Smart technology in the home: time for more clarity

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Abstract

The idea of the smart home has been around for decades but smart homes (under most definitions) are extremely rare, although digital technology and automated appliances are commonplace in the more affluent regions of the world. This commentary argues that there are inherent difficulties with expectations for smart homes and with making them viable; and with definitions and roles of 'users' in smart systems. It considers what a smart home might be and the problems that smart homes might address, identifying two types of narrative in the smart energy literature. One centres on the highly-automated dwelling with integrated appliances, emphasising state-of-the-art technology, convenience and, in some sense, efficiency. The second narrative type focuses more on system-level issues such as peak demand, ancillary services and the spread of microgeneration, and on selective applications of information and communication technology (ICT) to address these. Both raise questions about the identity of users, nature of control, boundaries of the home and ecological impact.

The idea of a smart home

A special issue dedicated to 'bringing users into building energy performance' may not seem like the ideal place for commenting on smart technology. But ICT and energy systems are altering the meaning of 'user' *and* changing the performance of homes, and not necessarily in ways that address the policy challenge of responding to climate change while providing or maintaining reliable, affordable energy services. Hence the argument that follows, **very much focussed on users and other actors**, for tightening up the language we use when discussing and evaluating smart technology in buildings.

There are many definitions of the smart home in research and marketing literature, but they fall into two broad categories. As examples, this definition focuses on a smart home as a home, and what it can do for its occupants:

> *[A smart home is] a residence equipped with a communications network, linking sensors, domestic appliances, and devices, that can be remotely monitored, accessed or controlled and which provides services that respond to the needs of its inhabitants.* (Balta-Ozkan et al., 2014, p.66)

A second, more generic in that it includes non-domestic buildings, focuses on the building itself – not mentioning occupants at all – and on its connection with energy systems:

> *Smart buildings are flexibly connected and interacting with the energy system, being able to produce, store and/or consume energy efficiently* (Building Performance Institute Europe, 2017)

While one definition is home- and user-focussed and the other is building- and system-focusses, what they share is the significance of communications networks to link appliances or subsystems with each other and to enable remote access and control along with the provision of services. That is, the level of connectedness goes well beyond the use of ICT in smart metering, or remote control of a TV from the sofa. Thus the BPIE report cited above contains an example of a dozen Belgian houses, old and new, 'equipped with a range of technologies to provide a maximum of load-shifting potential' with the aim of balancing the neighbourhood network: solar photovoltaics and thermal capture, heat pumps, and fuel cells or batteries, along with a monitoring and control system. Another example includes homes with electric vehicles and their potential as storage devices, especially for rooftop solar generation. (ibid., pp27, 29)

The concept of a smart home offering new services can be traced back to futuristic display homes in 1930s America, developed at a time when electricity consumption was unproblematic and presenting 'unprecedented levels of luxury, relaxation and indulgence, with excessive consumption on display … efficiency did not relate to energy but… the benefits of modern living with less effort from householders' (Strengers, 2013, p25). The concept remained a specialised one for some time, only able to take shape for a mass market in the final quarter of the twentieth century as computing power became increasingly accessible and automated appliances more commonplace.

From an electrical systems perspective, though, 'smarting' began about four decades later with the upgrading of equipment in the transmission grid. This process continued outwards/downwards through the distribution network and large consumers until it became possible to think of small end-uses as ripe for automation, interconnection and remote control. In this way, the user-centred and system-centred visions came together to some extent, giving a boost to the former. Thus the introduction to a set of proceedings from a 1988 conference on home automation comments that *'One of the last bastions of low tech is the home, and it looks very much as though this too is about to fall in the face of the onslaught of modern technology to create… one of the largest consumer markets ever. It is … an application whose time has come… we shall be choosing, not to fill our houses with optic fibres or Liquid Crystal Displays, but to acquire a whole series of aids to make domestic life more comfortable, more efficient and more fun'* (RMDP 1988, p.1).

