Do smart homes know what people want and allow them to realize it?

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Abstract

American architect and author, Malcolm McCullough, recently posed the question 'Are smart buildings smart enough to allow me to open the window' (McCullough 2016). This question succinctly captures one of the central dilemmas of the trend in energy policy towards reducing the fullness of energy consumption in buildings to technology-driven performance, and in so doing, discounting occupant know-how and limiting flexibility in the ways people create comfortable home environments, including light, ventilation, views, access to surroundings (such as gardens and balconies) and interaction with other people, both in their own household and with others. Smart is dumb if it means locking buildings and people into pre-determined patterns and disabling creative low-energy and user-adapted comfort solutions. In this paper, we situate 'smart' technologies in a historical context within energy policy, flesh out conflicts between goals of smart comfort and smart energy and argue for a new focus that engages with people's know how and accommodates differences in among households of differing socio-economic and age groups, giving attention to building designs, building structures (materialities and technologies), embodied comfort, and smart interfaces. We sketch out the policy implications of this new focus for houses in the rich, high energy-using countries as well as in parts of the world that still rely on producing comfort through flexible, culturally grounded and climate-adapted building designs.

Introduction

One of the new thrusts in energy efficiency policy delegates the accomplishment of energy efficiency in homes to 'smart' building designs and technologies which are intended to deliver home energy services at low, or strongly reduced levels of energy use, compared to a 'dumb' house in which the production of comfort demands active householder interface with the house and the energy systems in it. In this paper we explore and critique the assumptions, theories and practices of smart design. We raise the questions: what do people want from smart homes? What do smart homes want from people? Has the delegation of comfort to smart technologies engaged with householder interests, knowledge and options for creating comfortable home environments? We explore the downsides to locking buildings and people into predetermined patterns and disabling creative low-energy and user-adapted comfort solutions. We will argue that smart houses and technologies bring with them many positive advances in the achievement of low energy comfort for households in certain socio-economic groups, for example, young, male, high income, technology interested, but smart could be smarter if it broadened its lens to engage with other societal segments.

We begin the paper with a historical contextualization of the smart transformation in houses and home technologies. We follow this with an overview of commercial actors in the USA involved in smart home design, their motives and the imagined smart householder in their design processes. We give examples of how smart buildings perform, drawing attention to the interactions between smart homes and the people living in them. In the subsequent section we critique the 'smart' building concept, arguing that design principles need to engage with people's culturally anchored expectations for comfort, as well as their know-how about how to accomplish heating, cooling, and ventilating. We end the paper by drawing out the research and policy implications of climate smart design.

The smart transformation in the achievement of home comfort and energy savings

The creation of a comfortable home environment is accomplished through the interaction between the people living in the house (householders), with their culturally grounded experiences, know-how and expectations on the one hand, and the material components of the house, including structural elements, technologies, and energy on the other. While we find no general consensus on the definition of a smart technology or smart home, we propose that the essence of the 'smart' transformation is a transfer of agency from householders to an array of technologies and structural elements that contribute to the production of energy services such as lighting, cleaning, cooking, heating, and cooling. While 'smart' only began to be widely used in energy research and policy in the 2000s, we propose that the transformation has a long history, beginning with the introduction of home technologies aimed at producing light and heat in the late 19th century. Houses and the technologies in them have become progressively "smarter" over the course of a century, replacing or reducing householders' physical labor with an array of technologies such as cooking equipment, washing machines, heating and cooling devices, and more recently through sophisticated control systems involving internet-enabled two-way exchanges of information, often through wireless devices such as smartphones and tablets. The structure of the house itself has also become 'smarter' over time, beginning with the 'tightening' of the house's envelop (materials, insulation, windows) and more recently including light and heat sensor-driven automatic controls of air flow and lighting.

