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ABSTRACT

Smart homes promise to significantly enhance domestic comfort, convenience, security and leisure whilst simultaneously reducing energy use through optimized home energy management. Their ability to achieve these multiple aims rests fundamentally on how they are used by householders, yet very little is currently known about this topic. The few studies that have explored the use of smart homes have tended to focus on special-interest groups and be quite short-term. This paper reports on new in-depth qualitative data that explore the domestication of a range of smart home technologies in 10 households participating in a nine-month field trial. Four core themes emerge: (1) smart home technologies are both technically and socially disruptive; (2) smart homes require forms of adaptation and familiarization from householders that can limit their use; (3) learning to use smart home technologies is a demanding and time-consuming task for which there is currently very little support available; and (4) there is little evidence that smart home technologies will generate substantial energy savings and, indeed, there is a risk that they may generate forms of energy intensification. The paper concludes by discussing the implications of these findings for policy, design and further research.

Introduction

> Imagine pressing a 'welcome home' button on a remote control as you pull into your driveway and having your pathway, front porch and hallway lights turn on. Your air-conditioner begins to warm or cool your living room, and your favourite music starts playing throughout your house. That's a smart home! (Clipsal, 2006, p. 1)

Visions of future smart homes are very seductive. Smart homes promise to enhance domestic comfort, convenience, security and leisure whilst reducing energy use through optimized home energy management. Some firms claim that smart home technologies (SHTs) can save up to 30% of energy costs without compromising comfort (Siemens, 2014). It is therefore hardly surprising that the smart home market is forecast to grow dramatically (International Energy Agency, 2013), or that they are seen as a key part of future energy transitions (*e.g.* Department of Energy and Climate Change, 2009; European Commission, 2015). At the same time, it is far from clear that SHTs will generate the level of energy savings their developers claim, or indeed any energy savings at all. Recent research, for example, has cast significant doubts on their energy-saving potential, suggesting that alluring visions may conceal numerous 'hidden energy costs' (Strengers, Morley, Nicholls, & Hazas, 2016) that could normalize and harden, or even potentially intensify and increase levels of energy demand (Nyborg & Røpke, 2011; Strengers, 2013). Ultimately, however, the success or failure of SHTs, and what impacts, if any, they have on energy demand, depends fundamentally on whether and how they are used by householders. To date, however, surprisingly little is known about this. A core aim of this paper, therefore, is to explore how householders learn about, use and adapt to SHTs as one means of casting greater scrutiny over optimistic claims about their energy-saving potential.

Whilst definitions of 'smart' homes vary considerably (Aldrich, 2003), they are generally understood to be:

> residence[s] equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, access or controlled, and provide services that respond to the needs of [their] inhabitants. (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013, p. 364)

Smart homes have typically been understood in technical terms. Most existing research on SHTs has focused on the technological challenges involved in developing them (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015). Despite growing interest in encouraging consumer adoption (*e.g.* Balta-Ozkan et al., 2013), there remains a significant gap in understanding how SHTs are actually used. The few studies that have explored this have focused on early adopter and special-interest groups such as enthusiasts and hobbyists (*e.g.* Bernheim Brush et al., 2011; Mennicken & Huang, 2012; Mozer, 2005) or on those with specific reasons for pursuing home automation, such as Orthodox Jews (Woodruff, Augustin, & Foucault, 2007). Further, these studies have typically been quite short-term, often neglecting longer-term trajectories and learning processes. This paper reports the in-depth qualitative findings of a field trial of SHTs installed in 10 households over a nine-month period. It aims to develop existing understandings of how householders learn about, use and adapt to SHTs in their own homes over the longer-term to help assess the potential role and value of SHTs in future energy transitions.

Domesticating smart homes

Smart homes and their users

Most previous smart home research has explored the technical challenges of delivering smart domestic environments (Cook, 2012). The majority of this work has given no consideration to users at all. As two recent reviews show, however, there is a growing interest in the users of smart homes (*e.g.* Mennicken, Vermeulen, & Huang, 2014; Wilson et al., 2015). The main focus of this work has been on encouraging user acceptance and adoption of SHTs by identifying and removing various 'social barriers'. Drawing on interviews and workshops with both experts and members of the public, Balta-Ozkan et al. (2013) summarize these barriers into five challenges:

- the fit with users current and changing lifestyles
- the ease with which SHTs can be administered (*e.g.* installation and maintenance)
- interoperability between systems
- reliability
- privacy and security

At the same time, whilst removing these social barriers receives a great deal of attention (*e.g.* Paetz, Dutschke, & Fichtner, 2012; Wilson et al., 2015), research that has explored how people actually use

smart homes has identified a different range of concerns that have a much more situated and social character. Mennicken et al. (2014), for example, identify three core themes. First, SHTs should not merely 'fit in' with current household aesthetics and routines, but need actively to support and augment households' social goals and values. Davidoff, Lee, Yiu, Zimmerman, and Dey (2006), for example, identified the importance to domestic life of 'enrichment activities' such as boosting physical fitness, creativity or teaching social values. Whilst vital in helping to create and sustain household identities, such enrichment activities potentially clash with attempts to automate or optimize domestic activities. For example, whilst switching lights off may be easy to automate, it reduces opportunities for parents to teach their children how not to be wasteful. Similarly, others have asked how smart homes might support the construction of gender identities (Richardson, 2009), create 'homey' homes (Takayama, Pantofaru, Robson, Soto, & Barry, 2012), or support religious or pro-environmental values (Woodruff et al., 2007; Woodruff, Hasbrouck, & Augustin, 2008). In short, smart homes should be meaningful as well as functional or instrumental technologies.

