

5-151-15 Hargreaves

Smart homes, control and energy management: How do smart home technologies influence control over energy use and domestic life?

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Abstract

By introducing new ways of automatically and remotely controlling domestic environments smart technologies have the potential to significantly improve domestic energy management. It is argued that they will simplify users' lives by allowing them to delegate aspects of decision-making and control - relating to energy management, security, leisure and entertainment etc. - to automated smart home systems. Whilst such technologically-optimistic visions are seductive to many, less research attention has so far been paid to how users interact with and make use of the advanced control functionality that smart homes provide within already complex everyday lives. What literature there is on domestic technology use and control, shows that control is a complex and contested concept. Far from merely controlling appliances, householders are also concerned about a wide range of broader understandings of control relating, for example, to control over security, independence, hectic schedules and even over other household members such as through parenting or care relationships. This paper draws on new quantitative and qualitative data from 4 homes involved in a smart home field trial that have been equipped with smart home systems that provide advanced control functionality over appliances and space heating. Quantitative data examines how householders have used the systems both to try and improve their energy efficiency but also for purposes such as enhanced security or scheduling appliances to align with lifestyles. Qualitative data (from in-depth interviews) explores how smart technologies have impacted upon, and were impacted by, broader understandings of control within the home. The paper concludes by proposing an analytical framework for future research on control in the smart home.

1. Introduction

Recent years have seen rapid growth in the development and diffusion of Smart Home technologies and contemporary predictions suggest that this growth will continue to accelerate dramatically (IEA 2013). "The idea [of smart homes] is that 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, minimizing the consumption of resources, and maintaining the health and safety of the home and residents" (Cook 2012, 1579). Smart Home technologies have been developed and are marketed to achieve a wide variety of different ends, from improved security, comfort, convenience and entertainment, through assisted living and health monitoring to – and the core focus of this paper - improved energy efficiency and management (Cook 2012; Wilson et al 2014).

With respect to energy efficiency and management, Smart Homes promise to offer a range of potential benefits from enhanced feedback on energy use, to advanced control of appliances (including remote and automated control), as well as the ability to integrate homes into wider Smart Grids through automated responses to variable tariffs and the integration of forms of microgeneration (e.g. Lewis 2012). Despite these potential benefits, it is increasingly recognised that Smart Homes have been developed off the back of strong technology push rather than market pull (Haines et al 2007). Partly as a result, several potential barriers to the wide diffusion of Smart Home technologies have already been identified, from technical issues around reliability and interoperability to social issues around lack of trust in energy utilities or concerns about privacy and security (e.g. Balta-Ozkan et al 2013; Paetz et al 2012). Further still, these concerns have been identified even before there has been much research conducted on "what actually happens to these technologies once they're inside the home" (Strengers 2013, 116). We would contend that this is a critical omission from research in this area precisely because "social studies of technology continually demonstrate that technology has never operated seamlessly in everyday life" (Strengers 2013, 116-7).

Amongst the relatively few studies that have focussed explicitly on users and the use of Smart Home technologies, the concept of 'control' has emerged as a centrally important theme (e.g. Davidoff et al 2006; Woodruff et al 2007; Strengers 2013; Wilson et al 2014). Perhaps the key point made by these studies is that whilst Smart Home technologies seek to give more control to householders e.g. through finer grained, remote or automated control over their appliances, this process is rarely clear cut and they can end up providing forms of control that users don't want (Davidoff et al 2006) or, worse, coming to control users rather than the other way around (Strengers 2013). In short, whether or not they succeed in providing advanced control over domestic appliances, Smart Home technologies always play a part in the "dynamic redistribution of control between people and things" (Strengers 2013, 118).

Precisely how Smart Home technologies serve to disrupt, reinforce or in any event redistribute control relationships in the home is the central focus of this paper. This research has been conducted as part of the wider

interdisciplinary REFIT project (www.refitsmarthomes.org) and draws on a selection of data gathered from a field trial of 20 homes in Loughborough, UK, that have had a wide range of smart home technologies installed within them. Specifically, this paper draws on data from four homes within this sample. This research is ongoing and, as such, this paper offers only a preliminary analysis.

The next section provides a brief literature review of existing work on control in the smart home before section 3 describes the technologies employed and methodologies used in this study. Section 4 then presents our results by looking in-depth at 4 homes within the REFIT field trial. Finally section 5 concludes the paper by tentatively proposing an analytical framework for future research on control in the smart home.

2. Control in the Smart Home Research Literature

In their systematic literature review, Wilson et al (2014) identify control to be one of the “central uncertainties” within research on smart homes and their users. Despite this, to date there has been very little explicit or sustained attention devoted to the concept of control within smart homes (Davidoff et al [2006] remains an agenda-setting exception). Instead, the concept of control is often implicit within or treated as a side-issue that emerges from research focussed on different topics. As a result there is, to date, no clear or coherent analytical or theoretical approach that could or should be applied to help understand control in the smart home. Instead, there are a number of contrasting perspectives and ideas that each understand control in different ways and, as a result, lead to different recommendations for how it should be treated (Wilson et al 2015). In their review, Wilson et al identify three distinct ‘narratives’ of work on smart homes and their users each of which frames control in different ways (see Wilson et al 2015 for further detail). In summary, the ‘functional narrative’ is an essentially techno-centric approach focussed on what different appliances can be controlled within smart homes and the barriers to this. The central assumption here is that more control over more appliances is always a good thing. By contrast, the ‘instrumental narrative’ focuses on user-technology interaction and, rather than seeing control as a good in and of itself, sees easy control of smart homes as a means towards a broader end; e.g. optimising energy management. Here, the focus of research rests on the usability of smart home interfaces. The core assumption here is that control is a potential problem for users that must be overcome e.g. through better design of user-interfaces. Finally, the ‘sociotechnical narrative’ focuses on smart homes as a small part of the much broader and co-evolutionary relationship between society and technology. The central assumption here is that control is distributed between and across society and technology in myriad different ways and that smart homes are important and interesting because they serve to redistribute this relationship. The focus of this work is less on control in and of itself but rather in its impacts on e.g. domestic life and broader sociotechnical trajectories.