Not everyone viewed the prospect of smart homes so optimistically. A critique from the same year comments that *'computer home scenarios have a narrow and instrumental fixation on technique – the "evolution" of the household is seen as an expression of some autonomous technological "progress". The dream is a domestic machine-utopia … in which human agents are passive and infantilized. In such technocratic scripts the household is severed from its surrounding (economic, social and political) contexts'* (Robins and Hepworth 1988, pp. 157-8). This infantilising and de-activating element of the smart home vision can certainly be traced in the literature, implicitly if not explicitly, in the planned shift from human to machine sensing and control, and the development of 'ambient intelligence' that is capable of learning. As an example, de Silva et al. (2012) describe a smart home application that can detect and recognise 'health conditions' of home occupants, collecting information to support their wellbeing. Another well-known example is the 'learning thermostat' (Yang and Newman, 2013)

The domestic machine-utopia has proved hard to realise, though. A report on smart homes and assistive technologies, prepared for the lengthy 'Application Home Initiative' trials in the UK, noted the inherent difficulty of 'smarting' the residential sector with its complex housing, complex needs, complex market forces and lack of enthusiasm even for the ICT application showing most promise: monitoring the elderly and infirm (Poulsen et al., 2002). This difficulty persists even though in many parts of the world it is commonplace for homes to host discrete ICT applications in the shape of computers, smartphones and internet-connected home entertainment, along with appliances such as washing machines that are at least partly automated. The problems arise in connecting these together (primarily because of technical and commercial issues) and in making any resulting package useful enough to persuade householders and/or system managers to adopt it.

The establishment of ICT in energy infrastructure and evolution of modern renewable electricity generation are transforming electrical systems from being demand-led ('predict and provide') to supply-led, requiring careful matching of demand and (variable) supply at levels that may vary from the individual prosumer or microgrid up to the national or regional grid. Difficulties with this transition may be felt most at neighbourhood or area level, for example if a number of households adopt solar generation, electric vehicles or heat pumps, causing imbalances at particular times of day. Hence the interest in whether and how 'smart homes in smart grids' might be part of a more sustainable future, their relatively small loads and varied activities assisting with network balance and paving the way for more renewable supply (e.g. Balta-Ozkan et al., 2014; research and policy programmes such as the European Horizon 2020 and EU Strategic Energy Technology plan.[i])

The growing significance of system issues strengthens the second type of smart home narrative: not so much the home that is automated for its own sake in order to provide comfort, convenience and fun, but the home that interacts with electricity networks in order to provide and receive services. These exchanges can involve storage and generation facilities in the home, but even households without microgeneration, batteries, storage heaters or hot water tanks have a potential resource in their demand, something which can be reduced or shifted when this will assist network or grid management. (Darby and McKenna (2012) set out a range of possibilities for this, with and without automated response.) With this narrative comes a more explicit recognition of the potential importance of energy management and energy data to householders, as in this account of smart home developments: *'there is an emerging trend of a special type of smart homes which can help occupants to reduce energy consumption of the house by monitoring and controlling devices and rescheduling their operating time according to energy demand and supply'* (da Silva et al., 2012, p.1313).

These overlapping priorities and discourses illustrate why we need to clarify what is meant by smart homes and what the spread of ICT into buildings means in terms of 'bringing users into building energy performance'. For example, the term 'use' can take on new meanings. Through ICT, users may now be 'using' energy and buildings indirectly. Even if they have been involved in decisions to purchase new control and communication technologies and even if they have set them up, some switching and appliance activity may now be controlled automatically. But the main problem lies with the term 'smart' itself, weighed down with many meanings and applied to many possibilities. There will be differences in terms of user involvement and outcomes between, say, a householder who decides to programme a washing machine through a 'smart plug' so that it will not operate at peak times, one who makes storage heaters available to facilitate use of locally-generated electricity (Boait et al., 2017), one who uses a smart thermostat with 'learning' features to control the heating (Yang and Newman, 2013) and one who adopts a fuller smart home package (Takayama et al., 2012). All could be described as using smart home technology but it would be misleading to lump them all together as living in smart homes, or to assume improvements in wellbeing and environmental impact in all cases. Hence the need to ask what domestic smart technologies are for, clarify the role of users in different situations, and evaluate building energy performance in terms of benefits and costs to different actors, now that the boundaries of 'home' have been extended, first by connection to electricity networks and then to the Internet.

