve a relatively peaceful co-existence (Baillie and Benyon 2008). Domestic life is characterised by routines which also involve breakdowns, improvisations, compromises and conflicts (Davidoff et al. 2006). SHTs must be able to cope with this complexity and avoid deriving 'mixed messages' from the multiple signals they may receive (Mennicken et al. 2014).

Third, it is vital that SHTs do not overwhelm or overpower their users with too many options or hard-to-use controls (Park et al. 2003). Many users with pressing daily needs may have little interest in knowing everything a smart home can do or understanding exactly how it works. SHTs should therefore be easy to configure and control, allowing users to communicate with them in natural ways rather than being bombarded with too much information or options or having to learn complex technical languages (Mennicken et al. 2014).

Mennicken and colleagues conclude that "living in and with an actual smart home today remains an imperfect experience" (Mennicken et al. 2014). They call for more 'in the wild' research exploring how SHTs are integrated into existing homes and domestic life.

1.3 Purpose and Overview of This Book

We take these emerging questions about smart homes and their users as a starting point for this book. Our purpose is to explore systematically how and why people use smart home technologies (SHTs), and what impact this has on domestic life and control over the domestic environment. Throughout the book we draw on new evidence and analysis to deepen understanding of smart homes and their users (Table 1.1).

We start by developing a new analytical framework for understanding smart homes and their users (Chap. 2). Drawing on new empirical research combining both qualitative and quantitative data, we then explore how SHTs are perceived by potential users, how they can be used to link domestic energy use to common daily activities, how they may (or may not) be integrated into everyday life by actual users, and how they serve to change the nature of control within households and the home (Chaps. 3–6). We conclude the book by synthesising our new insights on smart homes and their users, and identifying important research questions and policy implications that need addressing if a smart home future is to be realised (Chap. 7).

Table 1.1 Chapter-by-chapter outline

This Chapter: Introduction: Smart homes and their users	Sets out rationale and objectives of book. Summarises new data collected on in situ usage of smart home technologies
Chapter 2: Analytical framework for research on smart homes and their users	Reviews scientific literature on smart homes and their users. Develops analytical framework which inter-relates nine prominent research themes
Chapter 3: Perceived benefits and risks of smart home technologies	Analyses results of national survey of UK homeowners on the benefits and risks of smart home technologies. Contrasts user perceptions with industry marketing material
Chapter 4: Routines and energy intensity of activities in the smart home	Develops novel methodology for using smart home data to make inferences about which activities are happening at what times. Compares energy intensity and routineness of different activities within and between households
Chapter 5: Domestication of smart home technologies	Analyses data from in-depth interviews with householders both before and after installation of smart home technologies. Shows ways in which smart home technologies are incorporated into or rejected from domestic routines
Chapter 6: Control of smart home technologies	Identifies different forms of control by users of smart home technologies. Relates forms of control to dynamics of domestic life within households
Chapter 7: Conclusions and implications for industry, policy and research	Draws out common themes from empirical and analytical research on smart homes and their users. Outlines critical research needs and potential smart home contributions to public policy objectives

1.4 New Data and Analysis

In the empirical chapters of the book (Chaps. 3–6) we draw on a wealth of new data on the users and use of SHTs (Fig. 1.1). All these new datasets have been made publicly available via open-access data repositories (Table 1.2). Household-level data were collected from actual users of SHTs as part of an SHT field trial in the UK by the REFIT project team (see Acknowledgements). Complementary market-level data were collected through a national survey of UK homeowners and a content analysis of industry marketing material in the UK, EU and globally. Although much of this new data is from the UK where the authors are based, the analysis is broadly consistent with studies from other countries and regions including Australia (Strengers 2013), New Zealand (Ford and Peniamina 2016), the US (Karlin et al. 2015), Europe (BPIE 2017a, b), and globally (GfK 2016).

The REFIT project ran from 2012 to 2015 in the UK with the aim of understanding the use of SHTs and their potential impact on household energy demand (see Acknowledgements). It centred on a SHT field trial which ran for just over two years from April 2013 to August 2015 in Loughborough, UK (Fig. 1.2). In early 2013 the REFIT project team began recruiting households through posters, newspaper adverts and targeted leaflet drops. These recruitment materials presented the trial as an opportunity to experience new SHTs related to energy management, security and convenience in the home. The materials placed no emphasis on potential energy or financial savings. Responding households completed a screening survey to ensure diversity against the following criteria: household composition; experience with smart technologies; property type and age; existing energy efficiency or micro-generation technologies; and length of stay in the current home.

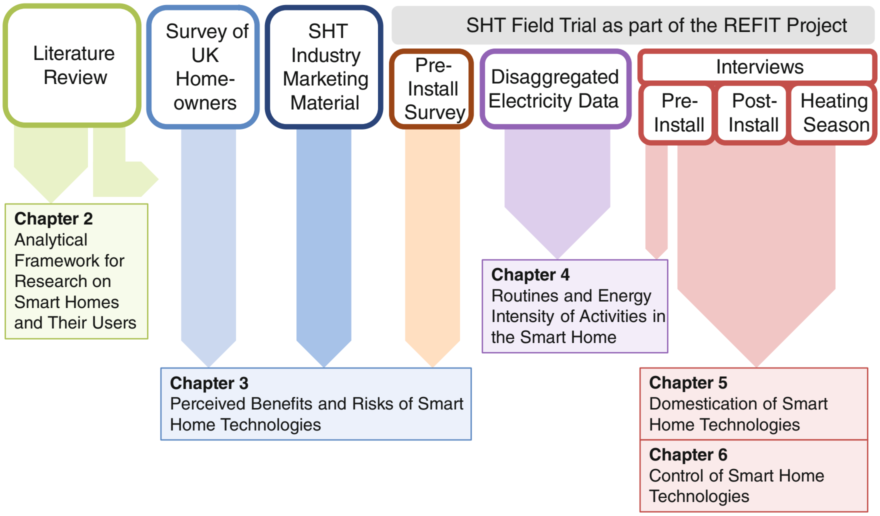

Fig. 1.1 New datasets analysed in this book

Table 1.2 Open access data repositories

Dataset	Use in this book	Open access repository
Data from *national survey* of consumer perceptions of smart home technologies	See S in Fig. 1.2; explained further in Chap. 3	ReShare data repository of the UK Data Service: URL = http://reshare.ukdataservice.ac.uk/852366/
Qualitative *interview data* from 20 households participating in the SHT field trial	See I1, I2 and I3 in Fig. 1.2; explained further in Chaps. 5 and 6	ReShare data repository of the UK Data Service: URL = http://www.reshare.ukdataservice.ac.uk/852367/
Electrical load measurements at 8 s intervals from 20 households participating in the SHT field trial	See A in Fig. 1.2; explained further in Chap. 4	Strathclyde University Knowledge Base: URL = http://dx.doi.org/10.15129/9ab14b0e-19ac-4279-938f-27f643078cec
Building survey data (including appliances) from 20 households participating in the SHT field trial	See A in Fig. 1.2; explained further in Chap. 4	Loughborough University FigShare: URL = https://doi.org/10.17028/rd.lboro.2070091
Sensor measurements (e.g., air temperature) from 20 households participating in the SHT field trial	Additional open access dataset generated by the SHT field trial but not analysed in this book	Loughborough University FigShare: URL = https://doi.org/10.17028/rd.lboro.2070091

A final sample of 20 households were selected, spanning a range of household types including single occupancy, dual-income families with children, and retired couples. Household members ranged in age from 10 to 74, and were drawn from professions that included students, carers, IT consultants and those not currently in paid work (Table 1.3).

All participating households were offered the same set of three SHTs. Each set of SHTs fulfilled three criteria: (1) they were commercially available; (2) they were functional, reliable and allowed the research team access to data; (3) they offered a range of smart home services including energy management, security and home monitoring, and automated and remote control of devices. These criteria ensured that the data generated on how SHTs were used in situ were representative of current smart home market developments. Multiple SHT systems were used to span a range of functionality. Although this created inter-operability risks, multiple systems performing specific tasks arguably mirrors the real-life experience of 'piecemeal' smart home installations (Edwards and Grinter 2001).

The three SHT systems installed in participants' homes during the SHT field trial were:

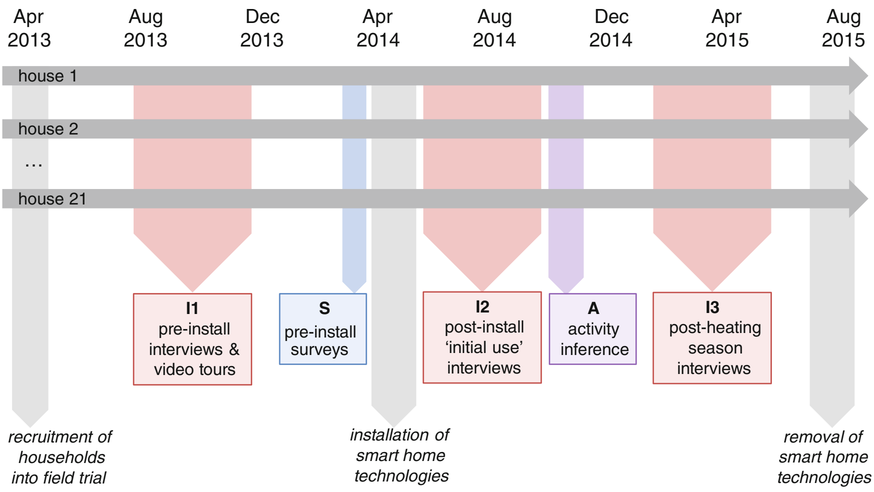

Fig. 1.2 Timeline of data collection during SHT field trial as part of the REFIT project

(i) *RWE Smart Home*: The *RWE* system provided monitoring and control functions for individual space heating radiators and home security. *RWE Smart Home* controllers were connected to each house's broadband router to allow the remote control of smart devices and the activation of automation 'profiles'. Each house was given up to 10 smart radiator thermostats, six door and window sensors, four motion sensors, an alarm/smoke detector, three room thermostats, two wall-mounted switches (which could be configured to activate any profile or combination of profile) and a remote control (which could be configured in the same way as the wall-mounted switches).

(ii) *British Gas Hive*: The *Hive* system allowed users to set up to six heating and hot water schedules per day (e.g., between the hours of X and Y to ensure a temperature of Z). It also allowed users to configure reminders based on their location (e.g., turn the heating off when arriving at work). One difference between the *Hive* and *RWE* systems is that the *Hive* system controlled the heating system as a whole and did not allow users to distinguish between different rooms or zones within the house. The *Hive* system was incompatible with some boilers so was only installed in 14 homes.

(iii) *Vera Z-Wave*: The *Vera* system provided households with real-time feedback on electricity use as well as the ability to control up to four electric appliances via smart plugs. The system also enabled the automation of these four appliances through either time, event or rule-based profiles. The *Vera* system could be remotely accessed and controlled via an online interface.

Table 1.3 Participants in SHT field trial as part of the REFIT project

House ID[a]	Household size	Age of household members	Occupation of household members
House 1 (H1)	2	55–64	University administrator
		65–74	Retired health visitor
House 2 (H2)	4	25–34	Technical specialist
		35–44	Full-time mother
		Under 18	Pre-school
		Under 18	Pre-school
House 3 (H3)	2	55–64	Semi-retired mechanical engineer
		65–74	Retired homemaker
House 4 (H4)	2	55–64	Retired IT sales support consultant
		55–64	Retired university administrator
House 5 (H5)	4	45–54	Senior IT developer
		45–54	Senior lecturer
		Under 18	At school
		Under 18	At school
House 6 (H6)	2	45–54	Retired IT manager
		55–64	Semi-retired social work tutor
House 7 (H7)	4	35–44	Electronics and software engineer
		35–44	Health visitor (on maternity leave)
		Under 18	Pre-school
		Under 18	Pre-school
House 8 (H8)	2	65–74	Retired greengrocer
		75–84	Retired
House 9 (H9)	2	55–64	Company director
		55–64	Company director
House 10 (H10)	4	35–44	Retail manager
		35–44	Homemaker
		Under 18	Pre-school
		Under 18	Pre-school
House 11 (H11)	1	65–74	Retired
House 12 (H12)	3	55–64	Technical
		45–54	Professional
		18–24	Student
House 13 (H13)	4	25–34	Control engineer
		25–34	Teacher
		Under 18	Pre-school
		Under 18	Pre-school

(continued)

Table 1.3 (continued)

House ID[a]	Household size	Age of household members	Occupation of household members
House 14 (H14)	Dropped out of trial		
House 15 (H15)	1	45–54	Community nurse
House 16 (H16)	6	45–54	Product manager—automation
		45–54	IT accounts manager
		18–24	Student
		Under 18	At school
		Under 18	At school
		Under 18	At school
House 17 (H17)	3	55–64	Researcher
		55–64	Care assistant
		Under 18	At school
House 18 (H18)	2	65–74	Retired textiles engineer
		65–74	Retired IT support
House 19 (H19)	4	45–54	Analyst programmer
		35–44	Not in paid work
		Under 18	At school
		Under 18	At school
House 20 (H20)	3	55–64	IT process analyst
		55–64	Homemaker
		25–34	Student
House 21 (H21)	4	35–44	Speech therapist
		25–34	IT product manager
		Under 18	At school
		Under 18	At school

[a]Houses were numbered sequentially from H1–H21. House 14 dropped out of the trial, so House 21 was recruited to ensure a sample size of 20

Each SHT system had its own user interface which was accessible via an internet-connected computer, smart phone or tablet app. Each SHT system also offered a range of control options including:

- time profiles in which devices could be switched on or off between specified times (*RWE*, *Hive*, *Vera*);
- event profiles in which an event (e.g., touching a remote control button) could trigger pre-specified outcomes (*RWE*, *Vera*);
- rule profiles in which participants could establish rules (e.g., ‘if door/window is open, turn radiators on/off’, or ‘if motion detected, trigger alarm’) (*RWE*, *Vera*).

Collectively, the three SHT systems installed as part of the SHT field trial provided a wide range of control and automation possibilities for heating, hot water, electrical appliances and security systems.

Figure 1.2 provides an overview of the SHT field trial as part of the REFIT project, and the points at which datasets analysed in this book were collected. These are explained further in relevant chapters but are summarised here as:

- pre-install survey of perceived benefits and risks of SHTs (45 individual members of 18 households); see S in Fig. 1.2, and Chap. 3 for details.
- one-month of real-time electricity data captured by smart meters, plug monitoring and *Vera* systems, and then disaggregated to the appliance level (10 households); see A in Fig. 1.2 and Chap. 4 for details.
- interview and video ethnography data before installation of SHTs (20 households), and interview data after installation of SHTs (10 households); see I1, I2 and I3 in Fig. 1.2 and Chaps. 5 and 6 for details. To manage exposure to the research team, the 20 households participating in the SHT field trial were divided into two groups of 10 for post-installation research: one group of 10 took part in successive in-depth interviews on SHT usage (reported here); the other group of 10 participated in design-focussed activities on retrofit decision support (Kane et al. 2015).

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Chapter 2
Analytical Framework for Research on Smart Homes and Their Users

Abstract Through a systematic analysis of peer-reviewed literature, this chapter takes stock of the dominant research themes on smart homes and their users, and the linkages and disconnects between these themes. Key findings within each of nine themes are analysed in three groups: (1) views of the smart home—functional, instrumental, socio-technical; (2) users and the use of the smart home—prospective users, interactions and decisions, using technologies in the home; and (3) user-related challenges for realising the smart home—hardware and software, design, domestication. These themes are integrated into an analytical framework that identifies the presence or absence of cross-cutting relationships between different understandings of smart homes and their users. This analytical framework serves to organise, link, and integrate the empirical analysis in Chaps. 3–6 of the book. More broadly, the analytical framework shows how research on smart homes and their users can benefit by exploring and developing cross-cutting relationships between research themes and traditions.

2.1 Introduction and Key Questions

Interest in smart homes has risen rapidly over the past 10 years (Fig. 2.1a). Published research on smart homes and their users is also expanding. Yet analysis of reports, studies, websites, and promotional material produced by smart home technology developers and service providers reveals a notable absence of user-focused research (Hargreaves and Wilson 2013). A clear understanding of who smart home users are and how they might use smart home technologies is missing from a field being strongly pushed by technology developers (Haines et al. 2007).

In this chapter we ask two related questions:

Q1 What are the main themes of scientific research on smart homes and their users?

Q2 What are the linkages and disconnects within research on smart homes and their users?

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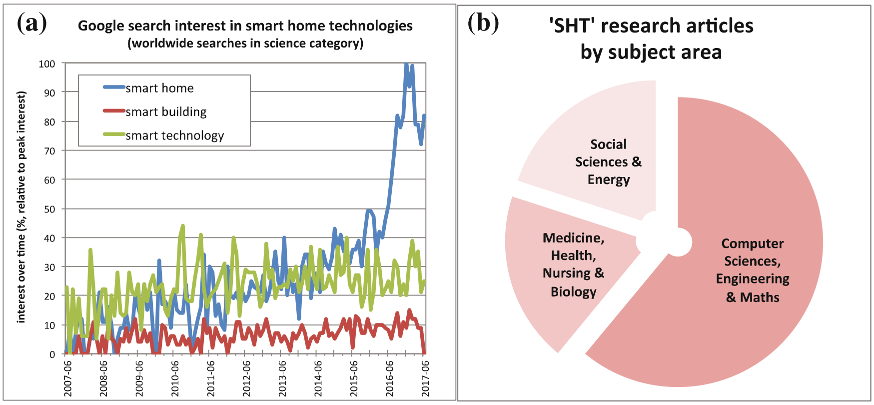

Fig. 2.1 Interest in SHTs over time and peer-reviewed SHTs research (Notes: Left panel shows rising interest in smart homes based on Google search; Right panel shows disciplinary classification of 150 scientific publications on smart home users)

To answer these questions, we analyse peer-reviewed scientific literature to identify the dominant themes, emphases and arguments on the users and use of smart home technologies (SHTs). This enables us to develop an analytical framework for research on smart homes and their users. We then show how the framework helps to identify cross-cutting linkages as well as disconnects between research themes. In subsequent empirical chapters (Chaps. 3–6) we use the framework to organise and inter-link our new data and analysis on smart home users. In this way, we demonstrate the framework's purpose: to bring coherence and comprehensiveness to an important and growing field of research.

2.2 Research Themes

The starting point for our analytical framework was to identify existing themes in research on smart homes and their users. We conducted a systematic literature review and thematic analysis of academic publications that explicitly address "smart homes" and "users". Specifically, we searched the Scopus database using the search string 'Smart' AND 'Home' AND 'User' AND 'Technology' and included a total of 23 synonyms and variants (e.g., 'Residen*' and 'Hous*' in lieu of 'Home', with the *capturing different possible word endings, e.g., 'House', 'Housing'). For further details on the search protocol, see Wilson et al. (2015).

After screening out spurious hits including articles on smart homes that did not focus on users either directly or by inference, we identified a final sample of 150 peer-reviewed articles. These articles either explicitly investigated prospective or actual users of smart homes, or implicitly considered users through inferences on the usability, design, or attractiveness of smart home technologies. Using the Scopus disciplinary classifications, we classified this set of 150 articles by discipline (Fig. 2.1b). Engineering and computer sciences dominated (61%) with the remainder split evenly between health-related disciplines (19%) and the social sciences and energy studies (20%).

From the 150 peer-reviewed articles analysed, we identified nine inter-related themes of research and the key findings within each (see Wilson et al. 2015 for details of the thematic analysis). We organised these under three groups or meta-themes: views and visions of the smart home; understandings of users and the use of smart homes; and user-related challenges to the realisation of smart homes.

The first set of research themes describes three views or 'grand narratives' of the smart home future. These views provide the context and underlying rationale for industry activity and scientific research. They offer different and at times competing visions or interpretations of what smart homes are and what they are for.

1. Views of the smart home
   - (i) functional view
   - (ii) instrumental view
   - (iii) socio-technical view.

The second set of research themes relate specifically to the users and use of smart homes. They begin with basic questions about who smart home users are, and what specific characteristics they have. They then extend to different views of the form, frequency, and function of user interactions with SHTs.

2. Users and the use of the smart home
   - (i) user needs and wants
   - (ii) user-technology interactions
   - (iii) homes as complex places.

The third set of themes turns to the principal challenges for realising the smart home in the near-term future, distinguishing hardware and software development issues from design and usability challenges. More fundamental questions are also asked about the users of SHTs amidst the complex and irregular rhythms and patterns of everyday life in the home.

3. Challenges for realising the smart home
   - (i) hardware and software
   - (ii) acceptability and usability
   - (iii) domesticating technologies.

In the next sections we explain each of these themes in more detail, drawing out relevant literature which represents the main arguments and findings.

2.3 Views of the Smart Home

The first meta-theme of research on smart homes and their users is concerned with the views, visions or 'grand narratives' of a smart home future. Why is the smart home a growing and potentially important field of research and development? Three broad views are evident in the literature: a functional view, an instrumental view, and a socio-technical view. The *functional* view sees smart homes as a way of better managing the demands of daily living through technology. The *instrumental* view emphasises smart homes' potential for managing and reducing energy demand in households as part of a wider transition to a low carbon future. The *socio-technical* view sees the smart home as the next wave of development in the ongoing electrification and digitalisation of everyday life.

The functional view

Proponents of the functional view argue that extending and integrating the functionality already provided in homes by a range of information and communication technologies (ICTs) will contribute to 'better living' (e.g., Friedewald et al. 2005; Park et al. 2003). Much of the technologically-oriented literature on smart homes presents their benefits for end users as both obvious and manifold: comfort, security, scheduling tasks, convenience through automation, energy management and efficiency; and for specific end-users, health and assisted living (Cook 2012; Rashidi and Cook 2009). Balta-Ozkan et al. (2013) group these benefits in three categories: lifestyle support, energy management, and safety.

User-centric research clearly emphasises the enhancement of existing services not the provision of new ones: "the point of technology is not to replace experiences that we already enjoy today with our families … (but to) support or enhance experiences you already enjoy … but in new ways" (Heath and Bell 2006, p. 258). As examples, smart homes can deliver better-connected workspaces (Chae and Kim 2011), enhance existing televisions through interactivity (Bernhaupt et al. 2008), and even help overcome digital divides by including elderly and other households currently marginalised from the information society (McLean 2011).

The functional view points to a wide variety of tasks and activities that smart homes could help people achieve: remotely controlling specific appliances, improving memory and recall through automated reminders, enhancing security through simulated occupancy when homes are empty, and so on (Cesta et al. 2011; Demiris et al. 2004, 2008; Orpwood et al. 2005; Park et al. 2003). These correspond in broad terms with users' perceived needs for improved comfort, convenience, security, and entertainment (Aldrich 2003).

The most clearly resolved functional view of 'better living' is articulated by researchers in the health and social care domain. Here, smart homes can "contribute to the support of the elderly, people with chronic illness and disabled people living alone at home … (by improving) the quality and variety of information transmitted to the clinician" (Chan et al. 2009, p. 93). This decision-support functionality is centred on monitoring through wearable, implantable, and sensing devices to facilitate preventative care and detect adverse health incidents (Chan et al. 2008). Other health researchers examine specific vulnerabilities, such as individuals living with serious mental illness, emphasising that caregivers rather than individuals are often the direct beneficiaries (Giger and Markward 2011).

The instrumental view

A more clearly instrumental or goal-oriented view of smart homes emphasises their roles as the means towards a defined end of energy demand management, with associated benefits for households, utilities, and policymakers (Darby 2017). The aims of households trying to save money and energy align with the efforts of utilities trying to improve energy system management and the objectives of policymakers pursuing greenhouse gas emission reductions and a secure, affordable, reliable energy supply. The instrumental view sees the smart home as a technological contributor to a low-carbon energy transition (e.g., Lewis 2012; Martiskainen and Coburn 2011) or sustainability more generally (Chetty et al. 2008). As Wilhite and Diamond (2017) argue: “smart homes are grounded in the thinking that efficiency, optimization, standardization and automatization are the keys to reducing residential energy use.” This instrumental purpose of smart homes is consistent with research in the commercial and institutional sectors on smart or ‘intelligent’ buildings with automated energy management systems (BPIE 2017b; Bull et al. 2013; Wong et al. 2005).

The SHTs most relevant to the instrumental view are smart meters, smart energy-using appliances, and energy management functionality to enable user control and programmed optimisation of appliance use and micro-generation (Paetz et al. 2012; Tiefenbeck 2017). Energy smart homes thus encourage a transformation of passive end users into ‘micro-resource managers’ (Strengers 2011, p. 227; see also Geelen et al. 2013) and a transformation of homes into ‘dynamic micro-energy hubs’ (BPIE 2017a). Personalised, tailored and real-time information and feedback on energy use (and tariffs) via smart meters and in-home displays helps to ‘make energy visible’ (Hargreaves et al. 2010; Wallenborn et al. 2011). Smart technologies also open up a suite of options for household energy management that were not possible under previous ‘dumb’ systems of monthly feedback via energy bills. Smart homes, this view suggests, will enable energy to be cut, trimmed, switched, upgraded, or shifted (Pierce et al. 2010).

However, demonstrated energy savings from the use of SHTs in studies or field trials are relatively small. Large-scale trials of smart meters and in-home displays in the UK demonstrated around 3% energy reductions on average (AECOM and OFGEM 2011). Potential savings (or ‘shaving’) during peak times can be more pronounced (Darby 2006; Davis et al. 2013; Wood and Newborough 2003). But households’ appetite or capacity for reducing energy bills in response to information feedback and price incentives appears limited, and interest in information and price signals rapidly wears off (Hargreaves et al. 2013; van Dam et al. 2010).

Energy utilities are key proponents of the instrumental view but are interested less in household-level energy savings and more in the rollout of smart meters. These will provide utilities with real-time information on both supply and demand distributed across the millions of nodes of the distribution network (Palensky and Kupzog 2013). Linked in-home displays communicating usage and cost information to end users enable utilities to charge for electricity at its marginal cost, providing a price signal to shift or curtail demand when supply is expensive or in short supply (Allcott 2011; Herter et al. 2007). Individual homes are thus integrated into wider 'smart grids', with considerably improved energy management functionality for utilities, and potential efficiency gains with associated financial and environmental benefits (Paetz et al. 2012). This utility-driven instrumental view is already strong in the US (e.g., Davis et al. 2013; Enright and Faruqui 2012) and is also a central part of the rationale behind smart meter rollouts and smart grid development in the EU (e.g., Christensen et al. 2013; Darby 2010).

The socio-technical view

The functional and instrumental views dominated the literature reviewed, but a third 'socio-technical' perspective on smart homes was also evident. Rather than focussing on the specific functions smart homes can offer or seeing smart homes as useful tools to realise broader energy objectives, the socio-technical view sees smart homes as simply the latest episode in the coevolving relationship between technology and society. The socio-technical view emphasises how the use and meaning of technologies will be socially constructed and iteratively negotiated, rather than being the inevitable outcome of assumed functional benefits (Axsen and Kurani 2012; Strengers 2013).

Røpke and colleagues contextualise "the pervasive integration of ICT into everyday practices" (Røpke et al. 2010, p. 1771) as part of what they call the 'third round of household electrification'. Building on Schwartz-Cowan's (1983) seminal work on the 'industrialisation of the home', they see the electrification and digitalisation of the home as the latest round of socio-technical change. Previous rounds involved lighting (early 1890s) and power and heating (1940s–1970s). The core technology of the current round is the micro-chip, which has enabled the creeping digitalisation of almost all aspects of everyday life.

Technology developers' visions nourish this socio-technical interpretation. Park et al. (2003), for example, sketch out working prototypes for smart pens, pillows, dressing tables, doormats, picture frames, sofas, walls, windows and so on, with a correspondingly broad array of services, from remembering, reminding, smelling, lighting, recognising, sounding, connecting and reinvigorating. Taylor et al. (2007) emphasise the potential for almost all 'surfaces' (doors, walls, bowls) to become 'smart' digital displays in an 'ecology of surfaces' with and through which users interact. Even in the health domain with its more overt surveillance and monitoring function over vulnerable household members, SHTs are to be "embedded seamlessly in the everyday objects of our lives" (Hussain et al. 2009, p. 539).

The socio-technical view of smart homes is distinctive in arguing that such technological developments always, and necessarily, co-evolve with broader and longer-term societal changes that may include indirect and unintended consequences. Smart homes are important and interesting precisely because of these potentially transformative but as yet unknown effects (Strengers 2013). The activities constituting everyday life at home may be combined or scheduled in new ways (Nyborg and Røpke 2013). Differentiated identities and gender roles associated with activities such as housework and leisure may be reinforced or destabilised (Berg 1994; Richardson 2009). SHTs may also change how householders understand, experience, and construct meaning around their homes and domestic life more generally (Baillie and Benyon 2008; Davidoff et al. 2006; Strengers and Nicholls 2017).

