Smart people in stupid homes: the skill in creating preferred thermal environments

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Abstract

A popular strategy in reducing energy consumption in dwellings has been to remove 'the user' from the operation of the building and its systems as far as possible. Occupants and their 'inconvenient' behaviour are seen as uncertainties to be set outside the loop. Research conducted by the authors suggests this may not be the most effective strategy for two main reasons. First, many people demonstrate a sensitivity to their thermal environments, a clear understanding of what they want from them, and the ability to operate their homes to achieve those conditions. Second, when users are thwarted in their attempts to create desired thermal experiences there is a risk they will bypass controls and constraints – for example, by using portable electric heaters – resulting in significantly greater energy consumption than expected. This paper suggests that some occupants have a deeper understanding of how their homes work thermally than is usually acknowledged in top-down imposed energy interventions that limit the occupants' control of their home environment. The authors will argue that users' intuitive understanding often exceeds the capabilities of automated or 'black box' heating control systems by embracing control mechanisms, such as windows and doors, that are not normally considered part of the whole environmental control system.

The paper draws on the results of a project jointly funded by the UK's Engineering and Physical Sciences Research Council and Électricité de France under the People Energy and Buildings initiative: *Conditioning Demand: Older People, Diversity and Thermal Experience*. This project studied householders' attitudes to the introduction of low carbon technologies for heating. Their responses show a sophisticated understanding of the thermal environment and suggest there is a need to investigate people's understanding of how buildings work and the skills they acquire in getting the best from their homes to provide the thermal conditions they want. The paper explores the division of agency between people, building designs and systems in creating desired thermal environments. It positions occupants as the primary intelligence in operating homes and their energy systems and calls for greater recognition of the role of end-users in the efficient and effective operation of thermal systems in the home. The paper argues that by exploiting people's intuitive understanding of how buildings work will inform effective low carbon strategies to reduce household energy consumption.

Keywords: occupants, users, skills, low energy homes, smart homes, home automation

Introduction

Studies of energy use in the home often blame occupant behaviour for the 'performance gap' between predicted and actual energy consumption following energy efficiency upgrades (Sunikka-Blank and Galvin, 2012), and for wide variations in energy consumption across similar properties (Morley and Hazas, 2011). Despite the lack of clear evidence that individual behaviour accounts for large differences in energy consumption, government policies on behaviour change point the finger at occupants (ZCH, 2014). Smart technologies are posited as one way to increase the efficiency of operation of energy systems in the home thereby sidelining the occupants and removing their idiosyncrasies from the control-feedback loop.

However, as suggested by the literature, home occupants' actions and routines are not primarily motivated by energy efficiency concerns (Strengers *et al*, 2014; Frederiks *et al*, 2015). Energy is the medium that facilitates the satisfaction of needs and desires of comfort and home living; it tends to be invisible to the end-users (Gram-Hanssen, 2011). In the home context, occupants' actions go beyond energy efficiency goals or functionality of energy efficiency strategies. Energy systems and controls therefore are enmeshed with other aspects of operating a home and are not easily disentangled from them, which poses challenges for the developers of smart controls.

In contrast, there is evidence that occupants understand how their homes and associated systems work and have developed mental models to help with this. The work by Kempton (1986) shows that people hold representations about how heating systems work, the 'valve' and the 'feedback' theories. The users' theories affect the way systems are controlled and the energy usage. More recently, the representations of heating systems by house occupants has been explored by Revell and Stanton (2014), suggesting there are several 'heating theories' held by house occupants: 'valve' and 'feedback' (Kempton, 1986), 'Timer' (Norman, 2002) and 'Switch' (Peffer *et al*, 2011). The aim of this paper therefore is to begin a debate about the differences between occupants' manual control of energy systems in the home versus the move towards automation proposed by smart systems. The paper briefly considers the state of home automation before a digression into theoretical perspectives on situated learning. This is followed by observations derived from field studies of how people operate the energy systems in their homes. The final section discusses the main points of these studies before suggesting how the debate might continue.