2.1 Control in the functional narrative

Within the functional narrative, the focus is on how the control of more and more appliances in ever finer-grained ways can serve to enhance everyday life. As noted above, the central assumption of this body of work is that more control is always better. The home automation company Control4 exemplify this approach in their ‘smart home solutions’ brochure when they state: “Imagine living in a home that obeys your every command...where virtually every device can be controlled remotely and fully automated. You can use your tablet to control your home theatre, dim the lights, lock the doors turn up the heat, and arm the alarm. Or your smartphone to do the same from not just anywhere in your house – but from anywhere in the world” (Control4 2014). As this quotation illustrates, the focus of this narrative is both to identify more devices and appliances to control and to increase the number of ways in which users can control them (e.g. from different user-interfaces, remotely and through automation). Park et al (2003) provide an early example of this kind of approach in their attempt to illustrate the myriad ways in which ‘digitally engineered domestic life’ can provide a ‘better home life experience’ (Park et al 2003, 189). Here they show how almost all aspects of the home could be digitally enhanced from, for example, smart dressing tables and wardrobes that incorporate a digital ‘fashion coordinator’ to smart gate posts that remind you if you’ve forgotten something before you leave your driveway, to smart pillows that can read you bedtime stories, play you soothing music to help you sleep and then monitor your health and well-being while you rest.

A core concern within this narrative is therefore around the best ways of achieving the control and configuration of multiple smart devices. Here, a number of technological issues are highlighted, such as developing monitors, sensors and algorithms that can accurately infer user-activity, developing devices that can reliably deliver the promised functions and services, and ensuring the interoperability of multiple different devices within the internet of things (e.g. Cook 2012; Perez et al 2011; Friedewald et al 2005). Here, a particular concern is around achieving retrospective compatibility between smart home technologies that are purchased and installed at different times and have different technological standards and compatibility issues.

2.2 Control in the instrumental narrative

The instrumental narrative broadens the focus of research away from technologies in and of themselves and towards the interactions between technology and users. Here, rather than simply trying to increase the quantity of things that can be controlled, the aim is to understand how (and how easily) users can control smart home technologies. A central concern in this narrative is that, ironically, the more devices and appliances that get brought under control, the more complex and challenging such control may become. As Bainbridge expresses it: “the more advanced a control system, the more crucial may be the contribution of the human operator” (1983, 75). To address this concern, much research has focussed on the usability of different kinds of smart home controls. The UK Department for Energy and Climate Change, for example, has a whole research programme on ‘Smarter Heating Controls’ that has examined how people use existing controls, what they want from their heating controls, how different kinds of control impact on energy demand and has also incorporated usability testing (DECC, undated). Further, this kind of research has fed into the development and evaluation of a wide range of different kinds of user-interfaces from, for example, mobile phone or tablet apps, websites, wall-mounted bespoke interfaces each of which may incorporate motion, voice or touch sensitive controls (e.g. Koskela and Väänänen-Vainio-Mattila 2004). The core aim of this body of research is to design smart home controls and interfaces that allow users access to the near limitless possibilities for control afforded by smart homes, whilst avoiding “overpowering them with complex technologies” (Park et al 2003, 189).

A second strand of the instrumental narrative that relates to control is less about the usability of smart home controls, and more the societal or user-acceptability of smart homes more generally. Here, recent research has highlighted user concerns related to trust in smart home developers (particularly when smart home technologies are being promoted by energy utilities (e.g. Paetz et al 2012; Balta-Ozkan et al 2013) and also growing concerns about privacy within smart homes and the security of user-supplied information (Geelen et al 2013; Cook 2012; Demiris et al 2008). The core aim of this research is to overcome potential barriers to adoption by developing strategies that reassure potential users that acquiring smart home technologies will not equate to surrendering control over their data, their security or their privacy at home (e.g. Balta-Ozkan et al 2013).

2.3 Control in the sociotechnical narrative

The sociotechnical narrative broadens the understanding of control still further. Where both the functional and instrumental narrative are essentially concerned with the smart home itself and helping it to facilitate more control over the domestic environment, the sociotechnical narrative instead positions the smart home as merely one small part of the much broader and co-evolutionary relationship between society and technology. Here, the focus is not on what appliances can be controlled nor on specific examples of user-technology interaction, but rather on the ways in which smart homes serve to disrupt and redistribute pre-existing relationships of power and control across society and, in turn, understand what impacts this might come to have on broader sociotechnical trajectories.

Some of this research is focussed on pre-existing control relationships within homes and how these are or are not addressed by smart home technologies. For example, research has focussed on gender relations in the home and how smart home technologies are often designed with male-users in mind through a focus (intentional or otherwise) on the kinds of activities that men typically engage in at home (e.g. energy management, leisure and entertainment) rather than those traditionally associated with women (e.g. typically around domestic tasks such as cooking, cleaning etc.) (e.g. Richardson 2009). Beyond gender, several studies have highlighted the many complex and value-laden ways in which domestic environments are already organised and controlled (e.g. Haines et al 2007; Baillie and Benyon 2008; Swan et al 2008) and the fact that many smart home technologies simply ignore these pre-existing domestic control relationships. In their agenda-setting study, for example, Davidoff et al (2006) highlight that whilst smart home technologies are typically designed to provide “control of devices. [Instead] families want more control of their lives” (Davidoff et al 2006, 19). Here, Davidoff et al contrast the often value-based and long-term goals that families seek to pursue and the frequently chaotic, flexible and improvisational strategies they adopt to achieve these goals, with the narrowly functional, routine and often short-term focus of much smart home technology development.

Going still further, Strengers (2013) explores how home automation technologies might impact upon social practices and highlights how, by redistributing control between people and things they can come to control people (or ‘act back’ in her terms) rather than the other way around. Drawing on Woodruff et al (2007), Strengers shows how automated and scheduled use of devices can be seen as casting moral judgements on users’ domestic activities and that, as a response, users can come to adapt their daily routines and practices to fit in with the technology, rather than the technology adapting to their routines. Although not focussed on smart homes directly, Røpke et al (2010) contextualise the rapid rise of information and communication technologies (ICTs)

as ‘a new round of household electrification’. They note that, “previous rounds of electrification [based around lighting, heating and the electro-motor] have co-evolved with broad social transformations” and thus suggest that ICTs too “will gradually become part of radical socio-technical transformations, although the direction of these changes is not yet clear” (Röpke et al 2010, 1772).

Rather than identifying particular barriers, obstacles or problems to be overcome in order to facilitate and accelerate smart home adoption and diffusion, the sociotechnical narrative instead takes a step back to explore how smart homes as a whole are impacting on pre-existing control dynamics and relationships within society. In this perspective, smart homes become puzzling problems in and of themselves and important questions are asked about how smart home technologies redistribute and disrupt control dynamics within and across broader sociotechnical systems.