Second, in-depth explorations of domestic life reveal the immense complexity of homes. They are meaning and emotion-laden places in which, often, multiple household members with different roles and relationships with technology (Mennicken & Huang, 2012; Nyborg, 2015) must interact and negotiate their wants and needs to achieve a relatively peaceful co-existence (Baillie & Benyon, 2008). Further, domestic life is characterized by routines that involve regular breakdowns, improvisations, compromises and conflicts (Davidoff et al., 2006). SHTs must be able to cope with this complexity and avoid deriving 'mixed messages' (Mennicken et al., 2014) from the multiple signals they receive.

Third, SHTs must not overpower their users (Park, Won, Lee, & Kim, 2003) with too many options or hard-to-use controls. Many users may have little interest in understanding everything a smart home can do or how they work, because they are focused on more pressing daily needs. SHTs should thus avoid leaving users feeling out of control through forms of 'human–home collaboration' (Mennicken et al., 2014). This requires systems that allow users to communicate with SHTs in ways that make sense to users themselves, rather than having to learn complex technical languages and commands, and technologies that can make suggestions about how they might be used and the impacts they might have.

Mennicken et al. conclude that 'living in and with an actual smart home today remains an imperfect

experience' (p. 113). They call for more 'in-the-wild' research exploring how SHTs are integrated into existing homes.

Domestication of technologies

Early research on the 'diffusion of innovations' (Rogers, 2003) described the process by which innovations diffuse as information on their attributes, costs and benefits is communicated across society and so reduces uncertainty and perceived risks of adoption. A core aspect of this work was to emphasize how particular characteristics of technologies affect their diffusion rate. Specifically, innovations that are perceived as being less complex, having greater relative advantage, compatibility with existing lives, trialability and observability, diffuse more quickly.

Domestication theory emerged in direct response to this work and argued instead that the diffusion of innovations approach was too linear as it viewed technologies as pre-given, unchanging entities that simply diffuse through society, and thus provides a passive role for users 'who simply adapt to what is offered to them' (Lehtonen, 2003, p. 364). Instead, the concept of domestication emphasizes the active work involved in 'taming' 'wild' technologies to bring them into and make them functional within homes (Berker, Hartmann, Punie, & Ward, 2005). Specifically, domestication requires that users undertake three types of work (Sørensen, 1996):

- *cognitive*: learning about the technology and what it can do
- *practical*: learning how to use the technology
- *symbolic*: learning about and constructing the meaning of the technology and how to incorporate it in identities

Domestication stresses how, through this work, technologies and their users co-evolve as technologies enable new routines and identities and are thus given particular functions and meanings (Haddon, 2006; Oudshoorn & Pinch, 2003). Domestication is rarely a 'harmonious process' (Sørensen, 1994). Rather, it involves negotiations and conflicts between householders – as they become main users, partial or even non-users (Wyatt, 2003) – or as some technological features come to be seen as useful whilst others are ignored (Isaksson, 2014).

Whilst domestication is seen as having been 'successful' when 'technologies are not regarded as cold, lifeless and problematic, but as comfortable, useful tools … that are reliable and trustworthy' (Juntunen, 2014, p. 2), the domestication process is never complete. Rather, technologies can always be re- or de-

domesticated as faults emerge, newer technologies are acquired, or as users grow older, have children or move home (Sørensen, 1994). In these ways, domestication theory moves beyond a linear model of the diffusion of innovations by demonstrating how users are constantly innovating with and adapting to new technologies to make them work in their own everyday lives. Thus, the innovation process is seen to extend into (and indeed back out of) households with no clear end point, as technologies take on different functions and meanings in different contexts and as these are responded to in the design and development process.

Domestication has recently been applied to a range of energy technologies such as small-scale renewables (Juntunen, 2014), passive houses (Isaksson, 2014) and energy feedback devices (Hargreaves, Nye, & Burgess, 2010). To our knowledge, however, aside from Nyborg (2015), it has not yet been used to explore how householders use SHTs.

Methods: the REFIT field trial

In early 2013 the REFIT project ('Personalised Retrofit Decision Support Tools for UK Homes using Smart Home Technology') recruited 20 households in Loughborough, England, for a field trial of SHTs. Recruitment materials including posters, newspaper adverts and leaflets presented the trial as an opportunity to experience new SHTs related to energy management, security and convenience. The materials placed no emphasis on potential energy or financial savings. Respondents completed a screening survey to ensure diversity against the following criteria: household composition; experience with smart technologies; property type and age; existing energy efficiency or microgeneration measures; and length of tenure. The final sample of 20 households were all offered the same SHTs but, to avoid research overload, were divided into two groups of 10. Half the sample participated in design-focused activities related to generating retrofit decision-support tools (Kane et al., 2015); the other half engaged in a series of in-depth qualitative interviews focused on how they used the SHTs. This paper reports on this second group, which comprised a mixture of retired singles, couples and families with children of different ages (Table 1).

The trial sought to explore how households use market-ready SHTs, rather than beta-testing prototypes. Key requirements thus included that the technologies were functional, reliable, provided access to data, and that they offered a range of smart home services including energy management, security and home monitoring, and automated and remote control of devices. Meeting these criteria resulted in three SHT systems being used.

Table 1. Participant details.

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

Notes: [a]House IDs were assigned as they joined the trial. There are 21 IDs because house 14 dropped out.
[b]All names are pseudonyms. Ages are those given at the start of the trial.
[c]House 11 did not participate in I2.