What problems are smart home technologies supposed to address?

As noted above, smart home technologies (where 'smart' referred to automation rather than ICT) were developed at first for luxury home living with a modern flavour and a tang of efficiency. Only later did the idea of putting home automation, sensing and remote control at the service of the electricity network come into being. Since then, there has often been a sometimes confusing mix of the two, as when smart '*demand management… [is] offered as part of other services that the consumer is willing to pay for – notably within entertainment, health, security, comfort or* *convenience. Parallel to the concept of 'greenwashing', this trend could be characterized as 'funwashing': … electricity companies may try to persuade consumers to buy their 'boring' management products by bundling them with more attractive feature'* (Nyborg and Røpke 2011, p1850).

The balance between these two broad conceptions of what a smart home is will influence outcomes in terms of energy consumption within the home and network management beyond it. As smart home development has never been primarily concerned with environmental impact, there is cause for concern that it creates a demand for previously unwanted products and services and, in the process, adds to the inventory of climate and habitat damage caused by modern energy services (Darby, 2007, Louis et al., 2015, Friedli et al., 2016). Readers may recognise this damage as a 'super wicked' problem: urgent, in need of solution by the very people who cause the problem, with weak central authority and where policy responses discount benefits and costs irrationally (Levin et al., 2012). Such problems, by definition, have no correct or optimal solutions; only outcomes that can be better or worse for particular stakeholders and processes. As such, they call for reflexive approaches that recognise path dependencies, uncertainty, conflicting values and distributional issues (Tainter et al., 2006). Yet most research into household interactions with electricity networks is conducted from a fairly limited technical or economic standpoint, with only a small body of work on meanings, household dynamics and activities, and customer-utility relations (e.g. Nyborg and Røpke, 2013; Wilson et al., 2015; Gram-Hanssen and Darby, 2016). And, although end-use efficiency, absolute demand and system efficiency are all important considerations when assessing the place of homes in energy systems and their environmental impact, there is very little evaluation of the first two and only partial evaluations of the third. Instead of a distributed approach to a wicked problem, we have patchy research that addresses small segments of the problem. The following two sections are based on the definitions of smart homes and smart buildings in the Introduction, looking at the user-friendliness or workability of smart homes as homes or sites for everyday life, then at homes in relation to electricity systems; at end-use and system efficiency.

Smart homes as homes: workability and end-use efficiency

There is very little evaluation of smart home initiatives in terms of end-use efficiency, apart from a few reports relating to assisted living arrangements for elderly people and people with disabilities (e.g. Demiris and Hensel, 2008). Indeed, there is a striking contrast between the many research papers that *estimate* potential benefits from smart appliances/systems on the basis of simulations or trials in carefully-controlled lab conditions and the handful that report on *measured* performance and acceptability in real-life conditions. I could find only one published instance of home automation that had been accepted and even welcomed over an extended period by whole families. This is in the account by Woodruff et al. (2007) of a system used by orthodox Jewish families since 1985 to control lights and appliances on Sabbaths and other holy days, when normal household routines are suspended. This early type of smart home stands out as one that met some very specific requirements, well-understood by the designer. The technology was also introduced into households with shared commitments to strict Sabbath observance, so we might expect they would adapt to it fairly easily. It was not a seamless 'fit and forget' technology adoption: users reported that they had found themselves changing some of their routines in order to fit in with the system. But they appreciated the way in which it met their stated need for a weekly respite from normal housekeeping tasks, including control of their appliances.

Smart home testing procedures typically try to capture the 'user experience' in laboratories or single-occupant apartments, missing out on the complexities of home life where practices are shared and negotiated between residents and their visitors, often with differing priorities (Wilson et al., 2015). There are now a few studies of smart home use 'in the wild', offering welcome insights into how people have not only adopted but adapted technology to meet their needs, over relatively short periods of time (e.g. Mennicken and Huang 2012; Takayama et al., 2012). But in the absence of comprehensive reviews of acceptability, and given the pace of change, consumer reviews may offer the most reliable indicators of progress in achieving homes with a 'complete integration of domestic services through the use of computers and networks' (to quote the RMDP report of 1988). Some of the few in-depth evaluative studies show how little smart capacity may actually be used, even in the homes of techno-enthusiasts (Andersen and Christiansen 2013; Nyborg and Røpke 2011). Even the more popular applications are vulnerable to changes in the businesses that supply the service and may discontinue it abruptly; for example, in response to a query about whether it was worth buying a remotely-controlled thermostat, a customer warned that '*we're in the middle of one of the biggest format wars in history – the Internet of Things… you have to ask yourself, what products is it compatible with? You might end up locked into a vendor or a communications standard for automated housing that might fall flat.'* [ii,iii]