The introduction of electricity enabled an array of technologies that replaced bodily engagement with the production of home services. Take the cleaning of homes and bodies with heated water as an example: prior to the advent of electricity, it was necessary to acquire a fuel (such as wood or coke), build and maintain a fire, and heat water in a cauldron or pot. If clothes were to be washed they needed to be soaped, rinsed, beaten, and rung out. The introduction of the water heater in the USA in 1889 eliminated the need to build and sustain the fire, and the washing machine, which became commercially available in 1904, eliminated the manual washing tasks. The electric fan, electric iron and cooking devices such as toasters, hotplates and waffle irons were all introduced by the beginning of the 20th century. After the electric plug was standardized in homes in 1917, electric appliances such as the vacuum cleaner and washing machine became more common. The refrigerator came on the market in the 1930s and by 1937, half of electrified homes had one (Cross 2000: 27). The refrigerator and freezer are super-smart appliances from the perspectives of convenience and time saving, creating a 'mini-market' (Shove and Southerton 2000) in the home that saves time and travel in shopping and food preparation. For most of its history 'smart' has been associated with a substitution of energy-using devices for bodily activity with the aim of improving comfort or convenience.

In its more recent usage, smart has been associated with making household energy use more efficient, leading to some ambiguity and contradictions in smart policies. The refrigerator saves energy by reducing the need for frequent shopping excursions, but enables new food practices such as those based on frozen foods, meat and convenience foods that demand energy throughout the production and consumption chain. The same can be said of the air conditioner, which facilitates cooling comfort, but at a high energy cost. Even the smartest of air conditioners uses more energy than houses that are capable of being cooled without them, using for example building designs that allow shading and air flow management through the active use of windows, fans, and screened porches. The numbers and kinds of these and other home energy appliances have grown and multiplied in step with increased expectations on comfort and the growth in the physical dimensions of the average house. House size, a significant determinant to the household's total energy use, is an indifferent variable in the smart energy agenda, making smart dumb from a climate/environment perspective.

The most recent phase of the smart evolution has equipped household appliances with ever more sophisticated control systems, from on-off switches to dials with multiple settings, to programmable controls. Taking clothes washing as an example, the first washing machines were built to heat water to preset temperatures and to have a single generic washing cycle for all types of clothing. The skills involved in using a technology like this are intuitive: one simply puts in the dirty clothes, adds soap and turns the switch to the 'on' position to start the wash. As the washing machine evolved, multiple cycles were enabled for different types of clothing using different water temperatures, centrifuge speeds, and amounts of soap used, all of which are achieved by turning dials to the appropriate setting. Similarly, electric-resistance ovens could be set at different levels of heating, by using a dial with settings like 'low' and 'high', or with numbers from one to some arbitrary maximum. The transformation from on-off settings to dialed programs provided multiple options for achieving comfort and the potential to save energy in virtually every domain of household practices. The technologies were smarter from both a comfort and energy perspective, but in order to exploit their potential they demanded a householder who understands the various options and is motivated to use them. These multiple-setting, dial-controlled technologies demanded an increase in know-how from users, but optimal use was fairly intuitive and could be mastered by the average householder without the need to reference a user guide.

The next phase of technology development moved into what is most commonly identified today with smart, involving a transition from dials to programs, many of which have complex technology interfaces. These control technologies allowed users to program appliances in order to control inputs of variously, light, energy, water, and heat during differing time intervals. The most recent phase of smart involves two-way Internet communication that enables system control through a display on the appliance, or available on a smart device such as a phone or tablet. This feature allows the householder to control things like heating systems, lighting and other devices from a distance – for example to turn on the central heating system a couple of hours before returning from a weekend excursion – and in addition, allows for a delegation of these changes to web-based systems that have access to data on home practices.

Our review of the literature on smart homes shows that there are differing uses of the terminology in different parts of the world. For instance in Europe and Oceania, 'smart' is more broadly defined as home technologies that are programmable and involve an interactive display, such as programmable thermostats. In the U.S. and Canada, the definition is narrower, encompassing devices that are seamlessly connected through the 'internet of things.' One representative definition of smart from the U.S. (Internet of Things 2016) addresses this feature:

> A smart home or building is a home or building, usually a new one, that is equipped with special structured wiring to enable occupants to remotely control or program an array of automated home electronic devices by entering a single command. For example, a homeowner on vacation can use a Touchtone phone to arm a home security system, control temperature gauges, switch appliances on or off, control lighting, program a home theater or entertainment system, and perform many other tasks.