Although a single, unified system would have been preferable, no such system could be identified. Further, the pragmatic approach taken arguably mirrors real-life experiences of 'piecemeal' smart home development (Edwards & Grinter, 2001). Key features of the systems were:

- *RWE Smart home*[1]
  Allowed zonal control of radiators and various home security features. Specific devices included: 10 radiator thermostats; six door/window sensors; four motion and brightness sensors; an alarm and smoke detector; three room thermostats; two wall-mounted switches; and a remote control handset.
- *VERA Z-Wave*[2]
  Provided real-time feedback on electricity use and remote and automated control of four appliances via smart plugs.
- *British Gas HIVE*[3]
  Provided remote control of heating and hot water. This system was incompatible with some boilers so was only installed in eight homes.

Each system had its own user interface, all of which were accessible via an internet-connected computer, smartphone or tablet app. Further, each system offered a range of control options including: *time profiles* (all three) in which

devices could be switched on/off at specified times; *event profiles* (RWE and VERA) in which an event, *e.g.* flicking a switch, could trigger prespecified outcomes; and *rule profiles* (RWE and VERA) in which participants could establish rules, *e.g.* 'if door/window is open, turn radiators on/off' or 'if motion detected, trigger alarm'. Finally, the HIVE system allowed users to configure location-based reminders, prompting them to turn heating and hot water on or off when at particular locations. In summary, the three systems provided a vast array of control and automation possibilities for heating, hot water, electrical appliances and security systems.

Qualitative data were collected at three points (Figure 1). An initial interview and household video tour (I1) was conducted with all household members before installation of SHTs. Lasting two to three hours, I1 explored how participants used their homes, and household dynamics and decision-making around new technologies. A second interview (I2) was conducted within two months of installation and lasted for 30–45 minutes. Conducted by phone with adult household members, these interviews explored initial uses and responses to the SHTs. Nine households participated in I2. A third interview (I3) occurred after an initial heating season, six to nine months post-installation. Lasting one to two hours in a face-to-face group interview with all household members, I3 explored longer-term use of the SHTs and participants' wider perspectives on smart technologies. See Appendices 1–3 in the supplemental data online for all interview protocols. All interview data are also publicly available via the UK Data Service's ReShare data repository (collection 852367).

All interviews were recorded and transcribed verbatim. Transcripts were hand-coded to identify similarities and differences between households related to themes derived from the literature on both the use of smart homes and domestication theory.

Findings: living inside a smart home

Motivations

Four distinct motivations for participation were identified. Most common ($n = 8$) was a desire to save energy and associated costs. Participants hoped to achieve this through optimized control of their heating systems and appliances. For several participants, this was part of a longstanding interest in energy management involving prior use of energy monitors and/or installation of solar panels.

The second most common motivation was an interest in new technology and home automation ($n = 6$). Here, participants desired automated control of devices for convenience and to enhance security. Despite these
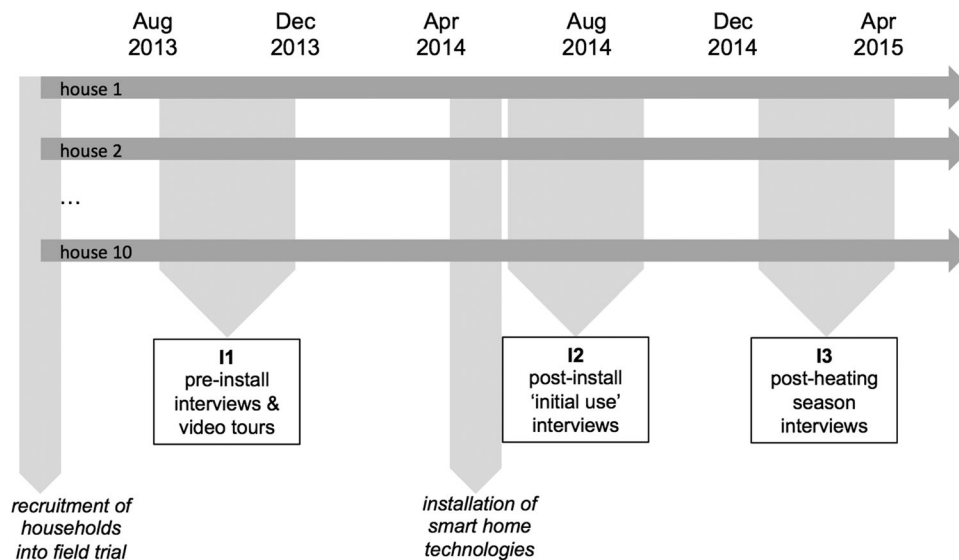
Figure 1. Timeline of qualitative research methods.

interests, only one participant described themselves as an 'early adopter', with most suggesting they took an 'if it's not broke, why fix it?' (Steven, H17I1, p. 19) approach to technology adoption.

Third, two participants expressed an interest in protecting the environment. They were the only ones to express initial scepticism regarding the potential for SHTs to help reduce energy use.

Fourth, and finally, was a general desire for improved control at home. For some this meant more comfort, others wished for more convenient control of appliances, and still others wanted better control over hectic lives (cf. Davidoff et al., 2006).

A combination of these motivations had typically driven participation, with different household members often motivated for different reasons.