There is a striking dearth of evidence on home energy consumption pre-and post-smarting; nothing comparable with the body of literature that records consumption before and after standard end-use efficiency improvements and quantifies rebound effects. Energy demand analysts have shown the way with, for example, research into the rebound effect (e.g. Herring and Roy, 2007); change and continuity in household practices (Gram-Hanssen 2011; Stephenson et al., 2010); the fine detail of technology adoption (Caird, Roy and Potter, 2012); and the situations of householders worldwide who are taking part in energy transitions (Sovacool, 2012). All such studies demonstrate how it is impossible to predict outcomes even from 'passive' or 'fit and forget' technology deployment without reference to householder understandings, choices, activities and social networks. A smaller body of literature makes comparable points about energy use in non-domestic buildings (e.g. Bordass and Leaman, 2001; Janda, 2014). Studies of how programmable thermostats affect consumption (e.g. Sanquist et al. 2010; Shipworth et al. 2010), and post-occupancy evaluation of buildings with smart features (e.g. Bordass et al, 2001) indicate that it would be unwise to expect end-use efficiency gains from smart home packages. A further consideration is that home automation accounts for a small but growing proportion of overall electricity use: whether or not this is justified in terms of increased system efficiency is a question that urgently needs addressing. A recent IEA report states that mains-connected sensors, switches and connected appliances in home automation systems consume standby electricity estimated at 0.4 - 2.2w per device, headed for global growth from 7-36 TWh between 2015 and 2025 – almost 80% of the predicted increase from Internet of Things over that period (Friedli et al., 2016). Further environmental impact comes from mining, processing and disposing of materials in smart devices (Louis et al., 2015).

In the absence of comprehensive in-use evaluation, it is probably safe to assume that the net effect of home automation on fuel and electricity consumption is neutral or negative: if it were positive, manufacturers would surely be publicising this. At the same time, the striking shortage of published smart home evaluations suggests an unwillingness to address the possibility that they might only 'work' for small subsets of the population who are primarily interested in assisted-living technology or in novel technology for its own sake. Yet ICT is having a major impact on expectations for energy services and on relationships between users, buildings and artefacts within energy systems. What are the prospects for deploying ICT in homes to improve *system* efficiency and pave the way for renewables-based electricity supply[iv]?

Smart homes as elements in electricity systems

The Internet stretches the boundaries of the home into cyberspace; put another way, the outside world can now sense what goes on within the home and influence some of what happens there. The home-in-cyberspace may be simply an extension of the home-connected-to-utility infrastructure. But it is arguably different in kind from the pre-ICT home because it is not only a site for resource flows (electricity, heat, gas, water, information) but a site with the potential for external control of those flows. The old saying 'my home is my castle' remains valid only if we imagine a castle with the drawbridge open, allowing messengers to come and go and to take charge of some functions. The term 'user' can also take on new meaning. In a home with external controls of some functions, the system operators are arguably able to 'use' the building and its occupants to assist in managing the system. Bringing users into building performance, in other words, can mean bringing network operators into building performance so that they too influence patterns of demand through time.

To offer a little background to this claim: when the new wave of smart home technologies was being discussed in the 1980s, ICT applications were largely restricted to high-voltage/ transmission level equipment in electricity grids. Now they have spread into distribution networks, distributed generators, storage, metering and the appliances which provide heating, lighting and other services. Homes and their occupants can be more obviously connected to network operation than before, through devices and processes such as time-varying tariffs, improved feedback, net metering, load-capping and direct load control, in networks and grids that rely increasingly on interactions between distributed actors. Examples are the local use of microgeneration (Boait et al., 2017) or direct load control of water heating (Saele and Grande, 2011). Far from being severed from its contexts, as Robins and Hepworth envisaged in 1988, the smartened home may be more tightly connected than before, at least where energy supply is concerned.