These smart systems generally consist of switches and sensors connected to a central hub, or gateway, from which the system is connected via a user interface that is controlled through a wall-mounted terminal, a mobile phone software, a tablet computer, or other web interface. A precursor to external control through the internet was the so-called home-automation network technologies such as the X10 communication protocol for electronic devices, using electric power transmission wiring for signaling and control, commercially available in the USA in 1975. By 2012, there were 1.5 million home automation systems installed in the USA (ABI Industries). These systems have been characterized as consisting of three distinct generations of home automation: The first generation involved a wireless technology with a proxy server, e.g., Zigbee automation; in the second generation, artificial intelligence controls electrical devices, e.g., Amazon Echo; in the third generation a robot buddy interacts with humans, e.g., Robot Rovio, Roomba (Li et al. 2016). According to recent industry reports (Parks Associates, 2016) smart home energy management solutions in the U.S. today are in an 'early adopter phase' with 10 % of broadband households owning a "smart energy device (SED)", which Park Associates defines as a programmable thermostat, light bulb, power strip, outlet, or plug adapter capable of connecting to the internet.

Many of these products are deployed as part of a home control or home security system. The key exception is the smart thermostat – 56 % of these devices are purchased as standalone products.

From an energy savings perspective, if smart interfaces are used optimally, they have the potential to reduce energy use through the adjustment of lighting, heating, and cooling devices throughout the day, including turning systems down or shutting them off completely when there is no one in the house. We return to the question of whether the smart evolution and in particular its most recent phase of web-based interface is capable of delivering energy savings. First we explore the constellation of actors involved in producing and marketing 'smart' homes and technologies.

Actors, markets and business models behind smart homes

In order to understand how new smart technologies are designed, marketed, and purchased by homeowners, we need to know who are the players in the design and delivery of smart home technologies. In the USA, Smart technologies are being produced by a wide range of manufactures, including several industry leaders, who see this technology as a large growth opportunity. The players and products include: Apple HomeKit, Alphabet Nest, Amazon Echo, and Samsung SmartThings, among others. These manufacturers have extensive marketing divisions that are constantly assessing what consumers want from smart products. They depend on a number of market actors in the packaging and delivery of smart technologies, including telecom companies, cable operators, security service providers, electric utility providers, home remodeling outlets, contractors, and others. At a recent energy leaders conference, the new business models for smart homes were described as follows:

> Energy providers are now leveraging new business models and forming new partnerships with smart home platform vendors that promise to enhance the consumer experience while simultaneously increasing energy efficiency [Smart Energy Summit: Engaging the Consumer, February 2015]

From our review of the recent wave of smart products we see the following aspects being promoted for the consumer:

- **Convenience**, e.g., scheduling of lights, heating, air conditioning either remotely or from in the home. Remote accessibility is often cited as the most important consumer feature in valuing smart technologies (U. S. Department of Energy 2016).
- **Entertainment**. Smart technologies are promoted for entertainment value, allowing homeowners to program or record music and videos for later use
- **Health**. A major target for smart technology is the feasibility of ensuring comfortable home temperatures in warm climates during heat storms or other extreme events. These features are being marketed to the elderly, as a specifically vulnerable group.
- **Security**. The ability to remotely check home security systems, lock or unlock doors and report break-ins is a strong selling point for integrated smart home technologies. Ironically, these very capabilities allow for the potential for external hacking and disabling of security systems.
- **Energy savings**. In addition to programming temperatures to more closely track occupied times and homeowner preferences, increased functionality is available for dollar savings from time-of-use and demand response

Clearly these aspects will appeal to different marketing segments, and producers are targeting specific consumers with smart technologies that can best meet their needs. Traditional product manufacturers are now working with third parties such as home-improvement retailers, utilities, contractors, and others, to promote the adoption of these new technologies.