Despite their interest in the trial, several participants expressed concerns about new technologies. This included general complaints about the rude use of mobile phones in public, but also more specific unease about automated systems making people lazier, about being unable to control or maintain SHTs, or about whether technologies could be trusted to regulate themselves. As these concerns show, SHTs could not be divorced from wider cultural unease about technology (Smits, 2006) such that their domestication would unavoidably occur against this backdrop. In this respect, some of the cognitive and symbolic work required to domesticate the SHTs occurred before they were even acquired in the trial and was informed not by the SHTs themselves but by participants' experiences with other technologies they perceived as somehow related. This reveals the importance of understanding SHTs and their domestication as occurring not in isolation,

but within and against much wider and harder-to-define social and technological networks.

Participation in the trial was generally driven by a single householder – usually a man with some experience or interest in using computers. This individual did not always go on to become the main user of the SHTs after installation, however (see below).

Installation

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

The RWE and VERA systems could only be fully configured via computer, but smartphone apps did allow partial control. The HIVE system could be fully controlled via smartphone. Here, where computers had

often served to restrict access, smartphones appeared instead to open access up more widely, even if they only granted partial rather than full control. Sally, for example, was initially very sceptical about the SHTs and did not use them as they were configured on Simon's computer. Once she started using the HIVE system on her smartphone, however, she became a very active user, checking it almost daily. Sally's experience shows how the practical work of learning to use SHTs is shaped by users' prior domestication of other, related technologies. In this respect, as much as SHTs are domesticated in and of themselves, this is perhaps best understood as the latest episode within a much wider process of domestication that spans across multiple discrete technologies.

Initial use

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

> It's just taken months to just use it and realise where it's useful. … It wasn't intuitive what parts of it you can do straight away. (H2I3, p. 11)

For still others, the installation process had made them realize the systems were complex and would take time to configure fully, time they could not always find as other aspects of their daily lives prevented them from engaging in the demanding work of domestication:

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

The potential benefits of the SHTs were thus not immediately apparent, nor did they necessarily apply all year round (*i.e.* outside the heating season). Perhaps because of the number of functions the systems offered, participants had to work hard to identify exactly how they could be useful and, only once they had done this, could they then start the demanding task of making it happen. In short, participants found the cognitive and practical work of domestication very challenging.

Once participants did start using the SHTs, however, seven distinct types of use were identified:

(1) room-by-room heating schedules (RWE system; $n = 9$)
(2) remote control of heating (HIVE; $n = 4$) or lights (VERA; $n = 2$)
(3) time schedules for lights when away from home (VERA; $n = 4$)
(4) rule profiles for radiator use (RWE; $n = 2$)
(5) remote monitoring of doors, windows, lights or radiators (RWE, HIVE; $n = 3$)
(6) boost buttons or kill switches for multiple radiators or appliances (RWE; $n = 2$)
(7) manual use of heating via room or radiator thermostats (RWE); two households did this exclusively, although most combined automated with some manual control.

Some of the more technically proficient participants stated a desire to 'play' or 'experiment' with more advanced, automated features of the systems, such as developing forms of automation through 'rule' profiles (*e.g.* to switch radiators on/off if a door or window had been left open), using the systems to control multiple appliances at once or remotely controlling the heating or lights (use types 2–4 and 6 in the list above). Once participants started using the systems, however, they generally did so in more basic ways, such as through manual control, using the system as if it were a programmable thermostat, or to monitor remotely, but not control, the heating or lights (use types 1, 5 and 7).

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

Where the most technically competent individual did become the main user, they often had to negotiate how to use the SHTs with other household members. Jason, for example, spoke of his worry that if the more advanced things he tried went wrong, this would inconvenience others:

> You worry that you've installed this system and screwed everything up. … It's a bit of fun … but now it's caused everyone grief. (H5I2, p. 15)

Whilst this may have limited some uses of the systems, in Henry and Louise's case, such negotiations led to arguments and, ultimately, abandonment of the SHTs:

> There was a wonderful day when I turned something to manual and changed it and then Henry went online and changed it automatically and neither of us knew what the other one was doing … it did cause arguments. … That's just two of us, what if you'd got an entire family? … You know, who's in charge? (Louise, H4I3, pp. 4–5)

In five households the technical demands of the systems created non-users of at least their more advanced, automated functions. In two of these cases this led non-users to resist the SHTs and ultimately to their abandonment. In the three other cases it led to users being either unable or unwilling to use the systems and, for some of these, a feeling of loss of control inside their homes. Several of these non-users expressed unease about feeling watched or monitored when the systems were first installed. This was not helped by the small noises made by the RWE radiator when they automatically adjusted themselves, making them a constant and often irritating presence. These examples of resistance, feeling out of control or being monitored by the SHTs reveal the significant challenges participants faced in conducting the symbolic work of domestication – that is, constructing the meaning of the technologies and incorporating them into self- and household identities.

In summary, in the early stages of domesticating the SHTs, participants found the cognitive, practical and symbolic work of domestication challenging. Importantly, these different forms of work were not necessarily all undertaken by the same individual nor were they evenly distributed among householders. Whilst some technically proficient participants may have enjoyed the practical and cognitive work of learning to use the SHTs, this could easily be thwarted by other householders who may have found the symbolic work too demanding and thus resisted their incorporation. This reveals the critical importance of treating the household as a whole system when analysing new technologies (cf. Nyborg, 2015), and of understanding the many potential roles of both users and non-users in domestication processes.