2.4 Users and the Use of Smart Homes

The second meta-theme of research on smart homes and their users is concerned with understanding who the users are, and how they use SHTs. User-oriented studies in smart home environments are notable exceptions rather than the rule (e.g., Paetz et al. 2012). Current understanding and representation of *actual* smart home users is based largely on inference from research with *prospective* smart home users. Within this body of research, there are three important themes: (i) who prospective users of smart homes might be; (ii) how these users might interact with and make decisions about SHTs; and (iii) how broader conceptualisations of the home as the adoption environment for SHTs conditions both users and use.

The needs and wants of smart home users

There are few specific and differentiating characteristics of smart home users identified in the literature. The major exception is in smart homes for assisted living which emphasises active ageing and independence, self-determination and freedom of choice, and changing and inter-dependent needs of an ageing population (Friedewald et al. 2005; McLean 2011). Specific needs of elderly smart home users include easily accessible contact with emergency help, assistance with hearing or visual impairments, and automatic systems to detect and prevent falls (Beringer et al. 2011; Cesta et al. 2011; Demiris et al. 2004, 2008; Hoof et al. 2011). Vulnerable users in assisted living smart homes comprise more than just the elderly. Chan et al. (2008), for example, highlight the potential for smart homes to incorporate wearable and implantable devices that can monitor various physiological parameters of patients. Giger and Markward (2011) focus on those with serious mental illness. Orpwood et al. (2005) highlight the specific user-interface requirements of dementia sufferers.

Beyond these specific characteristics of health-related users, the identities of prospective smart home users have to be inferred. In the functional view of SHTs, technophile users are attracted to an ICT-enhanced lifestyle, and the potential for control and automation offered by the smart home (e.g., Cook 2012; Park et al. 2003). According to the instrumental view, users are information and price-responsive, and broadly rational in seeking to manage domestic energy use (e.g., Darby 2010; Lewis 2012). A small number of articles imply another type of user: the incremental home improver. The development of modular, affordable and accessible SHTs enables their incorporation into existing as well as new-build homes. Potential users may therefore include low and middle income households, as well as high income technophiles (e.g., Martiskainen and Coburn 2011). A final type of prospective user, prevalent in the more socio-technical studies reviewed, identifies women, children and families rather than unitary households or individual users (Davidoff et al. 2006). Richardson (2009) and Berg (1994), for example, emphasise that women and children will be smart home users as well as men and therefore that distinct gender roles and identities should be recognised during technological design and development.

These types of prospective smart home user—elderly or vulnerable householders, rational energy users, technophiles, home improvers, and differentiated families—are not exclusive. Whether collectively they constitute a strong market potential for SHTs is an open question which we address more fully in Chap. 3. Some researchers are circumspect: “If the history of research into this area attests to anything, it is the narrowness of the appeal of smart homes to a wider population” (Taylor et al. 2007, p. 383).

User interactions with smart home technologies

Users must interact or interface with SHTs in some way. These interactions can be more or less frequent, and more or less active (e.g., Herczeg 2010). In an influential depiction of the smart home, Cook (2012) reduces user interactions with smart home systems to one-off goal-setting: “computer software playing the role of an intelligent agent perceives the state of the physical environment and residents using sensors, reasons about this state using artificial intelligence techniques, and then takes actions to achieve specified goals, such as maximizing comfort of the residents” (Cook 2012, p 1579). Users are interpreted as having fixed and stable needs and preferences that homes, rather than the users themselves, can manage optimally. Smart homes as intelligent and context-aware learning systems remove the need for any active user involvement by automating functions according to users’ revealed habits (e.g., Das et al. 2002; Ma et al. 2005; Saizmaa and Kim 2008).

These visions of intelligent homes are countered by the complexity, potential inflexibility and poor manageability of fully automated smart homes that are cited as key barriers to their adoption (Balta-Ozkan et al. 2013; Bernheim Brush et al. 2011). A long-standing irony in human-computer interactions is that “the more advanced a control system, the more crucial may be the contribution of the human operator” (Bainbridge 1983, p. 775). End users rate automation as a desirable feature of smart homes, but this is qualified by calls for automation to be strictly limited to chains of functions that users can program or set up themselves: “computers should not make choices for users, but the other way around” (Koskela and Väänänen-Vainio-Mattila 2005, p. 240). An important role of the smart home is to provide useful information to users about various aspects of household functioning (e.g., room temperatures or occupancy, appliance conditions, energy usage) in an effort to help them make more informed choices and decisions.

User interactions with SHTs might therefore range from a one-off input of preferences for the domestic environment (‘set-and-forget’) to ongoing, repeated, and adaptive decision-making and control. This latter possibility leads to a small strand of research focussed on how users make decisions about SHTs. The instrumental view assumes users respond rationally to improved feedback, information, and price signals (Tiefenbeck 2017; Wood and Newborough 2003). Alternative framings of domestic decision-making have emphasised its emotional, negotiated and pragmatic character. Friedewald et al. (2005), for example, recognise users as being 'emotional' and having moods, as holding cherished ideals, and as valuing communication and interactions with people. Such characteristics orient decisions about the use of SHTs very differently from preferences for minimising energy costs. The domestic environment is also characterised by 'co-presence', meaning one individual's goals and preferences may not be shared by others and so must be pragmatically negotiated (see also Haines et al. 2007; Hargreaves et al. 2010).

Homes as complex places: Characterising the 'home' in smart homes

Within much of the technologically-focussed literature on smart homes, the domestic environment is simply the 'taken for granted' backdrop within which technology will be used (Richardson 2009). In their content analysis of smart home marketing materials, Hargreaves and Wilson (2013) found that most images of smart homes depicted them as sterile, bland and neutral spaces that appeared unlived in. Such depictions are unsurprising given that much of the technological research and testing of SHTs occurs in artificially constructed test homes or living labs (e.g., Chan et al. 2008). These are little more than "a set of walls and enclosed *spaces*" (Taylor et al. 2007, p. 383 our emphasis). A more complex understanding of homes sees them as internally differentiated, emotionally-loaded, shared and contested *places*.

Ethnographic and sociological research on the use of ICTs in domestic contexts finds homes are actively divided by their occupants into functionally and interpretively distinct places. Communication technologies tend to be used and stored in different places within the home for quite different purposes (Crabtree and Rodden 2004). These places may be 'ecological habitats' (where communication media is kept), 'activity centres' (where media is produced, consumed and transformed) or 'coordinate displays' (where media is displayed and made available to others in order to coordinate activities). All these places play significant roles in the flow and communication of information within homes. The spatial layout of specific technologies also actively divides up homes, with certain activities being undertaken in particular places (e.g., Baillie and Benyon 2008; Heath and Bell 2006; Venkatesh et al. 2003). Swan et al. (2008) also note that forms of mess and 'clutter' are an active if idiosyncratic and often ambiguous part of how people organise, construct and generate meaning within the home. Instead of trying to make homes ordered, clean and efficient, therefore, designers might consider how SHTs could help create uncertainty within homes to become part of the perpetual project of organising and constructing homes as distinct and unique places (Swan et al. 2008). These forms of meaning making and internal differentiation within homes matter for how, where, how often, and by whom SHTs are likely to be used.

Domestic environments can also be emotionally charged. Haines et al. (2007) identified the importance of memories and relationships in a study of what end users might value in smart homes. Baillie and Benyon (2008, p. 227) similarly argue that “homes are places loaded with emotion, meaning and memories”. SHTs will not serve solely functional purposes, but will be used and understood within broader and pre-existing household ‘moral economies’—the unique sets of values, routines and practices that underpin domestic life (Silverstone et al. 1992; Takayama et al. 2012).

Moreover, although households may be a convenient unit of analysis, families are plural (e.g., Davidoff et al. 2006). Homes must be understood as shared and contested places in which different household members may have different understandings, preferences, rights, responsibilities and emotional associations (Nyborg 2015). Richardson (2009), for example, focuses attention on the gendered nature of technology use (see also Berg 1994). She illustrates how technologies are often designed in ways that fail to respond sufficiently to how women as opposed to men and children use domestic spaces. Baillie and Benyon (2008) further distinguish between more active users—who set and enforce the rules for technology use at home—and more passive users who comply with (and at times resist) these rules (see also Mennicken et al. 2014).

2.5 User-Centred Challenges for Realising the Smart Home

The final meta-theme of research on smart homes and their users is concerned with the challenges of realising the smart home future. SHTs are not yet widespread despite apparent consumer demand (GfK 2016). The technical literature that dominates smart home research (Fig. 2.1b) identifies the key technological challenges and design challenges to be overcome. These two sets of challenges are in line with the social barriers to the adoption of smart homes identified in public deliberative workshops by Balta-Ozkan et al. (2013): loss of control, reliability, privacy, trust, cost. But there is also a third set of challenges that more explicitly situates users in the adoption environment of the home, and examines how and whether SHTs may be effectively domesticated.

Hardware and software: Developing smart home technologies for users

SHTs require extensive research, development, testing, and trialling before their widespread commercialisation becomes a realistic prospect. Key technical issues identified by Cook (2012) include: (1) monitors and sensors that can reliably detect and sense what is going in the home; (2) algorithms that can accurately infer activities and patterns from the resulting abundance of data; (3) interoperability and retrospective compatibility of SHTs, supported by well-designed and flexible standards; (4) functional reliability and manageability (Cook 2012). The salience of these technological challenges varies widely depending on technology developers' underlying vision for the smart home.

For Friedewald et al. (2005), reliability is the central challenge as this attribute will underpin user-friendliness and empowerment. Smart homes must neither fail nor do unpredictable things. Edwards and Grinter (2001) highlight several different aspects of the reliability challenge, including: debugging smart homes created 'accidentally' by technologies introduced piecemeal; administering and fixing smart homes through self-healing systems that remove the need for household or third party system administrators; and inferring occupancy activity from sensor data that may be both ambiguous and unreliable. Reliability is most important in smart homes for assisted living in which failures to sense or make inaccurate inferences about the nature of occupant behaviour could have life-threatening consequences. As Orpwood et al. (2005, p. 162) note in relation to dementia sufferers: "judgements made (on human behaviour) are always going to be probabilistic, and the designer has to incorporate means of dealing with errors, particularly in safety critical situations".

A recurring theme in research on reliability, debugging, and interoperability of SHTs is the importance of 'future proofing' to ensure compatibility both between successive generations of SHTs as well as between interacting components. Modularity, flexibility, and retrospective compatibility are frequently cited as necessary technological attributes (e.g., Perez et al. 2011). Future proofing also insulates SHTs from changes in regulatory frameworks, standards, and policy objectives, particularly in the energy domain (Martiskainen and Coburn 2011).

Acceptability and usability: Designing smart home technologies for users

The acceptability of smart homes to users is closely linked to issues of security, privacy and trust as well as practical and ergonomic concerns with user-friendliness. These issues present critical design challenges for how users interact with SHTs.

With respect to security, for example, Cook observes that "many individuals are reluctant to introduce sensing technologies into their home, wary of leaving digital trails that others can monitor and use to their advantage, such as to break in when the house is empty" (Cook 2012, p. 1578). In smart homes for assisted living, Demiris et al. (2008) similarly note user concerns with privacy. Technologies that detect and monitor activity within the home risk being seen as intrusive violations in the domestic environment. For energy smart homes, concerns around both data security and the potential for utilities to monitor or even control household demand have led to consumer backlashes against smart metering (AlAbdulkarim and Lukszo 2011; Darby 2010). In the UK, a study on attitudes and values towards energy-system change found general support for the development of smart homes, but with caveats around data sharing and a perceived loss of control through remote interference by utilities (Parkhill et al. 2013). Paetz et al. (2012) report similar findings from Germany.

How smart homes are designed will condition their acceptability to prospective users. Cook (2012) advocates for clearly defining and guaranteeing levels of privacy and the safety and security of technologies. Paetz et al. (2012) suggest the need for much greater levels of transparency and accountability on behalf of smart home developers—particularly energy utilities—and the need to be explicit about how all stakeholders may benefit from smart home development.

Several other studies highlight more narrowly-framed design challenges regarding the user-friendliness of smart homes. Park et al. (2003, p. 189), for example, outline the immense variety of potential smart applications but caution against 'overpowering' users with 'complex technologies'. Several studies have highlighted the difficulties of creating intuitive and easy-to-use user-interfaces given the level of complexity and number of user-control options that can potentially lie behind the interface (e.g., Demiris et al. 2004; Koskela and Väänänen-Vainio-Mattila 2005; Park et al. 2003).

User-centred design is widely cited as an appropriate response to smart home design challenges. Rohracher (2003) argues that many issues might be avoided through more participatory approaches to design. He suggests engaging with a wide range of different stakeholders even at the visioning stage for SHTs to ensure the widest possible range of interests and concerns are recognized and addressed. Orpwood et al. (2005) identify a number of simple design solutions that could help overcome specific difficulties faced by dementia sufferers, including wariness of new devices and forgetfulness. By working with carers, researchers could identify simple and often low-tech solutions such as making devices look familiar, concealing them from view so as to avoid causing alarm, and providing prompts and reminders rather than taking control away from users. Different groups of users are likely to require different design solutions, not just between households but also between cultures. Jeong et al. (2010), for example, reveal stark differences in the understanding of control functionality between US and Korean smart home users.

Domesticating technologies: Situating smart home technologies amid everyday life at home

"More than control of their devices, families desire more *control over their lives*" (Davidoff et al. 2006, p. 20 emphasis in original). A core user-related challenge for the realisation of smart homes is to align and adapt technologies with the messy and differentiated nature of users' everyday lives at home (Herczeg 2010).

New technologies are rarely used in homes in the ways their designers intend because they must always enter pre-existing environments that are contested, emotionally-charged and dynamic (e.g., Heath and Bell 2006). These environments already possess their own 'smartness' or 'intelligence' in the way, for example, that households manage communications (Crabtree and Rodden 2004), make use of surfaces such as tables or fridges (Taylor et al. 2007) or organise the flow of clutter and mess through the home (Swan et al. 2008). SHT development to date has assumed everyday life is made up of specific, repetitive and relatively predictable routines and schedules. But on closer examination, life at home is "organic, opportunistic and improvisational" (Davidoff et al. 2006, p. 19).

This generates new sets of design principles for SHTs that support users in managing everyday life. Technologies should be robust to "ambiguity, instability, concealment, and disinterest, and to be treated casually" (Swan et al. 2008, p. 21). Davidoff et al. (2006) offer a set of seven principles that suggest new technologies should account for "the organic evolution of routines and plans", "periodic changes, exceptions and improvisation", "breakdowns", "multiple, overlapping and occasionally conflicting goals" and that they should "participate in the construction of family identity" (Davidoff et al. 2006, p. 28).

Unless the smart home concept is re-thought in these ways it is unlikely to succeed. Yet as Howard and colleagues caution, such principles would be "fiendishly difficult to apply to technology research" (Howard et al. 2007, p. 329). Perhaps the central user-related challenge for the realisation of smart homes is therefore not to improve the reliability or functionality of technologies, nor to design out concerns around trust, privacy or user-friendliness, but to re-define the notion of 'smart' itself, recognising that it emerges within users' everyday lives and in the ways technologies are used in the home. As Taylor and colleagues explain: "it is people who imbue their homes with intelligence by continually weaving together things in their physical worlds with their everyday routines and distinct social arrangements" (Taylor et al. 2007, p. 383).

2.6 Analytical Framework for Research on Smart Homes and Their Users

We have identified three meta-themes in the literature on smart homes and their users: (1) views or 'grand narratives' for the smart home; (2) users and their uses of smart homes; and (3) user-related challenges to realising smart homes. Within each of these meta-themes, we distinguished three distinct lines of enquiry in peer-reviewed research. These are organised in Table 2.1 into a comprehensive analytical framework for research on smart homes and their users. The 3×3 framework shows how different lines of enquiry provide contrasting answers to key research questions.

Although Table 2.1 distinguishes nine research themes grouped into three meta-themes, there is clearly much overlap. Figure 2.2 shows the main interrelationships between the nine themes identified. The strong links in Fig. 2.2 between 'functional', 'user-technology interactions' and 'hardware and software' typify the engineering and technical scientific approach. Similarly, the strong links between 'socio-technical', 'home as complex places', and 'domesticating technologies' characterise a critical social scientific approach. The solid vertical lines in Fig. 2.2 therefore represent the concerns of different research traditions and disciplines shown in the final row of Table 2.1, and of the competing perspectives and understandings within the research community.

Table 2.1 Analytical framework for research on smart homes and their users

Views of the smart home	**Functional view**	**Instrumental view**	**Socio-technical view**
What is the smart home?	A monitored, sensed environment that informs occupants allowing active control or automation	An optimally-managed building energy system allowing information and price-responsive adjustments to behaviour	A digital, technological, networked vision confronted by the mundane realities of domestic life
What is the purpose of the smart home?	Improve quality of home life through new services and enhanced functionality	Enable energy demand reduction in the home and improved system management by utilities	No inherent purpose, functions emerge as SHTs are incorporated into domestic life as part of digitalisation of homes
Users and use of the smart home	**User needs and wants**	**User-technology interactions**	**Homes as complex places**
Who uses smart homes?	Users with specific health needs or users who are price or information responsive in both existing and new-build homes	Users seeking control over the domestic environment and energy usage through flexible or schedulable behaviours	Differentiated households with negotiated roles within the distinct spaces of the home
How is smart home technology used?	Varies according to application with assisted living smart homes emphasising passive usage and energy smart homes active usage	From continuous and active user-mediated control to passive one-off 'set and forget'	A gradual and adaptive process of domestication into the existing dynamics of routines and practices
Challenges for realising the smart home	**Hardware and software**	**Acceptability and usability**	**Domesticating technologies**
How can smart homes be realised?	Develop and improve technologies to ensure robustness and reliability as basis for social acceptability	Participatory co-design for user needs, address privacy concerns through clear and transparent rights and roles, and participatory co-design	Ensure technologies are adaptable to everyday domestic contexts, and allow flexibility for domestication and appropriation
What research approaches are useful?	Computer science, electrical engineering, design	User-centred design, human-computer interaction, behavioural and social psychology	Sociology, ethnography, science and technology studies, innovation studies

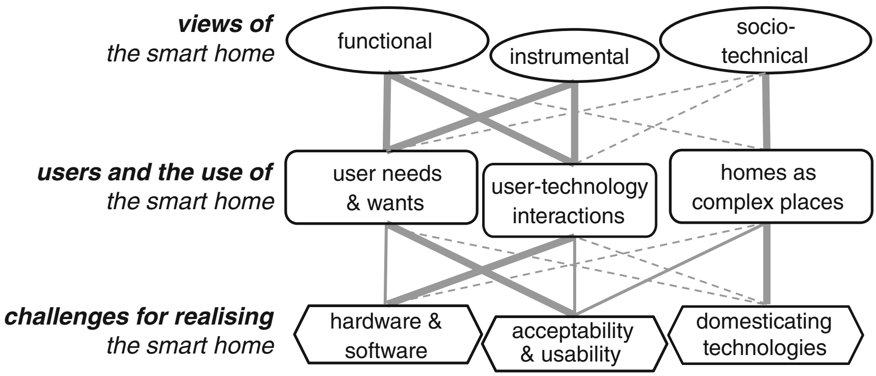

Fig. 2.2 Interrelationships between research themes on smart homes and their users (Notes: Thick solid lines = strong interrelationships; Thin solid lines = weak but explicit interrelationships; Thin dashed lines = implicit or inferred interrelationships)

The functional view of SHTs is limited to a series of technological and design challenges around how enhanced functionality can be efficiently and reliably delivered. This includes a detailed consideration of interactions between users and technology around issues such as control and automation. The instrumental view of SHTs is similarly concerned with providing for users' needs and wants but these are more tightly drawn around energy-management goals, and assume users respond to information and price signals. The socio-technical view of SHTs is strikingly different, setting up a wider and more foundational set of challenges relating to the balance between users and technologies in smart homes. This recognises the complex and contested nature of homes as places for technology adoption and use.

This coherence and consistency between the lines of enquiry identified in the vertical relationships of Fig. 2.2 has come largely at the expense of strong cross-cutting horizontal linkages between research themes. Yet as and when SHTs diffuse more widely into the fabric of everyday life at home, the functional, instrumental and socio-technical views will increasingly interact and combine, presenting more (and potentially more intractable) challenges.

The technological optimism and clarity of the functional view will confront the just-the-next-thing normality of the sociotechnical view with all its ambiguities and uncertainties. Functional service enhancements in areas such as comfort and convenience will confound the energy-management goals of the instrumental view. Smart homes may even generate more resource-intensive trajectories of socio-technical change (Koomey et al. 2013; Strengers et al. 2016). Introducing new technologies changes service expectations and use patterns. This in turn conditions users' wants and needs for new technologies and the resources they consume (Heath and Bell 2006; Nyborg and Røpke 2013).

These disconnects between research positioned within the functional and instrumental views, and research contributing to the socio-technical view are clearly shown in Fig. 2.2. Efforts to develop stronger horizontal linkages provide a clear avenue for future research. In the empirical chapters of this book which follow, we illustrate the strengths of such an approach. In Chap. 3 we ask both prospective and actual SHT users how they perceive different elements of the functional, instrumental and socio-technical views of a smart home future, focusing particularly on perceived benefits and risks. In Chap. 4 we use energy data consistent with a narrowly instrumental view of smart homes to make inferences about the complex rhythms and routines constituting domestic life. In Chap. 5 we go deeper into this socio-technical view of smart homes by examining what actual domestication trajectories of SHTs tell us about technological and design challenges for realising a smart home future. In Chap. 6 we focus on a critical issue with SHTs—control and controllability—and show how control is a multi-faceted construct which will shape the prospects of a smart home future.

2.7 Suggested Further Reading

A longer version of this chapter was published as a peer-reviewed article:

- Wilson C, Hargreaves T, Hauxwell-Baldwin R (2015) Smart homes and their users: a systematic analysis and key challenges. Personal and Ubiquitous Computing 19 (2):463-476. doi: 10.1007/s00779-014-0813-0

For other conceptual reviews of research on smart homes and users, we suggest:

- Mennicken S, Vermeulen J, Huang EM (2014) From today's augmented houses to tomorrow's smart homes: new directions for home automation research. Paper presented at the Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, Seattle, Washington, USA. doi: 10.1145/2632048.2636076
- Strengers Y (2013) Smart energy technologies in everyday life: Smart utopia? Palgrave Macmillan, New York, USA. doi: 10.1057/9781137267054

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Chapter 3
Perceived Benefits and Risks of Smart Home Technologies

Abstract This chapter characterises the perceived benefits and risks of smart home technologies (SHTs) from multiple perspectives. A representative national survey of over a thousand UK homeowners finds prospective users have positive perceptions of the multiple functionality of SHTs including energy management. Ceding autonomy and independence in the home for increased technological control are the main perceived risks. An additional survey of actual SHT users participating in a SHT field trial (see Chap. 1) identifies the key role of early adopters in lowering perceived SHT risks for the mass market. Content analysis of SHT marketing material finds that the SHT industry is insufficiently emphasising measures to build consumer confidence on data security and privacy. These multiple perspectives draw on insights from across the functional, instrumental and socio-technical views identified in the analytical framework for research on smart homes and their users (Chap. 2 and Table 2.1).

3.1 Introduction and Key Questions

The starting point for our empirical analysis of smart homes and their users is an in-depth consideration of actual and potential market demand. Do prospective users clearly see the value of SHTs? Do perceived benefits outweigh any potential risks? The market-level analysis presented in this chapter serves as a backdrop for our more in-depth household-level analysis of actual SHT users which follows in Chaps. 4–6.

In this chapter, we ask three important questions regarding the market for SHTs:

Q1 How do prospective users perceive the *specific benefits* and *risks* of SHTs?
Q2 Do *early adopters* have distinctive perceptions of SHTs?
Q3 Is industry marketing of SHTs *aligned* with the perceptions of prospective users?

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In posing these questions, we provide a user-centric perspective on two meta-themes in our analytical framework: ‘views of the smart home’ and ‘users and use of the smart home’ (see Table 2.1 and Chap. 2).

Prospective users are more circumspect about SHTs than technology developers. Previous market analysis found that “market players, industry and retailers need to collaborate to create awareness of smart homes and to communicate the features, but especially, the benefits of these systems” (Harms 2015). As discussed in Chap. 2, an instrumental view of SHTs focuses on their potential benefits for energy management. This contrasts with a functional view that emphasises a wide range of benefits including improved security and security, enhanced leisure and entertainment services, personal independence through healthcare provision and assisted living (Nyborg and Røpke 2011; Chan et al. 2009).

Within the population of prospective users, early adopters attracted by the novelty of SHTs are particularly important. Early adopters ‘seed’ market growth by trialling and testing innovations and communicating their benefits and functionality to the more risk-averse majority of consumers (Rogers 2003). The profile of potential early adopters willing to take greater risks in being the first movers to adopt SHTs is largely unknown.

Both early adopters and the wider population of prospective users are part of a constellation of interests behind smart home market development. Clear expectations shared by all these interests can take on “performative force”, stimulating and coordinating activity, fostering investment (van Lente et al. 2013), and guiding, legitimising, and reducing uncertainties with market development (Borup et al. 2006; OECD 2015). The three principal interest groups in the SHT market are users, industry (including technology developers), and policymakers. Policymakers are particularly concerned with the instrumental potential of SHTs to deliver a smart and efficient energy system (see Chap. 2). Our focus here is on users and industry, and the extent to which these key actors on the demand and supply sides share similar expectations for smart home market development.

3.2 Method and Data

We analyse three new data sources (see Chap. 1 and Fig. 1.1): a national market survey of prospective SHT users (n = 1025); an early adopter survey of SHT field trial participants (n = 45); content analysis of SHT industry marketing material (n = 62). The national survey was conducted in the UK, a major consumer market into which smart meters are currently being rolled out, and SHTs are becoming commercially available. The early adopter survey was conducted as part of the SHT field trial also in the UK (see Chap. 1 and Fig. 1.2). The content analysis of industry marketing material focused on the SHT industry active in EU markets, with a subsample of smaller UK-focused companies.

Here we provide details of the different datasets used in the analysis, the data collection instruments and sampling procedures, and the sample characteristics of each dataset. SPSS version 22 was used for all the survey data analysis. Further details on the method and samples can be found in Wilson et al. (2017).

National survey

We developed a survey instrument to measure prospective users' perceptions of the benefits, risks, and design attributes of SHTs, as well as general issues of consumer confidence in SHTs. The survey instrument was structured in two parts. Part One contained socio-demographic questions (respondent age, respondent gender, household size, household income, home tenure) and a basic question on smart home awareness used to screen respondents. The screening question was included to minimise hypothetical response biases from homeowners with no prior knowledge about SHTs. The screening question was "Do you know what 'smart home technologies' are?". Response options ranged from "no idea", "vague idea", "general idea", "good idea" to "already have some installed". Respondents answering "no idea" were screened out and did not continue the survey. All other respondents passed the screening question and moved on to Part Two.

Part Two of the survey began with an open-ended question asking respondents to provide a few words "that first come to mind when you think about 'smart home technologies'?". Respondents were then asked about the information channels through which they had found out about SHTs (six response options). The remainder of Part Two comprised detailed questions measuring perceptions of SHTs. Perceptions were measured on a 5 point Likert scale (from 1 = strongly disagree to 5 = strongly agree) with an additional "don't know" response option. Questions measuring prospective users' perceptions were ordered as follows:

- the *main purposes* of SHTs (nine response options);
- the *potential benefits* of SHTs (12 response options);
- the relevance of SHTs for specific *domestic activities* (eight response options);
- the *design features* of SHTs (seven response options);
- the *control* of SHTs (seven response options);
- the *potential risks* of SHTs (12 response options).

For each question, diverse sets of response options were included to cover the range of views of smart homes and their users identified in our analytical framework (see Table 2.1 and Chap. 2). All survey questions and response options were iteratively tested and refined for clarity and comprehensibility prior to implementation. No background information was provided to respondents at the beginning of the survey to minimise priming effects on responses. The order of response options within each block of questions was randomised to minimise potential ordering effects on responses (Choi and Pak 2005).

The survey was implemented online by a market research company, SSI (Survey Sampling International). SSI scripted an online version of the survey instrument using their proprietary software. Once checked by the research team, SSI sent unique person-specific links to the survey to individuals in their respondent panel who had previously agreed to take part in survey research in exchange for

Table 3.1 Prospective users' prior knowledge of SHTs

Do you know what 'smart home technologies' are?			
Response options	Pre-screening	Post-screening (final sample)	Groups based on prior knowledge
No idea	10.7%	-	
Vague idea	21.8%	24.4%	Low prior knowledge (= late majority)
General idea	34.0%	38.0%	Medium prior knowledge (= early majority)
Good idea	29.7%	33.3%	High prior knowledge (= early adopters)
Already have some installed	3.8%	4.3%	
	n = 1150	n = 1025	

incentives. The sampling frame for this study comprised UK homeowners over the age of 18. Survey responses were collected online by SSI from 18 September to 14 October 2015 until the minimum target sample size of 1000 was exceeded. The average survey completion time was just under 7 minutes.

