Control in the Smart Home

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1. Introduction: smart homes and energy demand

In recent years, Smart Homes have increasingly been positioned as playing an important role in reducing and managing energy demand as part of transitions to a low-carbon energy system (e.g. DECC 2009). Fundamentally, smart homes are seen as able to help people save energy by giving them more *control* over their energy use at home. They do this by variously 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). In essence, the additional forms of control offered by smart homes seek to enable rational energy management within the domestic environment. Claims of the potential energy savings that can be achieved by smart homes range from 10% to over 40% and these sorts of claims are helping to fuel huge predicted growth in the smart home market (e.g. IEA 2013).

Despite strong technological push behind smart homes (e.g. Haines et al 2007), however, 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. In 2003, for example, Randall coined the term 'the control paradox' to describe the fact that, in his study, the more advanced the control capabilities provided to householders by smart home systems, 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 (e.g. 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 (e.g. control of devices, control of others, control over lives etc. – e.g. Davidoff et al 2006). Thus, the simplistic notion that smart homes can provide *more* control is misleading. Understanding control is important because it mediates the impact of smart homes on energy demand. However, whilst control has long been a core concern of research on smart homes (Wilson et al 2015), there remains surprisingly little research on the lived realities of control in actual smart home environments. This paper hopes to start addressing this research gap by exploring the dynamics of control in 10 homes equipped with a range of smart home technologies. We argue that more attention should be turned to how it is that smart home

systems serve to reconfigure the dynamics of control in domestic environments (e.g. Strengers 2013). In particular, we argue that control should be understood as an emergent property of the interactions between smart home technologies, users, and domestic life (see Figure 1) and, crucially, that it is the nature of the interactions and relationships between smart home technologies, users and domestic life that mediate the impact of smart homes on energy demand.

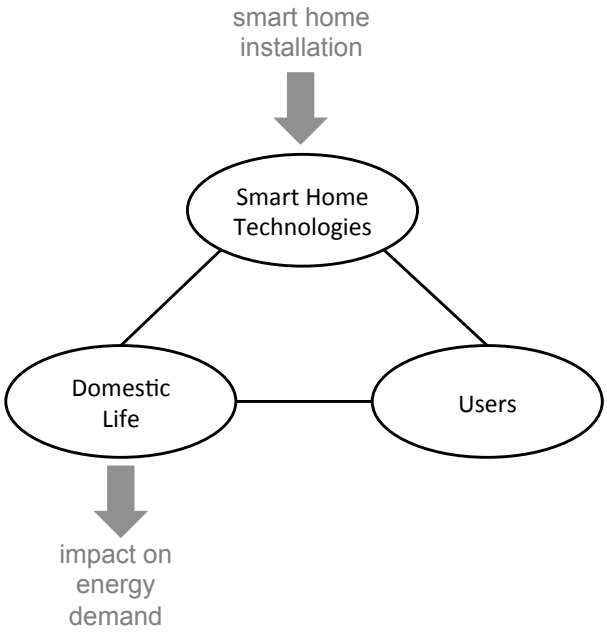

Figure 1: Interactions between smart home technologies, users and domestic life mediate the impact of smart homes on energy demand

The next section briefly reviews the research literature on control in smart homes before describing our conceptual framework in more depth. In particular, it describes three distinct types of control that emerge from these interactions that each have different implications for thinking about energy demand. Section 3 describes the smart home technologies and qualitative methods employed in the REFIT research project. Section 4 then applies the analytical framework to new empirical data to explore control dynamics in smart homes. Finally, section 5 concludes the paper by discussing the implications of our findings for future smart home technologies and for energy demand.

2. Control in the smart home literature

We conducted a systematic review of the research literature on smart homes and their users (see Wilson et al 2015 for full details). Control was identified as a core cross-cutting theme within this review. As such, we subsequently conducted an additional, more focussed review on control specifically. These reviews identified that whilst the same term, 'control' was being widely used, it was being employed to emphasise quite different aspects of life inside smart home environments. In particular, we identified three distinct emphases within work on control on smart homes: i) control of technology, ii) control by users, and iii) control of lives and relationships.

2.1 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 that 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, p3).