Longer-term use

Over the longer-term participants generally settled into a pattern of use that made less rather than more use of the systems' more advanced functionality. Two households reverted to exclusively manual control, avoiding computers or smartphones altogether. Most stopped checking door/window sensors as regularly, and stopped using timer schedules for lights whilst away from home. Indeed, rather than becoming more advanced in their use of the systems as they became more confident, the opposite occurred as simpler forms of use, utilizing fewer functions, tended to take hold. Whilst some automated functions remained in use throughout, the experience for most was, as Ingrid put it, that it:

> just pottles along in the background and I don't tend … to do so much with that nowadays. (H21I3, p. 1)

Several participants mentioned that they now simply 'tweaked' their settings when necessary. Jason argued that the more advanced capabilities of the systems had:

> complicated our lives, [because] before we would blissfully set everything, leave it for 6 months, have another look when the clocks change, leave it … [but] we now more often tweak and administer it. (H5I3, pp. 18–19)

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

A dominant theme in the interviews was that using SHTs demanded a significant amount of learning. Three types of learning were described. The first related to the practical work of learning how to configure and use the SHTs. Here, almost all participants were negative about the design of the SHTs (with the exception of the HIVE system), which were almost universally described as complicated, fiddly and awkward. These perceptions gave rise to a feeling amongst some that they were precarious and easy to break. Added to this, where participants had experienced problems, they mentioned that there was a general lack of support for maintenance and repair, whether through a lack of sufficient instructions or online support, or because plumbers or electricians lacked the necessary skills.

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

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

The second form of learning involved the cognitive work of establishing what the SHTs could be used for. Several participants mentioned that, beyond controlling the heating, they could not identify additional worthwhile uses. For example:

> I get this feeling that there's probably some more that I can get from it. (Simon, H2I3, p. 10)

Participants often felt they were not using the SHTs to their full potential and called for more help. Several felt it would be useful for the systems themselves to make suggestions, such as advice on energy saving, or templates that demonstrated their potential functionality (cf. Mennicken et al., 2014). Others mentioned asking friends, other family members, or plumbers and other professionals for ideas, but usually found little useful knowledge or experience.

The third form of learning focused on the symbolic work of incorporating SHTs into identities and working out how to adapt to get more out of them. Several interviewees described how they felt that 'smart' technologies would increasingly become the norm and that there was therefore a need 'to get into the culture of using this stuff' (Steven, H17I2, p. 4). Ingrid, for example, suggested that realizing the full benefits of smart technologies may require that 'you have to look at the other things that they link into' (H21I3, p. 21), and thus to acquire still other SHTs that could be connected into a wider home network. Indeed, the introduction of the SHTs served to disrupt and unsettle the status of some older technologies in the home. For example, several participants came to perceive their existing computers or smartphones as 'old' or somehow insufficient and in need of replacement. The same was true for old heating systems which participants worried would not be able to cope with the additional demands they perceived the SHTs would place on them. Finally, two households commented that the VERA system could not be used fully to switch on their devices because they turned on in stand-by mode. In short, the introduction of the SHTs caused other technologies to be re-domesticated in ways that made them seem old and in need of replacement. This reveals how the symbolic work of domesticating SHTs called into question and reopened the meaning and symbolism of other, older domestic appliances.

Despite these examples, the general feeling among participants was that 'We shouldn't react to the system, the system should react to us' (Jason, H5I3, p. 8). Indeed, most suggested that rather than adapting themselves to the systems, they had instead symbolically adapted their understanding and use of the SHTs so they came to resemble familiar technologies, such as a 'traditional heating system' (Ingrid, H21I3, p. 19).

Making sense of smart homes

Three different domestication pathways were identified in the trial that shaped how the SHTs were (or were not) used.

First, three households could be described as having successfully domesticated the SHTs. Here, the SHTs had come to be seen as a helpful and convenient part of the household. Further, these households expressed interest in, or had already acquired, additional SHTs to link in with the trial technologies. Although each of these households had encountered difficulties – such as finding the SHTs fiddly, irritating or being frustrated at a lack of interoperability – they also described how they checked the SHTs regularly and, as such, had come to depend upon them. For example, when their HIVE system had a minor malfunction, Sally commented that:

> we were a bit lost without it. We didn't realize how dependent on it we were. (H2I3, p. 1)

Importantly, there was little interest in this group in making use of the more advanced and automated features of the systems. Instead, these households had mostly made use of heating schedules on the RWE system, and the ability to monitor remotely the status of, for example, lights, doors, windows or radiators. In these ways, as Ingrid argued, they had made the systems fit around them:

> I haven't felt I've had to go and work out what the other stuff does. … I feel it's working for us as it is. (H21I3, p. 16)

Arguably, therefore, 'successful' domestication depended precisely on the abandonment of the SHTs' more advanced features to make them function effectively within a particular household. In this respect, the cognitive work involved in learning what to use SHTs for was shaped not merely or even mainly by the capabilities of the SHTs, but rather by a much wider range of concerns relating to the effective accomplishment of everyday life.

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

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

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

Five households followed a second pathway that could be described as 'precarious' domestication. Here, the SHTs were being used, but not regularly, and their use was often perceived quite negatively. For this group, the SHTs had much potential but required further development. The dominant trope among this group was that the SHTs were excessively complicated, and thus that the practical work of learning how to use them was too

challenging. As a result, this group tended to use them only for room-by-room heating schedules, or controlled them manually.

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

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

For some, despite awareness of their potential, the basic ways the SHTs were being used made them seem to be little more than expensive radiator valves or timer switches.