Connections between (external) electricity system, building and occupants may influence building performance in various ways. For example, the building can be used as a site for storing energy from periods of abundant electricity generation in hot water tanks, storage heaters, freezers or batteries; users can decide to alter their normal routines in order to use less electricity at times of high demand; they can sign a contract that allows their supplier or a third party to adjust their supply to meet system needs in exchange for a favourable tariff; or their supply may be cut off if the power demand rises above the level agreed in the customer's supply contract and be restored only after one or more appliances has been switched off.

All are examples of demand response, a process in which demand is adjusted to match available supply. Demand response can be understood as an expression of the way in which a building and its occupants form an integral part of a system or infrastructure of supply and demand, no longer simply consumers, end-users or 'load'. With the advent of demand response in electricity systems, metrics for building performance are already beginning to change: for example, demand response capability can now earn credits for LEED certification by the US Green Building Council.[v]

Control for specific purposes, such as shifting major loads away from peak demand periods, is arguably where ICT, allied with more traditional communications, offers the best prospect of social and environmental benefit: through closer monitoring, better feedback and ability to record and pay for distributed generation, storage and load-shifting, there is some evidence that a household can become an actor in transition from demand-led to supply-led electricity systems. This is never a purely technical process, though, at any scale (Grünewald et al., 2012; Darby et al., 2015); and the *type* of demand response and the actors will vary according to the nature of a problem. Thus the most familiar form of demand response, demand reduction, brings down both overall demand and the peak demand that determines the size/capacity of the system. It can occur through changes in equipment (efficiency) and/or changes in the delivered energy that the user is prepared to settle for (behaviour/change in energy service/change in energy culture): there will be a relatively high degree of human involvement. At the other end of the scale is fast frequency response to balance the grid, a technical exercise that can be carried out without any conscious human intervention apart from the decision to install a smart freezer or other suitable appliance[vi]. In between lie gradations of demand response that can be provided through some combination of voluntary/manual action and automation, all with implications for householder activity, utility programme design and system operation (Darby 2013).

Demand response, looked at closely, turns out to depend on many actors and processes. It is not smart in the sense of being slick but it does open a window into the previously closed world of electricity system operators, as surely as it opens up the home or business to a different relationship with other elements of the system, especially the network operator.

Summary and conclusions

Two types of narrative appear to be at work when we look at the literature on smart home technologies. They have some overlapping actors, artefacts, goals and processes, but offer quite different perspectives on what smartness is intended to achieve and how it is distributed between human and nonhuman actors. There has not been space to do more than touch on the question of what a home means to those who live in it, regulate the resources that flow into or out of it, and otherwise interact with it. But meanings of 'home' do connect with the potential and actual meanings of a *smart* home, and with how technology is used there.

How the term 'smart' is operationalised in homes and how it might figure in possible energy futures matters greatly, if we are to adopt sensible priorities in living with electricity and ICT. What we know to date about equipping a home with a high degree of automation and networked appliances indicates that we can expect such a home to be more, not less, environmentally damaging than a similar but non-smart one: building performance suffers and the user fades from view, at least temporarily. In operation, we would expect additional standby and in-use consumption, as occupants become distanced from the business of using their senses and activity to achieve a pleasant living environment. As an object for research and development, the image (mirage?) of the smart home arguably diverts attention and resources from activities, skills, materials and relationships that already show success in addressing ecological and social dysfunction, well-documented in the pages of this journal. The fully smart/connected home, it seems, has little or nothing to do with end-use efficiency, let alone demand reduction, and often seems to disappoint when it comes to convenience and workability. The search for interoperability and for automated homes on the grand scale, I would argue, distracts attention and resources from more pressing issues of affordable shelter and basic energy services. It does not offer a credible response to the wicked problem of environmental harm arising from modern energy services, but a partial response to problems that may well have other solutions (security and health monitoring, for example) and may be largely illusory (the 'problem' of having to switch on a light or kettle, or lower a blind).