A critique of smart and a new framing

In this section we review theory and empirical evidence on the challenges of realizing the potential for energy savings through the use of smart technologies. Many of these problems stem for a lack of acknowledgement of or engagement with the cultural importance of the home. Studies conducted in a number of national and socio-economic contexts have consistently reaffirmed the cultural importance of home and how this affects the shaping of household energy use in ways that are not anticipated in energy policy (Wilk and Wilhite 1986; Gullestad 1989; Hackett and Lutzenhiser 1991; Aune 2007). In a cross-cultural comparative study of energy use in Japan and Norway, Wilhite et al. 1996 found that the 'cultural anchoring' of practices around lighting, heating and cleaning (bodies and clothes) was responsible for significant differences in household energy use in the two countries not explainable by economic or technology-centered models. Research shows that energy use in the home is also related to the household's social identity. Energy-dependent practices involving food, entertainment, heating (and cooling) and lighting must be dimensioned to meet social expectations for light, heat, food and entertainment for family and guests (Wilhite and Lutzenhiser 1999). For younger, more highly educated households, the house and the things in it should demonstrate the family's cognizance of, and economic power to purchase the latest home technologies and individualized devices such as phones, tablets and gaming systems (Bollinger and Gillingham 2012). Research on home energy use around the world points to the importance of accounting for control, comfort, security and sociality in technology design. Based on our review of empirical studies of household-smart technology interactions, we point to four key aspects that need to be given greater attention in smart design: 1) flexibility and control in the exercise of comfort, 2) know-how mismatches, 3) invasiveness and security of smart systems, and 4) the way in which the architect or designer can lock in designs, structures, and comfort norms through the selection of smart technologies.

FLEXIBILITY AND CONTROL

Flexibility and control are elements that many people associate with a comfortable home. People want automated delivery but on the other hand want to exercise control over air flow (drafts) shading and natural lighting. This finding emerged from an ongoing study of household energy practices in apartment buildings in Oslo (Standahl et al. in press). One of the buildings studied was constructed on a sensor-controlled shading system and 'smart' mechanical ventilation for regulating inside temperatures and airflow. Shading and mechanical ventilation is necessary because the building has a double bank of south-facing windows to capture passive solar heat. Only a few of the families interviewed understood the workings of the smart interface for ventilation controls and even fewer used the interface as it was intended to be used. Most of the residents regulate heat and ventilate by overriding automatic thermostatic controls (manually adjusting temperature settings) and regulating fresh air by opening and closing balcony doors and windows. The majority of those interviewed said they preferred to have control over (actively regulate) heat and drafts and were skeptical of the delegation of comfort regulation to automated technologies.

These and other smart technologies tend to lock practices into patterns that can be difficult to override. American architect and author, Malcolm McCullough (2016) asks 'Are smart buildings smart enough to allow me to open the window.' This succinctly captures one of the central dilemmas of the trend in energy policy towards reducing the fullness of energy consumption in buildings to technology-driven performance, and in so doing, discounting occupant know-how and limiting flexibility in the ways people create comfortable home environments, including light, ventilation, views, access to surroundings (such as gardens and balconies) and interaction with other people. In her book, Smart Utopia, Australian Yolande Strengers (2013) sites evidence from a number of studies that people are skeptical of the idea of ceding control of comfort to smart technologies (Vyas and Gohn 2012); that people living in smart houses often do not use them in ways intended by designers (Valocchi and Juliano 2012); and that one of the reasons for these problems is that technology designers imagine an energy consumer who is much like themselves, a consumer who Strengers defines as a 'resource man': a male who makes decisions for the entire household; is well educated; is interested in energy data; is techno-savvy; and responds rationally to price signals. This imagined householder corresponds to only a small segment of the Australian households she studied, and is very distant from the realities of many households, such as single-parent, elderly, and low-income households. While designers imagine householders as technology buffs, interested in mastering complex interfaces and in minimizing energy costs, the evidence shows that this represents only a small segment of the residential population anywhere in the world.

KNOW HOW

The evolution of home technologies described in section 2 reveals how controls at the user-technology interface have increased in complexity over time. An appliance such as a refrigerator or freezer can tolerate a passive user. These are both equipped with dials for controlling cold air and hot water respectively, but these settings are seldom touched by users (Shove and Southerton 2000). The other standard household appliances, including washing machines, dishwashers, heating systems, and air conditioners need to be managed using dials and programs. Significant amounts of energy can be saved by using them actively and correctly. Unfortunately from an energy savings perspective, there is lots of evidence that appliance controls are not used as intended. This is clearly demonstrated in the research of Pierce et al. on people-appliance interfaces in the USA households, (Pierce et al. 2010: 5). In their study of washing machine practices, most of the respondents in the study settled on a single setting for washing clothes and never used any of the other available settings. In one representative household, the female head of household said that she had 'always' done the wash by putting the clothes in the machine and turning the dial to setting '9'. When asked why, she responded 'I've been doing this for a long time …, My mother told me to do that. … I don't think 'regular 9.' Like, I've never said to myself, hmm: 'regular nine', nine o'clock.' I just know it goes to here [demonstrating setting]. I don't consciously think about the 9.' Another respondent said 'I've also never ever, ever turned this dial to anything but here [indicating "normal" cycle]. … But yeah, as far as that goes, I have no idea at all as to what those things would do. I've never, ever not done this.' When asked what it would take to change washing practices from using warm water for washing to using cold water wash cycles, another respondent answered 'I don't know… I guess, if they started making washing machines with only that option, because everything was all right with cold… They must be giving you these options for a reason. Now, I suppose if I bought a washing that only had a cold cycle on it, then that's what I'd do.'