For this group, therefore, the domestication status of the SHTs at the end of the trial was precarious. Some components were seen as useful, but many called for further development of the systems – particularly related to user–interface design and interoperability – to make the practical work of domestication easier. Some also suggested that the SHTs might be useful for other households, but not them. Appropriate households were seen as those that were online all the time, or that had more electrical gadgets. As Noelle explained:

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

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

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

As Marion's quotation suggests, however, for this group the SHTs were always close to being abandoned if they came to be seen as being too complicated or things started to go wrong. It is of course possible that participants in this group persevered with the technologies because they were part of a field trial and that, without this research context, they may have abandoned the technologies. Whilst no participants mentioned this, either explicitly or implicitly, this does point towards potential limitations of this study and the need for more studies that extend beyond research-led trials.

The third domestication pathway was observed in two households and resulted in rejection of the SHTs. In these cases, participants expressed little interest in

technology and were not regular users of smartphones or computers when the trial began. The SHTs then came to be seen as a waste of time that risked making things worse for either the environment or society. Common in these homes were stories of being 'overruled' by the SHTs, which generated a sense of losing control over the home. Both Sarah and Louise, for example, mentioned occasions when their attempts at manual control were frustrated by the SHTs. For example, Louise complained that 'the computer would override what you wanted to be happening in the room' (H4I3, p. 4), and Sarah that the system 'would be overriding my own judgement about what I think is the best thing to do' (H11I3, p. 7).

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

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

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

> The human body has nothing to do any more, it's going to get fat and slobby isn't it? (H4I3, pp. 24–25)

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

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

In summary, the SHTs followed very different domestication pathways in different households. For some they came to be seen as positive, futuristic technologies that made life easier, for others they had potential but were

excessively complicated, whilst for still others they became an elaborate waste of effort with potentially negative implications. Crucially, these different pathways reveal the importance of all three types of work involved in domestication. Whilst different households appeared to find different kinds of work more or less challenging, at various points all three kinds of work threatened to derail the domestication process. This points towards the need for designers and developers to consider actively all three types of work when developing new SHTs, not least because it appears that SHTs, at least those used in this trial, are currently quite difficult to domesticate.

Discussion and conclusions

This paper represents one of the first in-depth, qualitative studies on how householders use SHTs over the longer-term. Its core aim was to explore how householders learn about, use and adapt to SHTs in their own homes as one means of scrutinizing claims around SHTs' energy-saving potential. This concluding discussion distils four core findings from the study before discussing their wider practical, research and theoretical implications.

First, SHTs are disruptive technologies for domestic life. Even when successfully domesticated, this was far from smooth. In addition to new monitors, sensors and control interfaces, SHTs also introduce a new layer of control functionality onto existing domestic appliances and devices. In this way, as well as requiring domestication themselves, SHTs also demand that many other aspects of the domestic environment are re-domesticated into the new 'smarter' home. Through this process, SHTs serve not only to disrupt existing technologies in the home but also to unsettle existing roles and relationships among householders as they open up potential new ways of controlling and doing things, and place new demands on householders.

Second, households adopt a range of adaptation strategies to cope with the disruption SHTs cause. Alongside forms of non-use, resistance and rejection, these strategies include partial domestication, using only some of SHTs' potential functionality to make them more familiar and less disruptive. One of the key trends was for participants to use the SHTs in less rather than more sophisticated ways as the trial evolved, and to limit their application to only certain areas of domestic life. Very little research attention has been devoted to understanding non- or partial use of SHTs or to how such non- or partial users interact with and negotiate possible applications of SHTs with their lead or main users (cf. Mennicken & Huang, 2012; Nyborg, 2015).

Third, domesticating SHTs is very demanding and requires considerable work from householders for which there is very little support available. This lack of support includes a lack of awareness of or experience with SHTs among friends, family or other such 'warm experts' (Lehtonen, 2003), meaning participants struggled to identify potential uses for SHTs. There was also a lack of expertise among trades such as plumbers, heating engineers or electricians who require new skills to deal with the SHTs and the interactions between devices they bring about.

Fourth, a core aim of this paper was to understand how people use SHTs in order to scrutinize claims that they can or will lead to significant energy savings. Unfortunately, work to establish how the SHTs impacted on patterns of energy demand among participating households is still ongoing. Nonetheless, it seems unlikely that the trial will have resulted in energy savings of the order predicted by many SHT advocates. Typically, participants in the trial made either limited or no use of the SHTs to manage their energy use, and the trial generated no evidence of substantial changes being made by participating households to manage their energy use. Whilst SHTs certainly hold out the possibility for improved energy management, several households expressed concern that SHTs may lead to more rather than less energy use, such as by creating new forms of energy demand, *e.g.* through pre-warming rooms, by normalizing or even raising energy-intensive expectations, *e.g.* of what counts as a comfortable indoor temperature, or simply by encouraging the increasing adoption of energy-consuming technologies, such as SHTs, which may bring substantial loads of their own (Nyborg & Røpke, 2011; Strengers et al., 2016).

Policy implications

Each of these findings has implications for future policy-making in relation to SHTs. It is vital that the energy-saving claims are properly scrutinized to ensure SHTs are not being developed and sold on the basis of unrealistic and potentially misleading claims. Policy-makers have a potential role to play to generate standards, benchmarks and guidelines that ensure SHTs are developed, tested and evaluated in ways that minimize the potential for energy intensification. As part of this, there may be a need to make more sense of the 'melting pot' of SHT purposes (Nyborg & Røpke, 2011) and to distinguish more clearly between those components of SHTs that seek to improve energy management, and those which serve other functions and desires. Further, many SHTs require at least some form of professional

installation. There is thus an opportunity for installers, as key points of contact between developers and users, to be trained and accredited to encourage householders to use SHTs in ways that improve energy management.