The sample pre-screening comprised n = 1150 respondents (Table 3.1). A total of n = 125 respondents with "no idea" about SHTs were screened out (10.7% of pre-screening sample). This means that the final sample post-screening slightly over represents homeowners familiar with SHTs. The final sample post-screening comprised n = 1025 respondents. The average (mode) household size was two household members; respondent age and gender were distributed evenly (Table 3.2).

Respondents were grouped according to their levels of prior knowledge: low, medium, high (including respondents who already have some SHTs installed) (Table 3.1). The high, medium, low prior knowledge groups are proxies for the early adopter, early majority, and late majority market segments which have different propensities towards the adoption of new technologies (Rogers 2003). Similar segmentation based on prior knowledge has been used in the UK's consumer engagement plan for the smart meter roll-out (SMCDB 2013).

We are particularly interested in the subsample of respondents with high prior knowledge of SHTs. We label this subsample as 'potential early adopters of SHTs' (n = 385). This subsample is drawn from the full sample of respondents to the national survey which we label as 'prospective users of SHTs' (n = 1025). 'Potential early adopters' are therefore a subset (i.e., not independent) of 'prospective users' (Table 3.2).

Early adopter survey

To explore whether early adopters have distinctive perceptions of SHTs, we surveyed participants in the SHT field trial to measure their perceptions of benefits and risks. Details of the SHT field trial, data collection procedure, and sample

Table 3.2 Sample characteristics of national survey and early adopter survey

Survey sample (and sample size)		National survey (full sample, n = 1025)	National survey (subsample with high prior knowledge, n = 385)	Early adopter survey (n = 45)
Referred to in the text as		Prospective users of SHTs (%)	Potential early adopters of SHTs (%)	Actual early adopters of SHTs
Respondent age	Under 35	18.7	27.1	26.6%
	35–44	18.0	22.1	17.8%
	45–54	20.1	20.6	15.6%
	55–64	19.3	14.8	20.0%
	Over 64	23.8	15.4	20.0%
Respondent gender	Male	49.3	61.6	48.9%
	Female	50.7	38.4	51.1%
Household size	1	17.5	13.5	5.6%
	2	42.6	34.3	44.4%
	3	17.5	20.8	16.7%
	4	17.2	22.3	27.8%
	5 or more	5.3	9.1	5.6%
Household income	Under £25,000	24.1	19.5	Not known
	£25,000–£40,000	35.4	30.1	
	Over £40,000	34.2	45.5	
	Prefer not to say	6.2	4.9	

characteristics, are explained in Chap. 1 and Fig. 1.2. We label this group of respondents as ‘actual early adopters of SHTs’ (n = 45).

Through their informed consent to participate in the field trial, respondents were aware of the general characteristics of SHTs. However, the survey was implemented before any SHTs were actually installed. Up to this point the research team running the field trial had been careful to frame information about SHTs in generic terms and to minimise possible priming effects on respondents’ perceptions of SHTs benefits and risks. The survey was implemented in May–August 2014 (at least two weeks prior to SHTs being installed in participants’ homes) (see Fig. 1.2).

The survey instrument was identical to that used in the national survey with three exceptions: (1) no screening questions were included; (2) an additional block of questions on the design of SHT interfaces was included; (3) the block of questions on SHT risks was excluded to avoid unduly raising concerns among households about to have SHTs installed.

Surveys were distributed to members of the 20 households participating in the field trial. Unlike the national survey with one adult respondent per household, multiple respondents including children were sampled from the same households in the early adopter survey. The right-hand column of Table 3.2 summarises the sample characteristics. Of the 20 households participating in the field trial shown in Table 1.3, only Houses 13 and 14 did not respond to the survey.

Industry marketing material

To explore whether the SHT industry shared similar expectations for SHT market development as prospective and actual users, the content of marketing material from companies active in the smart home market was systematically analysed. Content analysis is a widely used method for characterising texts, documents, and other published material through simple quantitative descriptors such as the frequency of occurrence of a defined set of 'codes'. The codes are linked to specific words, phrases or meanings of the textual content. Recent applications in the energy domain include content analyses of online marketing by green electricity providers (Herbes and Ramme 2014), of images associated with different forms of energy production (O'Neill et al. 2013), and of the underlying dimensions of energy-related behaviours (Boudet et al. 2016).

To analyse industry marketing material on SHTs, a comprehensive set of codes was developed under three themes: design and function; users; control and management. Each of these themes comprises multiple codes capturing more specific and discrete issues raised in research on smart homes and their users (Chap. 2); see also (Wilson et al. 2015). The set of codes therefore provided a systematic basis for analysing the content of industry marketing material on SHTs.

A wide range of companies active in the smart home market were sampled from a list of participants at a major smart home industry conference, supplemented by web searches for UK-based companies. For each company, marketing materials were identified that related either to specific SHTs or to more general smart home visions. Materials included print, web, and video publications. The final sample comprised 62 companies.

The characteristics of the companies sampled are summarised in the upper half of Fig. 3.1, and the characteristics of the marketing material sampled in the lower half of Fig. 3.1. Characteristics are non-exclusive, so the totals per pie chart can exceed 62.

The majority of companies were EU-based but active in multiple markets. The majority of material analysed was text or video on company websites (n = 46) as well as brochures (n = 10). The material was much more likely to be a sales pitch advertising specific SHTs available in the market (n = 52) than a broader vision of a smart home future (n = 12). Marketing material was targeted at other businesses and at prospective users (households) in roughly equal proportions.

The sample of companies and marketing material is not designed to be representative. However it does cover different types of material from a wide range of companies active in smart home markets. We tested for associations between principal region of operation and coding results and found no associations. In other

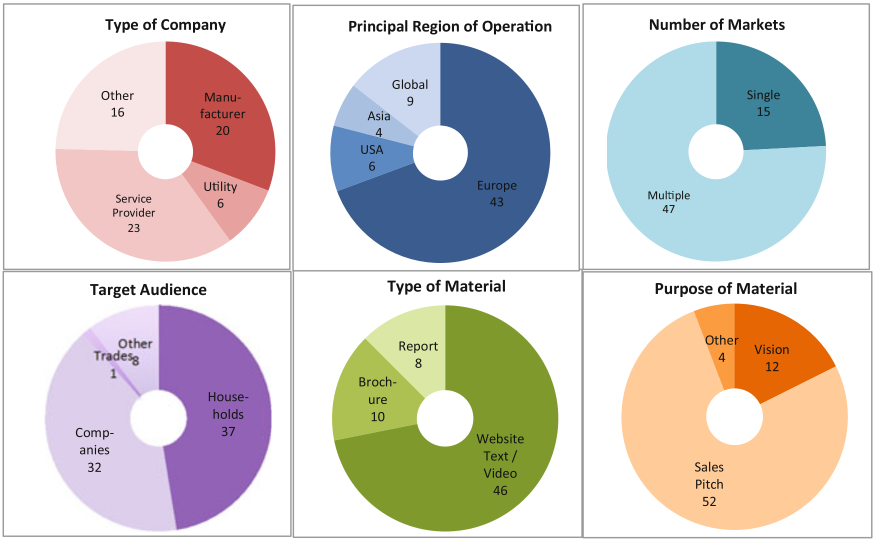

Fig. 3.1 Sample characteristics of industry marketing material (Notes: Upper three pies show characteristics of companies; Lower three pies show characteristics of marketing material; Totals that are greater than n = 62 are due to non-exclusive characteristics)

words, for our sample, the principal markets in which sampled companies were active do not affect the content of material analysed. For further details on the method and analysis, see Hargreaves et al. (2013).

3.3 Results: Prospective Users' Perceptions of Benefits and Risks

Perceived benefits

The national survey characterised how prospective users perceived benefits and risks of SHTs. Survey respondents clearly perceive the *main purposes* of SHTs to be controlling energy, heating and appliances (Fig. 3.2a, left panel). Over 86% of respondents agreed or strongly agreed with these three response options. The smart home is dominantly seen through an energy management lens. Other purposes of the smart home for making life at home more convenient (83% agree or strong agree), providing security (71%), and enhancing entertainment and communication (60%) are also clearly perceived.

The potential benefits of SHTs for prospective users are clearly related to these purposes. Respondents perceive the *potential benefits* of SHTs to be saving energy, time, and money, as well as making domestic life less effortful (Fig. 3.2b, right

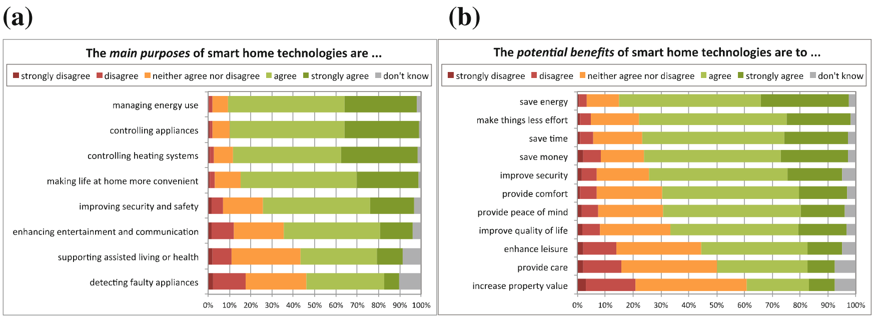

Fig. 3.2 Prospective users' perceptions of the purposes and benefits of SHTs

panel). Again, there is overall agreement for all response options with response means exceeding the midpoint of the response scales.

Perceived functionality

Questions on the design and control of SHTs were included in the survey to understand how prospective users perceive SHTs affecting domestic life. Control over the domestic environment is the principal purpose of SHTs (Fig. 3.3), and how control is exercised and by whom depends on the design of SHT interfaces and devices. Respondents perceived their role as controllers of SHTs in both active and passive ways (Fig. 3.3a, left panel). SHTs enable control *by* households, but also automate control *for* households, although always running in the background. Respondents similarly perceive SHTs both to be *always on* and active, and to operate *only when activated*. In both cases these apparently contradictory modalities of control and operation indicate the multiple ways in which SHTs can be configured. Prospective users have clear perceptions of how SHTs are controlled on a day-to-day basis: through a combination of pre-set scheduling, automated responses, and user inputs or adjustments; using multiple not single devices; and by multiple not single users (Fig. 3.3b, right panel).

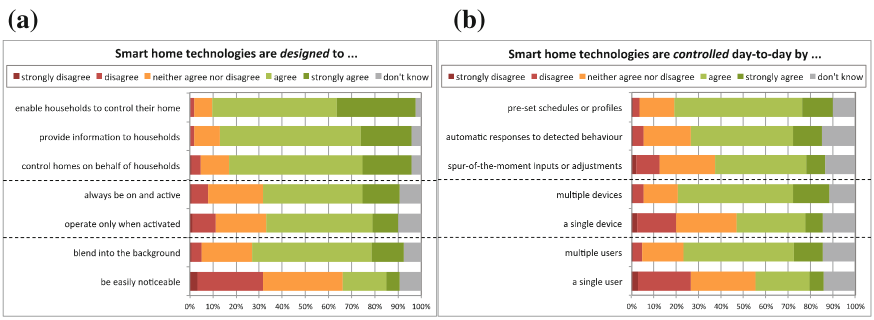

Fig. 3.3 Prospective users' perceptions of the design and control of SHTs

An additional question in the survey asked about the *domestic activities* most likely to be affected by SHTs. Activities included cooking, cleaning, washing, leisure, socialising, or working. Responses were extremely similar overall. Respondents weakly agreed that all activities were of similar relevance, and were unable to distinguish particular aspects of domestic life that would be made more convenient, easy, or comfortable. Our interpretation of these results is that prospective users have not considered in any detail how SHTs might be assimilated into everyday life in their homes. This highlights the importance of research on the domestication of SHTs into the home as a complex adoption environment (Table 2.1); see also Chap. 5.

Perceived risks

Prospective users also perceive risks associated with SHTs (Fig. 3.4a, left panel). However despite public and media attention on monitoring, privacy and data security issues with smart technologies in the home, much broader issues are of greater concern. Prospective users of SHTs more strongly perceive *potential risks* in the increasing dependence of domestic life on systems of technology provision (77% agree or strongly agree) and electricity networks (63%) (Fig. 3.4a, left panel). The benefits of increased control over the domestic environment come at the expense of reduced autonomy and independence of the home from encompassing socio-technical systems.

However, respondents also considered that SHT designers, developers and providers can take a range of steps to ensure *consumer confidence* (Fig. 3.4b, right panel). At least 80% of respondents agreed or strongly agreed with each of the six response options. SHTs should be designed to be reliable, easy to use, controllable, and easy to over-ride. The market applications of SHTs should guarantee privacy, confidentiality, and secure data storage. SHTs should also be provided by credible companies with resources to provide performance warranties. These criteria for SHT design and commercialisation are consistent with two of the three research themes grouped under 'Challenges for realising the smart home' in our analytical framework (Table 2.1).

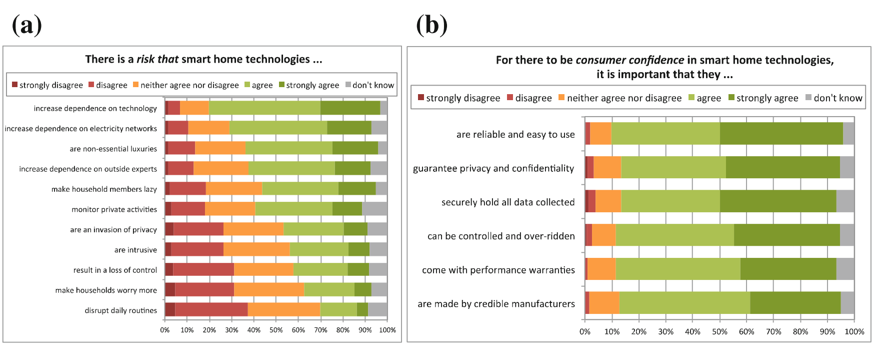

Fig. 3.4 Prospective users' perceptions of risks and confidence-building measures for SHTs

3.4 Results: Distinctive Perceptions and Characteristics of Early Adopters

Potential early adopters

Prospective users with high prior knowledge of SHTs are indicative of a potential early adopter market segment. The characteristics of early adopters have been well characterised in the technology diffusion literature (Rogers 2003). Based on this literature, we set out a series of simple hypotheses (H). Relative to later adopter groups in the mass market, we hypothesised that early adopters:

(H1) have higher prior awareness of SHTs;
(H2) are wealthier and have more diverse social networks;
(H3) actively seek information on SHTs from a variety of sources;
(H4) are less susceptible to interpersonal influence;
(H5) perceive stronger benefits of adopting SHTs;
(H6) perceive risks of adopting SHTs to be more manageable.

Using high prior knowledge of SHTs (H1) as a proxy for potential early adopters allows the distinctive characteristics of this important market segment to be tested. Potential early adopters comprised 37.6% of the final sample (n = 385, see Table 3.2).

Chi-squared (χ^2) tests showed high prior knowledge to be significantly associated with socioeconomic characteristics (Table 3.3). Specifically, respondents with high prior knowledge were significantly *more likely* to be younger, be male, live in larger households, and live in higher income households. These associations are

Table 3.3 Association between prior knowledge of SHTs and socioeconomic characteristics (Note: Columns do not sum to 100% as only one response option per socioeconomic characteristic is shown to illustrate key differences with full sample of all prospective users)

Socioeconomic characteristics	All prospective users (n = 1025) (%)	High prior knowledge group (n = 385) (%)	Association between prior knowledge and socioeconomic characteristics[a]	Socioeconomic characteristics of high prior knowledge group
Age (<45)	36.7	49.2	$\chi^2 = 56.1$, df = 8, $p < 0.01$	Young
Gender (male)	49.3	61.6	$\chi^2 = 48.5$, df = 2, $p < 0.01$	Male
Household size (4 or more)	22.4	31.4	$\chi^2 = 51.2$, df = 8, $p < 0.01$	Large households
Household income (>£40,000)	34.2	45.5	$\chi^2 = 39.9$, df = 6, $p < 0.01$	High income households

[a]Association was tested on disaggregated data between three prior knowledge groups and all socioeconomic characteristics response options

Table 3.4 Information channels on SHTs for potential early adopters compared to all prospective users (Notes: Columns do not sum to 100% as response options were non-exclusive)

How do you know about ‘smart home technologies’?			
Response options for information channels	All prospective users (n = 1025) (%)	High prior knowledge (n = 385) (%)	Association between prior knowledge and information channel[a]
Internet	62.2	78.7	$\chi^2 = 87.0$, df = 2, $p < 0.01$
TV, news or magazines	48.6	53.5	$\chi^2 = 17.6$, df = 2, $p < 0.01$
Home or electrical stores	13.0	22.6	$\chi^2 = 51.1$, df = 2, $p < 0.01$
Energy companies	30.5	35.1	$\chi^2 = 7.7$, df = 2, $p < 0.05$
Word of mouth	34.0	35.8	$\chi^2 = 1.1$, df = 2, n.s.

[a]Association was tested on disaggregated data between three prior knowledge groups and all informational channel response options

broadly consistent with expectations for early adopters in general (H2), and with users of information and communication technologies (ICTs) more specifically (OECD 2008). Larger households imply families with children (or elderly people) living at home, with potentially greater needs for control and convenience in home management.

Potential early adopters were significantly more likely to have found out about SHTs through all information channels with the exception of word of mouth (Table 3.4). This is also consistent with expectations for early adopters (H3 and H4). Later adopters who are less aware of new technologies are more likely to receive information through interpersonal networks and less likely to actively seek information through the media or internet.

Kruskal-Wallis H tests were run to determine whether potential early adopters perceived stronger benefits and lower risks of SHTs compared to later adopting groups (H5 and H6). Kruskal-Wallis is a nonparametric test of difference appropriate for use on ordinal Likert scale data (equivalent to one-way ANOVA for parametric data). The tests found statistically significant differences ($p < 0.01$) between adopter groups on all eight response options for the *main purposes* for SHTs, and on all eleven response options for the *potential benefits* of SHTs (see Fig. 3.2). Post hoc pairwise comparisons were performed using the Dunn procedure with a Bonferroni correction for multiple comparisons. In all except two cases, the early adopter group (high prior knowledge) had significantly stronger perceptions of the *main purposes* of SHTs and the *potential benefits* of SHTs than both the early majority and late majority groups (medium and low prior knowledge respectively). The two exceptions were ‘controlling heating systems’ and ‘managing energy use’ as *main purposes* of SHTs for which early adopters were significantly different from the late majority, but not the early majority.

Overall, there is good evidence that finding out more about SHTs significantly strengthens potential early adopters’ positive perceptions of benefits. This is consistent with expectations for early adopters (H5).

Potential early adopters might be expected to perceive lower risks with SHTs as a corollary of perceiving stronger benefits. However this is generally not the case. There were only three cases in which the early adopter group perceived significantly lower risks: ‘increase dependence on outside experts’, ‘result in a loss of control’, ‘are non-essential luxuries’. But in each of these three cases, early adopters were significantly different only from the late majority (low prior knowledge) but not from the early majority (medium prior knowledge).

Overall, there is only weak evidence that potential early adopters perceive they will be more able to independently configure and effectively use and control SHTs without relying on technical experts. This is only partially consistent with expectations for early adopters (H6).

Actual early adopters

The early adopter survey measured perceived benefits and risks of SHTs in households committed to having SHTs installed in their homes as part of the SHT field trial (see Chap. 1 and Fig. 1.1). Although a small sample, responses from these *actual* early adopters provide a useful reference point to compare against the *potential* early adopter group (with high prior knowledge) from the national survey. This also helps determine if the actual early adopters who volunteered to participate in the SHT field trial have similar perceptions to the broader population of potential early adopters.

Mann-Whitney U tests were run to determine whether actual and potential early adopters had similar perceptions of SHTs. Mann-Whitney U is a nonparametric test of difference appropriate for use on ordinal Likert scale data (equivalent to t-tests for parametric data). Differences were tested on all the response options related to the *main purposes* of SHTs and to *consumer confidence* in SHTs. (Perceptions of the *potential risks* of SHTs were not measured in the actual early adopter survey).

For the *main purposes* of SHTs, there were no statistically significant differences between actual and potential early adopters, with two exceptions: ‘enhancing entertainment and communication’, $U = 4396$, $z = -3.75$, $p < 0.001$, for which actual early adopters’ responses were significantly lower; and ‘managing energy use’, $U = 5886$, $z = -2.59$, $p < 0.01$, for which actual early adopters’ responses were significantly higher.

For *consumer confidence* in SHTs, there were no statistically significant differences between actual and potential early adopters, with two exceptions: ‘reliable and easy to use’, $U = 5431$, $z = -2.91$, $p < 0.01$; and ‘come with performance warranties’, $U = 5391$, $z = -2.04$, $p < 0.05$. In both cases, the responses of actual early adopters were significantly higher than potential early adopters.

Overall, responses are very similar between actual early adopters ($n = 45$, early adopter survey) and potential early adopters ($n = 385$, subsample of national survey with high prior knowledge of SHTs). The few differences can be explained by the field trial setting in which actual early adopters’ perceptions were measured. SHTs installed in homes participating in the field trial related to heating, hot water, lighting and security (see Chap. 1). However ‘smart’ TVs linked to ‘enhancing entertainment and communication’ are by far the dominant SHT by sales and so are more likely to have shaped the perceptions of potential early adopters (Harms 2015). Actual early adopters also place more emphasis on specific measures for building consumer confidence. Uncertainties about technology performance and ease of use are likely sharpened in households about to have SHTs installed.

3.5 Results: Alignment of Industry Marketing with User Perceptions

Alignment between prospective users' perceptions and industry marketing is an important indication of shared and consistent expectations for SHT market growth. The content analysis provides a systematic picture of how industry is representing the benefits, function, design, and use of SHTs to prospective users. In general this picture is similar across a range of different SHT companies.

Sampled marketing materials describe the main benefit of SHTs as helping households manage their energy use (Fig. 3.5a). SHTs are also commonly marketed as a means of improving household security (e.g., open door or window alerts, occupancy simulation) or as a means of enhancing leisure activities (e.g.,

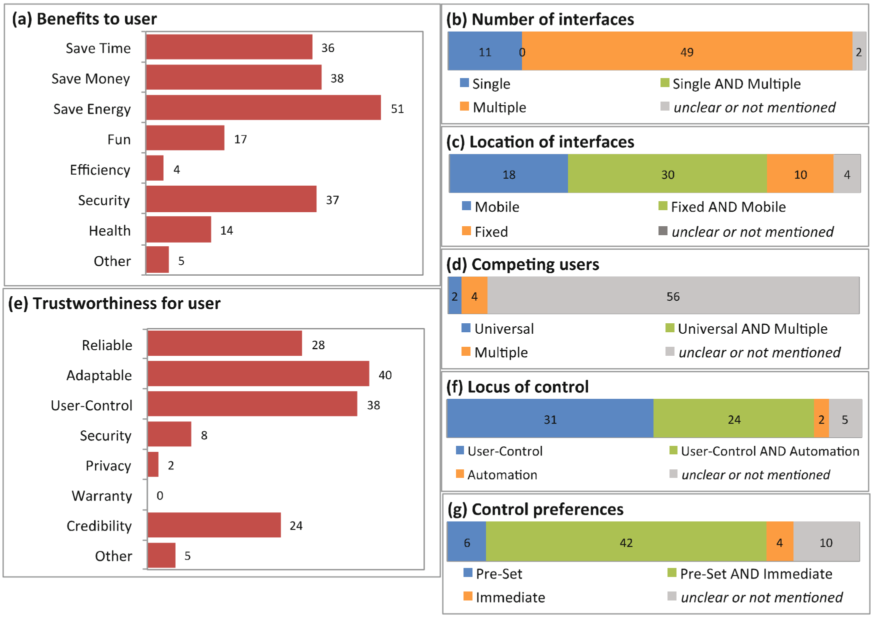

Fig. 3.5 Coding of smart home marketing material (Notes: Bars show frequency of codes in sampled material (n = 62); numbers per bar show frequency (n); Red bars in left panels (**a**, **e**) are for coding categories with multiple, non-exclusive codes (so total n > 62); Blue, green, orange bars in right panels (**b**, **c**, **d**, **f**, **g**) are for coding categories with bi-dimensional, exclusive codes (so total n = 62))

scheduling entertainment and media services). This provides benefits to users through time savings, convenience, efficiency as well as entertainment. Improving health (e.g., physiological monitoring, communications with healthcare providers) is a niche market.

In the industry marketing material, user-technology interactions are through multiple rather than single interfaces (Fig. 3.5b) which are both fixed and mobile (Fig. 3.5c). Some interfaces might be wall-mounted or integrated into smart appliances, whereas others might be accessed through smart phone applications or standalone in-home displays. Although the marketing material recognises that homes are lived in by households and families, little attention is paid to how multiple SHT users may interact or to how conflicting preferences or settings may be resolved (Fig. 3.5d). Yet these are core themes within the socio-technical view of smart homes and their users (see Chap. 2).

Measures to build consumer confidence in SHTs do not centre on privacy and security. Data security is only mentioned in eight of the marketing materials from the sample of 62 companies (Fig. 3.5e). Only five of these eight mentioned that data would be encrypted. Rather, industry marketing material seeks user trust and confidence by emphasising users being in control, and technologies being adaptable and reliable. Certain manufacturers also emphasise their credibility either through years of experience in the field of consumer electronics or through various design and technology awards.

Throughout the marketing material, user control of SHTs is a central concern (Fig. 3.5f). As Philips assure prospective users, "*your home is as individual as you and the way you live should be determined by you, not the system*". Both user control and automation are possible with 'set and forget' functionality in which users pre-set initial rules and conditions but can then step back allowing the technologies to take over. Despite a strong emphasis on pre-set scenes to account for regular routines, the marketing material also makes clear that users can always immediately over-ride a particular function (Fig. 3.5g). The ability to over-ride pre-sets is presented as essential for giving users a sense of 'control' over their SHTs while not imposing this as a requirement or burden. This is also clearly evident in the rule-based and event-based control functionality of the RWE, Hive, and Vera systems used in the SHT field trial (see Chap. 1).

There is strong overall coherence within industry marketing material on the communication of what SHTs should be able to do, and how they should be designed. SHTs are marketed as:

- being inconspicuous technologies running in the background, with only some of the interfaces being conspicuous within the home;
- allowing users to 'set and forget' their control preferences;
- focusing on enhancing lifestyles rather than delivering single, task-specific functions;
- being universally relevant to an all purpose audience rather than distinguishing specific types of users (with the exception of a specialised market niche for assisted living).

3.6 Synthesis

The survey data and content analysis of industry marketing provide a cross-sectional snapshot rather than a time-dependent trajectory of technological and market development. However, the comparative analysis of three separate datasets usefully characterises the emerging smart home market (Table 3.5). This provides a rich picture of user perceptions, industry marketing, and the extent to which both of these are consistent with policymakers' envisaged role for SHTs within smarter energy systems.

Q1. How do prospective users perceive the **specific benefits** ***and*** **risks** ***of SHTs?***

Prospective users have positive perceptions of SHTs aligned to their multiple functionality of managing energy use, controlling the domestic environment, and improving security. Prospective users perceive a clear value proposition centred on cost, control and convenience. This confirms a strong market potential for SHTs, and situates user perceptions of benefits within the functional and instrumental views of smart homes and their users identified in our analytical framework (Table 2.1).

The impact on energy demand of SHTs once adopted is less clear. Users perceive SHTs to have potentially competing benefits. SHTs help users to achieve both instrumental outcomes (e.g. saving energy, money or time, enhancing security or health) as well as hedonic goals (e.g. providing entertainment, having more fun). SHTs certainly enable energy management (e.g., control of heating and lighting systems by remote) but also facilitate energy consumption either by providing new

Table 3.5 Mapping of SHT datasets onto research questions

Data collection		National survey		Early adopter survey	Companies at SHT conference + web search
Dataset (sample)		Prospective users	Potential early adopters	Actual early adopters	Industry marketing material
Q1	How do prospective users perceive the *specific benefits* and *risks* of SHTs?	X			
Q2	Do *early adopters* have distinctive perceptions of SHTs?		X	X	
Q3	Is industry marketing of SHTs *aligned* with the perceptions of prospective users?	X	X		X

services (e.g., pre-heating homes or running automated security routines while absent) or by intensifying existing services (e.g., audiovisual entertainment, internet connectivity). As well as being energy-consuming products themselves, SHTs may have the effect of entrenching ever more resource-intensive social conventions of comfort and convenience (Strengers 2013).

With respect to potential risks, prospective users' perceptions of data and privacy concerns with SHTs are not as prevalent nor as salient as has been the case with smart meters. Smart meters have a less clear value proposition, and are rolled-out to households by energy utilities with low levels of consumer trust (Balta-Ozkan et al. 2013). By comparison SHTs are voluntarily purchased as value-adding products from manufacturers of households' own choosing. However, there is concern among prospective users over ceding autonomy and independence in the home for increased technological control. Ensuring SHTs are controllable, reliable, and easy-to-use can help mitigate these perceived risks, and build consumer confidence.