In summary the existing research literature on smart homes and their users identifies control as a critically important theme yet rarely addresses it explicitly in a systematic or detailed manner. Partly as a result, we witness multiple discrete understandings of and approaches to control but few attempts to look across these approaches to explore how they offer different insights (whether complementary or conflicting). In this paper we attempt to do this for the first time. The next section describes our methodology.

3. Methodology

As part of the wider REFIT research project, 20 homes in the English town of Loughborough were recruited to take part in a field trial of a range of different smart home technologies. Key requirements for the technologies used in the trial included functionality, reliability (e.g. maintaining wireless connection) and ease of access to the sensor data by the research team. The trial also sought to utilise established technologies that are already available for households to purchase. Preliminary testing of a variety of technologies was undertaken prior to the procurement of the devices for the study sample. The testing identified difficulties using a unified system that would meet the requirements of the study. Therefore, two separate smart home systems were installed in each of the homes to provide the households with real-time feedback information and increased levels of control, relating to the use of electricity (via one system), and space heating and home security (via a second system). Although not ideal, this pragmatic approach proved a reliable solution and had the benefit of exposing the participants to different technologies and user interfaces (it also mirrors real-life experiences of smart home development that is often incremental and not vendor specific). The key features of the two main types of Smart Home systems (and focus of this paper) installed in the study homes are briefly described below.

- **Vera™ Z-Wave system** (referred to hereafter as the Z-Wave system): the Vera interface provides access to real-time electricity feedback which is accessible from any location with Internet access via a web browser. Two Z-Wave smart plugs (*TKBHome TZ88* appliance plugs) were also connected to each home’s system. In addition to providing appliance level electricity usage feedback, the smart plugs can control connected appliances (i.e. on/off) remotely either via the Vera web interface or via a smartphone/tablet app. It is also possible to automate the smart plugs with schedules via the Vera interface. By combining appliances plugged-in to one smart plug, they can also be used as ‘kill switches’ to turn off multiple appliances at once. Additionally, data from the Vera is pulled in real time from a database server hosted at the University of Strathclyde, which logs all measurements, for further analysis.
- **RWE Smarthome™ system** (referred to hereafter as the RWE system): this system provides monitoring and control functions for individual space heating radiators and home security. RWE Smarthome controllers were connected to each home’s router to allow the remote control of smart devices and the activation of automation ‘profiles’ via a user interface. This can be accessed, from any location with Internet access, via a smartphone/tablet app or a computer with a web browser. The systems installed include up to 10 radiator thermostats (incorporating temperature and humidity sensors), 6 door and window contact sensors, 4 motion sensors (incorporating a brightness sensor) and an alarm/smoke detector. The alarm can be triggered by the motion and/or contact sensors. The user interface facilitates real-time feedback about room temperature and home security (observation of doors and windows) and 3 room thermostats, 2 wall mounted switches and a remote control were provided to give additional control mechanisms within the homes. When accessing the user interface via a computer, it is possible to set up three main types of automation ‘profiles’: i) *Time profiles*: enable individual or multiple radiators to be turned on and off at designated time periods; ii) *Event profiles*: allow radiators and the alarm to be controlled by specified events; for example, pressing a button on the remote control to trigger the alarm or turn designated radiators on and off; and iii) *Rule profiles*: logic-based profiles involving one or more conditions; for example, turning a radiator on or off at certain temperature and/or humidity levels when a window is open. A key feature of the RWE system is that data from the RWE sensors can be downloaded as .csv files. This includes the “actual” room temperature

(measured by the RWE radiator thermostats) and the “nominal” room temperature (the radiator thermostat setting nominated by the building occupants).

This paper draws on three main types of data gathered from the field trial homes, all of which seek to shed light on how households have actually used the two smart home systems to control their domestic environments. First, the paper draws on two rounds of in-depth qualitative interviews. The first round of interviews, undertaken several months before installation of the smart home technologies during winter 2013-14 sought to understand the everyday routines and activities of householders and the place of different kinds of technologies within these. Essentially this was a means of trying to understand how they used technologies within their homes prior to the installation of novel smart home technologies. The second round of interviews was undertaken within 2 months after the installation of the smart home systems (in Autumn 2014) and sought to examine how they had used and experienced the technologies installed. Second, monthly screenshots of the online interfaces for both the RWE and Z-Wave systems were captured (from August-December 2015). Whilst these screenshots provide only snapshots of particular moments in time and, as such, do not show households real-time interactions with the systems, they provide valuable insights into the kinds of automation profiles that householders have set-up and, by so doing, provide some indication of what the households are trying to achieve through their use of the smart home systems. Third, and finally, to access the real-time use of the smart home systems this paper is also based on a range of monitoring data gathered from within the field trial homes. This includes usage data, via the database, from the two smart plugs distributed with the Z-Wave system to indicate when, how often and for how long these smart plugs have been switched on/off.

As the field trial is still ongoing, with both data collection and analysis still underway, this paper draws on only a sub-sample of the total amount of data that will be gathered. Specifically, it focuses in depth on 4 different homes to explore how they have used the smart home systems. These homes were chosen because they provide different but comparable demographics (two retired couples and two families) and different levels of engagement with the smart home systems. The next section proceeds house-by-house to explore how the four smart home systems have been used in the trial and how this has impacted on control dynamics within the home.

4. Results and Analysis

4.1 House 3: John and Jane¹

John and Jane live in a 4-bedroom detached house. Their children have all left home in recent years although they continue to visit regularly, and both John and Jane also frequently look after their young grandchildren in the home. John is a semi-retired mechanical engineer and Jane is a homemaker. They follow what might be described as quite ‘traditional’ gender roles in the home with Jane responsible for the day-to-day running and upkeep of the domestic environment e.g. through cooking, cleaning, laundry etc., whilst John takes a keen interest in the technologies and appliances in the home. In particular, John expresses a strong desire to try and save energy in the home in order to reduce their operating costs (something he sees as particularly important in retirement). As part of this aim, they have both solar thermal and solar photovoltaic panels installed and John has regularly updated a spreadsheet to monitor their energy use for some years. John is very clearly the key driving force for their participation in the field trial and, throughout interviews John has strongly expressed his desire to gain more control over their energy use in order to save both energy and money. For example: *“I expect to be able to control the heat in every room far more closely. I also expect to be able to pre-warm a room if I know there’s a guest coming...I expect to be able to do that quite comfortably without any fuss or bother... I really expect ultimately...to see less energy being used”* (John). By contrast, Jane is clear that John is in charge of technologies within the home and that she is only interested in ‘the practical side’ of things, by which she means whether or not the heating, lights, washing machine etc., are working properly, and when she wants them to.