Design implications

Regarding the future design and development of SHTs, it is clear that users need to be better accounted for or even actively drawn into the design and development process. Our findings highlight three core ways this could be done. First, greater attention should be paid to the cognitive work involved in identifying what SHTs could or should be used for. This might involve creating more collaborative SHTs (Mennicken et al., 2014) that rather than relying solely on users themselves to understand what is possible and what they want to achieve, instead make suggestions about what to do, how to do it, and about the impacts different courses of action might have (*e.g.* on energy use).

Second, to ease the practical work that users engage in, as well as continuing to improve user-friendliness and interoperability, designers need to recognize that there are multiple different types of user and that the work of domesticating SHTs is often distributed throughout households. SHTs could therefore be designed with multiple entry points to account for different levels of technological proficiency. Designers should also plan longer-term pathways of engagement that guide users towards greater levels of energy management, and that address the risk of SHTs being abandoned early.

Third, to support the symbolic work of domestication, designers and developers should be fully aware that the meaning of SHTs is not clear-cut. There are multiple potential configurations of SHTs and this generates a wide range of meanings and forms of adaptation. As well as developing a better understanding of the multiple market niches for SHTs, and differentiating SHTs accordingly, this also points to a need for developers to work with users to generate multiple, yet shared, visions of smart energy futures. These must account for different types of user to minimize potential tensions between the energy saving and other services offered by SHTs.

Research and theoretical implications

This paper has examined only 10 households, so it is clear that more research is required with more households, in different contexts, with different configurations of SHTs and over longer time periods before firm conclusions can be drawn. This research must encompass 'in the wild' studies of voluntary early adopters as well as further field trials to ensure a range of different user types are included. Further, these further studies should focus explicitly on: the various forms of technological and social disruption SHTs cause; the differing types and extents of use of SHTs; the multiple roles that users play in relation to SHTs and the social dynamics between them; and identifying the forms of social support networks required if SHTs are to be more widely adopted and used.

The authors have found domestication theory extremely valuable in identifying and distinguishing between the different types of work different householders perform when domesticating SHTs. At the same time, our study points to three ways domestication theory might be further developed and extended. First, whilst domestication theory tends to focus on the use of a single, discrete technology, SHTs are made up of multiple components with different functions and interpretations, and their domestication depends on the re-domestication of many other aspects of the domestic environment. Domestication theory could thus be extended to better account for networked and multicomponent technologies, and more needs to be done to understand different relationships between suites of old and new technologies in domestication processes (Ingram, Shove, & Watson, 2007).

Second, whilst domestication theory identifies the household, rather than individual users, as the core setting of technology adoption, our study shows that the work of domestication is unevenly distributed. Domestication theory could usefully generate a stronger conceptualization of these different user roles and the relationships between them.

Finally, this study has shown that an understanding of domestication must not be limited solely to new technologies. Domestication depends just as much on the properties of SHTs themselves as it does on the wider personal biographies and everyday lives of their users. Domestication theory should therefore pay more attention to the longer-term domestication biographies of different users in order to encompass the wider influences on everyday lives and practices (cf. Nyborg, 2015) that ultimately shape the impacts – positive or negative – that SHTs will come to have.

Notes

1. See http://www.rwe.com/web/cms/en/455660/rwe/innovation/projects-technologies/energy-application/rwe-smarthome/ (accessed August 31, 2016).
2. See http://getvera.com/ (accessed August 31, 2016).
3. See https://www.hivehome.com (accessed August 31, 2016).

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References

Aldrich, F. K. (2003). Smart homes: Past, present and future. In R. Harper (Ed.), *Inside the smart home* (pp. 17–39). London: Springer.

Baillie, L., & Benyon, D. (2008). Place and technology in the home. *Computer Supported Cooperative Work*, 17, 227–256. doi:10.1007/s10606-007-9063-2

Balta-Ozkan, N., Davidson, R., Bicket, M., & Whitmarsh, L. (2013). Social barriers to the adoption of smart homes. *Energy Policy*, 63, 363–374. doi:10.1016/j.enpol.2013.08.043

Berker, T., Hartmann, M., Punie, Y., & Ward, K. J. (2005). Introduction. In T. Berker, M. Hartmann, Y. Punie & K. J. Ward (Eds.), *Domestication of media and technology* (pp. 1–17). Maidenhead: Open University Press.

Bernheim Brush, A. J., Lee, B., Mahajan, R., Agarwal, S., Saroiu, S., & Dixon, C. (2011). *Home automation in the wild: Challenges and opportunities*. Paper presented at the ACM CHI Conference on Human Factors in Computing Systems. May 7–12, 2011. Vancouver, Canada.

Clipsal. (2006). Your home, smart home, smart living. Telford: Clipsal.

Cook, D. J. (2012). How smart is your home? *Science*, 335 (6076), 1579–1581. doi:10.1126/science.1217640

Davidoff, S., Lee, M. K., Yiu, C., Zimmerman, J., & Dey, A. K. (2006). Principles of smart home control. *Lecture Notes in Computer Science*, 4206, 19–34. doi:10.1007/11853565_2

Department of Energy and Climate Change. (2009). Smarter grids: The opportunity. London: Department of Energy and Climate Change.

Edwards, W. K., & Grinter, R. E. (2001). At home with ubiquitous computing: seven challenges. *Lecture Notes in Computer Science*, 2201, 256–272. doi:10.1007/3-540-45427-6_22

European Commission. (2015). Towards and integrated Strategic Energy Technology (SET) Plan. Accelerating the European energy system transformation. Brussels: European Commission.