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

Underpinning this approach is the central assumption 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 the domestic energy use to be automated or optimised. The implications of smart home technologies on energy demand are thus seen as clear and unequivocal in this view. If smart home technologies are designed and used as intended, they will lead to energy demand reductions through rational, optimised and automated control of the domestic environment.

2.2. 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, p69)

Developing from Randall's (2003) 'control paradox' this second, less common approach to control focuses on the finding that even if a great deal of control of technologies is successfully provided in smart homes, this may render their users feeling 'out of control'. Here then, the object of control is 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, this approach can overlap with a focus on control of technology in trying to provide easy-to-use or 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 the users' levels of trust in utility companies (Paetz et al 2012), their worries about security and data-privacy (Cook 2012), or their 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. As research in this area shows, this perception of control can relate to very different aspects of domestic life, from intuitive user-interfaces on devices to trust in energy companies, but in essence it argues that if smart homes 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 replicated widely, for example, the implication is that the wide diffusion of smart home technologies will 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 smart homes' impacts on energy demand will hinge fundamentally on which aspects of the domestic environment users perceive themselves to be in control of, and to what extent.

2.3 Control of lives and relationships

"[M]*ore than control of their devices, families desire more control of their lives." (*Davidoff et al 2006, p20)

A third approach to control in the smart homes literature on smart homes focuses on how smart homes do (or do not) allow users to control their lives and relationships in different ways. 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. For example, Davidoff et al (2006) highlight the need for smart homes 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.

Core research in this approach thus seeks to understand and explore the different ways in which smart homes affect domestic life. Several authors have commented on how smart homes may impact on gender roles and relations in homes, and particularly how they have often been designed with men in mind and tended to ignore what is traditionally seen as 'women's work' (Berg 1994; Richardson 2009; Strengers 2015). Others have argued that, as currently designed, smart homes often do little to create a sense of 'home' or homeliness which may demand an absence of technological intervention at times (Leppanen and Jokinen 2003). Going further, Strengers (2013) illustrates how smart homes can 'act back' on domestic routines encouraging householders to act in different ways in response to technological signals.

The central assumption behind this approach is that people desire control over their domestic lives in a broad sense and that smart homes, at least as they are currently designed, may or 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. Thus, in this view, whilst smart homes may still help to manage energy demand, they may also give rise to new and more energy-intensive ways of living (e.g. Nyborg and Røpke 2011).

2.4 Conceptualising control in the smart home

This section has highlighted three different emphases in existing research on control in the literature on smart homes: control of technologies, control by users and control of lives and relationships. We argue that each of these different emphases or approaches to control refers to a distinct type of control and, thus, we 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 1 (below) summarises the core features of these three distinct approaches to control.

	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 people's 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'.	Smart homes may lead to demand reduction, but may also generate more energy-intensive lives

Table 1: Three types of control in smart homes

Whilst the literature on smart homes thus grapples with different types of control and tends to address them in isolation from one another, we argue that it is the inter-relationships between them that matter most significantly for how each of them are felt or experienced and, therefore, for how each of them might be shaped or influenced. Critically, we argue that each type of control places priority on different relationships between smart home technologies, users and domestic life. A focus on artefactual control places priority on technologies themselves, focussing on how smart home technologies are used to schedule activities and enable particular household functions. A focus on perceptual control places priority on users, and seeks to understand how user perceptions of control emerge and change through their efforts to use smart home technologies and how this helps or hinders domestic life. Finally, a focus on relational control places priority on domestic life and seeks to understand how this may be affected (or not) by smart home technologies and their users. These relationships are summarised in Figure 2 below.

In the rest of this paper we will seek to explore this conceptual understanding of control in new empirical data collected from households participating in a field trial of smart home technologies. For the first time, this will allow a systematic exploration of the notion (and dynamics) of control in real world smart home environments.