Given John’s clear aims and objectives for participating in the field trial, it is perhaps of little surprise that they started using the smart home systems fairly soon after installation. Within the first few months, screenshots indicate that they had set up three time profiles for the RWE system. These comprised a ‘lounge’ and ‘dining room’ profile to schedule radiators in these rooms to come on in the morning and late-afternoon/evening 7 days week and a ‘towel rails’ profile to turn the bathroom towel rails on for two hours in the mornings. As time passed, they added an additional ‘Bedroom 2’ time profile to provide a three-hour burst of heating in this room in the evenings. Screenshots and monitoring data indicate that their interactions with the RWE system have continued over time. Following some discussions with the research team about the RWE system’s functionality, after around 4 months, in December, they consolidated the ‘dining room’ and ‘lounge’ profiles into a single ‘Ground Floor All’ time profile that included heating periods in the morning, middle of the day and late-

¹ All participant names are pseudonyms.

afternoon/evening (see figure 1). The motivation for this consolidation into a single profile is unclear, but it would appear to reduce the effort required to control all the downstairs radiators and is thus consistent with John's desire to control his radiators 'without any fuss or bother'. Besides these time profiles there is no evidence of further interaction with the RWE system e.g. to use the various security features it offers such as monitoring doors/windows etc.

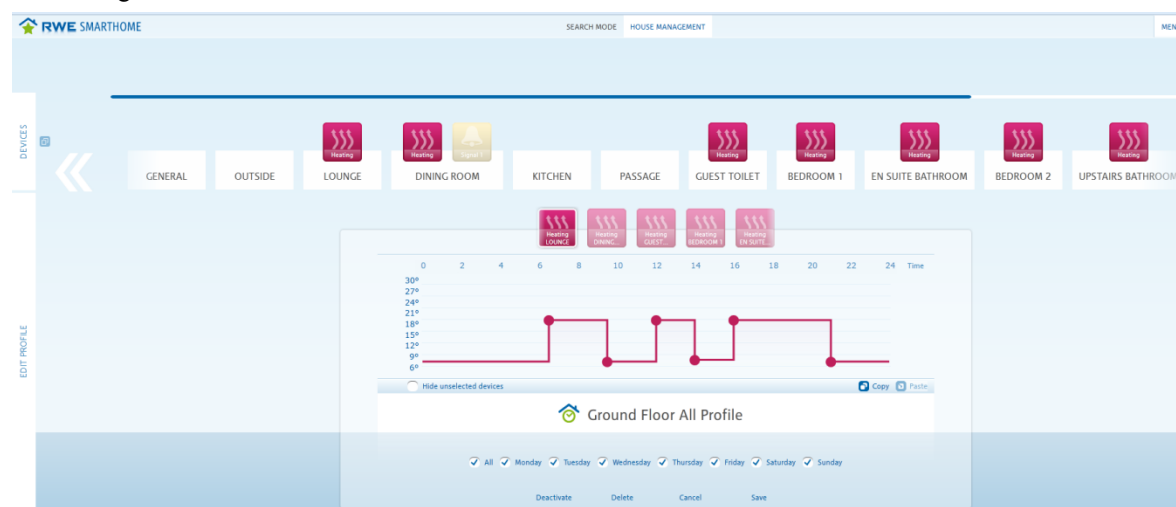


Figure 1: Screenshot of House 3 'Ground Floor All' profile (taken on 09/12/14, 4mths after installation)

House 3 is also the only house out of those reported here to have set up automated time schedules on their Z-Wave system to control lights. Specifically, as evenings became darker (two months after installation in October) they set up two time profiles to control the 'lounge' and 'passage' lights such that they came on from 6-10pm and 6-10.30pm, respectively. These were both amended a month later to come on at the earlier time of 4.30pm. Control of the smart plugs varies. They have used one of these plugs irregularly since they received it (see H3P1 in figure 2), but the other one has been switched on/off daily in the afternoon/evening since it was first acquired (see H3P2 in figure 2) but this use does not follow any pre-set schedule. We do not have data on exactly how they have switched the smart plug on or off (e.g. via smart phone/tablet app, online or through manual switching in the home), but in interviews they did mention they were trying to switch lights on/off for security purposes.

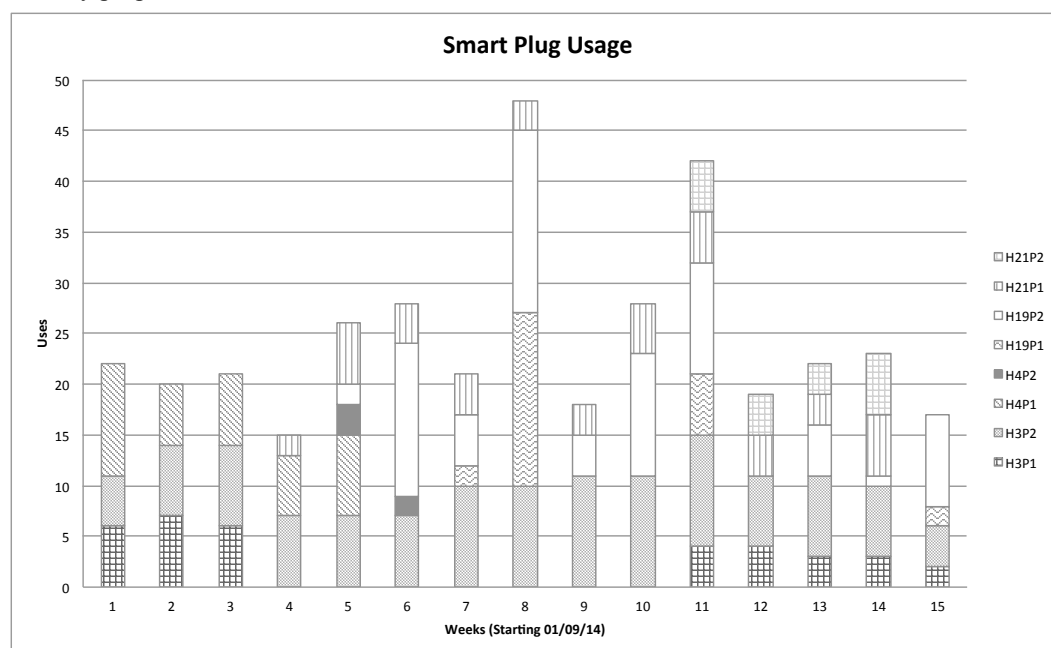


Figure 2: Histogram to show total number of uses of both smart plugs per week across all four homes