Q2. Do **early adopters** *have distinctive perceptions of SHTs?*

Potential early adopters of SHTs among UK homeowners are younger, wealthier, live in larger households, and actively seek more information on SHTs relative to all prospective users. However, the small sample of actual early adopters participating in the SHT field trial shows other household compositions and life stages (including retired couples) clearly form part of the early adopter market segment.

Figure 3.6 compares data on perceived benefits, control functionality, and consumer confidence in SHTs from the different user surveys as well as the industry marketing material. Different measures are used to represent the surveys (% of respondents in agreement) and the content analysis (% of marketing material mentioning a code). However these measures are broadly analogous. For marketing material to make explicit mention of a particular code is equivalent to an agreement that this code is a relevant and salient feature of SHTs. However, as the measures are not identical, the visual comparison in Fig. 3.6 of user perceptions and industry marketing should be interpreted in terms of relative importance only.

Focusing for now on the users of SHTs, Fig. 3.6 shows that potential early adopters see stronger benefits of SHTs but otherwise share similar perceptions of control functionality and consumer confidence with the full market of prospective users. As early adopters acquire greater knowledge of SHTs, their positive perceptions of benefits are strengthened. This creates a virtuous cycle of reinforcing market demand. However, greater knowledge of SHTs does not significantly weaken early adopters' perceptions of risks. This emphasises the importance of measures to strength consumer confidence as SHTs become available commercially.

Figure 3.6 also shows that *actual* early adopters are more circumspect across the board than *potential* early adopters. Actual early adopters have less strong perceptions of benefits and control functionality, but also risks. As a caveat, the sample size of actual early adopters was small, and consisted of multiple members from each household with potentially different levels of prior knowledge and awareness.

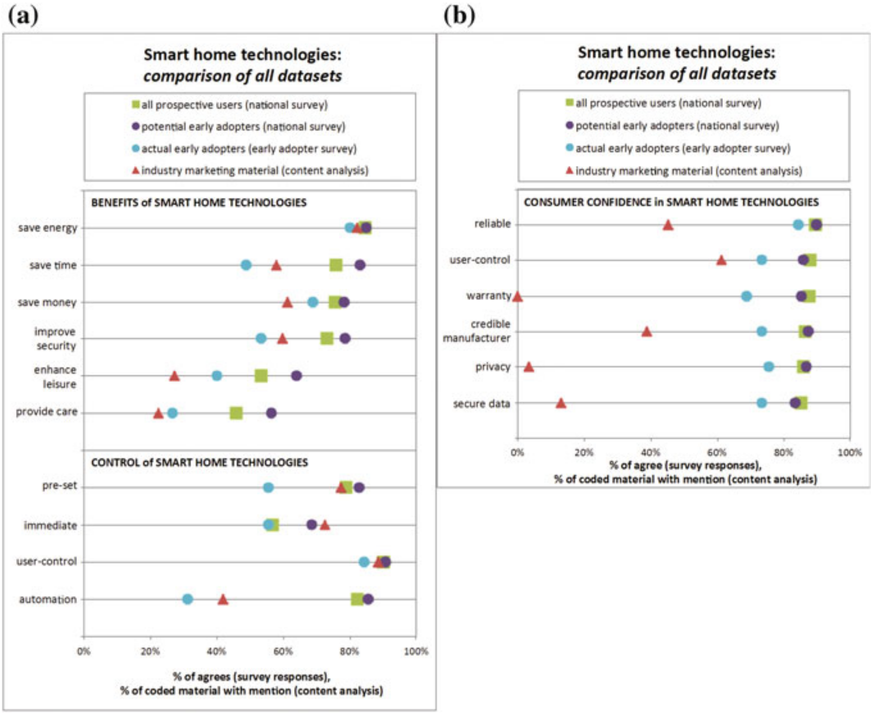

Fig. 3.6 Comparison of all SHT datasets (Notes: Left panel (**a**) shows benefits and control; Right panel (**b**) shows consumer confidence; Data from national survey (prospective users and potential early adopter market segment) and early adopter survey show % of respondents in agreement (agree + strongly agree); Data from content analysis of industry marketing shows % of marketing material mentioning code)

Q3. Is industry marketing of SHTs **aligned** *with the perceptions of prospective users?*

The industry marketing material is very clear on the energy-saving benefits of SHTs. This is consistent with user perceptions and the instrumental view of smart homes and their users (see Chap. 2). The industry marketing material also emphasises other types of benefits as well as SHT control functionality in a similar rank order to users (Fig. 3.6a). One exception is that industry marketing material downplays automation in favour of active user control. This may be aimed at mitigating perceived sociotechnical risks of increasing dependence on technologies and experts.

Industry marketing clearly diverges from user perceptions in relation to consumer confidence (Fig. 3.6b). There is a high demand for risk-mitigating measures from prospective users, including early adopters, but these are only weakly emphasised in marketing material.

Final remarks

Although the market outlook for SHTs from both users' and industry's perspective is positive, there are also important risks and issues that need addressing. Prospective users have positive perceptions of the multiple functionality of SHTs including managing energy use, controlling the domestic environment, and improving security. The value proposition for SHTs centres on cost, control and convenience. But although SHTs certainly enable energy management, they also facilitate energy consumption either by providing new services or by intensifying existing services. The impact of SHTs on energy demand ultimately depends on how they are designed and used (see Chaps. 5 and 6).

Users' perceived benefits of SHTs are broadly consistent with both the functional and instrumental views of smart homes and their users distinguished in our analytical framework (Table 2.1). Interestingly, perceived risks are more clearly aligned with the socio-technical view. Both prospective users and actual early adopters also express caution towards ceding autonomy and independence in the home for increased technological control. These broader socio-technical risks are perceived more strongly than the privacy and data security concerns that have affected smart meter rollouts in the EU. The SHT industry can increase their efforts to help mitigate perceived risks by ensuring SHTs are controllable, reliable, and easy-to-use as measures for building consumer confidence. Confidence-building measures are particularly important in the emerging SHT market to ensure that positive experiences of early adopters are communicated through social networks to create a virtuous cycle of reinforcing market demand.

3.7 Suggested Further Reading

A longer version of this chapter was published as an open-access peer-reviewed article:

- Wilson C, Hargreaves T, Hauxwell-Baldwin R (2017) Benefits and risks of smart home technologies. Energy Policy 103: 72–83. doi:10.1016/j.enpol.2016.12.047

For other studies of SHT market demand and/or user perceptions, we suggest:

- Harms E (2015) Smart home—good things come to those who wait. Paper presented at the 8th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'15), Luzern, Switzerland, 26–18 August 2015. doi:10.2790/012477
- Balta-Ozkan N, Davidson R, Bicket M, Whitmarsh L (2013) Social barriers to the adoption of smart homes. Energy Policy 63: 363–374. doi:10.1016/j.enpol.2013.08.043

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Wilson C, Hargreaves T, Hauxwell-Baldwin R (2015) Smart homes and their users: a systematic analysis and key challenges. Pers Ubiquit Comput 19(2):463–476. doi:10.1007/s00779-014-0813-0

Wilson C, Hargreaves T, Hauxwell-Baldwin R (2017) Benefits and risks of smart home technologies. Energy Policy 103:72–83. doi:10.1016/j.enpol.2016.12.047

Chapter 4
Routines and Energy Intensity of Activities in the Smart Home

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Abstract The instrumental view of smart homes and their users is premised on active management of energy demand contributing to energy system objectives. In this chapter we explore a novel way of using data from smart home technologies (SHTs) to link energy consumption in homes to daily activities. We use activities as a descriptive term for the common ways households spend their time at home. These activities, such as cooking or laundering, are meaningful to households' own lived experience. We set out a novel method for disaggregating a household's electricity consumption down to the appliance level allowing us to make inferences about the activities occurring in the home in any given time period. We apply this method to analyse the pattern of activities over the course of one month in 10 of the homes participating in the SHT field trial described in Chap. 1. We show how both the energy intensity and temporal routines of different activities vary both within and between households. Our method also clearly reveals the complexities of everyday life at home which shapes the domestication of SHTs.

4.1 Introduction and Key Questions

The analytical framework introduced in Chap. 2 identifies research themes on the 'home as a complex place' characterised by both routine and regularity, as well as variability and vicissitude. Against this backdrop, domestic energy use is the largely invisible consequence of activities taking place within the home (Gram-Hanssen 2014; Katzeff and Wangel 2015). Activities such as cooking, washing, listening to music or playing computer games are more consistent with households' own experiences of life at home. Activities are a simple descriptive term for these common ways in which households spend their time, and are used in time-use statistics collected by national statistical agencies to characterise the everyday life of households (ONS 2000a). From an energy perspective, activities are also a more stable constituent of domestic life whereas appliances may be commonly replaced or retrofitted (Schwartz et al. 2014).

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In this chapter, we ask three important questions on the linkages between energy use and domestic activities in smart homes:

Q1 How can data from SHTs be mapped onto domestic activities?
Q2 What is the energy intensity and routineness of different activities?
Q3 How do activity patterns vary within and between households?

To answer these questions, we present a novel data-processing methodology using both quantitative and qualitative data to make inferences about electricity-consuming activities in the home. We apply this method to look in-depth at the time profile and energy intensity of a set of 10 activities that constitute everyday life in a smart home.

4.2 Method

Smart meter data provide real-time information on aggregate energy consumption in homes. Disaggregating smart meter data via intrusive or non-intrusive means helps understand how appliances consume electricity in individual households (Zeifman and Roth 2011). Load disaggregation effectively breaks the electricity consumption of a household down to the individual appliances that contribute to the total load at any point in time (An electrical load is a component of an electrical circuit that consumes power, e.g., an appliance or light). Monitoring consumption at the plug level using individual appliance monitors (IAMs) is becoming affordable, but it is also intrusive particularly if monitoring the 30 or more appliances in a typical home. An alternative is to use non-intrusive approaches based on algorithms to infer load profiles from smart meter data. Non-intrusive appliance load monitoring (NILM) disaggregates a household's total electricity consumption down to specific appliances (Zeifman and Roth 2011; Zoha et al. 2012). NILM effectively creates virtual power sensors at each appliance using software tools alone. In principle, NILM using smart meter data can disaggregate which appliances were used, when they were used, for how long, and with what consequence for electricity consumption.

In this chapter we present a novel methodology to infer the occurrence and associated electricity consumption of domestic activities using smart meter data. The methodology is based on an activity recognition algorithm that identifies appliance usage events: (i) by directly monitoring appliances via individual appliance monitors (IAMs); (ii) by using non-intrusive appliance load monitoring (NILM); and (iii) by defining activity ontologies using qualitative data from interviews and physical home surveys.

Our methodology consists of five steps which are applied separately for each home analysed:

1. *Activity selection*: Select activities relevant to a specific home from a set of 10 activities that characterise domestic life.

2. *Data collection*: Collect real-time electricity data from smart electricity meters and IAMs. Collect data on home and household characteristics including routines and appliance usage patterns.
3. *Load disaggregation*: Disaggregate electricity data using NILM to identify operation of all appliances that are not monitored directly by IAMs.
4. *Activities ontology*: Formally map relationships between activities and appliances to build an 'activities ontology'.
5. *Activity inferences*: Use activities ontology and disaggregated electricity data to make inferences about when and for how long activities are occurring, and with what consequence for electricity consumption.

We summarise the key features of each step below. For a more detailed explanation of the methodology, see: Liao et al. (2014a), Stankovic et al. (2015).

Activity selection

We identified a comprehensive set of activities based on the UK's Office of National Statistics (ONS) double-digit (disaggregated) codes for time-use studies (ONS 2000a, b). We excluded two types of activity: (i) activities that do not take place within the home (e.g., travel), or only take place within the home under specific circumstances (e.g., volunteering, sport); (ii) activities that are not clearly associated with energy-using appliances (e.g., sleeping, eating). We aggregated the remaining ONS double-digit codes into a set of 10 activities which are linked to specific energy-using appliances and which constitute the majority of life at home. These are summarised in Table 4.1; for further details, see Wilson et al. (2015).

Table 4.1 Activities and common marker technologies for a set of 10 activities

	Activity	Common marker appliances	Detection method
Daily routines	Cooking	Kettle, microwave, oven, toaster, dishwasher, electric cooker	NILM
	Washing	Electric shower, hair dryer, hair straightener	NILM
	Laundering	Washing machine, tumble dryer	NILM
	Cleaning	Vacuum cleaner, steam mop	NILM
Leisure and computing	Watching TV	Television, DVD player, recorder, set top box	NILM, IAM
	Listening to radio	CD player, hi-fi	IAM
	Games	Gaming console	IAM
	Computing	PC, printer, scanner	NILM, IAM
	Hobbies	Exercise machine, electric drill, sewing machine	NILM
	Socialising	[*Indirect associations through linked activities*]	N/a

Our set of 10 activities can be distinguished broadly as daily routines (cooking, washing, laundering, cleaning) or as leisure and computing (watching TV, listening to radio or music, playing computer games, all other computing, hobbies). Socialising is an activity that constitutes daily life but does not directly consume energy. However, it can be inferred indirectly from linked activities, e.g., listening to music (Table 4.1).

Data collection

We collected a combination of quantitative and qualitative data in each home being analysed.

Quantitative data comprise aggregate and individual appliance active power in Watts (W) sampled every eight seconds, similar to the specifications of smart meters being rolled out nationally in the UK (DECC 2014). Up to nine IAMs were used in each home to collect data on individual appliances. The electrical consumption of the remaining appliances were all obtained via load disaggregation using NILM (Liao et al. 2014a). All electricity data used in this study are publicly available (see Table 1.2).

Qualitative data comprise: (1) appliance surveys; (2) semi-structured household interviews on activities; (3) video ethnography on technology ownership and usage. The appliance surveys are to help identify unknown signatures obtained during NILM. The qualitative interview and video ethnography data procedures are explained further in Chap. 5; see also Wilson et al. (2015). We used the interview and video data to identify domestic routines and appliance usage that helped us map relationships between activities and technologies for each household (see below).

Load disaggregation

Information on when different appliances were running was either measured by IAMs or inferred from the aggregate readings via NILM. We used a mix of physical sensors (IAMs) and virtual sensors (via NILM) for two reasons. First, monitoring every single appliance in a home via a physical sensor is expensive and unpractical. As a result, we only used up to nine IAMs in each home which kept acquisition, processing and storage cost and complexity manageable. Second, NILM introduces inference uncertainty. The performance or accuracy of NILM is dependent on the smart meter data time-resolution, an up-to-date repository of appliance load signatures, algorithmic complexity, and robustness of the algorithm to unknown signatures detected in any given home. As a result, we did not rely exclusively on NILM.

The output of the disaggregation process is detailed information about each appliance use or event, detected within the chosen period of disaggregation. Specifically, this comprises the time when the appliance was switched on and when it was switched off, the duration of that event, appliance label, average effective power (W) and the total consumption (in kWh) of the appliance during that event. Our disaggregation algorithm accurately detects as many events as possible to account for electricity-using appliances which contribute to the aggregate load at any given point in time.

Activities ontology

The load disaggregation provides a list of specific appliances used together with their time of use. This information is related to particular activities using an 'activities ontology' specific to each home. An activity ontology maps out all known relationships between activities and the appliances used in those activities. The purpose of the ontology is to link measurable information on appliances to the set of activities characterising everyday life at home.

Mappings between appliances and activities are non-exclusive, i.e., one activity can be mapped to one or more appliance, and vice versa. Any given appliance can *definitely, possibly,* or *indirectly* indicate that an activity is occurring. These are distinguished in the ontology through three corresponding codes: *marker appliance, auxiliary appliance,* and *associated activity*.

Marker appliances are appliances whose use tells us when an activity is definitely occurring. For example, a washing machine is one of the marker appliances for the laundering activity. Table 4.1 shows a general mapping of common marker appliances for all activities (except socialising) and how the electrical loads of these marker appliances are measured quantitatively. Disaggregation cannot capture the use of devices that are highly mobile or that operate on battery power (either permanently or while not plugged in). As a result, mobile or battery-powered devices are not used as marker technologies in the activities ontology.

Appliances used for several different activities cannot be used unambiguously for making activity inferences. Whereas marker appliances identify when an activity is definitely going on, *auxiliary appliances* indicate that an activity is possibly going on. For example, a householder could use a PC (marker appliance for the computing activity) for the 'listening to radio' activity (which is defined as listening to any audio regardless of the device used).

An *associated activity* refers to the use of an appliance that is a marker for one activity which is in turn concurrent with or linked to a second activity. For example, a hi-fi is a marker appliance for 'listening to radio' but might also indicate the 'socialising' activity, which is therefore an associated activity. Conventional distinctions between audio, visual, communication, and computing devices are rapidly collapsing. This increases the difficulty of making inferences about specific types of ICT-related activities. To avoid the risk of inference errors, ICT-based activities could be collapsed into a higher order 'all ICT-related' activities but this is less useful as a descriptive characterisation of domestic life.

Activity inferences

The output of the activity inference procedure is a set of activities, together with their start times and end times to estimate duration. With the disaggregated electrical consumption obtained from IAM or NILM, we can then determine the electrical load associated with each activity from the temporal associations of appliances which form one activity event.

Our methodology can under-predict activity time use because some appliances may be off during part of the activity, e.g., when loading the washing machine during the laundering activity, or preparing meat or vegetables for the cooking activity. On the other hand, our methodology can also over-predict the duration of an activity if marker or auxiliary appliances are on for prolonged periods beyond the duration of an activity, e.g., a radio or TV left on all day, regardless of whether a householder is actually listening to the radio or watching TV. Making inferences solely from appliance usage is not reliable as a sole basis for inferring the time profile of activities. However, given that the disaggregated loads from specific appliances are known and can then be linked to activities based on the ontologies, the energy intensity of domestic activities can be reliably calculated.

Uncertainties in activity inferences

The disaggregation introduces some uncertainty due to IAM sensor malfunctions or NILM misclassification if two appliances have similar active power signatures. Uncertainty is also introduced by the stochastic nature of human behaviour as there are many ways an activity can be carried out. As an example, certain activities may use different subsets of appliances within the defined ontology at different times. This is a common problem in domestic activity recognition studies. These two uncertainties are termed *disaggregation uncertainty* and *context uncertainty* respectively (Liao et al. 2014b).

We classified each of our activity inferences at one of five levels of uncertainty:

1. *Non-inferable*: Activities associated with non-detectable appliances which cannot be monitored (e.g., a battery-operated appliance like a portable radio) or with mobile, chargeable devices (e.g., laptops or tablets).
2. *Possibly inferable*: Activities associated with non-detectable appliances because additional quantitative and/or qualitative data is required for disaggregation. An example is the washing activity using gas water heating which could be monitored by additional temperature or humidity sensors.
3. *Inferable with uncertainty*: Activities associated with appliances whose signatures have not been verified but can still be detected via disaggregation, or medium-powered appliances whose signatures can ‘get lost’ in the aggregate data. An example is the cooking activity which is associated with a large range of different appliances used at different times and for which all signatures cannot be verified.
4. *Partially inferable*: Activities associated with gas as well as electricity consumption (e.g., the washing activity associated with both an electric shower and gas-based domestic hot water) or with appliances which cannot be disaggregated due to low loads (e.g., the listening to radio activity which can be partly detected if there is an IAM attached to at least one associated appliance like a CD player).
5. *Inferable with certainty*: Activities associated with appliances detected reliably via NILM and/or IAMs. Note that the NILM appliances may incur marginal disaggregation error, but usually no more than 10% (Liao et al. 2014a).

4.3 Data

We applied our methodology to make inferences about 10 activities over 24 h daily cycles for each day of the month of October 2014. We selected this period as it was not during the summer (when households are more likely to be outside) and also not during school holidays or festive periods (when domestic activities in households may follow different routines).

We used data from a sample of 10 households participating in the SHT field trial (see Chap. 1). We selected the households to ensure variation in household compositions:

- pensioner couples (Houses 3, 4 and 8)
- families of four with two young children (Houses 2 and 10)
- families of four with two teenage children (Houses 5, 19, 21)
- other household compositions (Houses 17, 20).

For further details of the ages and occupations of household members in each of these houses, see Table 1.3.

For each household, an activities ontology was built to map activities which could be inferred with the appliances associated with each activity. Using House 17 as an example, Table 4.2 shows which activities can be inferred from the collected data, whether our inference algorithm can measure the duration of the activity as well as electricity use, and which appliances were related to activities or other electricity consumption. The appliance information was obtained through a combination of the appliance survey, qualitative data, and NILM. Not all appliances were reported in the appliance survey because they were either unused during the survey or they were not present in the house at the time of the survey.

We also estimated non-activity based electricity consumption, distinguishing cold appliances, electrical heating (if applicable), base load, and a residual which includes lighting (Table 4.2). The residual indicates how much of total electricity consumption we can neither disaggregate nor indirectly account for. Heating and lighting are both energy-intensive services but not activities per se. Heating and lighting-related energy use could be apportioned to activities taking place in specific rooms for time periods during which those rooms are lit or heated (De Lauretis et al. 2016). We chose instead to account for heating and lighting separately to maintain only direct linkages between activities and energy consumption.

Figure 4.1 shows which of the full set of 10 activities could be detected in each of the 10 households in our sample, together with associated uncertainties. As an example, we could detect watching TV in all households with high certainty (coded 4) because of marker appliances (e.g., TVs) monitored by plug monitors. Similarly, we could detect laundering in all households with high certainty because marker appliances (e.g., washing machines, dryers) have well defined signatures for NILM. Some activities were inferable through their associations with a different activity (e.g., socialising was inferred indirectly from listening to radio if the two were associated in the ontology for that household).

Table 4.2 Activity inferences from detected appliances in House 17 (Notes: Uncertainty for each activity is coded from 0 (non-inferable) to 4 (inferable with certainty); see text for details)

Activities and other types of electricity consumption		Inferences			Appliances
		Time use	Electricity use	Uncertainty	
Activity-related	Cooking	Yes	Yes	2	Kettle, microwave, coffee maker, toaster, blender, electric cooker, sandwich maker
	Washing	Yes	Yes	2	Electric shower, hair straightener
	Laundering	Yes	Yes	4	Washing machine, tumble dryer
	Cleaning	No	No	1	N/a
	Watching TV	Yes	Yes	4	Television, DVD, set-top box, speakers
	Listening to radio	No	No	1	N/a
	Games	No	No	0	N/a
	Computing	Yes	Yes	3	Desktop computer
	Hobbies	No	No	0	N/a
	Socialising	No	N/a	0	N/a
Other	Cold appliances	N/a	Yes		Fridge-freezer, two freezers
	Electric heating	N/a	Yes		Electric heater
	Base load	N/a	Yes		N/a
	Residual	N/a	Yes		N/a

House	2	3	4	5	8	10	17	19	20	21
cooking	4	2	2	2	2	2	2	4	3	2
washing	4	3	1	1	4	3	2	1	1	1
laundering	4	4	4	4	4	4	4	4	4	4
cleaning	1	2	1	2	2	1	1	1	2	1
socialising	4	1	1	1	0	0	0	3	0	0
watching TV	4	4	4	4	4	4	4	4	4	4
listening to radio	4	0	1	1	1	1	1	3	1	1
ICT-related games	1	1	0	0	0	0	0	4	0	0
computing	1	1	4	4	4	0	3	1	3	0
hobbies	1	1	2	2	0	0	0	1	1	0

Fig. 4.1 Uncertainties in activity inferences (Notes: Unshaded 0 = *non-inferable*; quarter-shaded 1 = *possibly inferable*; half-shaded 2 = *inferable with uncertainty*; three-quarters shaded 3 = *partially inferable*; fully shaded 4 = *inferable with certainty*)

4.4 Results: Time Profile of Activity-Based Electricity Demand

To illustrate our methodology, we generated the time profile of electricity demand for three daily activities (cooking, laundering and washing) and one leisure activity (watching TV) in the 10 households in our sample, broken down into weekday and weekend profiles (Fig. 4.2). The time profiles were averaged over the 23 weekdays and eight weekend days in October 2014.

Cooking occurs throughout the day across all households, but shows clear peak hours for breakfast, lunch and particularly dinner. However in most households cooking is less structured during weekends, occurring more consistently throughout the day with less pronounced peaks. Watching TV has a similar time profile to cooking, with evening peaks which are more pronounced during weekends. Washing has a very pronounced peak during weekday mornings. Although morning peaks are also evident during weekends, washing becomes more spread out through the day. Laundering also tends to peak mid-morning, but is spread throughout the day including into the evening. The time profile of laundering varies markedly from household to household, but is fairly consistent from weekdays to weekends.

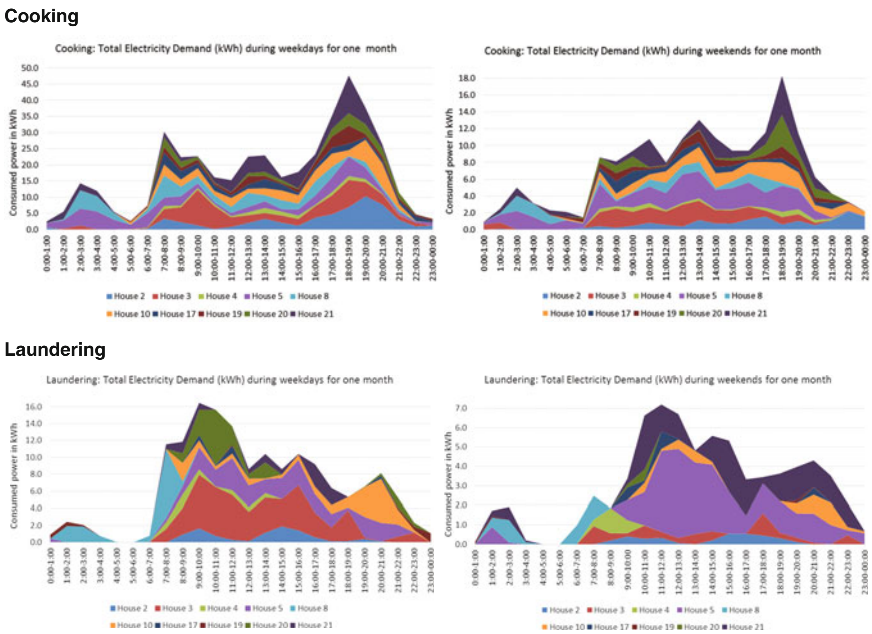

Fig. 4.2 Activity-based electricity demand during weekdays and weekends (Notes: Left panels show weekdays; Right panels show weekends; Demand was calculated for all 10 households for all activities shown, except washing which was calculated for five households)

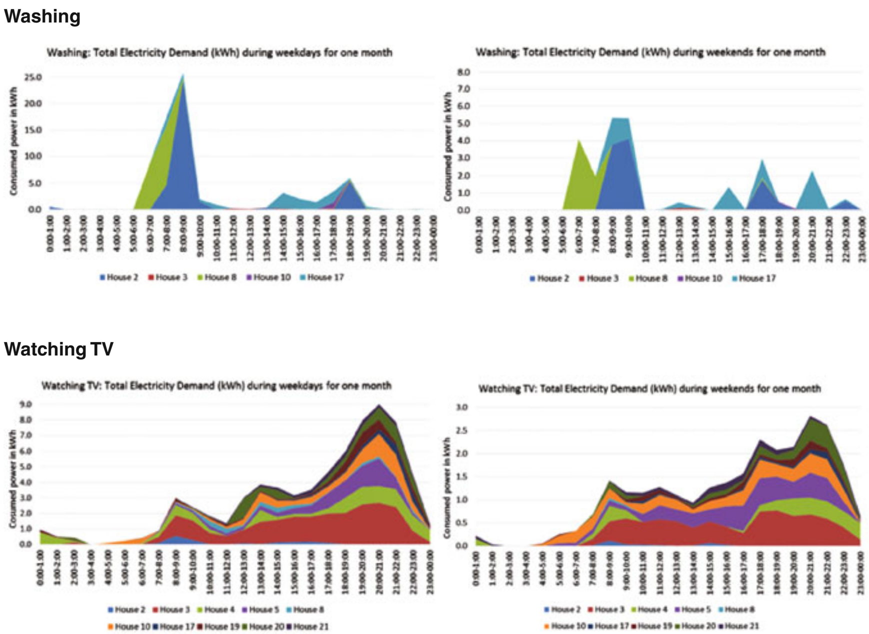

Fig. 4.2 (continued)

4.5 Results: Energy Intensity of Domestic Activities

To make standardised comparisons of activity-based electricity consumption within and across households, we defined an energy intensity metric to quantify the relative contribution of activities to total household energy consumption. We refer to this as the *energy intensity* or EI_a of Activity *a* which is calculated as the percentage of total electricity consumption attributable to Activity *a* during any given time period *T*. An energy intensity of 0% [i.e., $EI_a(T) = 0$] means that Activity *a* did not occur during time period *T*, whereas an energy intensity of 100% [i.e., $EI_a(T) = 1$] means that the entire household's electricity consumption over time period *T* is attributable to Activity *a*.