Haddon, L. (2006). The contribution of domestication research to in-home computing and media consumption. *The Information Society*, 22, 195–203. doi:10.1080/01972240600791325

Hargreaves, T., Nye, M., & Burgess, J. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. *Energy Policy*, 38, 6111–6119. doi:10.1016/j.enpol.2010.05.068

Ingram, J., Shove, E., & Watson, M. (2007). Products and practices: Selected concepts from science and technology studies and from social theories of consumption and practice. *Design Issues*, 23(2), 3–16. doi:10.1162/desi.2007.23.2.3

International Energy Agency. (2013). Energy efficiency market report: Market trends and medium-term prospects. Paris: International Energy Agency.

Isaksson, C. (2014). Learning for lower energy consumption. *International Journal of Consumer Studies*, 38, 12–17. doi:10.1111/ijcs.12045

Juntunen, J. K. (2014). Domestication pathways of small-scale renewable energy technologies. *Sustainability, Science, Practice & Policy*, 10(2), 28–42. Retrieved from http://sspp.proquest.com

Kane, T., Cockbill, S., May, A., Mitchell, V., Wilson, C., Dimitriou, V., … Firth, S. (2015). *Supporting retrofit decisions using smart metering data: A multi-disciplinary approach*. Paper presented at the European Council for an Energy Efficiency Economy (ECEEE) Summer Study. 1–6 June 2015. Hyeres, France.

Lehtonen, T.-K. (2003). The domestication of new technologies as a set of trials. *Journal of Consumer Culture*, 3, 363–385. doi:10.1177/14695405030033014

Mennicken, S., & Huang, E. M. (2012). Hacking the natural habitat: An in-the-wild study of smart homes, their development, and the people who live in them. *Lecture Notes in Computer Science*, 7319, 143–160. doi:10.1007/978-3-642-31205-2_10

Mennicken, S., Vermeulen, J., & Huang, E. M. (2014). *From today's augmented houses to tomorrow's smart homes: new directions for home automation research*. Paper presented at UbiComp 2014. 13–17 September 2014. Seattle, WA, US.

Mozer, M. C. (2005). Lessons from an adaptive house. In D. Cook & R. Das (Eds.), *Smart environments: Technologies, protocols and applications* (pp. 273–294). Hoboken, NJ: Wiley.

Nyborg, S. (2015). Pilot users and their families: Inventing flexible practices in the smart grid. *Science and Technology Studies*, 28(3), 54–80.

Nyborg, S., & Røpke, I. (2011). *Energy impacts of the smart home – conflicting visions*. Paper presented at the ECEEE 2011 Summer Study, Toulon, France. 6–11 June 2011.

Oudshoorn, N., & Pinch, T. (2003). Introduction: How users and non-users matter. In N. Oudshoorn & T. Pinch (Eds.), *How users matter: The co-construction of users and technology* (pp. 1–25). Cambridge, MA: MIT Press.

Paetz, A.-G., Dutschke, E., & Fichtner, W. (2012). Smart homes as a means to sustainable energy consumption:

A study of consumer perceptions. *Journal of Consumer Policy*, 35, 23–41. doi:10.1007/s10603-011-9177-2

Park, S. H., Won, S. H., Lee, J. B., & Kim, S. W. (2003). Smart home – digitally engineered domestic life. *Personal and Ubiquitous Computing*, 7, 189–196. doi:10.1007/s00779-003-0228-9

Richardson, H. J. (2009). A 'smart house' is not a home: The domestication of ICTs. *Information Systems Frontiers*, 11, 599–608. doi:10.1007/s10796-008-9137-9

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). New York: Simon & Schuster.

Siemens. (2014). Comfort and superior energy efficiency through intelligent home automation: Convenient control and switching of HVAC systems, lights, blinds and more – with the Synco living home automation system. Zug, Switzerland: Siemens Switzerland Ltd.

Smits, M. (2006). Taming monsters: The cultural domestication of new technology. *Technology in Society*, 28, 489–504. doi:10.1016/j.techsoc.2006.09.008

Sørensen, K. H. (1994). Technology in use: two essays on the domestication of artefacts. Centre for Technology and Society Working Paper 2/94. Trondheim, Norway.

Sørensen, K. H. (1996). Learning technology, constructing technology. Centre for Technology and Society Working Paper 18/96. Trondheim, Norway.

Strengers, Y. (2013). *Smart energy technologies in everyday life: Smart utopia?* Basingstoke: Palgrave Macmillan.

Strengers, Y., Morley, J., Nicholls, L., & Hazas, M. (2016). The hidden energy costs of smart homes. *The Conversation* (12 June 2016). Online at: Retrieved from https://theconversation.com/the-hidden-energy-cost-of-smart-homes-60306

Takayama, L., Pantofaru, C., Robson, D., Soto, B., & Barry, M. (2012). *Making technology homey: Finding sources of satisfaction and meaning in home automation*. Paper presented at Ubicomp 2012. 5–8 September 2012. Pittsburgh, PA, US.

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

Woodruff, A., Augustin, S., & Foucault, B. (2007). *Sabbath day home automation: 'It's like mixing technology and religion'*. Paper presented at CHI 2007, April 28–May 3, 2007. San Jose, CA, US.

Woodruff, A., Hasbrouck, J., & Augustin, S. (2008). *A bright green perspective on sustainable choices*. Paper presented at CHI 2008, 5–10 April, 2008. Florence, Italy.

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