In interviews, both John and Jane have been quite clear that it is John rather than Jane who has been responsible for configuring both the RWE and Z-Wave systems. Indeed, as Jane puts it: "I know you guys have all come in here and put your little instruments everywhere, [but] it hasn't infringed on my life in any way. John's

monitoring it obviously... For me, it's just there and I'm getting on with my life" (Jane). By contrast John explained that he is very interested in experimenting with the smart home kit to increase his control over energy use and has even compiled a list of things he would like to learn about and try out. With respect to the impact of the systems on control dynamics in the home, therefore, it would appear that both systems have served to concentrate control over heating and some appliances more squarely in John's hands. Indeed, Jane implies that the new systems have meant that she has lost some control over devices in the home: *"if anything happened to John I would be in deep trouble... because I wouldn't be able to control it I don't think, it's what troubles me"* (Jane). At the same time, although John has apparently gained increased control over devices in the home it is also clear that he's also trying to cater to Jane's wishes. For example, Jane stated in interviews that she liked warm towels in the morning so it is of little surprise that one of the first three profiles established on the RWE system was for the 'towel rails'. Although Jane may have lost some apparent control over devices, therefore, it is clear that she still has some say albeit that she must now enact this through John rather than directly herself.

John also shared a story with the research team about a time that his pregnant daughter and her 5-year old daughter had visited the house and he had had to go out. When he returned he found a post-it note from them that read: *"Please put the heating on because I'm freezing!"* This implies either that they did not think that manual over-ride of the system was possible or that they were reluctant to change and potentially interfere with the new heating system. In either interpretation, it appears that as well as reducing Jane's direct control over household devices, the new interfaces serve to shut out regular visitors to the household too.

Who was in charge of which activities seemed, overall, to remain broadly the same in this household. But the smart home systems appear to have redistributed the amounts of control that each householder possessed. John was granted finer grained control and, clearly through some discussion to cater for Jane's wishes, he has used this to set up automated schedules for both heating and lighting. In addition, they have used the smart plugs on a more ad hoc basis for security purposes. Jane, and other visitors to the house, however, appear to have been shut out or excluded from direct control over the system and must now ask John to make changes if so desired. This is despite the fact that Jane retains control over many day-to-day activities in the home such as cooking, cleaning, laundry etc. In summary, control relationships appear to have been reinforced by the smart home systems allowing finer-grained and automated control over a range of devices but they have also been concentrated squarely in John's hands, as it is he who is in control of the technologies even if he is not in always in charge of the activities to which they contribute.

4.2 House 4: Henry and Louise

Henry and Louise live in a 5-bedroom, detached house of which around half the home is a large extension (added between 1996 and 2002) to an original Victorian building. They are both in their mid-60s and retired from their careers as an IT sales support consultant (Henry) and University Administrator (Louise). In their initial, pre-installation interviews, they stressed that they had very independent schedules and routines around the home that involved them doing quite different things at different times even when both at home. Their main interaction during most days was around lunchtime and then in the evenings but one or other of them often went out to pursue particular hobbies or interests in the evenings too. Louise did emphasise, however, that prior to the installation of the smart home systems, she was *'in charge'* of the heating and, further still, that Henry *"doesn't know how to use it"* (Louise). Another point they were both keen to stress in the initial interviews was that, even despite Henry's expertise with and interest in computers, neither of them are what they described as *'entranced'* by technology. In short, they suggested that they see technology as useful only insofar as it supports their existing routines and have little interest in technologies in and of themselves.

Henry was present during the installation of the smart home systems and worked with the research team to set-up different 'zones' on the RWE system that grouped together different radiators in the home. But for the first 2-3 months after the RWE system was installed they apparently interacted with it very little. During this time, screenshots indicate that no profiles were set up and the only evidence of interaction with the system was the manual switching off of the back bedroom radiator. During this time Henry, who had initially suggested that he was quite keen to learn about and experiment with the system, did suggest that he found the system annoying, non-intuitive and difficult to use so this potentially explains their apparently limited use of the system.

In an interview with the research team in late October – 2 months after installation – Louise expressed some frustration with the system: *"this was one of the times when I was saying... 'you've set it to so and so on the computer but I think it's warm enough or it's too hot' and so then I wanted to change it without faffing about on the computer and doing all this kind of stuff and just go in and turn the heat on or off or up and down in the room"* (Louise). Here, she explains that she felt the house was too hot but that her normal response – to manually turn down the thermostatic radiator valves (TRVs) – wasn't working. This was because, at installation, Henry had zoned both radiators in their large living room together. As such, when Louise turned down one of the

TRVs the heating wouldn't respond as it would have done previously because, due to them being 'zoned' together, the RWE system was now synchronising both radiators. Shortly after this interview, and following discussion with the research team, a new zoning arrangement appeared in the screenshots to indicate that this large room had now been split into two distinct zones to allow the radiators to work independently of one another. Since this time, the screenshots indicate no further interaction with the RWE system and no attempt to use the various security functions it offers either.

Following some initial activity, evidence from screenshots and smart plug data indicates that Henry and Louise also interacted relatively little with the Z-Wave system. Screenshots indicate that they did not set up any automated schedules, but in an interview Henry did mention that he had enjoyed turning lights on and off remotely and on an ad hoc rather than on an automated basis when they had been away on holiday to make the house appear occupied. Figure 2, above, appears to support this. One smart plug (H4P1) was used almost daily for some lights for one-month post installation but has then dropped out of use whilst the other (H4P2) has been used for only a one-week period across weeks 4 and 5 in Figure 2.

Despite Henry helping to configure the systems at installation and his expressed interest in experimenting with the technology, evidence from the screenshots and monitoring data suggests he only sporadically used either system. In part this is perhaps due to his expressed frustration with the user-interfaces that he found difficult to use. At the same time, however, it is clear that Louise has resisted the use of the smart home systems both through trying to manually over-ride how it has been configured and also through arguments with Henry. For example: *"We had an argument...because I was saying: 'Look, I just want to be warm, I'm going to turn this thing up or down or whatever,' and he's saying: 'We should do it step by step, try one thing see what happens, try another thing tomorrow and see what happens,'" and I'm saying: 'I'm cold, I want to turn the radiator up or whatever'"* (Louise). The net effect of these discussions and Henry's frustration with the user-interface appears to be that neither of them have really used either of the two systems installed and, indeed, as the re-zoning of the large downstairs room suggests, they seem keen to return to the more immediate manual forms of control they were used to prior to installation.