Within a single household

We applied this energy intensity metric to analyse the time profile of electricity consumption of particular activities within a single household. Figure 4.3 shows data from House 5 during October 2014. House 5 is a four person household with two adults and two children in their early teens. Inferable activities account for 40% of the total monthly electricity consumption, with cooking, computing and

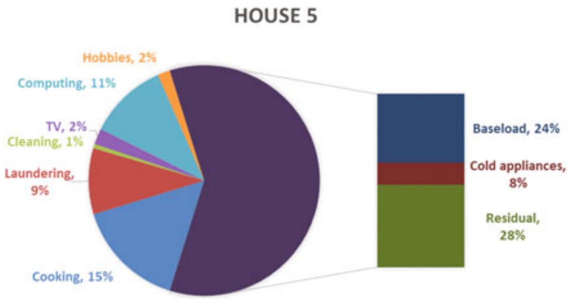

Fig. 4.3 Energy intensity of six activities in house 5 over a one month period

laundering the most energy-intensive activities ($EI_{Cooking}$ = 15%, $EI_{Computing}$ = 11%, $EI_{Laundering}$ = 9%). Over the whole month, the residual load (including lighting) unaccounted for by activities, baseload or cold appliances is 28% of total consumption.

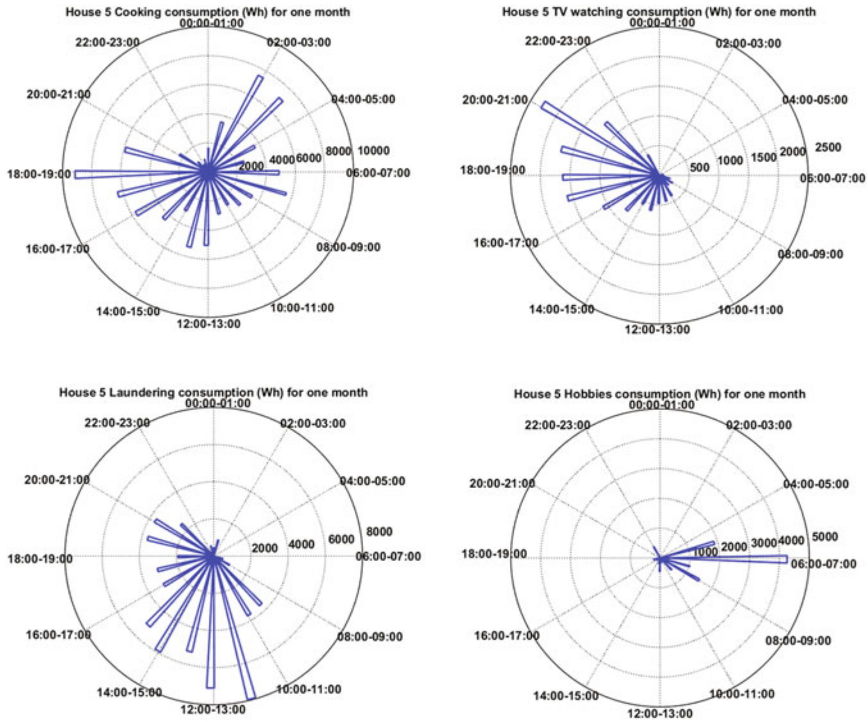

Fig. 4.4 The time profile of electricity consumption per activity in house 5 (Notes: Each hourly bin shows the total electricity consumption (Wh) over a month)

Although Fig. 4.3 is useful for comparing the relative energy intensities of different activities overall, it does not show their distribution over time. Figure 4.4 uses rose plots to illustrate the time profile of total monthly electricity consumption for four activities across each hourly time period summed over a month. Note that the scales of the radial axes (Wh) vary for each plot. Figure 4.4 clearly indicates peaks during particular time periods. For example, cooking occurs throughout the day, but with a clear evening peak from 6–7 pm. The distinctive overnight dishwasher usage in the cooking activity is shown as another peak from 2–4 am. Laundering is more spread out through the day, whereas hobbies (use of a treadmill) is limited to the early mornings. Watching TV is mainly an evening activity.

Between households

Our activity-inference methodology can be used to link electricity consumption to a common set of activities across multiple households. Table 4.3 shows the energy intensity of all activities inferred across our sample of 10 households. The energy intensity of inferable activities ranges from 13 to 41% across households over the whole month. Of all the activities which are generally inferable across households from available electricity data, cooking has the highest energy intensity with an average $EI_{cooking} = 16\%$. Laundering and washing are the next most energy intensive activities. Note that washing could only be inferred in a subset of households which did not also use gas for hot water.

Table 4.3 Energy intensity of all inferable activities in 10 houses over a one month period (Notes: Cells with no entry indicate no quantitative and/or qualitative data to make inferences)

House / ***Activities***	**2**	**3**	**4**	**5**	**8**	**10**	**17**	**19**	**20**	**21**
cooking	21%	20%	6%	15%	16%	17%	12%	15%	13%	23%
washing	14%	<1%			6%	<1%	7%			
laundering	4%	12%	3%	9%	4%	6%	2%	1%	6%	9%
cleaning		1%		1%	1%				1%	
watching TV	1%	7%	2%	2%	1%	3%	1%	2%	3%	1%
listening to radio	<1%							<1%		
ICT-related games								1%		
computing			2%	11%	2%		5%		1%	
hobbies			1%	2%						
socialising	<1%							<1%		
total activity-based electricity use	**40%**	**41%**	**13%**	**40%**	**30%**	**26%**	**26%**	**20%**	**24%**	**34%**
base load	17%	18%	22%	24%	15%	20%	21%	41%	30%	28%
cold appliances	9%	18%	31%	8%	6%	9%	22%	16%	23%	9%
electrical heater					1%	3%	13%			
residual (inc. lighting)	34%	23%	33%	28%	47%	42%	18%	23%	23%	30%

Other (non-activity) electricity consumption comprises cold appliances, base load, electrical heating, and a residual, including lighting and charging of portable devices or low-powered devices, which we could not disaggregate. This residual is 18–48% of total electricity use. Other studies have shown that lighting in the UK uses an average of 16% of a household's total consumption (Bertoldi and Atanasiu 2006).

4.6 Results: Routines and Rhythms in Domestic Activities

Our energy intensity metric, $EI_a(T)$, allows energy-using activities to be compared on a like-for-like basis between time periods within a household, or within time periods between households. However, it does not take into account how consistently activities occur during any given time period. As an example, activities may have similar energy intensities over a one month period if they occur daily and regularly for short periods (e.g., cooking), or for longer periods during only a few days (e.g., laundering).

We defined a routine metric as an indicator of how consistently activities occur during any time period. Our routine metric captures variability in each activity's duration in terms of both frequency during a given time period (i.e., how often the activity occurs) and consistency (i.e., whether the activity regularly occurs in the same timeslot). To measure routine occurrence we use the coefficient of variation, $R_a(t, T)$, also known as the relative standard deviation. We calculate $R_a(t, T)$ as the ratio of the standard deviation to the mean of the energy consumed by Activity a during time period T for each timeslot t. Larger values of the routine metric, $R_a(t, T)$, indicate that an activity occurs less frequently and/or occurs irregularly during timeslot t. Smaller values of $R_a(t, T)$ indicate that an activity occurs frequently with similar durations during timeslot t. No values or gaps in $R_a(t, T)$ indicate that an activity never takes place during that particular timeslot t.

Within a single household

Figure 4.5 shows the routine metric, $R_a(t, T)$, for House 5 for each hourly timeslot t in a day, averaged over a whole month. Computing has a very low R value because the desktop computer is switched on 24/7 so that this activity is both frequently and consistently occurring over the month. Watching TV occurs consistently and every day in the evenings (low R values) and inconsistently at other times of the day (high R values). Cooking happens consistently every day during breakfast and dinner times, and overnight (dishwashing), but is inconsistent at other times of the day. Laundering does not happen every day (infrequent) and also occurs at different times during the day (inconsistent). Hobbies take place consistently from 6–8 am, but do not occur every day (infrequent). Hobbies are also inconsistent at other times of the day.

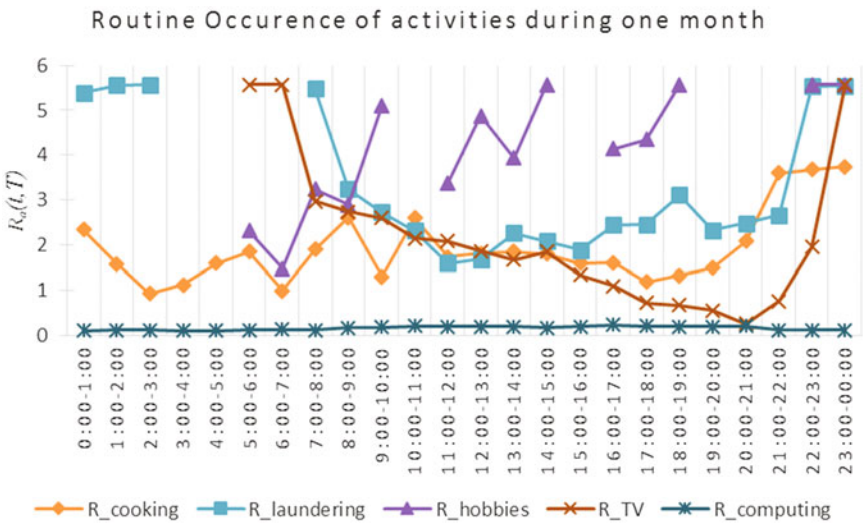

Fig. 4.5 Routine in the time profile of activities in house 5 during hourly timeslots over a one month period (Notes: Routine is measured using the routine metric, $R_a(t, T)$; High values of $R_a(t, T)$ indicate no routine during that timeslot (infrequent and/or inconsistent activities); Low values of $R_a(t, T)$ indicate routine during that timeslot (frequent and/or consistent); Gap in values of $R_a(t, T)$ indicates no activities during that timeslot)

Between households

In order to understand variability across households for each activity, Fig. 4.6 shows the $R_a(t, T)$ for for each hourly timeslot t over a one month period T for a sub-sample of households which represent the main household compositions. The plots have the same interpretation as Fig. 4.5 which shows multiple activities for a single household, but Fig. 4.6 shows a single activity across multiple households. As before, small $R_a(t, T)$ values indicate more routine occurrence; large $R_a(t, T)$ indicates less routine occurrence. Convergent or clustered $R_a(t, T)$ values indicate similar routines across households; divergent $R_a(t, T)$ indicates different routines across households.

Cooking generally has a clear routine time profile for breakfast, lunch and dinner timeslots across all households. Houses 5 and 19 watch TV with increasing consistency from early afternoon to evening. Houses 8 and 19 are distinctive in laundering overnight and never after 8 am. Both households are on the Economy7 tariff which has a lower off-peak cost overnight from 10 pm to 8 am (Murray et al. 2015). Houses 2 and 8 are very consistent in their washing routine in the morning, unlike House 17 which has large variability throughout the day.

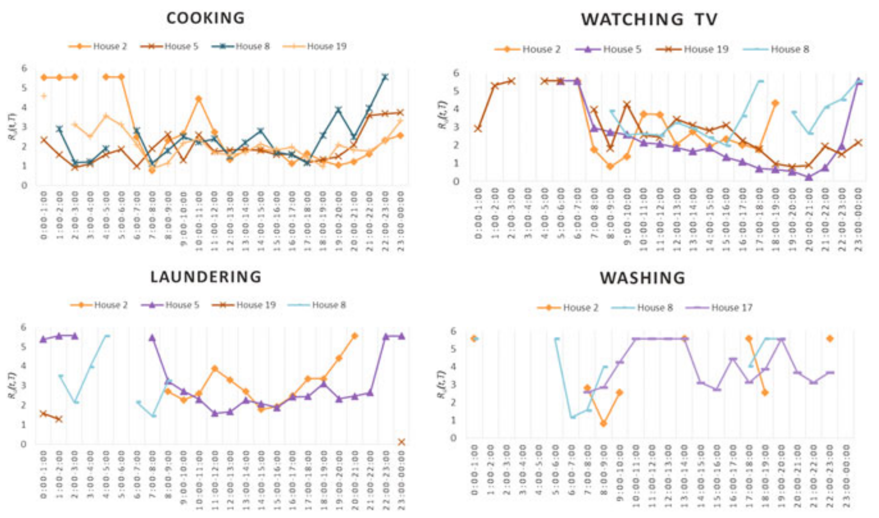

Fig. 4.6 Routine in the time profile of cooking, watching TV, laundering and washing in four houses during hourly timeslots over a one month period (Notes: Routine is measured using the routine metric, $R_a(t, T)$; High values of $R_a(t, T)$ indicate no routine during that timeslot (infrequent and/or inconsistent activities); Low values of $R_a(t, T)$ indicate routine during that timeslot (frequent and/or consistent); Gap in values of $R_a(t, T)$ indicates no activities during that timeslot)

4.7 Results: Activities in Households with Similar Composition

To test the influence of household composition on the occurrence and time profile of domestic activities, we compared the energy intensity and routine of activities within households of similar compositions. We used three distinct types of household within our sample: families of four with two small children (Houses 2 and 10); families of four with two teenage children (Houses 5, 19 and 21); and pensioner couples (Houses 3, 4 and 8).

Table 4.4 shows that there is no systematic association between energy intensity and routine on the one hand, and household composition on the other. Even if energy intensities of the activities are similar, the routines for these activities can be very different. For example, of the four member households with two teenage children, House 19 has a very different $EI_{laundering}$ and $R_{laundering}$ to Houses 5 and 21. This could be due to their use of the overnight Economy7 tariff. Conversely House 21 has the least routine laundering shown by the high value of $R_{laundering}$.

Table 4.4 Energy intensity and routine of cooking, laundering and watching TV activities across households of similar composition (Notes: Energy intensity is measured using the metric, $EI_a(T)$, and routine is measured using the routine metric, $R_a(t, T)$, with t as hourly timeslots and T as the one month measurement period; High values of $EI_a(T)$ indicate large % of total electricity consumption (and vice versa for low values); High values of $R_a(t, T)$ indicate no routine during that timeslot (and vice versa for low values))

Household composition	House	Total monthly electricity use (kWh)	Energy intensity			Routine		
			$EI_{cooking}$ (%)	$EI_{laundering}$ (%)	$EI_{watching\ TV}$ (%)	$R_{cooking}$ (%)	$R_{laundering}$ (%)	$R_{watching\ TV}$ (%)
Families of four with two small children	2	338	21	4	1	2.61	1.68	1.43
	10	417	17	6	3	1.62	2.18	1.49
Families of four with two teenage children	5	636	15	9	2	1.93	2.76	1.75
	19	248	15	1	2	2.09	1.04	2.70
	21	333	23	9	1	2.62	3.65	1.99
A pensioner couple	3	450	20	12	7	3.05	2.27	1.28
	4	254	6	3	2	1.75	1.49	1.47
	8	422	16	4	1	2.06	0.92	2.18

The energy intensity and routine for cooking in Houses 8 and 19 are similar despite the households having two and four members respectively. However, there is a marked difference in their cooking patterns and demand profile. In the family of four with children (House 19) there is one clear peak for dinner in the evening, whereas the pensioner couple (House 8) spread out their cooking activity with multiple peaks throughout the day. The routine value for cooking indicates that both households are consistent and frequent in their respective cooking routines.

4.8 Synthesis

In this chapter, we developed and demonstrated a novel methodology for inferring the energy intensity and time use profile of domestic activities using smart meter data and qualitative interview data to build an ontology mapping appliance end-use to activities. We implemented the methodology to analyse the energy consequences of activities, and how they vary through time and between households. Our analysis showed that all energy intensive activities such as cooking and laundering can accurately be identified and that a significant portion of a household's electricity load can be attributed to a set of routine activities. From a total set of 10 activities, a subset of 4–6 activities can be inferred for any given household accounting for 13–40% of total monthly demand. The remainder is accounted for by other electricity consumption by cold appliances, base load, and the residual including lighting. By defining standardised metrics for both the energy intensity and routineness of activities, we could show how the time profile of activities varied considerably both within and between households.

The motivation for this work was the disconnect in our analytical framework (Table 2.1) between the instrumental view of SHTs for managing energy demand on the one hand, and the complexities of domestic life on the other. This disconnect is shown in Fig. 2.2 by the lack of cross-cutting linkages between vertical 'channels' of research. Activities such as cooking, watching TV or hobbies are ways in which householders spend their time at home. Using SHT data to make inferences about when and for how long activities are taking place sheds light on the variability, routineness and potential flexibility of domestic routines. Linking energy-intensive activities to their time profile may also help identify potential for load shifting and demand side management. For example, understanding which households have less routine in activities indicates 'opportunistic' activities which might be shifted off-peak to help alleviate supply constraints. These are important considerations for utilities and service providers to address in developing scalable products and services for the smart home market.

4.9 Suggested Further Reading

A longer version of this chapter was published as an open-access peer-reviewed article:

- Stankovic L, Stankovic V, Liao J, Wilson C (2016) Measuring the energy intensity of domestic activities from smart meter data. Applied Energy 183: 1565–1580. doi:10.1016/j.apenergy.2016.09.087

For other studies of domestic activities, their time profiles and energy intensities, we suggest:

- Jalas M, Juntunen JK (2015) Energy intensive lifestyles: Time use, the activity patterns of consumers, and related energy demands in Finland. Ecolog Econ 113 (0): 51–59. doi:10.1016/j.ecolecon.2015.02.016
- Torriti J (2017) Understanding the timing of energy demand through time use data: Time of the day dependence of social practices. Energy Research and Social Science 25: 37–47. doi:10.1016/j.erss.2016.12.004

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De Lauretis S, Ghersi F, Cayla J-M (2016) Time use, lifestyle and energy consumption: lessons from time use and budget data for French households. Paper presented at the energy: expectations and uncertainty, Bergen, Norway, 19–22 June 2016

DECC (2014) Smart metering implementation programme: smart metering equipment technical specifications version 1.58. Department of Energy and Climate Change (DECC), London, UK

Gram-Hanssen K (2014) New needs for better understanding of household's energy consumption —behaviour, lifestyle or practices? Architectural Eng Des Manage 10(1–2):91–107

Katzeff C, Wangel J (2015) Social practices, households, and design in the smart grid. In: ICT innovations for sustainability. Springer, pp 351–365

Liao J, Elafoudi G, Stankovic L, Stankovic V (2014a) Non-intrusive appliance load monitoring using low-resolution smart meter data. In: IEEE international conference on Smart grid communications (SmartGridComm), IEEE, 2014, pp 535–540

Liao J, Stankovic L, Stankovic V (2014b) Detecting household activity patterns from smart meter data. In: International conference on Intelligent Environments (IE), IEEE, 2014, pp 71–78

Murray D, Liao J, Stankovic L, Stankovic V, Hauxwell-Baldwin R, Wilson C, Coleman M, Kane T, Firth S (2015) A data management platform for personalised real-time energy feedback. Paper presented at the 8th international conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'15), Luzern, Switzerland, 26–18 August 2015

ONS (2000a) National survey of time use. Office of National Statistics (ONS), London, UK

ONS (2000b) Survey on time use: activity coding list. Office of National Statistics (ONS) & Eurostat, London, UK

Schwartz T, Stevens G, Jakobi T, Denef S, Ramirez L, Wulf V, Randall D (2014) What people do with consumption feedback: a long-term living lab study of a home energy management system. Interact Comput 27(6):551–576

Stankovic L, Wilson C, Liao J, Stankovic V, Hauxwell-Baldwin R, Murray D, Coleman M (2015) Understanding domestic appliance use through their linkages to common activities. In: 8th international conference on energy efficiency in domestic appliances and lighting, 2015

Wilson C, Stankovic L, Stankovic V, Liao J, Coleman M, Hauxwell-Baldwin R, Kane T, Hassan T, Firth S (2015) Identifying the time profile of everyday activities in the home using smart meter data. Paper presented at the European Council for an Energy Efficient Economy (ECEEE) summer study, Hyeres, France, 1–6 June 2015

Zeifman M, Roth K (2011) Nonintrusive appliance load monitoring: review and outlook. IEEE Trans on Consum Electron 57(1)

Zoha A, Gluhak A, Imran MA, Rajasegarar S (2012) Non-intrusive load monitoring approaches for disaggregated energy sensing: a survey. Sensors 12(12):16838–16866

Chapter 5
Domestication of Smart Home Technologies

Abstract This chapter draws on in-depth qualitative data to explore how 10 households domesticated smart home technologies (SHTs) over a nine month period as part of the SHT field trial described in Chap. 1. The analysis is situated within the socio-technical view of smart homes and their users in our analytical framework (Table 2.1). We explore the co-evolution of SHTs and their users, and the forms of work and learning engaged in by householders when they adopt SHTs. We identify three distinct domestication pathways for SHTs which show why it is so important to pay close attention to homes as complex places and settings for the adoption and use of new technologies. In each of these pathways, we explain the negotiations, conflicts and resistances that SHTs generate as they are domesticated, and the multiple and sometimes uneven roles that different householders play in this process. We also demonstrate how the introduction of SHTs into homes can serve to disrupt and re-domesticate other aspects of the domestic environment. Pre-existing domestic technologies must be fitted-in with the newly 'smart' home. Three core themes emerge from this new analysis. First, SHTs are both technically and socially disruptive. Second, householders must adopt a range of adaptation strategies to cope with the disruption that SHTs generate and which can limit their use and potential. Third, domesticating SHTs requires considerable work from householders for which there is currently very little support available.

5.1 Introduction and Key Question

A central argument of this book is that SHTs' potential to transform domestic comfort, convenience, security and leisure whilst also reducing energy use rests fundamentally on whether and how they are adopted and used in homes. Chapter 3 has highlighted prospective and actual users' perceptions of the risks and benefits of SHTs. Chapter 4 has identified the potential for SHTs to link domestic energy use to common daily activities. In this chapter we move the analysis forward by drawing on new qualitative evidence to examine how householders actually use SHTs and how they are (or are not) integrated into homes and everyday lives.

T. Hargreaves and C. Wilson, *Smart Homes and Their Users*, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-68018-7_5

In this chapter, we ask a question central to the potential success of SHTs:

Q1: How do householders learn about, use and adapt to SHTs in their own homes?

To answer this question, we first introduce the concept of 'domestication' to help analyse how SHTs shape but are also shaped by their users and to lay bare the active work and learning involved in this process of co-evolution. Crucially, the concept of domestication highlights the importance of paying attention to homes as complex settings for the adoption of new technologies. It demonstrates how, far from being blank or neutral adoption environments, homes and their pre-existing social dynamics, routines and practices influence how SHTs are used or might be used in future. We then describe the different domestication pathways followed by households in the SHT field trial, focussing particularly on how householders used the SHTs over a nine month period, how this was impacted by pre-existing household dynamics, and the different kinds of learning engaged in by householders during this process.

Domestication

The concept of domestication emphasises the active work involved in 'taming' 'wild' technologies to bring them into and make them functional within homes (Berker et al. 2005). Specifically, Sørensen (1996) suggests that processes of domesticating new technologies involve three distinct but inter-related types of work:

- *cognitive work*—learning about the technology and what it can do;
- *practical work*—learning how to use the technology; and
- *symbolic work*—learning what the technology means and how to incorporate it in personal and domestic identities.

Domestication stresses how, through these work processes, both technologies and their users co-evolve. For example, new technologies enable or constrain the performance of routines and identities and are thus given particular functions and meanings. Users may also come to develop new interests and identities when they acquire and start to use new technologies (Oudshoorn and Pinch 2003; Haddon 2006).

Domestication is rarely a 'harmonious process' (Sørensen 1994). Rather, it is potentially conflictual, involving negotiations between householders—as some become main users whilst others become partial or non-users of particular technologies (Wyatt 2003)—or as some technological features come to be seen as useful whilst others are ignored as unhelpful (Isaksson 2014). For Lehtonen (2003), domestication represents a series of 'trials' in which technologies must constantly prove their worth whilst users must successfully carry out the work necessary to make them useful.

Domestication is seen as having been successful when "technologies are not regarded as cold, lifeless and problematic, but as comfortable, useful tools…that are reliable and trustworthy" (Juntunen 2014, p. 2). Nonetheless, no matter how successful, the domestication process is never complete. Rather, technologies can always be re- or de-domesticated as faults emerge and new technologies are introduced to the home, or as users grow older, have children, move home and so on (Sørensen 1994).

Whilst early work on domestication focussed predominantly on new information and communication technologies (ICTs), it has more recently been applied to a range of energy technologies such as small scale renewables (Juntunen 2014), passive houses (Isaksson 2014), and energy feedback devices (Hargreaves et al. 2010; Wallenborn et al. 2011; Winther and Bell 2017). To our knowledge, however, aside from Nyborg (2015), it has not yet been used to explore how householders use SHTs.

5.2 Method and Data

In Chap. 1 we explained the SHT field trial and provided details of the 20 participating households (Table 1.3). In this chapter, we draw on the interview data collected as part of the SHT field trial from a subsample of 10 households (Fig. 1.2). The interviewees from these 10 households are summarised in Table 5.1.

Qualitative data was collected at three points during the trial (Fig. 1.2). An initial interview and household video tour (I1) was conducted with all household members before installation of SHTs. Lasting 2–3 h, I1 interviews explored how participants used their homes, and household dynamics and decision-making around the use and acquisition of new technologies. A second interview (I2) was conducted within two months of the installation of the SHTs and lasted 30–45 min. Conducted with adult household members and by phone, I2 interviews explored initial uses of and responses to the SHTs. Nine households participated in I2. A third interview (I3) occurred after an initial heating season, 6–9 months after installation. Lasting 1–2 h in a face-to-face group interview with all household members, I3 interviews explored longer-term trajectories in using the SHTs and participants' broader perspectives on smart technologies.

All interviews were recorded and transcribed verbatim. Transcripts were hand-coded to identify similarities and differences between households related to themes derived from the literature on the use of SHTs and the domestication of technology. In the results sections, we report the results of this analysis, focussing on patterns of SHT usage throughout the trial, household dynamics and how they impacted on SHT usage, the learning processes undertaken by householders during the trial, and the different domestication pathways that emerged. We illustrate these results by drawing selectively on interview quotes [for example, with a label of H1I1 p4 denoting page 4 of Interview 1 (I1) transcript with House 1 (H1)].

Table 5.1 Interviewee details

House ID	Interviewee names (ages)[a]	Occupation	SHTs installed
House 2 (H2)	Sally (36); Simon (34); Harriet (3); William (1)	Full-time parent; technical specialist; pre-school; pre-school	RWE, Vera, Hive
House 3 (H3)	Jane (69); John (64)	Retired home-maker; retired engineer	RWE, Vera, Hive
House 4 (H4)	Henry (64); Louise (64)	Retired IT sales support; retired university administrator	RWE, Vera
House 5 (H5)	Jason (51); Cara (47); Ellie (12); Lola (10)	Senior IT developer; university lecturer; school student; school student	RWE, Vera, Hive
House 8 (H8)	Robert (79); Marion (72)	Retired greengrocer; retired home-maker	RWE, Vera, Hive
House 11[b] (H11)	Sarah (71)	Not in paid work	RWE, Vera
House 17 (H17)	Steven (62); Noelle (not given); Rachel (17)	University researcher; care assistant; school student	RWE, Vera, Hive
House 19 (H19)	Keith (48); Lucy (43); Aiden (11); Marcus (8)	IT programmer; not in paid work; school student; school student	RWE, Vera, Hive
House 20 (H20)	Roger (58); Lorna (55); Ursula (22)	IT process analyst; home-maker; student	RWE, Vera, Hive
House 21 (H21)	Ingrid (43); David (33); Ben (11); Sam (9)	Speech therapist; IT product manager; school student; school student	RWE, Vera, Hive

[a]All names are pseudonyms. Ages are those given at the start of the trial
[b]House 11 did not participate in I2

5.3 Results: Patterns of Use

Motivations

Four distinct motivations for participating in the SHT trial were identified. The most common motivation (n = 8) was a desire to save energy and associated costs. Participants hoped to achieve this through optimised control of their heating systems and appliances. For several participants, this was part of a long-standing interest in energy management involving prior use of energy monitors and/or installation of solar panels.

The second most common motivation was an interest in new technology and home automation (n = 6). Here, participants were interested in automated control of devices for convenience and to enhance home security. Despite these interests, only one participant described themselves as an ‘early adopter’, with most suggesting they took an "*if it's not broke, why fix it?*" (Steven, H17I1, p. 19) approach to technology adoption.

Third, two participants were motivated by an interest in protecting the environment. These participants were the only ones to express scepticism regarding the potential for new, energy-consuming SHTs to help reduce energy use.

Fourth and finally, there was a general desire among interviewees for improved control at home. For some this meant making it easier to achieve comfort such as through a warm and well-lit home; others wished for more convenient control of appliances; still others wanted better control over hectic lives (see Chap. 6).