The development of smart controls and systems

The resurgence of interest in all things smart has led to it being applied as a prefix, from smart meters to smart cities. Strengers (2013) coined the term 'smart utopia' to denote a "global and ubiquitous vision for smart energy technologies." It raises issues around the neutrality of technology and its impact on traditional ways of doing things. Strengers' aim is to hold utopian and non-utopian arguments in play without coming down on one side or the other, unlike Ihde's who highlights the non-neutral 'acidic' nature of technology as eroding traditional skills and practices (Ihde, 1994).

Despite the potential of automated controls and smart home technologies to support energy savings, a growing body of literature highlights the challenges in the deployment of these technologies in everyday living, for example: instrumental aspects of smart technologies are not prevalent, there is no intrinsic motivation for users to reduce energy consumption via smart technologies (Oliveira *et al,* 2015); users do not deploy the advanced functionalities of smart technologies (Hargreaves *et al,* 2015); the complexities of home living do not match the 'narrowly functional, routine and short-term focus of smart technologies' (Hargreaves and Wilson, 2013); occupants feel that there are conflicts between comfort and control and concerns about loss of control (Mennicken and Huang, 2012).

There is a dearth of evidence about the deployment of smart technologies in mainstream everyday home living, 'smart home has to reach higher level of maturity... leveraging a wide range of aspects, from both technological and non-technological domains' (Solaimani *et al*, 2015). Control technologies in the built environment are based on ideal representations of how users deploy the technologies. These

representations tend to limit the actions of the user and interaction with diverse components of the built environment. In the context of everyday home living, technologies could interfere with the preferred actions and routines of house occupants. Technologies might even be used in ways that defeat the intentions of their developers (Hargreaves *et al*, 2013; Balta-Ozkan *et al*, 2014; Wilson *et al*, 2015).

How we develop environmental skills

Studies of interaction between people and their environments, particularly the built environment, have benefited from the theoretical perspective provided by early phenomenologists, notably Merleau-Ponty. Phenomenology informed architectural theory since Norberg-Schulz (1963) and continues to do so today in the work of Pallasmaa (1996). Architectural theorists draw on these approaches to emphasise occupants' sensory experience of architecture.

Hubert Dreyfus, a leading interpreter of earlier phenomenological works and an important philosopher in his own right directs his phenomenological insights beyond interaction to look at the acquisition of skill through engaging with the world (Dreyfus, 1996). Most importantly, Dreyfus introduces the idea of affordance from ecological psychology alongside Merleau-Ponty's focus on the body as a locus of being in the world to develop a theory of skill acquisition. Ingold builds on this observation to develop a detailed description of how organisms in general establish ecological niches in the environment based on their positive affordances (Ingold, 1992; Ingold, 2000).

The key points to emerge from this are:

- The body is seen as a primary way of being in the world and as such is the vehicle through which people gain knowledge and develop understanding of how the world works.

- Organisms have a tendency to identify positive affordances in the environment that provide the conditions they need or desire.

- Organisms inhabit places that offer the most useful affordances and appear to have the ability to choose that that are most suitable and thereafter make the necessary alterations to improve the characteristics of the place.

It is no accident that Dreyfus has been a prominent critic of artificial intelligence (AI). The main plank in his attack on the more extreme claims of the AI project is that the early approaches, which relied primarily on rule-based systems, were incapable of replicating human thinking because they could never be situated in the world in the way that humans can because they live through the body as much as through the mind.

Smart systems and controls are an offshoot of the AI project, seeking to apply the tools and techniques of AI to control of the home. The idea of the intelligent home has been around since the 1950s (Solaimani, 2013), but has still to enter the mainstream. The development of technologies such as the *Nest* thermostat would seem to bring the ideal closer, but it is too soon to say how reliable that type of system could be for occupants beyond the current early adopters.

Smart users in action

The main study underpinning the discussion in this paper, *Conditioning Demand: Older People, Diversity and Thermal Experience*, was funded under the People Energy and Buildings initiative jointly supported by the UK's Engineering and Physical Sciences Research Council (EPSRC) and Électricité de France (EDF). This project investigated older people's experiences after new low carbon energy heating systems were installed in their homes. The project did not focus directly on the skills required to operate energy systems in dwellings, but the analysis of data revealed a high degree of awareness of the thermal environment and sophisticated practices for controlling thermal systems in their homes.