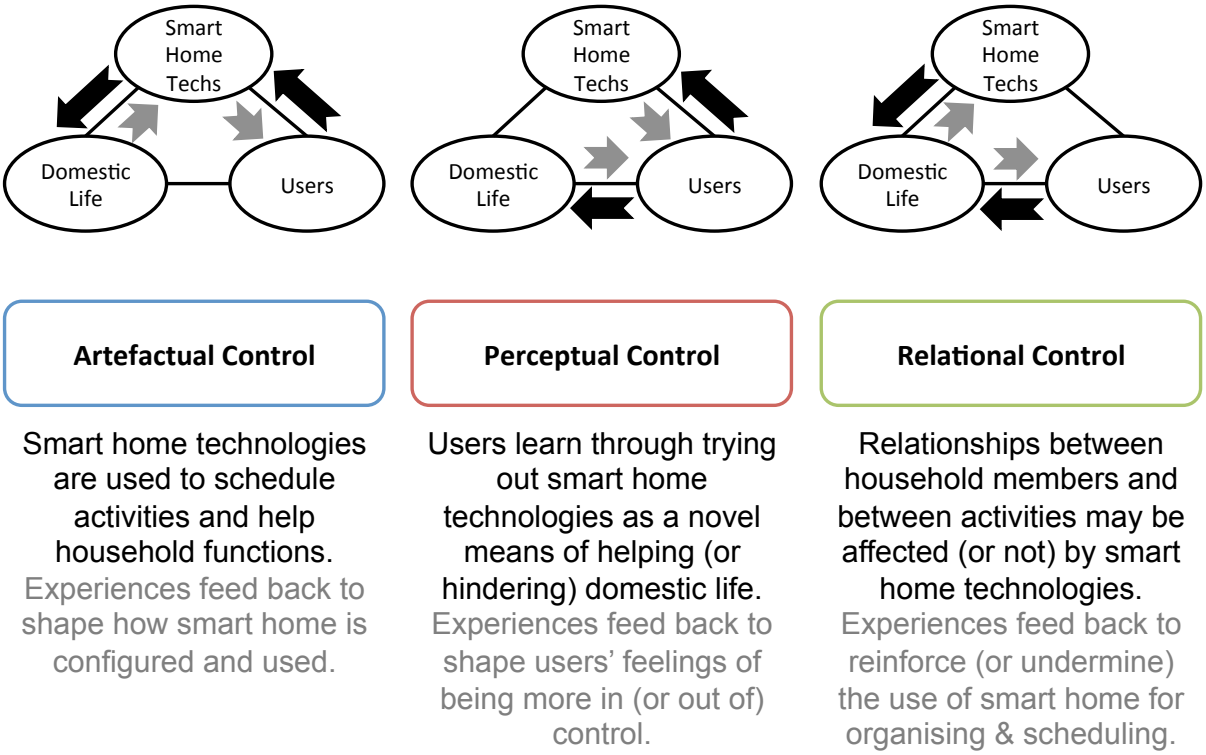

Figure 2: Types of control depend on the interactions between smart home technologies, users and domestic life

3. Method

As part of the broader EPSRC-funded REFIT research project, we recruited a sample of 10 homes in the English town of Loughborough to take part in a field trial of smart home technologies. Homes were recruited to cover a diverse range of: house types; family sizes and types; and levels of familiarity and experience with Information and Communication Technologies (ICTs). Table 2, below provides summary details of the participants.

Participating households were equipped with three distinct smart home systems. Further details on these systems are available in Hargreaves et al (2015), but the core features can be summarised as:

- *The RWE Smart Home system* (hereafter RWE): This 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' (these could be time-based schedules, event-based [i.e. turn on/off at the touch of a button, or rule-based [i.e. turn on/off radiator if window is left open]) via an online user interface and/or smart phone app. Each house was given: up to 10 smart radiator thermostats, 6 door and window sensors, 4 motion sensors, an alarm/smoke detector, 3 room thermostats, 2 wall-mounted switches (which could

be configured to activate any profile of combination of profile) and a remote control (which could be configured in the same way as the wall-mounted switches)

- *The VERA Z-Wave system* (hereafter VERA): 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 enables the automation of these four devices through either time, event or rule-based profiles. The VERA system could be remotely accessed and controlled via an online interface.
- *The British Gas Hive system* (hereafter Hive): The Hive system enabled participants to remotely control their heating and hot water via smart phone, tablet or PC. The system allowed users to set up to six heating and hot water schedules per day (i.e. between the hours of X and Y, ensure the house is temperature Z). It also allowed users to configure reminders based on their location e.g. to turn the heating off when they arrive at work. The key difference between the Hive and RWE systems is that the Hive system controlled the heating system as a whole and did not therefore allow users to distinguish between different rooms or zones within the house.