These motivations are broadly consistent with the more aggregated findings from the national survey reported in Chap. 3. Prospective users clearly perceive energy-management benefits of SHTs (consistent with an instrumental view of smart homes and their users) as well as a range of functional benefits related to control of the domestic environment. The survey of actual early adopters reported in Chap. 3 was drawn from the same sample of households participating in the SHT field trial, so these results are also consistent. However what was lost in the broad-brushed survey analysis was the differentiation of perceived benefits *within* the same household.

The interview data show that although four distinct motivations for participating in the SHT field trial were all expressed, participation had ultimately been driven by a combination of different motivations. In particular, different interviewees within the same household often expressed different motivations, and whilst the decision to participate in the SHT field trial was generally driven by a single householder—usually a man with some experience or interest in using computers—this individual did not always go on to become the main user of the SHTs after installation (see Sect. 5.4).

Despite their interest in the SHT field trial, several participants expressed concerns about new technologies in general. This included general complaints about the rude use of mobile phones in public but also more specific unease about automated systems making people lazier, and complaints about being unable to control or maintain smart technologies, or about whether technologies could be trusted to regulate themselves. These concerns suggest that SHTs could not be divorced from wider cultural unease about technology more generally (Smits 2006). The domestication of SHTs unavoidably occurs within and against this context. Just as prospective users had voiced concerns about the socio-technical risks of SHTs in the national survey (Chap. 3), so too did the SHT field trial households identify downsides linked to broader social and technological trends.

Installation

Installation of the SHTs was led by the research team with assistance from professional heating engineers where necessary. Participants in the trial had relatively little choice over where hardware should be located in the home. Thermostatic radiator valves, for example, needed to be placed on pre-located radiators. Participants did have some choice over where to place the software components of the systems. Although the RWE and Vera interfaces could theoretically be accessed from any internet-connected computer, in practice they were often perceived as residing on the particular 'owned' computer on which they were initially configured. For example, despite regularly checking the SHTs from her smart phone, Ingrid stated that she hadn't engaged with all parts of the SHTs because the "*full programme* [is] *on David's laptop*" (H21I2, p. 7). In seven other households, the need to use computers to configure the SHTs was enough to create several non- or at least extremely partial-users (Wyatt 2003), such as those who described themselves as 'technophobes' or who had rarely used computers due to lack of access or opportunity.

The RWE and Vera systems could only be fully configured via computer, but smart phone apps did allow partial control. By contrast, the Hive system was designed to be fully controlled by phone. Here, where computers had often served to restrict access to the RWE and Vera systems among some users, smart phone access opened it up more widely for the Hive system. Sally, for example, was initially very sceptical about the SHTs and did not use them as they were configured on Simon's computer. Once she started using the Hive system on her smartphone, however, she became a very active user, checking it on an almost daily basis.

Initial use

Whilst some configuration was completed during installation, several participants mentioned that they then largely ignored the technologies, sometimes for several months. Different reasons were given for this. For some, summer installation meant they were waiting for the start of the heating season and darker evenings before automating or scheduling heating or lights. For others, the delay occurred because they weren't sure what to use the SHTs for. As Simon stated:

> It's just taken months to just use it and realise where it's useful. When you get it, you sit down and you see it can do all this stuff, and you think 'do I actually need to turn that radiator off…when I open that window?'… It wasn't intuitive what parts of it you can do straight away. (Simon, H2I3, p. 11)

For others, the installation process had made them realise the systems were complex and would take time to fully configure, time they couldn't always find:

> The problem is it's trying to find the time with the software…learning how to use it I think, because it is quite demanding. (Roger H20I2, p. 3)

Common across these reasons is the observation that the potential benefits of the SHTs were not immediately apparent, nor did they necessarily apply all year round, particularly outside the heating season. Perhaps because of the number of functions the systems offered, participants had to work hard to identify exactly how they could be useful and, only once they'd done this, could they then start the demanding task of making it happen.

Although some of the more technically proficient participants stated a desire to 'play' or 'experiment' with more advanced, automated features, once participants did start using the systems they generally did so in relatively simple ways. As explained in Chap. 1, users could interact with the SHT systems through time profiles, event profiles and rule profiles. Interviews with households in the SHT field trial identified seven distinct types of use:

1. Room-by-room time profiles for heating (RWE, n = 9)
2. Remote control of heating (Hive, n = 4) or lights (Vera, n = 2)
3. Time profiles for lights when away from home (Vera, n = 4)
4. Rule profiles for radiator use (RWE, n = 2)
5. Remote monitoring of doors, windows, lights or radiators (RWE and Hive, n = 3)
6. Boost buttons or kill switches for multiple radiators or appliances (RWE, n = 2)
7. Manual use of heating via room or radiator thermostats (RWE); Two households did this exclusively, although most combined automated with some manual control.

Longer-term use

Over the longer-term participants generally settled into a pattern of use that made less rather than more use of the SHT systems' more advanced functionality. Two households reverted to exclusively manual control, avoiding computers or smart phones altogether. Most stopped checking door and window sensors as regularly, and stopped using time profiles for lights whilst away from home. Indeed, rather than becoming more advanced in their use of the SHTs as they became more confident with them, the opposite occurred. Simpler forms of use, utilising fewer functions, tended to take hold over time. Whilst some automated functions remained in use throughout, the experience for most was, as Ingrid put it, that it "*just pottles along in the background and I don't tend…to do so much with that nowadays*" (Ingrid, H21I3, p. 1). Several participants mentioned that they now simply 'tweaked' their settings when necessary. Jason, for example, argued that the more advanced capabilities of the SHTs had:

> complicated our lives, [because] before we would blissfully set everything, leave it for six months, have another look when the clocks change, leave it…[but] we now more often tweak and administer it. (Jason, H5I3, pp. 18–19)

Most participants, however, perceived little need to engage with the systems because: "*if it's working all right, then nobody will bother*" (Lucy, H19I2, p. 11).

5.4 Results: Household Dynamics

One reason why participants made only limited use of the more advanced SHT functionality stems from which householder became the main user. While participation in the trial and initial system configuration tended to be driven by a single user, this individual did not always go on to become the main user. Rather, main users tended to be those who were most present at home, even if these individuals were self-described 'technophobes'. In five of ten cases, the main user was indeed the most technologically-proficient householder and these circumstances did give rise to more advanced and automated use of the SHTs. In three other cases, the main user was not the most technically proficient individual. This meant SHT usage tended to be more basic, often via manual control. In the two other cases, no householders saw themselves as particularly technologically proficient and this resulted in exclusive manual use of the SHT systems.

If the most technically-competent individual did become the main user, this did not mean they had free reign to use the SHTs however they liked. Rather, they would have to negotiate what to use the SHTs for with other household members. In John and Jane's case, for example, whilst John was eager to use the system to drive down energy use within the home, Jane saw the benefit of being able to isolate and pre-warm the heated towel rail in their bathroom. Similarly, Jason spoke of his worry that if the more advanced things he tried went wrong, this would cause inconvenience for others:

> You worry that you've installed this system and screwed everything up. You feel stupid that you've let this thing in your house and didn't really need to. It's a bit of fun…but now it's caused everyone grief. (Jason, H5I2, p. 15)

Whilst this may have limited more advanced use of the SHTs in some homes, in Henry and Louise's case, these kinds of negotiations led to arguments and, ultimately, to abandonment of the SHTs:

> There was a wonderful day when I turned something to manual and changed it and then Henry went online and changed it automatically and neither of us knew what the other one was doing… it did cause arguments. (Louise, H4I3, pp. 4–5)

In five households the technical demands of the SHT systems created non-users of at least their more advanced, automated functions. In two of these cases this led non-users to resist use of the SHTs and ultimately led to their abandonment. In the three other cases it led to users being either unable or unwilling to use the systems and, for some of these, a feeling of loss of control inside their homes (discussed further in Chap. 6). Allied to this, several of these non-users expressed unease about feeling watched or monitored inside their homes when the systems were first installed. This was not helped by the small whirring noises made by the RWE radiator valves when they automatically adjusted themselves, making them a frequent and sometimes irritating reminder of the SHTs' presence in the home.

5.5 Results: Learning

Learning was a dominant theme across all interviews and, as suggested by the concept of domestication, this took three distinct forms: practical, cognitive, symbolic.

Practical learning

Practical learning focuses on how householders learnt to configure and use the SHTs. Here, almost all participants were negative about the design of the SHTs which were described as complicated, fiddly and awkward (with the exception of the Hive system). These perceptions gave rise to a feeling amongst some interviewees that, once installed, the SHTs were quite precarious and that it would be easy to make them go wrong. Further, when participants had experienced problems, they reported feeling that there was a general lack of support available for maintaining and repairing the systems, whether through a lack of sufficient instructions or online support, or because existing plumbers or electricians lacked the necessary skills to maintain networked technologies. As John mentioned:

> The house of the future will need not just integrated systems in the house, but a robust support infrastructure that can not only sell it and install it, but then maintain it. And at the moment I don't get the feeling that we're near that. (John, H3I3, p. 12)

The challenge of learning how to use and maintain the SHTs was thus considerable. Whilst some householders wrote lists of things to learn or try out, most saw it as a challenge of learning-by-doing. Marion, for example, likened the whole experience to having a new baby in which:

> You can read all the books about it…but when the thing arrives and it isn't operating [laughs] it's totally different… You learn as you go along. (Marion, H8I2, p. 6)

Cognitive learning

Cognitive learning focuses on how the householders learnt what the SHTs could be used for. In this case, there was much confusion and uncertainty among interviewees. For example, several householders mentioned that, beyond controlling the heating, they couldn't identify additional worthwhile uses for the SHTs:

> We're not aware of any more advanced functions. Has something passed us by? (Marion, H8I3, p. 13)

Interviewees often felt they weren't using the SHTs to their full potential and called for more help so they could work out exactly what the systems could do and how they might use them. Several felt it would be useful for the systems themselves to make suggestions, such as through advice on energy saving, or through pre-existing templates that demonstrated their potential functionality (see also Mennicken et al. 2014). Others mentioned that they had asked friends, other family members, or plumbers and other professionals for ideas but usually found little useful knowledge or experience from these sources.

Symbolic learning

Symbolic learning focuses on how householders made sense of the SHTs and incorporated them into their identities, routines and practices. A key theme within the interviews was about whether and how householders should adapt their own lifestyles in order to get more out of the SHTs. Several interviewees described how they felt that 'smart' technologies would increasingly become the norm and that there was therefore a need, as Steven put it "*to get into the culture of using this stuff*" (Steven, H17I2, p. 4). Ingrid, for example, suggested that realising the full benefits of smart technologies may require that "*you have to look at the other things that they link into*" (Ingrid, H21I3, p. 21), and thus to acquire still other smart technologies that could be connected into a wider home network. Indeed, the introduction of SHTs served to disrupt and unsettle the status of some older technologies in the home. For example, several participants began to perceive their existing computers or smart phones as 'old' or somehow insufficient and in need of replacement in order to function with the SHTs. The same was true for older heating systems which participants worried would not be able to cope with the additional demands they perceived the SHTs would place on them. For example Ingrid expressed concern that her "*old boiler would not be able to cope with* [motion sensitive control]" (Ingrid, H19I3, p. 19). Finally, two households commented that the Vera system could not be used to fully switch on their existing devices because they turned on in stand-by mode. In short, the introduction of the SHTs caused other technologies to be re-domesticated in ways that made them seem old and sometimes in need of replacement.

Despite these examples, the general feeling among participants was that: "*We shouldn't react to the system, the system should react to us*" (Jason, H5I3, p. 8). Indeed, most suggested that rather than adapting themselves to the systems, they had instead adapted their use of the SHTs by using only their more basic and often manual features to make them resemble more familiar technologies like a "*traditional heating system*" (Ingrid, H21I3, p. 19).

5.6 Results: Domestication Pathways

Reflecting across householder experiences with the SHTs, it is possible to identify three different domestication pathways that shaped how the SHTs were (or were not) used, and how they or further SHTs might be used in future. These three pathways were: successful domestication; precarious domestication; and rejection.

Successful domestication

Three households could be described as having successfully domesticated the SHTs. Here, the SHTs had come to be seen as a helpful and convenient part of the household. Further, these households expressed interest in, or had already acquired, additional SHTs to link-in with the SHTs installed as part of the field trial. The domestication pathways followed by these households were not problem free, however, and all of them had encountered some difficulties—such as finding the SHTs fiddly, irritating, or being frustrated at a lack of interoperability. Nonetheless, this group also described how they checked the SHTs regularly and had come to depend upon them. For example, when their Hive system had a minor malfunction, Sally commented that: "*we were a bit lost without it. We didn't realise how dependent on it we were!*" (Sally H2I3, p. 1).

Importantly, despite the successful nature of domestication in these homes there was little interest in making use of the more advanced and automated features of the systems. Instead, these households had mostly made use of time profiles for heating on the RWE system, remote control of lights or heating via the Vera and Hive systems, and the ability to remotely monitor the status of lights, doors, windows or radiators. In these ways, as Ingrid argued, they had made the SHTs fit around them: "*I haven't felt I've had to go and work out what the other stuff does…because I feel it's working for us as it is*" (Ingrid, H21I3, p. 16). Arguably, therefore, 'successful' domestication of the SHTs depended not on making use of all the advanced features on offer but on using only the more simplistic features to make the SHTs function effectively within pre-existing household situations.

Two households in this group were exploring options for acquiring more SHTs. Ingrid, for example, had purchased a fitness tracker that linked with the Hive system and David was researching smart lighting controls for their planned home extension. In making these plans, however, both expressed concern that future SHTs should not be excessively complicated, especially for other users of the home, such as Ingrid's parents:

> My Mum is not very happy, she's gone 'that means it won't just be the telly we can't use, it will be the whole house we can't use! [laughs] (Ingrid, H21I3, p. 16)

As these concerns show, even successful cases of domestication included sources of uncertainty and doubt and the potential for future de- or re-domestication.

Precarious domestication

Five households followed a second pathway which could be described as 'precarious' domestication. In these cases, the SHTs were being used, but on an infrequent basis, and their use was often perceived quite negatively. For this group, the SHTs had much potential but required further development. The dominant trope among this group was that the SHTs were excessively complicated for their needs. They were seen as too difficult to use and too demanding in terms of time or effort in relation to the benefits they offered. As a result, this group tended to use them only for room-by-room time profiles for heating or to control them manually.

At the same time, this group recognised that the SHTs could potentially do more, but either could not identify potential uses, or did not think it worthwhile to use their more advanced features. As Roger put it:

> I suppose the way things are…written about, you think there must be a lot more to it, but… we just haven't used much of the facilities that potentially are there…It's a lot smarter than we're giving it credit for I suspect. (Roger, H20I3, p. 19)

Despite awareness of the SHTs' potential, some were using the technologies in basic ways that made them seem to be little more than over-engineered and expensive radiator valves or timer switches.

For this group the domestication status of the SHTs at the end of the field trial was precarious. Some components of the SHTs were seen as useful, but many called for further development of the systems—particularly in relation to user-interface design and interoperability. Some also suggested that the SHTs might be useful for other households but not for them. In these cases, appropriate households were seen as those in which people were already online all the time or had more electrical gadgets. As Noelle explained:

> [Some friends live near] this sort of millionaire mansion. It ha[s] things like an infinity pool and…a wine cellar that you could control the temperature…from anywhere in the world. So that's somebody who might get the benefits [of SHTs]…but…we haven't got the gadgets that necessitate it. (Noelle, H17I3, p. 20)

Precisely because they could perceive potential benefits, however, these households persevered with using the SHT systems throughout the field trial, even if only in a relatively basic way. As Marion explained:

> At one stage it was going to be thrown out and I thought, 'No, I'm not going to be beaten by technology, dammit we'll get to grips with it!' (Marion, H8I3, p. 2)

As Marion's quote suggests, however, for this group the SHTs were always close to being abandoned if they came to be seen as too complicated or if things started to go wrong.

Rejection

The third domestication pathway was observed in two households and resulted in rejection of the SHTs. In these cases, participants expressed little interest in technology and were not regular users of smart phones or computers when the trial began. The SHTs then came to be seen as a waste of time that risked making things worse for either the environment or society. Common in these homes were stories of feeling 'over-ruled' by the SHTs which generated a sense of losing control over the home. Both Sarah and Louise, for example, mentioned occasions when their attempts at manual control were frustrated by the SHTs. For example, Louise complained that "*the computer would override what you wanted to be happening in the room*" (Louise, H4I3, p. 4), and Sarah felt that the SHTs "*would be overriding my own judgement about what I think is the best thing to do*" (Sarah, H11I3, p. 7).

As a result, households in this group came to resist the SHTs as excessively complicated, offering little of benefit to their own lives and therefore unnecessary.

> It's too bloody complicated and there's no point in it and it's doing me no benefit. Not worth having! (Louise, H4I2, p. 6)

Going further, they came to reject the whole enterprise of smart technologies as something that may in fact make matters worse either for the environment or society. Sarah, for example, was concerned that the ability to 'pre-warm' the home before arrival could encourage more rather than less energy use. This group complained about what they saw as an excessive number of batteries required to power the SHTs. Louise also suggested that automated homes could result in people becoming lazy:

> There was an article on the telly, one morning, about a guy who gets up, the house is fully controlled…it switches on his coffee for him, it opens his curtains, and I thought 'so what does the actual person do?'…The human body has nothing to do any more, it's going to get fat and slobby isn't it? (Louise, H4I3, pp. 24–5)

Whilst others also suggested that smart technologies would become increasingly common, this was perceived in a negative and somewhat fatalistic manner as being "*pushed*" (Louise H4I3, p. 9) down a particular technological path. As Henry put it, this risked raising expectations about technological requirements, without their potential impacts or benefits being clearly known:

> These things will sort of come in under our noses and new houses will have a lot of this kit installed in advance. People will walk into a house and expect to have a certain amount of control and I think it will become insidious its introduction…We will get more of it, but we don't know what it is. (Henry, H4I3, p. 26)

5.7 Synthesis

In this chapter we have explored an important element of the socio-technical view of SHTs by exploring how SHTs are domesticated into complex home environments. In so doing, we have revealed the importance of user-technology interactions, and drawn out implications for hardware and software development, and the acceptability and usability of SHTs. Drawing on new qualitative evidence, we have explored how householders actually used SHTs (as part of the SHT field trial) and how they were—or were not—integrated into homes and everyday lives. We used the concept of domestication to help identify the active work and forms of learning that householders engage in when adopting new technologies such as SHTs. In describing how householders learnt to use the SHTs and how this was impacted by existing household dynamics, we identified three distinct pathways of domestication. 'Successful' domestication saw the SHTs being used regularly and even relied or depended upon by householders, with some interviewees expressing a desire to purchase more smart technologies. However this success appeared to be premised upon using only the more basic features of SHTs, and actively avoiding or abandoning their more advanced and automated capabilities to make them fit-in with existing household roles and routines. 'Precarious' domestication saw householders persevering with using the more basic features of the SHTs, but often infrequently and marked by negative perceptions of the SHTs as over-complicated, fiddly and awkward. In this group, whilst the SHTs were still being used at the end of the trial they had never quite become fully accepted parts of these homes and appeared to be constantly on the verge of being thrown out and abandoned. Finally, 'rejection' saw householders actively abandon and come to resist the SHTs as a waste of time that may even make matters worse for the environment or society. Rejection was often marked by householders feeling as if the SHTs had over-ruled them which led to a feeling of loss of control within their own homes.

More work, and on a much larger scale, is needed to identify if these distinct domestication pathways would be followed in similar ways in other ‘smart’ households, or if still other domestication pathways would emerge. Nonetheless, even among the small sample of SHT field trial households, it is possible to identify some key issues that emerge when SHTs are domesticated and that require greater attention in future research.

First, SHTs are disruptive technologies. Even if SHTs were successfully domesticated, this process was far from smooth. As well as introducing new monitors, sensors and interfaces to households, SHTs also introduce a new layer of control functionality onto existing appliances and devices around the home. On top of requiring domestication in and of themselves, SHTs also demand that many other aspects of the domestic environment are re-domesticated into the new ‘smarter’ home. Through this process, SHTs also unsettle existing roles and relationships among householders as they open up new ways of controlling and doing things, placing new demands on householders including finding time to learn what to use SHTs for and how to configure them to achieve this (Strengers and Nicholls 2017). Alongside seductive visions of smart home futures, SHTs need to be recognised as disruptive technologies and the forms of technological and social disruption they cause should be taken far more seriously in future research and development.

Second, householders adopt a range of adaptation strategies to cope with the disruption SHTs generate. Alongside non-use, resistance and rejection, these strategies include forms of domestication that make only partial use of SHTs so as to render them more familiar and less disruptive. One of the key trends observed was for participants to use the SHTs in less sophisticated ways as the field trial progressed, and to limit their application to only certain areas of life rather than gradually expand their reach. This ‘shallow’ domestication runs counter to visions of fully smart, automated, energy-reducing homes depicted by some in the SHT industry (see Chap. 3). To date, very little research has explored non- or partial-use of SHTs nor how such non- or partial-users interact with and negotiate SHT usage with the lead or main users (Nyborg 2015; Mennicken and Huang 2012). There is an important need for differing types and extents of SHT use to be further explored, and for the wider social dynamics of households to be seen as central to how SHTs are used (or not).

Third and finally, there is currently little support available to help householders with the considerable work involved in domesticating SHTs. This lack of support includes a lack of awareness or experience among friends, family or other ‘warm experts’ (Lehtonen 2003). Participants struggled to identify potential uses for SHTs, and found professionals such as plumbers or electricians lacked necessary expertise and so needed to develop new skills to master the new technologies and device interactions SHTs bring about. Whilst many technical challenges associated with networked technologies remain, there is also a pressing need to develop supportive social networks and contexts if SHTs are to be more widely adopted and used.

5.8 Suggested Further Reading

A longer version of this chapter was published as an open access peer-reviewed article:

- Hargreaves T, Wilson C, Hauxwell-Baldwin R (2017) Learning to live in a smart home. Building Research and Information. doi: 10.1080/09613218.2017.1286882

Other recent research exploring in-the wild use of smart home technologies are:

- Mennicken S, Huang EM (2012) Hacking the Natural Habitat: An In-the-Wild Study of Smart Homes, their Development, and the People Who Live in Them. Lecture Notes in Computer Science 7319:143–160. doi:10.1007/978-3-642-31205-2_10
- Nyborg S (2015) Pilot Users and Their Families: Inventing Flexible Practices in the Smart Grid. Science and Technology Studies 28(3):54–80

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Wyatt S (2003) Non-users also matter: the construction of users and non-users of the internet. In: Oudshoorn N, Pinch T (eds) How users matter: the co-construction of users and technology. The MIT Press, Cambridge, Massachussetts & London, pp 67–79

Chapter 6
Control of Smart Home Technologies

Abstract In this chapter we focus on a specific theme that is central to research on SHTs: control. The potential benefits of SHTs are dependent on householders having more and finer-grained control over their appliances, homes and even their everyday lives and routines. Diving deeper into the qualitative interview material introduced in Chap. 5, we interrogate the many positive and negative ways in which control surfaces as an issue when householders use SHTs. We start by reviewing existing ideas of control in research on SHTs. We identify three distinct meanings of the term control: (i) 'artefactual' control which refers to the ability to use SHTs to control technologies and devices around the home; (ii) 'perceptual' control which refers to how SHTs impact upon householders' feelings of control inside their home; and (iii) 'relational' control which refers to how SHTs affect householders' control over their everyday lives, activities and relationships. We then explore how these distinct forms and meanings of control emerged and were experienced by householders in the SHT field trial. We also examine the inter-relationships between these distinct forms of control which can generate both positive and negative feedback loops impacting how householders use SHTs.

6.1 Introduction and Key Question

In Chap. 5 we explored how householders domesticated SHTs in quite broad and general terms. In this chapter we deepen the analysis by focussing in greater depth on the notion of 'control'. The manifold purposes of SHTs—to improve the quality of home life, help people to save energy, or help people organise their everyday lives more conveniently—are all provided for by offering householders more and finer-grained control over the domestic environment. SHTs do this in different ways by allowing their users to gather feedback on the domestic environment in order to make more informed decisions, to 'set and forget' schedules for each and every radiator or domestic appliance, to sense the domestic environment (e.g., for occupancy, light, humidity or temperature levels etc.,) and automate optimised responses, or even to control the home remotely (e.g., Cook 2012; Lewis 2012).

T. Hargreaves and C. Wilson, *Smart Homes and Their Users*, Human–Computer Interaction Series, https://doi.org/10.1007/978-3-319-68018-7_6

Whilst the provision of control is central to the potential value that SHTs offer to households, social scientists working in this area have long identified that it is by no means an easy task to simply give more 'control' to householders as if it were a single, quantifiable thing. Randall (2003), for example, identified what he called the 'control paradox' to describe the fact that the more advanced the control capabilities provided to householders by SHTs, the more 'out of control' they felt in their homes. Whilst it has long been a concern that automated technologies may wrest control away from humans (Norman 1994), more in-depth studies have sought to nuance the concept of control arguing that there are qualitatively different types of control involved in smart homes such as control of devices, control of others, control over lives, and so on (Davidoff et al. 2006).

Rather than focussing merely on how SHTs can be used to provide *more* control to households, the key question—and the focus of this chapter—should instead be:

Q1. In what ways do SHTs change the nature of control relationships within households?

In addressing this question, this chapter is situated within the socio-technical view of SHTs as it explores how SHTs are used inside complex domestic environments (Table 2.1). In developing this theme, however, strong cross-cutting links are made to the functional and instrumental views particularly in relation to user-technology interactions and the acceptability and usability of SHTs.

The term 'control' is widely used in the literature on SHTs, but to emphasise quite different aspects of life inside smart home environments. In particular, we identified three distinct approaches: (i) control of technology, (ii) control by users, and (iii) control of lives and relationships.

Control of technology

> Control from the perspective of smart home research, tends to focus not on life control, but on devices. Smart home systems often enable the home to automatically turn on lights… control a thermostat…close the blinds…[and] provide a single user interface for control over all home appliances (Lee et al. 2006, p. 3).

Control of technology is the dominant type of control in the literature on smart homes, but also in much policy and industry thinking in this area. This understanding of control suggests that smart homes serve principally to provide more control over domestic appliances in ever finer-grained, optimised and automated ways. Related research focuses on identifying ever more devices (from pens to fridges and wardrobes) to incorporate within smart home systems (Park et al. 2003), establishing new ways of sensing the domestic environment, developing predictive algorithms to increase the intelligence of smart home systems, and ensuring that smart home technologies are reliable (Friedewald et al. 2005) as well as interoperable with one another (Edwards and Grinter 2001; Cook 2012). Users are seen as 'end-user-programmers' (Strengers 2013) who essentially delegate control to SHTs by selecting which of their preferences are to be automated or by setting and forgetting device schedules.

This approach assumes that more control over devices is better. More control is seen as more useful and empowering for users and therefore more desirable. Critically, with respect to energy-demand management, more control is seen as important and necessary as it allows more aspects of domestic energy use to be automated or optimised. The implications of SHTs for energy demand are thus seen as clear and unequivocal: if SHTs are designed and used as intended, they will reduce energy demand through enhanced rational, optimised and automated control of domestic appliances.

Control by users

> One of the first problems that must be dealt with is the feeling of control. An important psychological aspect of people's comfort with their activities – all of their activities, from social relations, to jobs, to their interaction with technology – is the feeling of control they have over these activities and their personal lives. (Norman 1994, p. 69)

Developing from Randall's (2003) 'control paradox', a second and less common approach to control focuses on the finding that even if SHTs offer or successfully provide new control opportunities over devices within homes, this can render their users feeling 'out of control'. In this view, the object of control is not devices, but users' feelings and perceptions of control within their home. This approach to control focuses on identifying the various issues that impact upon users' perceptions. As such, it can overlap with a focus on control of technology by suggesting a need to provide easy-to-use and intuitive user interfaces that give users a perception of control over devices (e.g., Koskela and Väänänen-Vainio-Mattila 2005). At the same time, however, it can depart quite radically from this approach to explore wider, systemic issues such as users' levels of trust in utility companies (Paetz et al. 2012), their worries about security and data privacy (Cook 2012), or concerns that smart homes might render users lazy, complacent, dumbed-down and reliant on external experts to fix problems if everything becomes automated (Balta-Ozkan et al. 2013).

At the heart of this approach is a belief that users should *feel* in control inside smart homes. In essence this approach suggests that if SHTs fail to give users the sense that they are in control, they will fail to be adopted and used. The energy demand implications of this approach are far from clear. If Randall's 'control paradox' is widely replicated, for example, the implication is that the wide diffusion of SHTs could render users feeling out of control and, as a result, patterns of energy demand could go in any number of different directions. Fundamentally, however, this approach to control suggests that the impacts of SHTs on energy demand will hinge less on what devices or technologies SHTs allow their users to control and more on the extent to which SHTs give their users a sense of control over the domestic environment.