The second part of the commentary discussed the role of smart home technology in the context of transition from demand- to supply-led systems, looking at some specific technologies and at the emerging phenomenon of demand response. Here, space- and water-heating loads along with electric vehicles are prime candidates for 'smarting', because of their relative size and potential for load-shifting. But perhaps the main significance of demand response for readers of this journal is that it extends our understanding of what a user is (does the user use the electricity system, or vice versa? Is an appliance there for the person who bought it or for the remote operator that switches it on and off in accordance with system conditions?); and our understanding of what building performance is. It may even stimulate ideas about appropriately complex but pragmatic responses to the wicked issues posed by our reliance on electricity. Additionally, considering what is involved in demand response nicely demystifies some aspects of smart technology, uncovering some very ordinary combinations of people, things and processes that, together, can enable a system to function. Developing clear, careful language with which to talk about these combinations and their outcomes will be a necessary part of designing and carrying out building performance evaluation.

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References

Andersen, PVK and Christiansen, E (2013). *Digital Living at Home: User Voices about Home Automation and a Home-Keeping Design Discourse.* Nordic Contributions in IS Research: 4th Scandinavian Conference on Information Systems, SCIS 2013, Oslo, Norway, August 11-14.

Aune, M (2007) Energy comes home. *Energy Policy* 35 (11), 5457-65

Balta-Ozkan N, Boteler B and Amerighi O (2014) European smart home market development: public views on technical and economic aspects across the United Kingdom, German and Italy. *Energy Research & Social Science* 3, 65-77

Boait, P.J., Snape, J.R., Darby, S.J., Hamilton, J. and Morris, R.J.R. (2017) Making Legacy Thermal Storage Heating fit for the Smart Grid. *Energy and Buildings* 138, 630-640

Bordass B, Leaman A and Ruyssevelt P (2001) Assessing building performance in use 5: conclusions and implications. *Building Research and Information* 29 (2) 144-157

BPIE (2017_Is Europe ready for the smart buildings revolution? Mapping smart-readiness and innovative case studies. Buildings Performance Institute Europe. http://bpie.eu/wp-content/uploads/2017/02/STATUS-REPORT-Is-Europe-ready_FINAL_LR.pdf

Caird S, Roy R and Potter S (2012) Domestic heat pumps in the UK: user behaviour, satisfaction and performance. *Energy Efficiency* 5 (3), 283-301

Darby S (2007) *Enough is as good as a feast – sufficiency as policy*. Proceedings, European Council for an Energy-Efficient Economy Summer Study. Paper 1,255

Darby, SJ and McKenna, E (2012) Social implications of residential demand response in cool temperate climates. *Energy Policy* **49**, 759-769

Darby, S.J., Liddell, C., Hills, D. and Drabble, D. (2015) *Smart Metering Early Learning Project: synthesis report.* For the Department of Energy and Climate Change, London https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407568/8_Synthesis_FINAL_25feb15.pdf

Demiris G and Hensel BK (2008) Technologies for an ageing society: a systematic review of 'smart home' applications. *Yearbook of Medical Informatics*, pp. 33-40

De Silva LC, Morikawa C and Petra IM (2012) State of the art of smart homes *Engineering Applications of Artificial Intelligence* 25, 1313–1321

Gram-Hanssen K (2011) Understanding change and continuity in residential energy consumption. *Journal of Consumer Culture* 11 (1), 1-78

Gram-Hanssen K and Darby SJ (2016) *Are 'home' and 'smart' contradictory concepts or fluid positions that will converge?* Proceedings of the DEMAND Centre conference, 'What energy is for: the making and dynamics of demand', April 13-15, Lancaster University

Grünewald P, Cockerill TT, Contestabile M and Pearson PJG (2012) The socio-technical transition of distributed electricity storage into future networks – system value and stakeholder views. Energy Policy 50, 449-457.

Herring H and Roy R (2007) Technological innovation, energy efficient design and the rebound effect. *Technovation* 27 (4), 194-203

Friedl M, Kaufmann L, Paganini F and Kyburz R (2016) *Energy efficiency of the Internet of Things*. Technology and Energy Assessment Report prepared for IEA 4E EDNA. Lucerne University of Applied Sciences, Switzerland.