Reflecting on control in the home more broadly, Louise states: *"I feel I've lost control I suppose"* but despite the potential extra control that Henry has, wider household dynamics and poor usability mean he is not, currently at least, making much use of this. Arguably, therefore, they both feel as if the system has taken control away from them hence their apparent desire to return the house to the way it was before the systems were installed. Indeed, Louise states that they would consider uninstalling the system because: *"It feels like a very complex system that, for this particular household and the way it runs, doesn't give much return"* (Louise).

4.3 House 19: Keith, Lucy, Aiden and Marcus

Keith, Lucy, Aiden and Marcus live in a 3-bedroom semi-detached (1945-1964) house. Keith is an Analyst Programmer who works away from home for most of the week leaving Lucy at home with their two children Aiden and Marcus who are both at school. As she is present in the home for much of the week, Lucy is very much in charge of what goes on within the home and of everyone's comings and goings. Indeed, she saw the installation of the smart home systems as a potential means of helping her to 'optimise' her control of the home to reduce waste and improve comfort: *"I think to me it means kind of optimising the heating as closely as possible, so it's not on in places we don't need it, but that the house is comfortable when we come in, for example, that it's been warmed up a little before we get here and that kind of thing"* (Lucy).

Lucy's desire to use the system to optimise control of the home appears to be borne out by the comprehensive use of the systems installed. With the RWE system, for example, they set up 16 different automation profiles at installation, 13 of which were 'time profiles' giving different timings for heating in 13 different rooms, and three were 'event profiles' one for their towel rails, one for a heating boost in the bedrooms and a third for a heating boost in the downstairs rooms. As time has passed they have gradually refined and tweaked these profiles such as by making heating come on earlier or turn off later in response to the changing seasons. Notably, they have set up some quite intricate time profiles to try and match room temperatures with who is using different rooms and when. For example, and as the screenshot in Figure 3 shows, in December – 2.5 months after installation – an automated time profile was established for weekdays in the bathroom to try and achieve temperatures of 19°C from 6am-7am, 20°C from 7am-8am, then 18.5°C from 8am-9am before dropping to 16.5°C from 9am-8pm at which point it would rise to 19°C from 8pm-10pm, then 18°C from 10pm-11.30pm before dropping down to 14°C overnight. Keith and Lucy explained that this intricate heating profile in the morning was a deliberate attempt to cater for Keith's mother who was staying with them for a period in December. Keith explains that his mother likes much warmer temperatures so they tried to adjust both the bathroom and bedroom temperatures to fit around her routines. Keith goes further to explain that he felt that the additional control over heating in individual rooms has helped them to avoid potential conflict arising from different temperature demands: *"I*

would have anticipated more probably repressed conflict...because my mother is notorious throughout our family for being something of a hothouse flower as it were. She would readily say so herself and wanting the heating up 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). This is an interesting example of control over household dynamics being passed to the technology in order to avoid potential tension.



Figure 3: Screenshot of House19's weekday 'Bath' profile (taken on 9/12/14, 2.5mths after installation)

Beyond the screenshots, however, closer analysis of how radiator settings were being adjusted during the time that Keith's mother was staying with them suggests that some fine-tuning of the time profiles was still deemed necessary. Figure 4, below, shows a graph of scheduled (or nominal) temperatures taken from the RWE system against observed 'actual' measured temperatures in 'Bedroom2' which was where Keith's mother was staying. As well as giving some indication of the correspondence between actual and nominal temperatures (which householders may well have taken into account when setting their profiles), as the annotations indicate, the graph shows that the automated time profile was in operation between 6am and 9pm but that shortly after 9pm somebody manually turns the radiator back up to 20°C where it remains overnight, until the automated time profile takes over again the following morning. It is also apparent from the graph that there is a significant time lag between the nominal setting and actual room temperature being reached for this room. This may relate to the characteristics of the heating system (e.g. the time it takes hot water to reach to the room radiator, boiler performance etc.) or other factors (e.g. open windows). Consequently, the nominal temperature between 6am-7.45am is not achieved before the next stage of the automated schedule. Whether this type of factor influences how occupants control and configure their profiles will be explored through further research.

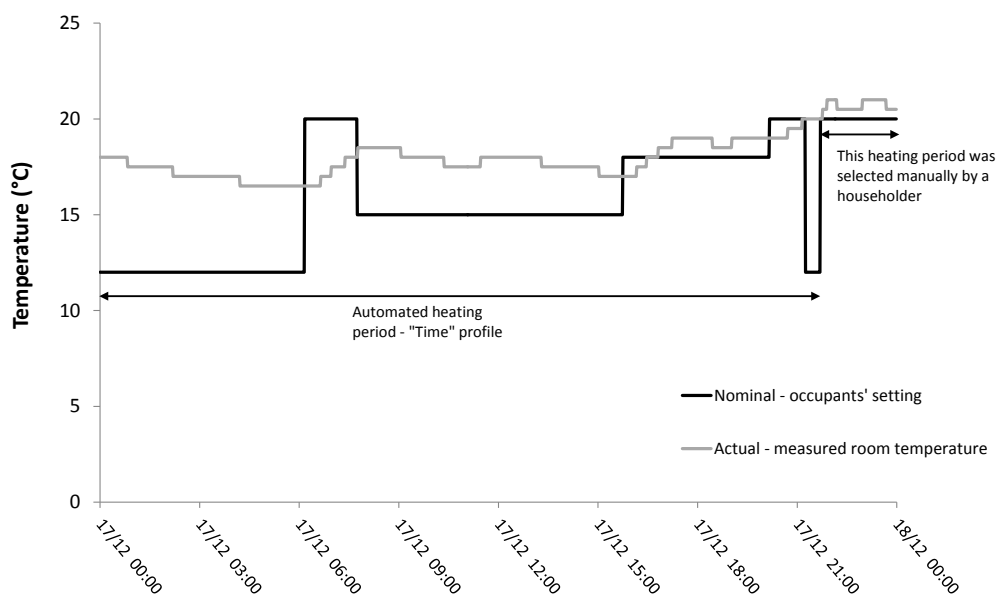


Figure 4: Graph showing nominal and actual temperatures in House 19's 'Bedroom2' on 17/12/14.