House number	Participant name (pseudonyms)	Age (at start of trial)	Occupation
2	Simon	34	Technical specialist
	Sally	36	Full-time mum
	Harriet	3	Pre-school
	William	1	Pre-school
3	John	64	Semi-retired mechanical engineer
	Jane	69	Homemaker
4	Henry	64	Retired IT sales support
	Louise	64	Retired University administrator
5	Jason	51	Senior IT developer
	Cara	47	Senior Lecturer
	Ellie	12	School student
	Lola	10	School student
8	Robert	79	Retired Greengrocer
	Marion	72	Homemaker
11	Sarah	71	Not in paid work
17	Steven	62	University researcher
	Noelle	Not given	Care assistant
	Rachel	17	School student
19	Keith	48	IT analyst programmer
	Lucy	43	Not in paid work
	Aiden	11	School student
	Marcus	8	School student
20	Roger	58	IT process analyst
	Lorna	55	Homemaker
	Ursula	22	University student
21	Ingrid	43	Speech therapist
	David	33	IT product manager
	Ben	11	School student
	Sam	9	School student

Table 2: Summary details of field trial participants

Semi-structured interviews were carried out with all participants on three separate occasions throughout the one-year field trial (see Figure 3). First, before any smart home technologies were installed, households took part in an interview and video tour around the home (identified below as I1). This interview focused on household roles and routines and how they used technologies in their homes. These interviews lasted between 2 and 3 hours. The second interviews (I2) were conducted by phone with each individual adult household member and took place within two months of the smart home technologies being installed. Lasting 30-45minutes, these interviews focused on participants' initial use of, and responses to, the installed smart home technologies. Finally, the third round of interviews (I3) took place six to nine months after the technologies were installed, but crucially after at least one heating season, to ensure all households had ample opportunity to make use of the smart home systems. These interviews focused on households longer-term domestication of the technologies and on how, if at all, they had impacted upon the household roles and routines discussed in the initial interviews.