Janda K (2014) Building communities and social potential: Between and beyond organizations and individuals in commercial properties. *Energy Policy* 67, 48-55

Levin K, Cashore B, Bernstein S and Auld G (2012) Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy Sciences* 45 (20), 123-152

Louis, J-N., Calo, A., Leiviskä, K. and Pongracz, E. (2015) *Environmental impacts and benefits of smart home automation: life cycle assessment of home energy management system*. IFAC –PapersOnLine 48-1, pp. 880-885

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*. In J. Kay, P. Lukowicz, H. Tokuda, P. Olivier, & A. Krüger (Eds.), *Pervasive Computing* (Vol. 7319, pp. 143–160). Springer, Berlin Heidelberg.

Nyborg, S and Røpke I. (2011). *Energy impacts of the smart home - conflicting visions*, ECEEE 2011 Summer Study, 6–11 June 2011, pp1849-60

Nyborg, S and Røpke, I (2013) Constructing users in the smart grid - insights from the Danish eFlex project. *Energy Efficiency* 6, 655-670

Poulsen D, Nicolle CA and Galley, M (2002) *Review of the current status of research on smart homes and other domestic assistive technologies in support of the TAHI trials*. Prepared for the Department of Trade and Industry. Loughborough University Institutional Repository. https://dspace.lboro.ac.uk/2134/1030

RMDP (1988) Automating the home '88: conference papers. Introductory comments.

Robins K and Hepworth M (1988) Electronic spaces. New technologies and the future of cities. *Futures*, April 1988, pp155-176

Saele H and Grande OS (2011) Demand response from household customers: experiences from a pilot study in Norway. *IEEE Transactions on Smart Grid* 2 (1), 90-97

Sovacool B (2012) The political economy of energy poverty: A review of key challenges. *Energy for Sustainable Development* 16 (3), 272-282

Stephenson J, Barton B, Carrington G, Gnoth D, Lawson R and Thorsnes P (2010) Energy cultures: a framework for understanding energy behaviours. *Energy Policy* 38, 6120-6129

Strengers Y. (2013) *Smart energy technologies in everyday life: smart Utopia?* Palgrave Macmillan

Tainter JA, Allen TFH and Hoekstra TW (2006) Energy transformations and post-normal science. *Energy* 31 910, 44-58

Takayama, L., Pantofaru, C., Robson, D., Soto, B., & Barry, M. (2012). *Making technology homey: finding sources of satisfaction and meaning in home automation.* Proceedings, UbiComp '12, Sep 5-Sep 8, 2012, Pittsburgh, USA

Wilson C, Hargreaves T and Hauxwell-Baldwin R (2015) Smart homes and their users: a systematic analysis and key challenges. *Personal and Ubiquitous Computing* 19 (20), 463-476.

Woodruff A, Augustin S and Foucault B (2007) *Sabbath Day home automation: "It's like mixing technology and religion".* CHI Proceedings, April 28-May 3, San Jose, California, pp 527-536

Yang R and Newman MR (2013) *Learning from a learning thermostat: lessons for intelligent systems for the home*. Proceedings, UbiComp '13, pp. 93-102. Zurich

[i] https://setis.ec.europa.eu/archive/technology-roadmaps

[ii] *The Guardian*, 19.3.16

[iii] See also http://uk.businessinsider.com/googles-nest-closing-smart-home-company-revolv-bricking-devices-2016-4?r=US&IR=T

[iv] ICT is not irrelevant to other sources of energy service such as gas supply and heat networks. But it is likely to be most significant in terms of managing electricity networks in real time: networks that rely on distributed renewable generation and call for an increasing proportion of 'active demand'.

[v] http://www.yourenergyblog.com/demand-response-finally-a-base-credit-for-leed-certification/

[vi] This is not, of course, risk-free. While some owners of heat pumps now have to sign contracts agreeing to specified levels of remote control, it remains to be seen whether standards for cold appliances can be achieved that are good enough to persuade people to agree to the electricity supply to them being switched off and on remotely, even if only for very short periods.