When it comes to programmable heating or cooling thermostats, there is lots of evidence that people ignore them or do not use them in the ways they were intended (see Rathouse and Young 2004; Woods 2006; Revell and Stanton 2014). Programmable thermostats were introduced in the mid-1980s. They continued to evolve in the 1990s, offering consumers more sophisticated programming capabilities such as seven-day scheduling (U. S. Department of Energy 2016). Based on estimates that programmable thermostats were capable of achieving up to 30 % in HVAC energy savings through optimized thermostat setpoint schedules, an ENERGY STAR certification program was established in 2003 to encourage households to purchase and use these tools to achieve ongoing energy and cost savings (U. S. Environmental Protection Agency 2003). An early study of the use of thermostats by low-income elderly showed that they consistently misused the thermostat, due to a combination of poor thermostat design, including green and red lights that signaled high and low energy use in a counterintuitive way (Diamond 1984). Later studies showed that people would use programmable thermostats to optimize their comfort rather than their energy use. Based on these and other studies, the U.S. EPA suspended programmable thermostats as an ENERGY STAR technology in 2016 and recommended that further studies be done on the design and use of programmable thermostats (U. S. Department of Energy 2016). One of the reasons cited for the suspension was "uncertainty about consumer behavior – specifically that many consumers were either not using or misusing the programmable functionality – and the resulting failure by many consumers to achieve the expected level of savings" (U. S. Department of Energy 2016).

The examples show that many people find short-cuts to using dials, controls and programs. The new generation of internet-based 'smart' technologies constitutes another leap in interface complexity that makes huge demands on users. Unfortunately from an energy-use perspective, there is evidence that with the exception of a small segment of affluent, educated and tech-interested households, most households do not make the effort, or in many cases, are not capable of using dials and programmable interfaces in the way in which they were intended to be used. Wade (2015) studied interaction between the installers and purchasers of smart central heating systems in London. She found that households of all ages and socio-economic groups had difficulties understanding the programmable interfaces that were intended to enable changes time-of-day temperature settings. As a result, the installers had given up on explaining how to use them according to the manual and had come up with a simple method that the purchasers could use to adjust the thermostats that was sub-optimal, but doable.

As pointed out, the demands of 'smart' interfaces on users can be particularly problematic for the elderly. "The recent advances made in tailoring home automation toward the elderly have generated opposition because many of the interfaces "are not designed to take functional limitations, associated with age, into consideration" (Cheek 2005). The cost of the systems has also presented a challenge for the elderly, because although the systems would be cheaper than the costs involved with moving into a long-term health care facility, the U.S. government currently provides no assistance to seniors who choose to install these systems (in some countries such as Spain the 'Dependency Law' includes assistance with installing and using these systems). The biggest concern expressed by potential elderly users of smart home technology is a "fear of lack of human responders or the possible replacement of human caregivers by technology" (Cheek 2005). This underlines the important point that home automation should be seen as something that augments, not replaces, human care.

INVASIVENESS AND SECURITY

Both users and designers of smart systems have expressed concern about delegating too much autonomy to computer-management of home systems based on a monitoring of data on household activity patterns. This also raises legal issues about unlawful or unsolicited intrusion. An example of this came to light in a recent lawsuit brought by the US Federal Trade Commission against Vizio. The Commission claims that the company used 11 million televisions to spy on its customer's viewing practices. According to consumer technology correspondent for the Washington Post, Hayley Tsukayama (2017), 'With the advent of "smart" appliances, customers and consumer advocates have raised concerns about whether the devices could be sending sensitive information back to their manufacturers.' The FTC says the Vizio case shows how a television or other appliance might be telling companies more than their owners are willing to share. The Dutch architect Rem Koolhaas articulates these concerns, writing (Koolhaas 2015):

> The door has become automated, transformed into an extension of the smart phone, with each opening and closure logged; elevators predict your intended destination by listening to your conversations and tracking your routines; toilets diagnose potential illness, building a catalogue of the user's most intimate medical data; windows tell you when they should be opened and closed for maximum environmental efficiency. You house may soon insist on an early bedtime to stop irresponsible consumption of energy.