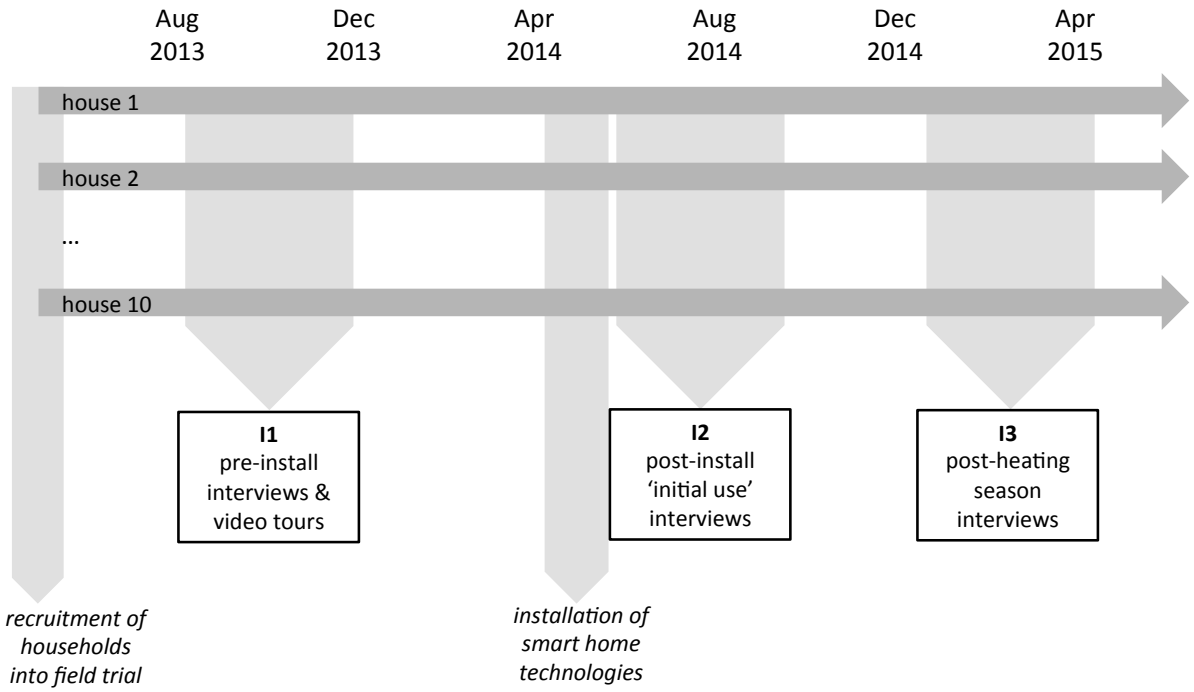

Figure 3: Timeline of 'REFIT project' field trial of smart home technologies (Loughborough, UK)

Qualitative analysis of this interview data focused on the three types of control identified in the conceptual framework summarized in Figure 2. Specifically, transcripts were coded for instances where the different types of control came to the fore and analysis has focused on different expressions of these types of control and on the relationships between them.

4. Results

4.1 Controlling artefacts: *"*[T]*hat's the over-arching thing for me, it's a bit complicated"* (Jason, I3, p1)

Many participants stated that the smart home systems installed had given them more or

better control over various aspects of their homes. A range of features of this artefactual control were highlighted as particularly significant. Several participants commented that the RWE system in particular allowed them to *"fine tune the heating system"* (Keith, I2, p5). One participant 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 in order to make decisions:

> *"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 because that was really useful because obviously you used to have a central control that would control all the rooms, whereas 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, I2, p6)

In addition to provided finer-grained control, participants also enjoyed the remote control functionality smart homes provided. The Hive system allowed remote control of the heating; the VERA system controlled lights (or other devices) when away from home.

> *"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, I3, p4)

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. for when children arrived home from school. Ingrid, perhaps the most avid user of the remote control capabilities provided by the systems, 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 higher than she wanted:

> *"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. So I've got a bit more control over the heating and how we use it really."* (Ingrid, I2, p1)

Still other participants commented that they liked the idea of setting different 'rule-based profiles' on the RWE system (e.g. to turn a radiator on if motion was detected) although in several cases they remained unsure if this had actually worked as it was intended to. Generally, these more advanced forms of automated control were little used, although some did comment that they liked the 'automatic' nature of the systems even if they could have achieved the same effects manually:

> *"We could do manually what it's doing automatically for us."* (Roger, I3, p9)

As the above quotations show, participants made use of the artefactual control afforded by the installed systems in a range of ways. At the same time, however, many also suggested

that this could have been made far 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 smart home systems installed. For example:

> *"To me, in my childish Tomorrow's World[1] 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, I3, p17)

Where participants suggested they had not made use of the artefactual control available to them, the main reason was that the new systems were seen as excessively complicated and thus that previous 'dumb' systems had been easier to use and more flexible.

In addition to these comments on whether or not artefactual control functionality was used, several participants highlighted potential limits to the amount of artefactual control these smart home systems 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. In essence, they couldn't find a valuable use for the additional artefactual control the systems 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 I3, p10)

Developing this theme, some others commented even though they had identified forms of artefactual control that would be valuable, the systems were unable 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... but if you've got your curtains closed for a week...people can see that they're closed all day."* (Louise, I2, p4)

> *"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, I2, p2)

[1] 'Tomorrow's World' was the British Broadcasting Corporation's flagship science television programme. Broadcast from 1965 until 2003 it regularly featured stories about new developments in science and technology.

As these quotes show, for some participants the system was not quite 'smart' enough either because it needed to be more extensive or require more components (such as motorized drapes/curtains) to function effectively, or because it wouldn't be able to respond rapidly enough to automated commands.

In summary, artefactual control did appear as a very common theme across all interviews and was a significant issue for all participants. Critically, however, and as the following sections will show, it was by no means the only or even perhaps most important form of control participants discussed and it was often shaped through inter-relations with other types of control.