With the Z-Wave system, by contrast, screenshots indicate that no automated time profiles have been set up at all. Keith suggests they have not really used the Z-Wave system: *"We haven't found the use for [Z-Wave] switches but something's set up for the TV and I don't know what that does to be honest"* (Keith). At the same time data from the smart plugs indicate that one of the switches (see H19P2 in Figure 2) has been used almost daily since 5 weeks after it was acquired whilst the other (see H19P1 in figure 2) has been used quite sporadically during this time. Although we do not know for certain how and why they are using the smart plugs, the data for plug H19P2 imply that they might be using it as a kind of on-demand 'kill switch' for their television e.g. to ensure all TV-related appliances are switched on and off at the same time at the touch of a single button. We will be exploring this issue in subsequent interviews.

Given Keith's absence from the home for most of the week it is of little surprise that Lucy has taken primary control of both smart home systems. Further, Keith suggests that if he wanted or needed to change to either system he might require Lucy's help: *"I feel I've not really engaged with it very well so far to be honest and if we were to try and make some change to the way the thing was set up, I find it very difficult to make a start on that"* (Keith). Lucy also explained that they have acquired an additional smart TRV for their older son's bedroom to allow him to manually control his own radiator but that they have refused to allow their children to have access to the online interfaces for fear that they might play about with it when outside the home.

With respect to how the smart home systems have impacted on broader control relationships in the home, it would appear that both the RWE and Z-Wave systems have served to reinforce the pre-existing relationships in which Lucy was essentially in control of managing the domestic environment. Arguably, they have gone further than this by concentrating finer-grained control over devices in the home in Lucy's hands whilst potentially making it harder for Keith to directly control either system himself. At the same time, as the evidence of manual control in Bedroom2 and the acquisition of an additional smart TRV for their older son indicates, the RWE system may also have provided more flexibility over heating control (albeit manually) in different rooms and, in so doing, helped to distribute control for specific rooms to those present in those rooms at particular times.

4.4. House 21: Ingrid, David, Ben and Sam

Ingrid, David, Ben and Sam live in a 4-bedroom detached house (1981-1990). Ingrid is a speech therapist and David an IT product manager and both Ben and Sam are currently at school. Although Ingrid is not necessarily any more present in the home than David, as with House 19 it is Ingrid who is very much in charge of domestic life and routine and this extends to control over the heating: *"she's always been in control [of the heating]"* (David). Throughout initial interviews it became clear that Ingrid enacts this control through various 'rules'. For example they have a rule that neither child can watch TV or play computer games if the other one is still doing his homework and they also have what they call the '3 layer rule' that no one should turn the heating up unless they are already wearing at least 3 top layers. At the same time, Ingrid described herself as something of a 'technophobe' so, prior to installation, it was far from clear how she might interact with the smart home systems.

With the RWE system very little activity was apparent for the first 2 months after installation apart from occasional and slight changes to the room temperatures that were most likely enacted manually by adjusting the smart TRVs. In December - 3 months after installation - screenshots indicate that 12 time profiles were established for different rooms in the home. These were relatively simple profiles by comparison to House 19's intricate bathroom profile. For example, the 'Bedroom Main' profile has a morning heating period at 20.5°C from 6am-8am and then an evening period at 20°C from 7pm-10.40pm from Mondays to Thursdays and a different profile with longer heating periods (7am-11am and 5pm-10pm) from Fridays to Sundays. Beyond these 12 time profiles there has been no apparent attempt to use the security or other features of the RWE system.

Ingrid mentioned in interviews that she had surprised herself with how often she was using the smart phone app to monitor the state of the home such as checking on room temperatures or whether or not lights were on: *"I didn't realise how much I would be looking at it I think. I'm quite surprised that every day I look at it and look at the temperatures and turn the lights on, turn the lights off and the more we have it the more I've done that. So sometimes I can look at it more than once a day just to look at the temperatures and things which I never thought I would do"* (Ingrid). In particular Ingrid noted that she would frequently check the temperatures in the children's rooms because although they were not programmed to, these would 'keep going high' (Ingrid) implying some interference from her children.

As with House 4 and House 19, screenshots suggest there has been no attempt to create automated schedules using the Z-Wave system but Ingrid did explain that she had used her smart phone to control lights remotely: *"It means when I'm on my way home from work I can think oh, it's dark now, I'll just put the lights on so they're on when I get home whereas before they used to be on timers but I prefer it this way because it means that they've coming on and off at random times so it means the people can't go 'oh, it's just because it's on a timer'. I feel it*

looks more like there's somebody in the house because they're just coming on and off at any given time really" (Ingrid). This ad hoc, non-scheduled usage of the Z-Wave system is supported by the smart plug monitoring data that indicates almost daily use of one smart plug to control lights from week 4 after installation (see H21P1 in Figure 2) with the second smart plug only being used since week 11 after installation but, from that point on, receiving almost daily use (see H21P2 in Figure 2).

As in the quotation above where Ingrid explains that the non-scheduled use of the Z-Wave system mimics real occupancy more accurately, she also explained that this more ad hoc use of the Z-Wave smart plugs fitted around their variable daily routines better than a rigid automation schedule would: *"We vary when we go to bed and when we get home [so] I've been just doing it [changing lights] manually [via my smart phone] rather than having it on the timer because I would be constantly having to change the timer on that"* (Ingrid).

Despite Ingrid describing herself as a technophobe in the initial interviews, use of both smart home systems has been strongly led by her. Indeed, she is clear that she's checking and controlling things quite regularly on her smart phone. In contrast, David says he's not really used either system at all and has been happy to let Ingrid have control: *"My experience is sadly limited I think it's fair to say. Due to a combination of just not being around when it was installed and the fact Ingrid's got it pretty much under control and she's quite happy to take it on which is really good"* (David).

Regarding broader control relationships in the home, it appears in this house that the smart home systems have extended Ingrid's control over the home by giving her finer-grained control over the heating system and different devices such as lights. Interestingly, and as with all the other houses discussed here, Ingrid has found that heating is relatively easy control through automated time profiles whilst other devices in the home – such as lights – are better used on a non-regular non-automated basis. One interesting observation from this home that is not immediately apparent in others is the manner in which Ingrid is apparently using the smart phone interface to monitor the state of the home on a quite regular basis. As part of this, the RWE system appears to have extended her surveillance over the home and perhaps allow her to more easily police the use of heating in the home (as implied by her regular checks on the children's rooms). Extending this idea further, and drawing on Strengers (2013) observations that smart homes can come to make certain demands of their occupants, it is interesting to note that the additional ability to monitor and control the home provided by the smart home systems has also led to Ingrid *"using it more than I thought I would"* (Ingrid). Here, we might suggest that by giving her the potential for more control, she, in turn, feels compelled to check and potentially exercise this control on a more frequent basis than she might otherwise do.