Control of lives and relationships

> [M]ore than control of their devices, families desire more control of their lives. (Davidoff et al. 2006, p. 20)

A third, and by far the least common approach to control in the literature on SHTs focuses on whether and how they allow users to control their lives and relationships. By virtue of their efforts to optimize, automate, schedule and remotely control the domestic environment in different ways, this approach sees smart homes as interventions in everyday life and relationships. Davidoff et al. (2006), for example, highlight the need for SHTs to be able to support flexibility, improvisation and breakdowns within domestic routines, as well as to be able to 'enrich' family activities emotionally and contribute to the formation of family identities, rather than merely providing rational, instrumental forms of control over domestic space and appliances. The object of control in this approach, therefore, is everyday domestic life, comprised as it is of activities, schedules, routines, relationships and so on.

Research which adopts this understanding of control explores how SHTs affect domestic life. Chapter 5 provided several examples by examining how the SHTs used in the field trial impacted upon household dynamics, how the SHTs changed householders' perceptions of other technologies in their home, or how the SHTs demanded that householders engage in new forms of work and learning to make the SHTs function. Other examples include research that has explored how SHTs impact on gender roles and relations in homes (e.g., Berg 1994; Richardson 2009; Strengers 2015), the extent to which they help create—or detract from—a sense of 'home' or homeliness for householders (Leppanen and Jokinen 2003; Takayama et al. 2012) and how, far from giving more control to householders, SHTs can also take control away by 'acting back' on householders and demanding that they adapt or change their domestic routines in response to technological signals (Strengers 2013).

The central assumption behind this approach is that people desire control over their domestic lives in a broad sense and that SHTs, at least as they are currently designed, may not help them achieve this. With respect to energy demand, the implications of this approach are again far from clear. Even if smart homes are able to provide people with more control over their domestic lives and relationships, there is no guarantee this will be used to reduce energy use. Rather, it may be used in ways that allow people to engage in new energy-intensive activities, or to engage in existing activities in more energy-intensive ways (Nyborg and Røpke 2011; Strengers et al. 2016).

As this brief review has shown, different approaches to control have long been a core concern of research on SHTs. Nonetheless, there remains surprisingly little research on the lived realities of control in actual smart home environments, with Hansen and Hauge (2017) a recent exception. We address this research gap by exploring the dynamics of control in the SHT field trial homes.

6.2 Method and Data

In this chapter we draw on the same interview data introduced in Chap. 5. Further details of the field trial context and SHTs installed are provided in Chap. 1.

Table 6.1 Three types of control in smart homes

	Artefactual	Perceptual	Relational
Object of control	Technologies, devices	Perceptions, feelings	Everyday lives, activities, relationships
Locus of control	Smart technologies	Users	Relationships between people and activities
Core assumptions	More control over more devices is better	People want to feel in control	People desire control over their domestic lives
Core research questions	How can new devices be controlled and user-interfaces made user-friendly?	What factors shape perceptions of control and how can these be managed?	How do smart homes affect lives and relationships and what can be done about this?
Implications for energy demand	Smart homes should lead to energy demand reduction through rational management	Smart homes may lead to demand reduction if users feel 'in control', but may also have little or negative impact if users feel out of control	Smart homes may lead to demand reduction, but may also generate more energy-intensive lives

To analyse this data for the impacts of SHTs on control relationships in the field trial households, we draw on the preceding review to distinguish between three different types of control in smart homes: artefactual—concerned with the control of technologies and devices; perceptual—concerned with householders' perceptions of control; and relational—concerned with householders' control over domestic lives and relationships. Table 6.1 summarises the main features of these three distinct approaches to control used to analyse the interview data. Specifically, transcripts were coded for instances where the different types of control came to the fore, focusing subsequent analysis on how different types of control were expressed, and on the relationships between them.

6.3 Results: Artefactual Control

Many interviewees stated that the SHTs installed in the field trial had given them more or better control over various aspects of their homes. A range of different aspects of artefactual control were highlighted as particularly significant. For example, several participants commented that the RWE system in particular allowed them to "*fine tune the heating system*" (Keith, H19I2, p. 5). Others commented that it was useful not only to control the heating differently in different rooms, but also to be provided with detailed information on the actual temperatures in different rooms to help inform decision-making:

> Well, certainly from the heating point of view, having more control over when it comes on, when it doesn't come on, and actually having the thermostats reading of what temperature

> the rooms are at. That was really useful because…now I can see all the rooms are at a decent temperature or, actually, no upstairs is a bit colder so I'll turn it up. (Ingrid, H21I2, p. 6)

As well as finer-grained control, several interviewees also enjoyed the remote control functionality the SHTs provided. For example:

> We enjoyed being able, as we were preparing to leave for London, to go into the Hive system and tell it to change from 19 to 12 for the time we're away…[and] we were able to tell it to go back to the normal heat a few hours before we got home…we had saved energy by avoiding burning gas in an empty house. (John, H3I3, p. 4)

Illustrating inter-connections between artefactual and relational forms of control, in some cases, participants mentioned that the ability to remotely control the home encouraged them to pre-warm the house before arriving home or to ensure lights were on for others (e.g., children arriving home from school). Ingrid, perhaps the most frequent user of the remote control capabilities provided by the SHTs, commented that she remotely checked the temperature of the house on most days and would frequently turn down her children's radiators if she noticed them being set too high:

> It means I've got a bit more control without having to necessarily go into their bedrooms and go 'excuse me, turn it down.' I just turn it down for them. (Ingrid, H21I2, p. 1)

In two cases, interviewees commented that they liked the idea of setting different 'rule profiles' on the RWE system (e.g., to turn a radiator on if motion was detected) although, as Chap. 5 showed, in these instances, interviewees were often unclear if or how well this had actually worked.

As the above quotations show, interviewees made use of the new forms of artefactual control afforded by the SHTs in a range of ways. At the same time, however, many also suggested that this could have been made easier to achieve and some others felt that the new systems had in fact reduced the amount of artefactual control they had. Among those who felt forms of artefactual control could have been made easier to achieve, the principal reasons for this related to poor user-interface design (particularly of the RWE and Vera systems) and to the lack of integration and interoperability between the three SHT systems installed. For example:

> To me, in my childish Tomorrow's World eye view of what an automated house should be like, you should have one really nice computer user-interface that lets you drag and drop things and events, and link things with little wires, and put bits of code in, say schedule this, do this on Thursdays, do this on my birthday. Absolutely every schedule that you can think of. React to external temperatures, react to external light, react to external windchill factor. That sort of thing would be amazing. But to have three separate systems, that are all very insular, it's very frustrating. (Jason, H5I3, p. 17). (Authors' note: Tomorrow's World was a BBC science and technology programme popular in the 1970s & 80s)

If participants suggested they had not made use of the full range of artefactual control available to them, the main reason given was that the SHTs were excessively complicated and that previous ‘dumb’ systems had been easier to use and more flexible.

Further, several interviewees raised concerns about potential limits to the amount of artefactual control SHTs could provide. For many, the limits were to be found in the fact that there were simply a limited number of artefacts that they wished to control in ‘smart’ or more intelligent ways. As we also showed in Chap. 5, it was not immediately clear to people precisely what to use the SHTs for or what the value was in the additional forms of artefactual control that the SHTs offered. This was particularly true for the Vera system with many participants stating that they had tried but couldn’t identify valuable uses for it. For example:

> I get this feeling that there’s probably some more that I can get from it, but I just don’t fully know how to use it. (Simon H2I3, p. 10)

Others commented that even though they had identified forms of artefactual control that would be valuable, the systems were not always able to provide this adequately. For example:

> So say you switch on and off remotely your lights in your living room, what about your curtains? If they’re open everybody can see that the room is empty and they also can see what’s worth nicking. (Louise, H4I2, p. 4)

> I really don’t see the sense, as a user…in getting a motion sensor to switch off the heating when I walk out, and switch it back on when I walk in, because the [time] lag is just too great. (John, H3I2, p. 2)

As these quotes show, for some participants the SHTs were not quite ‘smart’ enough, either because they needed to be more extensive or required more components to function effectively (e.g., motorized drapes or curtains), or because they were unable to respond rapidly enough to automated commands.

In summary, forms of artefactual control appeared as a very significant theme across all interviews. Critically, however, and as we will show in the following sections, it was by no means the only or even the most important form of control that was discussed and it was often shaped through inter-relationships with other types of control.

6.4 Results: Perceptual Control

For most interviewees, the SHTs appeared to offer the perception of increased control over their homes and appliances, even if at times they chose not to exercise this control. For example:

> We have the ability to be in control now. To be more in control. It makes you feel in control to a certain extent. (Marion, H8I3, p. 18)

Even if households perceived that they had more control, however, there was also strong evidence to support Randall’s (2003) concept of a ‘control paradox’ wherein the additional control capabilities provided by the SHTs left users feeling overwhelmed and out of control. This was particularly related to issues with user-interface design that serve to connect artefactual and perceptual forms of control. Despite saying she felt more in control for example, Marion also commented that she almost threw out the SHTs because they weren't sufficiently "*straightforward*" (H8I3, p. 4). Similarly, Louise argued that the RWE system "*actually feels less flexible*" (H4I2, p. 4) than her old 'dumb' system and that, ultimately, the additional layers of control provided by the SHTs were "*too much for me*" (Louise, H4I3, p. 16).

Interviewees also noted several ways the systems impacted negatively on their feelings or perceptions of control around the home. For example, several commented that, at least in the initial stages of the trial, the flashing lights on the occupancy sensors and the general awareness of being monitored had felt intrusive. For example:

> Researcher: *How do you feel with…the presence of the technologies in the house?*
>
> Simon: *I like it. I know that it's there to do a job that it's doing by winding it's little valves in and out.*
>
> Sally: *I think it was a little bit strange at first because we wondered if…someone was logging on and checking what rooms we were in.*" (Simon and Sally, H2I3, p. 9)

As we showed in Chap. 5, some interviewees commented that the SHTs made them feel out of control when they seemed to 'override' their own personal judgements about how they wished to live in their home. Sarah, for example, felt that the SHTs would simply be unable to cope with the complexity and irregularity of how she used her home, no matter how she tried to programme them.

Most interviewees noted that it took time to learn how to use the SHTs and that their feelings of control would grow through experience. The importance of being able to learn gradually how to use the SHTs, and to actively 'experiment' and 'play' with them was seen as crucial to interviewees in helping them build confidence. For example, Roger argued:

> It's like most things, it's easy when you know how. (Roger, H20I2, p. 1)

As we also demonstrated in Chap. 5, rather than using their experience or confidence to use the systems in more advanced ways to make use of the wide range of artefactual control possibilities provided, instead interviewees tended to limit their use of the SHTs, using them more like their pre-existing and more familiar systems.

As this section has shown, perceptual forms of control were of crucial importance to participants in the trial. Whilst interviewees felt that the SHTs offered them more artefactual control and thus a feeling of being in control more, most failed to exercise this. Rather, some felt that the systems were too complex and thus took control away from them, whilst others actively limited their use of the SHTs to retain a sense of control over their more familiar functionality. It is thus clear not only that control in the smart home is a multi-dimensional concept, but also that an over-focus on forms of artefactual control without corresponding interest in perceptual control fails to grasp how SHTs impact upon control relationships inside households.

6.5 Results: Relational Control

Relational forms of control also emerged as of vital importance to interviewees. SHTs impacted upon the relationships between people and activities in both positive and negative ways.

One of the most significant ways that relational control emerged in the interviews was in relation to which household member became the main user of the SHTs. When recruiting for the SHT field trial we attempted to recruit participants with a diverse range of experience with and enthusiasm for ICTs (see Chap. 1). However in the final sample of 20 households there was still a relatively high number of participants whose job was directly related to ICT (see Table 1.3 and also Table 5.1). Nonetheless, as we showed in Chap. 5, these individuals did not always become the main user of the SHTs once they were installed. Rather, the dominant logic for *who* used the SHTs related instead to the adult householder who was most present in the home. Despite David working as an IT project manager for example, Ingrid points out that his absence from the home including during installation meant that she had taken charge of using the SHTs even though she described herself as a 'technophobe':

> [David] isn't really sure what's going on because I was here when [they] installed it all, so I know more about it. And although I've told him about it, he's just left it to me really…I think it's just because I'm around the most, and I was here when it all got set up. It fell that way. (Ingrid, H19I2, p. 3)

The only time when this logic of presence was not followed was when both householders were equally present around the home and, in these cases, use of the SHTs fell each time to the individual who was most competent or experienced with ICTs. In Roger and Marion's case, because Marion enjoyed using the computer whilst Roger disliked it, this had meant that Marion had taken over the 'chore' of controlling the heating:

> It's just another chore [laughs] whereas Roger used to control all the heating. (Marion, H8I3, p. 6)

As these quotations show, although most interviewees argued that they felt the SHTs *should* be used by multiple householders, in practice the systems often served to concentrate control in one individual's hands. In almost all of these cases, this individual sought input from other household members. For instance, Jane advised John on the 'practical' ways in which the RWE system could be used such as to pre-heat towels in the bathroom, whilst Cara helped Jason think through the family routines in order to schedule the heating profiles accordingly. Despite these collaborative efforts, however, the SHTs often left those who were not the dominant users feeling as if they had lost control over their homes and had become reliant on others to do things that they had previously been able to do themselves.

> Do you know, if anything happened to John, I would be in deep trouble, you'd have to come and take it all out because I wouldn't be able to control it I don't think. It's what troubles me. So as long as he's around doing what he's doing that's fine. (Jane, H3I2, p. 6)

Despite concentrating control in one user's hands, this form of relational control did not always translate into a negative impact on perceptual forms of control. Several participants praised the way the SHTs had made their lives more simple or convenient by making it easier to perform activities:

> [We really like] the Vera [system], just from the ease of turning the lights on and off in here, just to make life easier. (Ingrid, H21I3, p. 1)

Whilst the SHTs made life easier in some instances, some interviewees noted that they complicated life in other ways. For some, the SHTs simply took too much time to learn how to configure and control and this was time that could be better spent on other more valuable and important activities.

> I'm not sitting staring at a screen all day, I've got a life! [laughs]. (Marion, H8I3, p. 13)

For others, the additional forms of artefactual control provided by the SHTs complicated their lives and thus had a negative impact on relational forms of control by compelling them to check the SHTs regularly or encouraging them to 'over-think' issues that had not previously been problematic.

> Jason: *We're getting a bit obsessed* [by it]
>
> Cara: *Right, I've got to check the radiators! [laughs]* (Jason and Cara, H5I3, p. 5)

In addition to either making lives simpler and more convenient, or more complicated, another way in which relational forms of control emerged as significant was in how the SHTs served either to cause or help avoid conflicts between householders. As we showed in Chap. 5, the SHTs did cause arguments between householders about whether, what and how they should be used and, in Henry and Louise's case, this led to their eventual abandonment with Henry stating that he was "*getting round*" (H4I2, p. 13) the SHTs by removing them. In other cases, however, participants felt that the more fine-grained forms of artefactual control provided by the SHTs had helped them to avoid potential arguments as it allowed household members to individually tailor different rooms to their own tastes. For example:

> I think I would have anticipated more probably repressed conflict over heat settings in the living room because my Mother [who has been staying with us] is notorious…for being something of a hothouse flower…and Lucy is potentially the opposite end of the spectrum and I've not heard, you know, even in private, I've not heard of any real issues along those lines. (Keith, H19I2, p. 4)

This section has shown how SHTs can serve to redistribute control over routine household activities or to reinforce existing roles. They can help to make lives easier but also complicate them in various ways. And they can both create as well as help avoid conflict between householders.

6.6 Synthesis

All three forms of control identified in Table 6.1 emerged as significant to interviewees in the SHT field trial, and all shaped the use and non-use of the SHTs in different ways.

Each type of control places priority on different relationships between SHTs, users and domestic life. Artefactual control places priority on technologies, focussing on how SHTs are used to schedule activities and enable particular household functions. Perceptual control places priority on users, and seeks to understand how user perceptions of control emerge and change through their efforts to use SHTs and how this helps or hinders domestic life. Relational control places priority on domestic life and seeks to understand how this may be affected (or not) by SHTs and their users. These relationships are summarised in Fig. 6.1.

We also find that the inter-relationships between the different forms of control matter for how each of them are felt and experienced and, therefore, for how each of them might be shaped or influenced. In particular, we observed that the three types of control are inter-related but in different ways in different homes. Here, we identified a number of both positive and negative feedback loops between different types of control that were significant in shaping the domestication pathways of the SHTs explained in Chap. 5. The potential forms these feedback loops may take are summarised in Fig. 6.2 and illustrated in the following short examples.

In Ingrid's case, for example, she found the forms of artefactual control provided by the SHTs to be useful which increased her perception of control over her home and encouraged her to use the SHTs to schedule activities in different ways (e.g., by

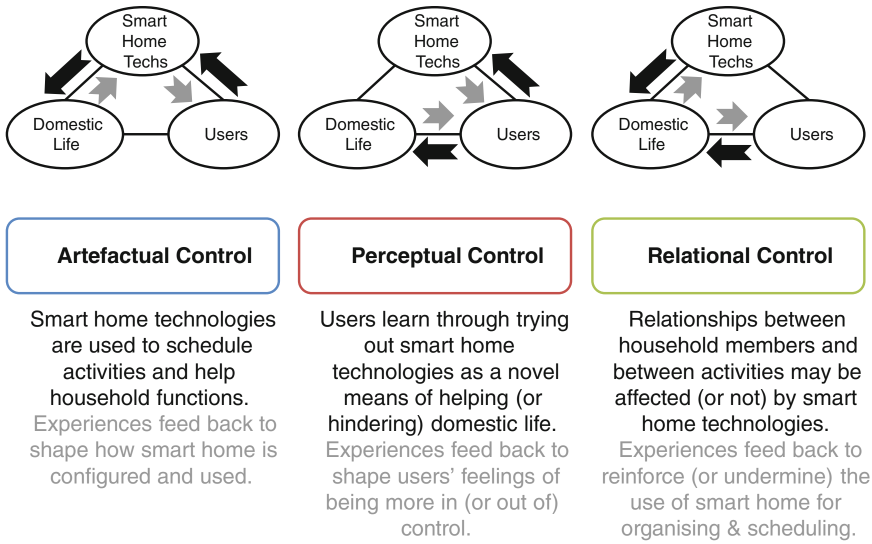

Fig. 6.1 Types of control depend on the interactions between SHTs, users and domestic life

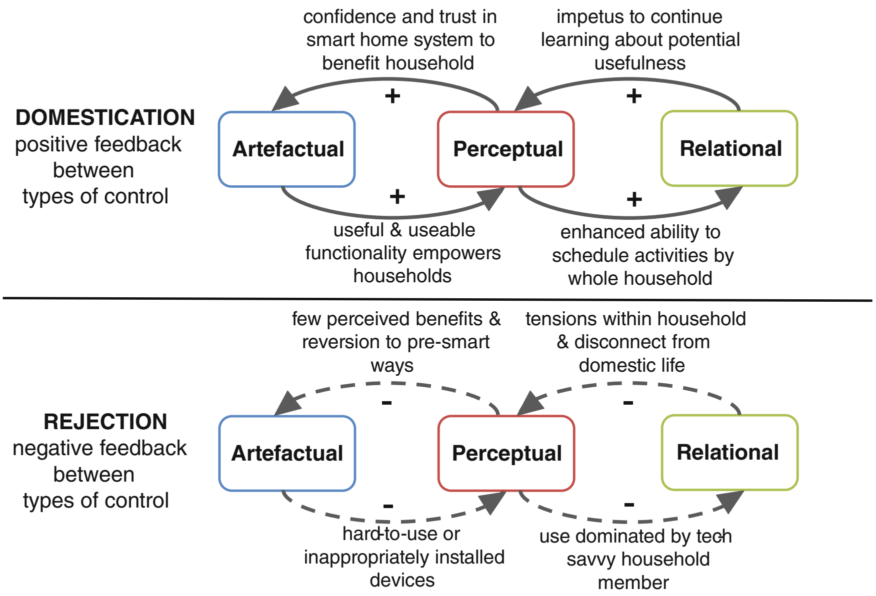

Fig. 6.2 Positive and negative feedback loops between different forms of control shape the domestication or rejection of SHTs

pre-warming or pre- lighting rooms before arriving home). In turn, these positive feedback loops encouraged her to look for more ways to use SHTs (upper half of Fig. 6.2). In the final interview, she explained she was looking into installing smart lighting controls in a planned home extension. If this path is indeed followed this may provide yet more impetus to continue learning about how SHTs could be used, further increasing her confidence and trust, and potentially leading to further SHT acquisitions.

By contrast, Henry and Louise's experience was marked by negative feedback loops. Here, both Henry and Louise found the new systems hard to use and more complicated than their old manual system (lower half of Fig. 6.2). This led to Louise feeling out of control in her home particularly as Henry, who had not previously been involved in programming the heating but was most experienced with ICTs, started to try and use the RWE system to set the heating. In turn, this led to arguments about who should use the SHTs and to what ends. This further undermined both Henry and Louise's perceptions of control at home. In combination, these negative feedback loops led them to take the joint decision to 'get round' the SHTs by removing them from the home and reverting to their old, manual systems.

In a third and final example, John and Jane's case shows signs of both positive and negative forms of feedback between types of control. For John, the SHTs offered a wide range of new and useful control functionality that gave him a greater perception of control over the home. At the same time, however, by concentrating control in John’s hands, Jane felt as if she was no longer in control of her own home. As a result Jane is not particularly keen to engage with the SHTs herself or to encourage John to use the systems to schedule activities in new ways or to install more SHTs that may further reduce her perception of control. Taken together, these feedback loops render John somewhat frustrated that the SHTs are not better integrated and easier to use (particularly for those with little experience using ICTs such as Jane) whilst Jane expresses concern that should anything happen to John she would be forced to remove the SHTs in order to take back control.

Final remarks

In this chapter we have further developed a number of themes identified in our analytical framework for research on smart homes and their users (Table 2.1). Although this chapter is most strongly situated within the socio-technical view of smart homes, control is an issue that cuts across almost all research on SHTs. For example, whilst the functional view of SHTs would see control as principally about bringing more domestic appliances into smart systems, we have shown in this chapter how bringing more devices under control in this way does not necessarily generate stronger perceptions of control among householders. Indeed, the opposite effect is possible wherein the inclusion of more appliances in SHTs may generate over-complicated systems that make user-technology interactions too difficult and render at least some householders feeling out of control inside their own homes. Further still, within the socio-technical view, these disruptions to pre-existing control dynamics inside homes can impact on householders’ roles and identities in important ways. For example, SHTs can concentrate control of devices in one householder’s hands causing others to resist their use or to feel still more out of control in their own home. These inter-relationships between different types of control all shaped the use and non-use of SHTs in important ways.

These findings have clear implications for future research and development of SHTs. First and foremost, they serve to illustrate that control is a critically important concept inside smart homes that deserves further attention. They show that control is far from a simple, single or quantifiable thing. Rather control is a multi-dimensional construct that emerges from inter-relationships between users, SHTs and domestic life (Fig. 6.1). As such, a full understanding of control in the smart home demands more holistic research approaches that actively identify and attempt to understand cross-cutting relationships between different forms of control and different views of SHTs.

6.7 Suggested Further Reading

A longer version of this chapter was presented at the DEMAND Centre Conference in April 2016:

- Hargreaves T, Wilson C, Hauxwell-Baldwin R (2016) Control in the Smart Home. Paper presented at the DEMAND Centre Conference, Lancaster, UK, 13–15 April 2016

For other studies on control relationships inside smart homes, we suggest:

- Davidoff S, Lee MK, Yiu C, Zimmerman J, Dey AK (2006) Principles of Smart Home Control. Lecture Notes in Computer Science 4206: 19–34
- Hansen M, Hauge B (2017) Scripting, control, and privacy in domestic smart grid technologies: Insights from a Danish pilot study. Energy Research and Social Science 25: 112–123

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Chapter 7
Conclusions and Implications for Industry, Policy and Research

Abstract In this chapter we synthesise the main findings from the four empirical chapters and summarise the arguments and themes developed throughout the book. These illustrate the importance of research that integrates across functional, instrumental and socio-technical views of smart homes and their users. These cross-cutting themes have important implications both for the SHT industry and for policymakers, particularly in the energy domain. We conclude this chapter by highlighting key issues for further research on smart homes and their users, and by setting out a range of new research questions.

7.1 Summary of Key Insights

We opened the book in Chap. 1 by arguing that our understanding of smart home *users* was limited, yet critical to the prospects for SHTs. We also set out the purpose of the book: to explore systematically how and why people use smart home technologies, and what impact this has on domestic life and control over the domestic environment, including energy management. The conceptual, methodological, empirical and analytical content that followed was designed to fulfil this purpose.

In Chap. 2 we developed a comprehensive analytical framework for research on smart homes and their users. We organised our framework around three meta-themes: views of the smart home; users and the use of smart homes; and challenges for realising the smart home. These meta-themes are interdependent. A given way of viewing the smart home is associated with a particular understanding of the users and use of smart homes. Similarly, a given framing of smart home users points to particular challenges for realising a smart home future.

The functional view of SHTs as ways to help manage daily life is associated with research on user needs and wants. This in turn frames future challenges in terms of SHT hardware and software development. The instrumental view of SHTs as ways to help bring about a low-carbon transition is associated with research on user-technology interactions. This in turn frames future challenges in terms of SHT acceptability and usability. The socio-technical view of SHTs as 'just' the next

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wave of electrification and digitalisation of everyday life at home is associated with research on how technologies become embedded in complex home environments. This in turn frames future challenges in terms of SHT domestication into household routines and identities.

We argued in Chap. 2 that the different ways of approaching research on smart homes and their users generate different insights. We illustrated this in Table 2.1 which summarises how research to-date provides contrasting answers to six overarching questions: What is the smart home? What is the purpose of the smart home? Who uses smart homes? How is smart home technology used? How can smart homes be realised? What research approaches are useful? In Chaps. 3–6 which make up the empirical core of this book, we have developed our own answers to these questions.

In Chap. 3, we examined the perceived benefits and risks of SHTs from both prospective and actual users. We found that prospective users have positive perceptions of SHTs associated with a range of functions from controlling the domestic environment to managing energy and improving security. However, the impact of SHTs on energy demand is less clear, as much of the SHT functionality seen as attractive to users can also facilitate energy consumption (e.g., automated security routines if the home is unoccupied). With respect to perceived risks, we found that prospective users are more concerned about becoming increasingly dependent on technologies than they are with the data security and privacy issues that have affected smart meter rollouts in the EU. Potential early adopters with high prior knowledge about SHTs tend to have stronger positive perceptions of benefits but similar negative perceptions of risks. Consumer confidence-building measures by the SHT industry are essential if early-adopting households are to communicate positive experiences of SHTs to mass-market adopters. The importance of bolstering consumer confidence is reinforced by the more cautious appraisal of SHT benefits by actual early adopters in the SHT field trial.

In Chap. 4, we developed and applied a novel method for using SHT data to make inferences about when and for how long different domestic activities were taking place within the home. We could then examine electricity consumption through the lens of activities like cooking, washing and laundering which are descriptively-realistic ways of characterising everyday life at home. Our analysis identified some generalisable patterns consistent with expectations. As an example, cooking showed clear peak hours for breakfast, lunch but particularly dinner during weekdays; however, cooking also became less structured during weekends. Cooking also tended to be the most energy-intensive activity across households. Other activities like watching TV and washing were also more consistent during the week, but their energy intensity varied between households as a function of composition, appliances and differences in domestic routine. Indeed this variability was the hallmark of our findings. As an example, we found marked differences in the energy intensity and temporal routines of activities between households of almost identical compositions. The use of SHT data to ‘reveal’ domestic routines in Chap. 4 clearly points to the complexity of everyday domestic life.

In Chap. 5, we drew on in-depth qualitative data to explore the domestication of SHTs in households participating in the SHT field trial. We found that use of SHTs involved a slow and gradual process of familiarisation and adaptation. Despite some initial excitement about the potential of SHTs, householders tended to use them in relatively basic ways and, over time, actively restricted and limited their use to make them more familiar and manageable. This process tended to be driven by a single householder but always in negotiation with others. We identified three distinct domestication pathways for SHTs: *successful domestication*, in which SHTs were relied upon and regularly used by householders albeit in quite simple ways; *precarious domestication*, in which the SHTs were tolerated by householders but seen as too complex and fiddly and so always on the verge of being abandoned; and *rejection*, in which the SHTs were rejected as pointless, over-complicated and as having the potential to make matters worse for either society or the environment. Whether successful or not, the domestication process in each case was seen as hard work and disruptive for householders, demanding large amounts of learning for which scant support was available.