4.2 Controlling perceptions: "dammit we'll get to grips with it" (Marion, I3, p2)

In general, for most participants, the smart home systems provided them with a feeling or perception of increased 'control' over their homes and appliances, even if they at times 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. You know, this is more finely tuned, possibly a new programmer would have even more options on it."* (Marion, I3, p18)

> *"Well, potentially there'd be more control with this if I wanted to keep altering the radiators in different rooms, but I don't want to. So I feel more in control. I've got used to this one now, but no I still use my old thermostat. It's still the main thing I use really."* (Sarah, I3, p10)

In other cases, though, there was evidence to support Randall's (2003) concept of a 'control paradox' wherein the additional control capabilities provided by the smart home systems were seen as making the house harder to control and manage. This was particularly related to issues with user-interface design that serve to connect artefactual and perceptual forms of control. Marion, for example, comments that she almost threw out the smart home technologies because they weren't sufficiently *"straightforward"* before deciding that she wouldn't *"be defeated by it"* (I3, p4), whilst Louise argued that the RWE system was *"actually feels less flexible"* (I2, p4) than her old 'dumb' system and that, ultimately, the additional layers of control provided by smart homes were: *"too much for me"* (Louise, I3, p16).

Participants noted several other ways in which the systems impacted negatively on their feelings or perceptions of control around the home. For example, several participants comments 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 and as if someone was watching over them when they were at home. 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: *We wondered whether it was a sinister experiment."* (Simon and Sally, I3, p9)

Others commented that the systems made them feel out of control when they seemed to 'override' their own personal judgements about how they wished to live in their home.

> *"To me, it would be overriding my own judgement about what I think is the best thing to do in terms of electricity."* (Sarah, I3, p7)

For Sarah the problem was that the system would simply be unable to cope with the complexity and irregularity of how she used her home, no matter how she tried to programme it.

The core theme to emerge from these discussions about forms of perceptual control relates to learning. Most participants commented that the systems took time to learn and that their perceptions of control were accrued through experience. This was not merely about learning *how* to use them but also, and as highlighted in section 4.1, to identify things to use them *for.* As the following quotations illustrate, participants frequently emphasised the importance of learning-by-doing:

> *"This might sound silly but to me it must be like having a baby, you can read all the books about it, like we've read all the technology, but when the thing arrives and it isn't operating* [laughs] *it's totally different. And what you imagine can go out of the window can't it? You learn as you go along. For me, this is the new baby."* (Marion, I2, p6)

The importance of being able to gradually learn how to use smart home systems, and to actively 'experiment' and 'play' with them was crucial to participants in the trial and, as some participants emphasised, it was only by going through this often challenging phase of learning-by-doing that they could develop confidence in using the smart home system and, as a result, potentially start to use the systems in more advanced and inventive ways and thus make more use of the wide-range of artefactual control possibilities provided.

> *"It's like most things, it's easy when you know how."* (Roger, I2, p1)

> *"Once you've become really au fait with everything you can locate it at your front door and as you walk out, hit it and it will shut down your central heating, it'll activate your lights that come on in a programmed manner, you know, it'll do all kinds of stuff like that."* (John, I2, p2)

As this section has shown, perceptual forms of control were of crucial importance to participants in the trial. In particular, by emphasising the importance of learning-by-doing and gradually developing confidence with smart home systems, these findings serve to illustrate that control in the smart home is a multi-dimensional concept that refers to perceptions and feelings as much as it does to devices and technologies.

4.3 Controlling relationships: "now, because you can think about it, you do think about it" (Jason, I3, p19)

Relational forms of control commonly emerged as import to field trial participants. Smart home systems impacted upon the relationships between people and activities in both positive and negative ways.

One of the most significant aspects of relational forms of control was in shaping which household member actually came to use the smart home systems installed. As noted in section 3 above, when recruiting for the field trial we attempted to recruit participants with a diverse range of experience with and enthusiasm for ICTs. As table 2 highlights, however, in the eventual sample there was still a relatively high number of participants whose job was directly related to ICT. Nonetheless, whilst these individuals may (or may not) have been the driving forces for participating in the trial itself, in many cases they were not the primary user of the smart home systems once they were installed. Rather, the dominant logic for *who* should used the smart home systems related instead to the adult householder who was most present in the home which, in several cases, included individuals who described themselves as 'technophobes' to some degree. Despite David working as an 'IT project manager' for example, Ingrid points out that his absence from the home including during installation, means that she has taken charge of the using the smart home systems:

> *"*[David] *isn't really sure what's going on because I was here when* [the engineer] *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, I2, p3)

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 systems 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, I3, p6)

As these quotations show, although most participants argued that they felt the smart home technologies *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 complexity of the smart home systems often left those who were not the dominant users feeling as if they'd lost control over their homes and become reliant on others to do things that they'd 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, I2, p6)

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 in which the systems had variously made their lives simple or more convenient by making it easier to perform some 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. It's just much easier than having the big lights on*" (Ingrid, I3, p1)

Whilst the systems seemingly made life easier in some instances, many participants commented that they also complicated life in other ways. For some, the systems took too much time to learn how to configure and control and this was time that, they felt, 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, I3, p13)

For others, control in an artefactual and perceptual sense complicated their lives by compelling them to check the system 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, I3, p5)

Elaborating further, Jason expressed some concern that the whole system had served to complicate his family's already hectic lives and that this additional 'grief' was perhaps not worth it for the sake of 'a bit of fun':

"[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, technically fun. But now it's caused everyone grief. A bit of luxury weighed against a lot of pain doesn't really weigh out does it?*" (Jason, I3, p15)

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 smart home systems served to either cause or help avoid conflicts between householders. For Henry and Louise, where Louise had previously controlled the home heating system, by concentrating control in Henry's hands, the new smart home systems rendered Louise feeling as if she'd lost control. This resulted in conflict between them when they both sought to configure the heating at he same time. Louise, via her old manual approach, and Henry via the new RWE smart home system:

"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...That's just two of us, what if you'd

got an entire family? I don't know, and if we've all got access to change it, you know, who's in charge?" (Louise, I2, p4-5)

In Henry and Louise's case, the series of conflicts and frustrations caused by the smart home systems led to their eventual abandonment with Henry stating that they ended up *"getting round"* (I2, p13) the system by removing it. In other cases, however, participants felt that the more fine-grained forms of artefactual control provided the smart home systems had actively 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 throughout our family for being something of a hothouse flower as it were…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, I2, p4)

Smart home systems use is shaped by the existing roles, schedules, or personal interests and experiences of householders. They 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. These are significant impacts that would be missed or ignored through the conventional ways of understanding smart home control as either artefactual or perceptual.

5. Discussion and conclusions

Our findings have shown that all three forms of control identified in our conceptual framework appear to be significant to participants in the field trial, and all shaped the use (or non-use) of smart home systems in different ways. Perhaps most importantly, however, the inter-relations between different forms of control seem especially significant. 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 appear to be critically important in shaping the domestication trajectories followed by smart home systems. The potential forms these feedback loops may take are summarised in Figure 4 and described in more depth in the following short examples.