5. Discussion and Conclusions

The previous section showed that, across the 4 homes included in this paper there was a wide variety of ways in which the smart home systems were used but that some more general tendencies are potentially emerging that deserve further consideration across all 20 field trials in subsequent analysis. Consistent with the 'melting pot' (Nyborg and Røpke 2013) of potential benefits from smart home technologies, even across these 4 houses we saw a wide range of different motivations for engaging with smart home systems ranging from saving energy and money to improving home comfort, increasing convenience by reducing the 'faff' of controlling appliances around the home as well as 'optimising' control. Despite these quite different motivations, across most of the homes use of the 2 systems installed seemed to be relatively consistent. For the RWE system, none of the 4 homes considered here had used this for security purposes but all except one had used it to help create often quite fine-grained time profiles for home heating. Only one home in this small sample had created any 'event profiles' and no 'rule profiles' were created across these 4 homes. Although in some cases it took a few months for the homes to set-up the RWE system across 3 of the 4 homes considered here we then witnessed increasing use over time as they experimented with and refined their settings and as they adjusted them to fit things like the changing seasons or visitors to the home. Only in House 4 had the RWE system not really been used due to conflict arising between householders and frustration with the user-interface. By contrast, for the Z-Wave system only one of the homes had set up time profiles and the rest appeared to use the Z-Wave system on a more on-demand or ad hoc basis for different kinds of reasons e.g. security, remote control, or as a 'kill switch'. Here we saw some evidence that householders liked the use of the smart phone interface that allowed them to check on and control devices in the home remotely. As with the RWE system, and with the exception of House 4, all other homes have gradually used it more frequently as time has passed.

We introduced this paper by introducing three 'narratives' of smart homes and their users, identified by Wilson et al (2015). Alongside control of appliances and usability of user-interfaces, a core focus of the sociotechnical narrative of smart homes and their users is on broader control dynamics within and beyond the home. Here, whilst it is apparent that the smart home systems have extended potential control over appliances we see that in 3

out of the 4 homes considered here they have served to reinforce existing control relationships in the home rather than significantly disrupt them. This is not to suggest that their impact has been insignificant, however, because even where existing control dynamics have been reinforced by the smart home systems, we also see evidence that the systems have served to concentrate control in one person's hands and, in so doing, often excluded others within the home from simple or direct control over devices. The only house where the smart home systems appeared to have dramatically disrupted existing control relationships is house 4. Here, it appeared that the individual with the ability to control the smart home technologies (Henry) was not also the person who had prior control of running the domestic environment (Louise). This led to some conflict and argument in the household, some resistance through manual over-riding of the system and, ultimately (it appears) to the abandonment of the system and a return to manual forms of control of appliances. Although tentative, these observations imply that there is no necessary correspondence between the person who controls the smart home technology and the person who controls what happens within the domestic environment more broadly. Further, that where there is correspondence between these two roles smart home systems can serve to reinforce and harden pre-existing control dynamics and that where there isn't correspondence this can lead to conflict and resistance. These are ideas that demand much further research before they can be substantiated however. A final, very tentative observation about how the smart home systems have impacted on control dynamics in the home relates to the way that, in House 21, the smart home systems appeared to be starting to make some demands on one occupant because, as it had given them more ability to monitor and control so, in turn, they felt some need or responsibility to use these abilities more frequently. Arguably this could lead to a situation where control potential begets control behaviour in a manner that could, ultimately undermine smart home technologies by making them too demanding for householders. This poses very difficult questions about exactly what level and what kind of control smart home systems should seek to provide.

As noted above, data collection in the REFIT research project is still ongoing and, as such, the analysis and conclusions presented here should be treated as preliminary. Furthermore, this paper draws on only 4 out of 20 homes in the REFIT field trial and additional work is already ongoing to further develop and substantiate some of the ideas and arguments offered here. Nonetheless, observations from these 4 homes already point to what we feel are some interesting and important themes related to control in the smart home that deserve further research attention. Most notably, our observations reveal the value of looking across the three core 'narratives' of smart homes and their users identified by Wilson et al (2014). To date, these narratives have tended to unfold in isolation with research looking at either control of devices, or usability of smart home systems, or broader sociotechnical implications. By looking across these narratives, however, we are able to see that all of them has much to offer in understanding if, how, why and how much smart home systems might be used and therefore whether or not they might realise their potential. We have seen, for example, that which appliance or device is being controlled (whether heating, lights, TVs etc.) makes a fundamental difference to what kind of control functionality might be required. Further, we have seen that user-interfaces can frustrate and lead to the abandonment of smart home systems just as they can facilitate increased use such as through smart phone apps. Further, this ability to remotely monitor and control may also serve to make considerable demands on users' time and energy. Beyond these concerns with technology and with user-technology interactions, however, we have also seen how pre-existing control dynamics in the home can be critical to the use of smart home systems and that they may reinforce, harden and disrupt these dynamics in important ways. Although we have not really discussed control relationships beyond the home in this paper, there is some evidence that interaction with the REFIT research team has been important in shaping how users have engaged with the installed systems.

Taken together, these observations point towards a tentative and multi-dimensional analytical framework for future research on control in the smart home. It is no longer sufficient for work to explore only one aspect of control because, as we have seen, all can be critically important in shaping how smart homes are used. We conclude, therefore, by suggesting that future research should simultaneously explore: what devices are being controlled in smart homes, through what kinds of user-interfaces, by whom and to what ends, how this interacts with pre-existing roles and dynamics within households and further, how control relationships beyond the home (e.g. to utilities, governments or research teams) impact on smart home usage.

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Acknowledgements

This work has been carried out as part of the REFIT project ('Personalised Retrofit Decision Support Tools for UK Homes using Smart Home Technology', £1.5m, Grant Reference EP/K002457/1). REFIT is a consortium of three universities - Loughborough, Strathclyde and East Anglia - and ten industry stakeholders funded by the Engineering and Physical Sciences Research Council (EPSRC) under the Transforming Energy Demand in Buildings through Digital Innovation (BuildTEDDI) funding programme. Ethical approval was granted by Loughborough University's Ethics Committee. For more information see: www.epsrc.ac.uk and www.refitsmarthomes.org.