In the recent study referred to above by the US DOE (U. S. Department of Energy 2016), it was found that security systems enabled by smart IT technology have an appeal for more affluent households, but that there a strong concern about the risk of hacking through the smart device and loss of security. This was the biggest concern reported by people considering smart home technologies. Echoing this concern, Edith Ramirez, chairwoman of the U.S. Federal Trade Commission, said in a recent speech at the Consumer Electronics Show (Ramirez 2015) that 'The trend toward having so many things constantly connected to the Internet presented serious risks that start-ups and big companies needed to take seriously… Any device that is connected to the Internet is at risk of being hijacked … Moreover, the risks created by that unauthorized access intensify as we adopt more and more devices linked to our physical safety, such as our cars, medical care and homes.' These concerns, voiced by Ms. Ramirez and other security experts include the widespread collection of personal information with or without consumers' knowledge, misuse of that information, and actual stealing of the data.

LOCKED-IN DESIGNS

Stewart Brand (1994) wrote in 1994 about the importance of building homes that could be retrofitted and adopted to changing conditions over their lifetimes. In the architectural literature, he has referred to this as 'the scenario buffered building', a building that was designed and built to be capable of being modified to compensate for changes in both exterior conditions, changing households and new technologies. He wrote that 'All buildings are predictions. All predictions are wrong.' In other words, buildings should be built in ways that make them malleable and adaptable. Brand asserts that the best buildings are made from low-cost, standard designs that people are familiar with, and are easy to modify. Brand based his observations on the idea of "shearing layers" a concept coined by architect Frank Duffy. The "shearing layers" include site, structure, skin, services, space plan, and stuff. These layers need to be designed to allow for maximum flexibility across different timescales (Brand 1994). These reflections on malleability and layering contradict the tendency in smart house designs that are rigid and not adaptable to changes in either the household over its lifecycle or to external changes in the local environment.

The evolution of buildings from natural (or passive) cooling designs to central air conditioning evokes this tendency to delegate and lock-in comfort and energy to buildings and technologies. In cases where cooling comfort is achieved without air conditioning, householders play an active role in controlling ventilation and shading using door and windows, drapes, and fans. Buildings built for central air conditioning displace these practices with energy-driven and thermostatically controlled cooling. Further, ideal indoor temperatures have been standardized and homogenized to 22 °C through ASHRAE building codes and norms for radiant temperatures, widely accepted by architects and engineers worldwide (Humphries 1994). There are a number of empirical studies that people are comfortable in a wide variation in temperatures and that the 22-degree norm is below what people are willing to accept (Busch 1992; Nicol and Humphries 2009). Still, structures built for air conditioning are not amenable to natural cooling practices, and lives lived in artificially cooled spaces (homes, cars, office buildings, shopping centres) lead to a habituation to cold comfort (Wallenborn and Wilhite 2014). If the current direction in smart design continues, it could potentially extend this lock-in and standardization to a wider range of household energy practices, disabling the capacity for households of differing backgrounds and age groups to adjust practices to their needs.

Making smart homes smarter: research and policy implications

A weakness that has plagued energy-savings research and policy throughout its 40-year history is being perpetuated in policy approaches to smart homes: an embracement of the reductionisms that portray households as undifferentiated and homogeneous in their motives, needs and practices, driven by economically rationality and both capable and willing to engage with complex technology interfaces. We have reviewed a number of empirical studies that show that in fact only a small segment of household populations anywhere resemble this imagined householder. Evaluations of policy and program failure are still lamenting a lack of understanding of household 'behaviour'. We insist that smart home and technology designs need to be aligned with householder's interests, know-how and capabilities if they are to enable deep reductions in household energy use (Pettersen 2015). Smart technology may have appeal for certain populations, e.g., millennials, elderly, early tech adopters, etc., but these technologies make heavy demands on user mastery of complex interfaces. The tendency to lock house and technology design into 'one size fits all' perpetuates a tendency in energy policy to neglect the diversity of household needs, knowledge and capacity to engage with complex systems. A home design that is really smart is one that is malleable enough to accommodate this diversity.