In Chap. 6, we again explored in-depth qualitative data to zoom in on a theme that cuts across existing research on smart homes: control. We identified three distinct ways in which households in the SHT field trial understood control as revealed in the interviews. An *artefactual* approach to control focused on providing more control over domestic devices. Interviewees discussed how SHTs had given them more control over appliances, devices or systems (like heating), or even how the SHTs had not gone far enough in this direction. A *perceptual* approach to control focused on the feelings and perceptions of control experienced and expressed by householders inside smart homes. Interviewees described how SHTs had made them feel more in control of their homes through new control capabilities, or conversely had made them feel out of control at home as they felt that the SHTs were over-riding their judgements about household management. A *relational* approach to control focused on householders' control over their everyday lives and relationships. Interviewees commented on how SHTs had concentrated responsibility for household management in the hands of particular individuals, how SHTs had created new demands on their time, and how SHTs had both caused and potentially helped to avoid conflict between householders. We also identified inter-relationships and feedback loops between these three forms of control. These linkages appeared to be critical for the adoption and domestication of SHTs discussed in Chap. 5. For example, by providing more control over artefacts, SHTs had the potential to increase householders' perceptions of control over their homes which, in turn, could help them better control their everyday lives and relationships. This positive feedback loop increases the likelihood that they might purchase still more SHTs, and so on. We also found evidence of negative feedback loops in which, for example, householders perceived the SHTs as offering little new control over artefacts, leading to a perception of them as over-complicated and making it harder to manage daily lives at home. In some cases, this led to the eventual abandonment of the SHTs.

From these chapter by chapter summaries we can distil some key lessons learnt about smart homes and their users. We do this in Table 7.1 by adding our own answers to the six overarching questions first introduced in Table 2.1. Whereas Table 2.1 was populated by answers from existing literature on smart homes and their users, Table 7.1 is populated by answers from the new empirical work presented in Chaps. 3–6 of this book.

7.2 The Importance of Cross-Cutting, Integrative Research on Smart Homes and Their Users

We argued in Chap. 2 that a particular view of the smart home 'channels' research down particular lines of enquiry on a range of other themes and questions. We represented this in the vertical relationships between research themes in Fig. 2.2 which characterised existing literature on smart homes and their users.

We then made the case for cross-cutting, integrative linkages between research themes: the missing diagonal lines in Fig. 2.2. We argued this was necessary and important because as SHTs diffuse more widely into the fabric of everyday life at home, the functional, instrumental and socio-technical views will increasingly interact and combine, giving rise to more and more challenges which are increasingly hard to solve. As examples, the technological optimism of the functional and instrumental views will confront the just-the-next-thing normality of the sociotechnical view with all its ambiguities and uncertainties. SHT functionality in areas such as comfort, convenience and security risk undermining the energy-management goals of the instrumental view. Smart homes may even reinforce resource-intensive trajectories of socio-technical change as new SHTs ramp up expectations for service provision (Strengers et al. 2016).

The importance of these cross-cutting, integrative issues will grow in relevance as SHTs confront the complexities of homes and households as adoption environments. Consequently, throughout this book we have sought to advance understanding of smart homes and their users across all three meta-themes in our analytical framework. We have summarised these advances in Fig. 7.1 which shows the cross-cutting breadth in each of our empirical chapters. Taken collectively, the four panels in Fig. 7.1 show how we have moved beyond the vertical 'channels' of existing research illustrated in Fig. 2.2.

Chapter 3 was centred around users' needs and wants (*U1* in Fig. 7.1a, top left panel). By surveying the general population, potential early adopters of SHTs, and a small sample of actual early adopters, we found users perceived benefits of SHTs to be broadly consistent with both the functional and instrumental views of smart homes and their users (linkages *V1–U1* and *V2–U1* in Fig. 7.1a, top left panel). However users perceived risks to be more clearly aligned with the socio-technical view, particularly in terms of trading off autonomy and independence in the home with increased technological control (*V3–U1*). These characterisations of users'

Table 7.1 New insights on smart homes and their users

Views of the smart home	Functional view	Instrumental view	Socio-technical view
What is the smart home?	A set of inconspicuous technologies offering multiple remote and automated opportunities to control the domestic environment (Chap. 3)	A domestic energy management system for cost and convenience (Chap. 3)	(Yet another) set of technologies and devices to be integrated with existing domestic appliances and routines (Chap. 5)
What is the purpose of the smart home?	Enhancing lifestyle and domestic life by improving convenience, security, entertainment and communication (Chap. 3)	Controlling heating and energy-using appliances (Chap. 3), and linking energy consumption to households' lived experience (Chap. 4)	Making control and monitoring of homes and appliances easier and more convenient as part of a long-running dynamic towards modernising homes (Chaps. 5 and 6)
Users and use of the smart home	**User needs and wants**	**User-technology interactions**	**Homes as complex places**
Who uses smart homes?	Relative to the general population, current early adopters are more likely to be younger males in larger houses with higher than average income (Chap. 3), although many types of household with varying domestic routines are also adopting (Chap. 4)	A subset of energy-conscious households who want a more active role in managing energy use at home (Chap. 3)	Single users (who may not be the most ICT-competent) or multiple users through negotiation (with some users resisting and/or being shut out) (Chaps. 5 and 6)
How is smart home technology used?	Multiple forms of both active and passive configuration, ranging from pre-set schedules and direct user input to automated or learnt responses to domestic activity (Chap. 3)	Managing energy costs and reducing energy waste (e.g., turning heating off in unoccupied rooms) as one of several rationales for SHT usage (Chaps. 3 and 6)	Gradual process of familiarisation and adaptation of SHTs by householders, with usage restricted to basic functionality (Chap. 5), against a backdrop of non-routine domestic activity (Chap. 4)
Challenges for realising the smart home	**Hardware and software**	**Acceptability and usability**	**Domesticating technologies**

(continued)

Table 7.1 (continued)

How can smart homes be realised?	Make SHTs more reliable, easy to use, controllable and easy to over-ride (Chap. 3), with clearer ways for users to understand what to use them for (Chap. 5)	Address consumer confidence issues around privacy and security as part of broader concerns about dependence on technologies & networks (Chap. 3), while catering for multiple different types of user (Chap. 5)	Provide both technical and social support to help users familiarise and adapt SHTs over the long-term (Chap. 5), taking into account different forms of control and how they interact (Chap. 6)
What research approaches are useful?	Studies with user-centred design approaches in real home environments	Studies jointly observing SHT usage and measuring energy consumption (with explanatory variables linked to domestic life)	Longitudinal ethnographic studies of SHTs in situ

needs and wants for SHTs in turn points to a wide range of technology development, design and domestication challenges. Perceived risks of a creeping dependency on black-box technologies, external experts (manufacturers, installers, service providers), and even wider electricity networks and systems pose urgent challenges for the SHT industry to develop hardware and software that is controllable, reliable, and easy to use (*U1–C1* and *U1–C2*). SHTs that deliver expected benefits and mitigate perceived risks stand the strongest chance of being successfully domesticated into everyday household life (*U3–C3*).

Chapter 4 was the most limited of our empirical chapters in terms of cross-cutting linkages (Fig. 7.1b, top right panel). The novelty of our research in Chap. 4 was as much methodological as empirical. We set out step-by-step a new approach for linking SHT data to activities taking place within the home. Our rationale for developing this methodology falls squarely within the instrumental view of smart homes as the end-user nodes of a smarter, more efficient energy system. Users actively seeking to reduce or manage energy demand based on real-time information are central to this view. Our methodology provides a means of linking energy-related information to activities meaningful to households' own lived experiences (linkage *V2–U1* in Fig. 7.1b, top right panel). Applying this methodology to a sample of households in the SHT field trial over the course of a month clearly revealed the complexities of homes as adoption environments for SHTs (*V2–U3*). It was hard to identify any robust generalities in how and when households use electricity as part of their daily routines. The time and energy intensity of the same activity varied day to day within a given household; and households of very similar compositions had markedly different activity dynamics. Chapter 4 thus provides an innovative analytical bridge between two hitherto disconnected research themes: energy-related information integral to the instrumental

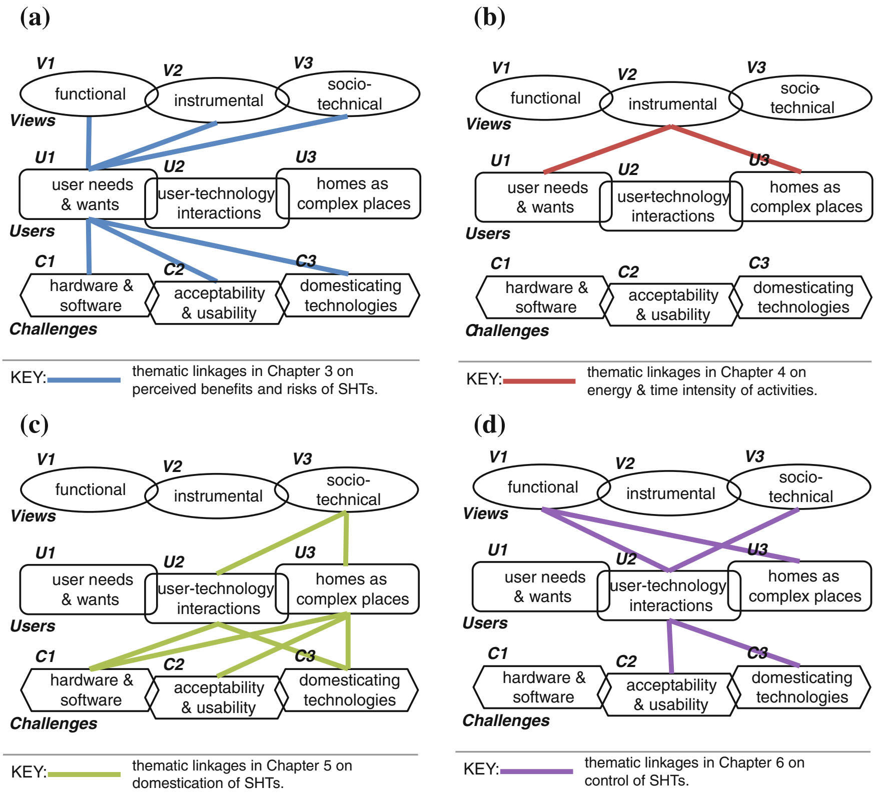

Fig. 7.1 New cross-cutting linkages between research themes on smart homes and their users (Notes: The shapes in each panel show 9 themes in our analytical framework for research on smart homes and their users; Lines show mapping of the new empirical research in this book onto the analytical framework; *Top left* panel (**a**) shows cross-cutting linkages for Chap. 3; *top right* panel (**b**) for Chap. 4; *bottom left* panel (**c**) for Chap. 5; *bottom right* panel (**d**) for Chap. 6; See text for an explanation of each linkage with, e.g., *V3–U1* denoting the linkage between *V3* (socio-technical view) and *U1* (user needs and wants))

view on smart homes and their users; and the complexities of everyday life at home which shapes the domestication of SHTs (Fig. 7.1b, top right panel).

In Chap. 5, we adopted a socio-technical view to explore how SHTs are domesticated inside complex home environments (linkages *V3–U3* and *U3–C3* in Fig. 7.1c, bottom left panel). We found that the micro-scale interactions between users and technologies are vital in shaping the domestication pathways of technologies and wider socio-technical systems and transitions. User-technology interactions in which users experienced SHTs as being fiddly and hard to use generated forms of familiarisation and adaptation that restricted their use and thus hampered their domestication (*U2–C3* in Fig. 7.1c). In turn, this led to concerns among some users about the potential for tricky user-technology interactions to shut out some types of user and thus widen digital divides in future socio-technical transitions (*U2–V3*). We also found that the complexities of existing homes, in the form of different roles, routines and competences among household members, shaped the perceived acceptability and usability of SHTs (*U3–C2*). For example, when self-described 'technophobe' users confronted the SHTs they were often seen as excessively complicated and unhelpful. At the same time, once in use, SHTs were judged against the complex material and aesthetic settings of the home and this often led to the new hardware and software of the SHTs making other household appliances seem old or out-of-date and requiring either their replacement or a restriction in SHT use (*U3–C1*). Finally, these insights generated novel suggestions for how the hardware and software of SHTs might be developed to better cater for user-technology interactions and homes as complex places, such as the need to design for longer-term pathways of engagement among multiple users with differing levels of competence (*U2–C1* and *U3–C1*).

In Chap. 6, we explored the concept of control and found that, far from fitting neatly within any distinct view, control emerges in different ways in the functional, instrumental and socio-technical views and generates interactions between them (Fig. 7.1d, bottom right panel). We observed a number of trade-offs between different types of control that cut across themes in our analytical framework. For example, the new functional SHT offerings provided users with the potential to control more parts of the home, but often led to complicated user interfaces meaning that user-technology interactions left some users feeling out of control (linkage *V1–U2* in Fig. 7.1d, bottom right panel). The new functional control capabilities offered by the SHTs also meant that controlling the domestic environment took longer as there were more possibilities available. For some users, this was simply too much and they felt they didn't have time for these interactions and instead preferred their pre-existing simplistic, manual controls as these already fitted in with existing routines in complex domestic environments and required less learning or effort (*V1–U3*). More broadly, some householders voiced concerns about conflicts between being able to easily and conveniently control their domestic appliances and a potential loss of control at a wider, sociotechnical level through society becoming dependent on technology (*U2–V3*). The perceptions of control that emerged from user-technology interactions were also significant in shaping the acceptability and usability of SHTs (*U2–C2*). For example, if SHTs were seen as enabling more control over appliances or domestic activities, they were seen as more useful and thus acceptable. By contrast, if SHTs left people feeling out of control they were seen as intrusive and invasive technologies that were unacceptable in private homes. Finally, we showed in Chap. 6 how SHTs can lead to control of the domestic environment being concentrated in a particular individual's hands. A focus on which user is interacting with SHTs is thus important because, to domesticate SHTs, these individuals often need to negotiate with others either to reach compromises or face resistance and the potential abandonment of SHTs (*U2–C3*).

By focusing on users throughout this book, we have made progress in breaking out of traditional siloes in research on smart homes. Comparing Fig. 7.1 (our research) with Fig. 2.2 (existing research), we have tried to emphasise the diagonal lines which represent cross-cutting, integrative lines of enquiry. We have not tried to integrate distinct functional, instrumental and socio-technical views of the smart home as each has the clarity of a singular approach. However, we have shown that drawing on particular elements of these views is not only an unavoidable consequence of trying to understanding the users and use of smart homes, but also greatly enriching for understanding. Each view can be informed by and has much to offer the others. Perhaps the acid test of the value of bringing multiple perspectives together place lies in the implications for the future development of SHTs. We turn to this in the final sections of this chapter by discussing the implications of our research for the SHT industry, for policymakers, and for the research community.

7.3 Implications for Industry

The existing literature on SHTs identifies implications for industry as primarily relating to hardware and software development to improve reliability, interoperability and ease of use (Cook 2012). These aims combine insights from technical and engineering concerns (e.g., interoperability) with insights from user-centred design (e.g., ease of use). Throughout this book, we have put users and how they confront and experience SHTs at the forefront of our analysis. The implications we can draw for the SHT industry build on those already recognised, but push them significantly further to recognise the complex worlds of real users with real everyday lives in real homes.

Improving the ease of use of SHTs is a long-standing issue in SHT research and is usually approached through attempts to improve user interfaces by simplifying them or making them more intuitive (Koskela and Väänänen-Vainio-Mattila 2005). This clearly reveals a need to think more about how users confront SHTs in specific and situated contexts of use, and thus to think about ways they might be made more salient for users.

Ease of use is as much about households knowing when and how SHTs are useful as it is about well designed user interfaces. Following Mennicken et al. (2014), we suggest that there may be value for the SHT industry in creating SHTs as more collaborative technologies which help their users work out what is best by making suggestions, providing examples, and revealing the possible outcomes and consequences of different forms of configuration.

In Chap. 4, we showed how the energy-management aspects of SHTs could focus not on engineer- or designer-oriented concerns about energy and kilowatt hours as is often the case (Hargreaves et al. 2010), but on ‘revealing’ energy consumption through the lens of activities such as cooking, washing or watching TV. Strengers (2013) makes a similar argument about putting social practices at the heart of analysis rather than merely developing technologies in isolation from the grounded realities of everyday life.

Beyond increasing the salience of SHTs to users in this way, ease of use also relates to the fact that SHTs may be used by multiple users. As we showed in

Chap. 5, different users have varying levels of interest, motivation, competence and tolerance for engaging with SHTs. SHT developers could develop SHTs with multiple entry points for different types of user. In households with 'negotiated' control over temperature or other aspects of the domestic environment, SHTs could also embody ways of avoiding the concentration of control in a single user's hands (see Chap. 6). Even if SHTs are configured by individual users, SHTs could be developed in ways that explicitly seek to encourage negotiation and consensus among householders about what they should be used for and how this might be achieved. Making the social negotiations behind the operation of SHTs more transparent may help to reduce potential resistance to SHTs and increase user trust.

This sort of approach also reveals an important need for industry to design SHTs for longer-term pathways of user engagement. Chapter 5 showed how user interactions with SHTs evolve over time. In the SHT field trial, we found this was often in ways that gradually restricted and reduced the use of SHTs. If SHTs are to realise their potential, developers and designers need to find ways of keeping users engaged by increasing the value of SHTs over time and avoiding overwhelming users with too many upfront possibilities. As well as improving the hardware and software to achieve this, SHT developers could also consider creating or expanding a technical and social support network to give users someone to talk to and deliberate with about what value SHTs offer and how pitfalls can be avoided. Peer-to-peer interaction can also be effective in improving users' ability to use their SHTs (Wilhite and Diamond 2017).

To take these points on board, the SHT industry needs a richer understanding of users and use-contexts of SHTs. Ease-of-use is about fitting-in with and supporting everyday life, rather than a matter of simple and efficient control. The same is true for other issues that are typically understood in narrowly technical terms such as interoperability. This is not merely about enabling and future-proofing devices to communicate with one another across platforms (Cook 2012). For users, interoperability also relates to how SHTs fit and become functional within the existing social and material context of homes. This poses new questions about the physical and aesthetic integration of SHTs. In Chap. 5, for example, we showed how SHTs can make existing domestic appliances seem old, out-of-date and in need of replacement which can in turn limit the use of SHTs. We also showed in Chap. 5 how SHTs in the field trial generated a large amount of new work for their users, work they did not always have either the time or the inclination to perform (see also Strengers and Nicholls 2017). This reinforces our earlier points about ease of use. A challenge for the SHT industry is to develop SHTs which cumulatively draw households in through increasing value-adding steps and which are differentiated to account for varying levels of user competence and interest.

In Chap. 3 we drew attention to a still broader type of interoperability: dependencies between SHTs and the wider technological system of which they are part. The main perceived risk of SHTs by prospective users related to a loss of autonomy mirrored by an increased dependency on technologies, on experts, and on the wider electricity system. This is thrown into stark relief by our findings in Chap. 5 that the SHTs in the field trial were often incompatible with the existing expertise of plumbers and electricians who were not trained to maintain SHTs or support users. For the SHT industry, the challenge of interoperability needs to be extended to understand how SHTs can be made more compatible with existing homes and appliances, with busy lives and routines, and also with existing support systems both within the home and beyond.

An underlying theme to all these implications for industry is that from users' perspectives, the meaning of SHTs is far from clear-cut. Users and the complex settings in which SHTs are used serve to complicate and deny the often seductive visions depicted by SHT designers and developers. There are multiple potential configurations of SHTs—and these potential configurations proliferate enormously when understood as involving both social and technical elements. In turn, this generates a wide range of different meanings of SHTs (Nyborg and Røpke 2011) and thus a wide range of potential ways in which users are likely to use and adapt to them. SHT developers need to work with users in generating multiple yet shared visions of smart energy futures which embrace differentiated SHTs in diverse market niches.

These broader, bolder challenges for the SHT industry sit alongside more conventional demands for market confidence-building measures as with any new technology's early commercialisation. In Chap. 3, we found a strong appetite among prospective users for industry-led measures to reduce adoption risks through, for example, performance warranties and manufacturer credibility. In the absence of a clear regulatory framework in the consumer-led SHT market, technology developers also need to make privacy and security more central to their smart home vision. Transparent measures to ensure quality control would also help reduce perceived technology risks. Risk mitigation measures during the initial commercialisation of SHTs are particularly important as the experiences of early adopters diffuse through social networks to reduce uncertainties perceived by later adopters in the mass market (see Chap. 3). The small sample of households participating in the SHT field trial faced frequent, minor but cumulative issues with SHT installation and operation that risked undermining their confidence in and use of the technologies. As evidenced in Chap. 5, SHTs for advanced home energy management typically require professional installers (electricians, gas engineers, plumbers) whose skills and knowledge will shape prospective users' experiences. The SHT industry should move towards developing quality control procedures, transparent standards, best practice guidelines, and rights of recourse for consumers if SHT installations are defective.

7.4 Implications for Policy

Policymakers' interest in SHTs relates principally to their potential contribution to a low carbon transition through energy-demand reduction (see Chap. 1). In this book we have not focused narrowly on the energy-management role of SHTs, although all the chapters are in some way relevant to this issue. Our main insight is that there is no simple deterministic relationship from SHT adoption to energy-demand reduction. Instead, the impact of SHTs on energy demand will depend on how users configure and use SHTs designed and marketed by developers, manufacturers and retailers.

Here, we can identify three potential pathways for the impact of SHTs on energy demand. First, as policy makers hope, SHTs may have a transformative impact in reducing energy demand through more informed, convenient and automated control of energy-using appliances and systems in homes. Second, SHTs may have a negligible or contingent impact on energy demand as they become absorbed into the dynamics of everyday life at home. Third, and most worryingly for policy-makers, SHTs may have a detrimental impact by increasing energy demand as more energy-intensive conventions and expectations become entrenched among householders (Strengers et al. 2016).

Although we did not directly test these three contrasting pathways in our research, we found little evidence to suggest that the SHTs used in our field trial were generating significant energy savings (see Chap. 5). None of the households adopting SHTs made substantial changes to their daily lives or routines. Some households raised concerns about energy intensification through, for example, pre-warming the home. This admittedly limited evidence from actual early adopters contrasts with the perceptions of prospective users who clearly expect cost savings from the energy-management functionality of SHTs (see Chap. 3).

The challenge for policymakers is to find and support ways of avoiding energy intensification from SHTs while instead realising SHTs' potential role in a smarter, more efficient energy system. We suggest three possible strategies.

First, clear policy guidelines can help ensure SHT hardware and software designs are compatible with smart meter-enabled communications from utilities during critical peak periods. This would enable SHT control algorithms to respond to supply constraints by shifting time-flexible domestic loads. Our analysis in Chap. 4 points to the variability in domestic routines across almost all activities—from washing and laundering to watching TV and computing. SHT data linked to domestic activities can reveal potential flexibilities in domestic demand profiles.

Second, benchmark guidelines for energy optimisation or minimisation algorithms can steer industry to include design features in SHTs that mitigate the potential for energy intensification. For example, SHTs which include energy-optimisation algorithms to reduce or shift demand, or to inform users if demand exceeds pre-set thresholds, may help lead to net demand reduction. SHTs which enable energy-intensive user preferences without constraints may have the opposite effect.

Third, marketing and advertising standards can be used to ensure a clear message to prospective users that SHTs do not inevitably result in energy and cost savings. As we showed in Chap. 3, prospective users clearly perceive cost reductions as a benefit of SHTs whereas actual users in the SHT field trial are more circumspect. Over-exuberant or unrealistic expectations for a new technology risk creating hype or bubbles which can then burst. This risks undermining consumer confidence, adoption propensity, and ultimately policy expectations. Although consumer-confidence measures fall largely to the SHT industry, policy can play a supportive role. As an example, policymakers in the UK have introduced a host of quality control measures in the industry for energy efficient home renovations. This includes a national system of independent certification of assessors, installers, and finance providers to ensure trustworthy, expert advice and practice (Pettifor et al. 2015). An analogous quality control framework for SHTs would similarly help reduce perceived technology risks. This would also create an incentive for the SHT industry to prioritise energy-management functionality over ancillary SHT benefits.

As a final point, in Chap. 3 we showed that early adopters of SHTs have similar socio-demographic characteristics to the early adopters of ICTs more generally (OECD 2008). A social risk of potential concern to policymakers is that SHTs extend the digital divide associated with ICTs further into homes. Later adopting market segments may include older households, lower income households, or geographically remote households (with poor internet access). This is particularly problematic if SHTs are enabling of health, quality of life or other social benefits. Policy initiatives to ensure universal broadband internet access have addressed the possible marginalisation of disadvantaged later adopters. Analogous policies could help avoid adverse distributional impacts of SHTs. As examples, grants, subsidies, or technical advice could be provided to vulnerable households to support adoption of SHTs for assisted living or for managing fuel poverty.

7.5 Implications for Research

More needs to be done to explore how users and the use of SHTs are imagined and understood in design and development processes (Strengers and Nicholls 2017). Our content analysis of industry marketing material (Chap. 3) revealed little meaningful engagement with users in this area and a number of important lacunae including around issues of consumer confidence and homes as complex adoption environments. More work on how industry and policy in this area understands and engages with users has the potential to be enormously productive. Similarly, there is considerable need for more in-depth and ethnographic studies of how householders actually use SHTs in real life settings. This requires larger and longer-term studies in different contexts and using a wide range of SHT configurations. These studies should focus on in situ or 'in the wild' studies of voluntary early adopters as well as further field trials to ensure a range of different user types are included. Our research points to critical themes for such studies to include: the forms of technological and social disruption SHTs cause; the differing types and extents of use of SHTs; the different kinds of social dynamics and learning involved in the use (and non-use) of SHTs. These themes all recognise the contingencies and complexities of everyday life at home.

Further, much more could be done to bring the designers and developers of SHTs together with their users. Participatory and action-oriented studies have much to offer here by generating dialogue and debate between developers and prospective users to develop shared visions for smart energy futures which are not in tension with other potential benefits of SHTs. Participatory design also engages prospective users of SHTs with experts in an interactive process generating appropriate technologies or interfaces that are used correctly in practice (Wilhite and Diamond 2017). Understanding users as ‘energy citizens’ rather than ‘energy consumers’ in this way may help to pre-emptively address risks around energy intensification (Goulden et al. 2014; Schot et al. 2016).

As well as pursuing these more user-centric research approaches, we have argued throughout this book that future research on smart homes and their users should develop and strengthen the cross-cutting relationships between research themes highlighted in our analytical framework (Figs. 2.2 and 7.1). We can illustrate how this integrative research might be done by using the critical issues of privacy and control as examples. Both these issues have surfaced throughout the book and will shape whether and how SHTs will be used and with what impact.

Privacy, access to data, and issues of trust, reliability and transparency is clearly of concern to prospective users of smart homes (Chap. 3; see also Demiris et al. 2008). A narrow interpretation of this challenge sees privacy and data security as issues to be addressed through appropriate design of SHT hardware and software (e.g., Cook 2012). But the instrumental benefits to utilities of real-time information on energy demand are founded on a recasting of how much privacy (on electricity and gas usage) should be exchanged for how much potential for optimising home energy systems (Geelen et al. 2013). A still wider socio-technical view of smart homes thus sets issues of privacy within broader considerations of how the pervasive influence of ICT-enabled networks and networking are blurring the lines between the private and the social, the domestic and the public (Goulden 2017).

The same is true for control. Control is far from a simple, single or ‘designable’ thing. Rather it is a multi-dimensional construct that emerges from interrelationships between users, SHTs and everyday domestic life. Control can be about households securing their domestic environments from outsiders, or it can be about automating various functions and services (Koskela and Väänänen-Vainio-Mattila 2005). Control can also be about autonomy and independence within the home, or about responding to information from outside the home (e.g., utility price signals, the weather). Further still, control can be about society becoming lazy and too dependent on technologies or electricity networks. These complexities are magnified if questions are asked about the nature of the home as the arena in which issues of control and automation play out. Household members have different roles in the home and in different spaces within the home. Control over the interface with SHTs thereby translates into shifts of control within the different genders and generations in a household. By failing to recognise that users value time, roles and relationships in their everyday lives, rather than narrowly circumscribed technologies and functionalities, researchers will miss the concern that SHTs are coming to dominate people, rather than the other way around (Davidoff et al. 2006).

Our analytical framework shows that core issues in SHT research, such as privacy and control, can mean different things depending on how SHTs are understood and approached. Defining such issues or problems narrowly and pursuing singular lines of enquiry precludes wider insights. The central implication for research from our book is the need to ask cross-cutting, integrative questions when attempting to understand smart homes and their users. Examples of such questions include:

- How, where and when do functional, instrumental and socio-technical understandings of SHTs align or conflict?
- How can lifestyle-enhancing SHTs be developed in ways that support instrumental energy-system goals?
- How will socio-technical systems shape and be shaped by new SHT functionality?
- Will the instrumental pursuit of energy-system benefits through SHTs be able to re-direct socio-technical systems onto more sustainable trajectories?
- Are activities meaningful to households' lived experience a useful lens through which to understand energy consumption in smart homes?
- In what ways do different user needs and wants shape user-technology interactions?
- How are user needs and wants negotiated and compromised in complex domestic environments?
- Can the hardware and software of SHTs be designed and developed in ways that make them more acceptable, usable and easier to domesticate?

These are new questions that demand integrative research approaches. This is far from easy. Given the growing pervasiveness of SHTs, their potential to accelerate or undermine low carbon transitions, and the relative lack of user-centric research on SHTs to date, it is vital that more is done to try and answer them.

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