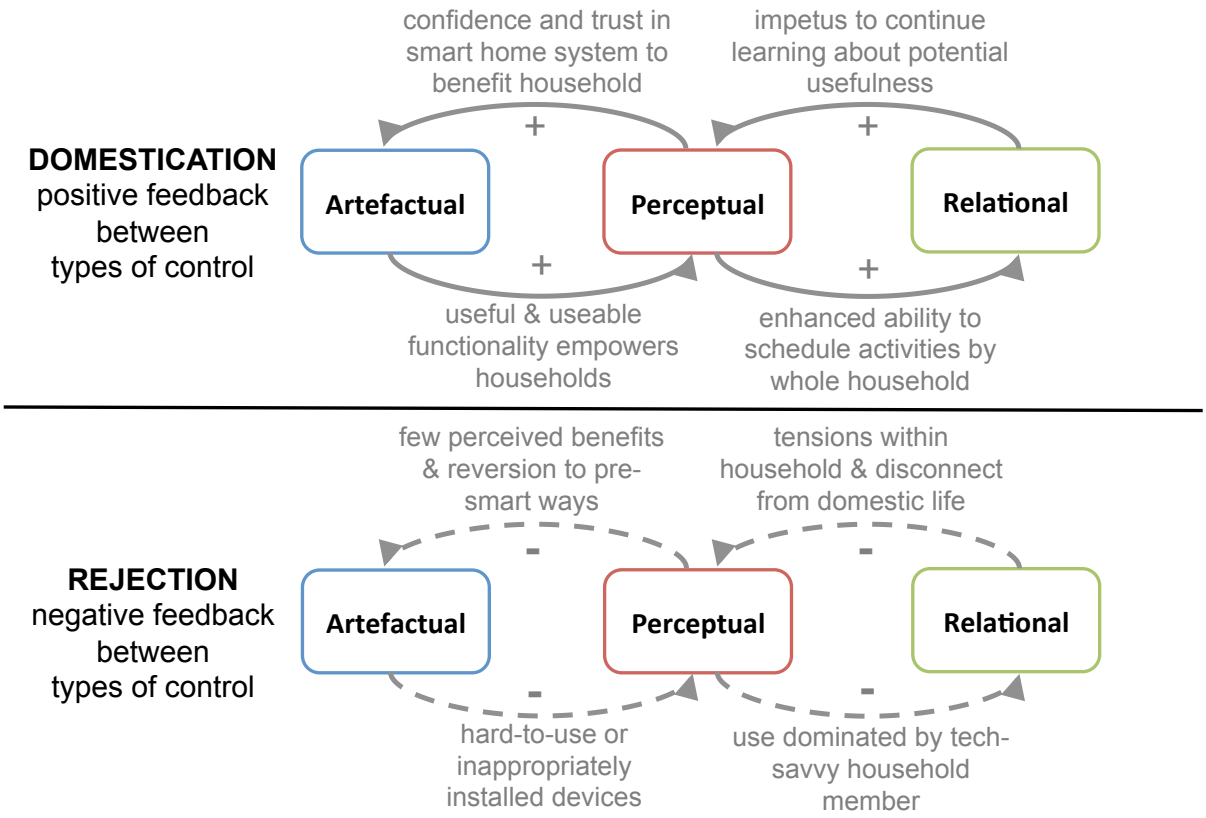

Figure 4: Positive and negative feedback loops between different forms of control shape the domestication or rejection of smart home technologies

In Ingrid's case, for example, she found the forms of artefactual control provided valuable which increased her perception of control over her home and encouraged her to use the smart home systems to schedule activities in different ways (e.g. by pre-warming or pre-lighting rooms before arriving home). In turn, these positive feedback loops have encouraged her to look for more ways to use smart technologies in her home – for instance, she is looking into installing smart lighting controls in a planned home-extension. If this path is indeed followed this will provide yet more impetus to continue learning about how smart home systems could be used, which has the potential to further increase her confidence and trust in the smart home system leading, potentially to the acquisition of still more smart home technologies.

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. 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 a series of conflicts and arguments about who should use the system and to what ends which served to further undermine both Henry and Louise's perceptions of control at home. In combination, these negative feedback loops led Henry and Louise to take the joint decision to 'get round' the smart home systems by removing them from the home and reverting to their old, manual means of control.

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 smart home systems provide a wide range of new and useful control functionality that gives him a greater perception of control over the home. At the same time, however, by concentrating control in John's hands, Jane feels as if she is no longer in control in her own home so is not particularly keen to engage with the smart home systems herself or to encourage John to use the systems to schedule activities in new ways or to install more smart home technologies that may serve to further reduce her perception of control over the home. Taken together, these feedback loops render John somewhat frustrated that the smart home systems are not better integrated and easier to use (particularly for those with little experience using ICTs) whilst Jane expresses concern that should anything happen to John she would be forced to remove all of the smart home technologies in order to take back control.

These findings have clear implications for future research on and development of smart home systems. First and foremost, they serve to illustrate that control is a critically important concept inside smart homes that deserves further critical attention. Going further, however, they show that control is far from a simple, single or quantifiable thing but rather that it is a multi-dimensional construct that emerges from inter-relations between users, smart home technologies and domestic life. The different types of control we identified all emerged as significant in shaping the use (or non-use) of smart home systems in different kinds of ways across all participating households. In short, all forms of control need to be understood in future research and smart home design as smart homes diffuse more widely.

The implications of our findings for energy demand are more uncertain however. What is clear is that there will be no simple one-to-one relationship between the diffusion and adoption of smart homes and energy demand reductions. Instead, the relationship between energy demand and smart homes will be mediated by the new forms of control smart home systems give rise to and the inter-relations between them.

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