We have argued that smart homes are grounded in the thinking that efficiency, optimization, standardization and automatization are the keys to reducing residential energy use. The smart aim has been to reduce the amount of energy needed to produce home energy services, an absolutely essential goal if total energy use is to be reduced, but from a climate perspective, where volume of emissions is the problem, smart energy policy needs to put a greater focus on reducing the volume of energy produced and consumed, period. For the longer term, it is unimaginable from a climate perspective that a global middle class consisting of hundreds of millions of households will be residing in houses approaching the sizes we see in USA and Europe today, no matter how energy smart they are. House size, or more precisely, per capita living space will need to be reduced in the rich countries of the world and increases curtailed in rapidly developing countries. The future of smart could involve standards and regulations directed at encouraging moderate house size as well as support for social innovations now taking place in a number of 'niches' around the world involving experiments with co-housing and community housing (Geels 2011; Seyfang and Smith 2007; Shove and Walker 2010). These forms for household are still rare in mainstream urban communities - with a few exceptions such as Danish cities and in a few pioneering communities in the USA, yet are growing rapidly in alternative communities such as in the approximately 1100 towns and cities in Europe and North America belonging to the Transition Movement (formerly Transition Town). Studies show that these forms for household reduce the per person living space, the numbers of tools and technologies used and the energy dedicated to heating and cooling as compared to nuclear family households (Lietaert 2010). Adding this dimension to smart living would necessitate a greater engagement between technology designers and the people who intend to live in smart houses, including participatory design and experimentation (Wallenborn and Wilhite 2014).

The aim of participatory design is to create a forum for design through an interaction between experts and users. Peer-to-peer interaction can also be effective in the mastery of new technologies. Participatory design engages the intended users of technologies with experts in an interactive process that leads to technologies or technology interfaces that are appropriate and used correctly when set out into practice. This form for learning, sometimes referred to as practical learning, is underexploited in energy research and policy, yet could be appropriate for transitions to smart living, whether it be adaptation to complex technologies or exposure to new types of household sharing arrangements. Practical learning is accomplished by creating learning environments where people learn by doing and by participating with others who have already adapted new practices. Publically financed demonstration homes such as those established in Davis, California in the 1970s and 1980s are good examples of how policies that create spaces for the exposure of people to new ways of doing things can be a stimulus to relearning and reshaping household interactions with new technologies. The most effective demonstration homes are not technology showcases, but rather living spaces in which the occupants have adjusted to new home technologies. By observing how people like themselves live in these houses and talking with residents, people demystify new technologies and learn practical ways to deal with them. From a policy perspective, practical learning is initially costly, but is a more effective and powerful form for learning than providing information pamphlets that are seldom read and often misunderstood.

In developing/emerging countries, 'smart' could mean finding ways to reinforce existing flexible, affordable and climate-adapted building designs. In warm climates such as those in India, parts of China and Indonesia, house designs and structures using locally produced, inexpensive, porous materials are gradually being replaced by concrete structures that inhibit air flow and necessitate artificial cooling. This change in design and materials launches houses into the same technology trajectory that we have described in the USA and Europe, in which altering the comfort demands and reducing the needs of tight and inflexible structures are addressed by retrofitting with efficient technologies and smart interfaces. An alternative smart trajectory would invoke Brand's 'shearing layers' concept in retaining flexible designs and making improvements using improved components and simple technologies. There are a few examples of this in Asia, including architects such as those working in the tradition of architect Laurie Baker in India (Wilhite 2008). The State of Kerala has provided government support for the 'Baker' design and construction of housing for low and middle income families in Kerala that use unfired bricks, cement mixed with locally available limestone, tiled roofs designed to keep out the rain, but which allow air circulation, and use of design elements such as Baker's classic arch designs that can support multiple story structures built of unfired brick. These houses draw on local cultural preferences for the house's layout, are structurally sound and are capable of keeping houses cool without the need for air conditioning. This is only one of many examples that could form the basis for a culturally grounded, flexible articulation of smart. The future of smart housing should not only acknowledge social and cultural diversity in household demographics, know-how, and familiarity, but should allow a diverse spectrum of householders to choose from a range of technologies from low-tech to complex.

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