The *Conditioning Demand* project used qualitative methods to elicit participants' perceptions and use of heating technologies. The results reported in this paper were obtained from semi-structured interviews with the research participants conducted in different seasons, before and after the installation of the low carbon heating technologies.

This paper reports the findings of the interviews to eleven private 'rural' households in South Wales with retrofitted low carbon heating technologies: air source heat pumps, ground source heat pumps and biomass boilers. The age of the research participants ranged from 55 to 78 years.

Results

Although the sample size is small, and therefore the findings cannot be generalised, the results identify behaviour among occupants that are relevant to debates about automated controls and their effectiveness in delivering the expected energy savings.

The data suggest that older people have developed a sensitivity to thermal environments and exhibit different levels of understanding about how the home's thermal environment works. We detect two main types of understanding in users' responses. The first relates to an intuitive understanding of the natural environment and particularly how the weather conditions change during the year. The second type informs, rightly or wrongly, visible actions by occupants to achieve desired thermal states.

Understanding the microclimate in and around a building is an important first step to developing a more nuanced sensitivity to thermal environment. This lies at heart of the anonymous understanding exemplified by much vernacular architecture which is so revered by architects.

An intuitive understanding of microclimate is evident in the data collected across multiple occupants interviewed on this project: "It's south facing that way … and this is north, so it's always colder in the front of the house."

Others demonstrate a greater sophistication in their understanding, making the link between the microclimate and how it affects the internal environment:

> *Because what we've done is we've got cavity wall insulation,… we're south facing, we get all the solar coming through the windows, so the house is always warm when we get home at night… ."*

And this knowledge includes the systems as well as the building fabric:

> *We've got a thermostat on the wall there which is in the kitchen, but on reflection I don't think that is the best place to have had the thermostat, because on a Sunday lunchtime now, if we're cooking for a lot of people and it gets hot in here … you're going into … the dining room, and then you're wondering well it's bloody cold in here. So the thermostat being there isn't the best of ideas.*

However, the more interesting revelations from one interviewee is when she operates the building to achieve specific goals. In this case:

> *We've got five thermostats and they're all set at the same, they're on the ground floor, and what we do then is we leave all the upstairs doors open so that the heat rises and it transfers from downstairs to upstairs, so the radiators, if they're not performing particularly well, which they're not, in a sense it doesn't matter because heat's made up for by what comes from the ground floor, and it goes out and spreads itself over the house.*

This suggests a level of refinement in understanding that goes beyond familiarity with basic principles of the thermal behaviour of buildings. A different householder reasons overtly about how to bypass

limitations of the heating system and demonstrates a high level of awareness of the behaviour of the heating system:

> *So that radiator is always hot, right, whereas for example the radiator on the landing is often not hot at all because it gets very warm on the landing. So when it gets warm in a room the thermostat switches the radiator off, or stops warm water going through the radiator, so the thermostat must be sensing the temperature in the room, mustn't it?.... Because, for example, this, in our bedroom we have the thermostats turned down really low, so the room is much cooler, and then sometimes I go in if I want to do something up there, then I just turn them up and the radiators start belching out heat.*

People's understanding of how their thermal environment works informs the strategies to achieve comfort, including minor interventions, the use of additional devices for the provisioning of comfort (electric fire) and other components of the environmental system (curtains, doors). Elements of the building are not separated from the electronic systems.

> *We make sure all the windows are closed and the doors are closed. And we use the electric fire in the lounge...We do draw the curtains, some people leave their curtains in the evening, we do draw them to keep the heat in."*

However, there is a recognition that a change of system requires taking on board new knowledge and developing new practices:

> *... by only sort of heating the rooms you're in and shutting the, keeping the doors shut and all that kind of stuff. But with this, this is where we've got to learn I suppose, because it's, all of a sudden it's all sort of nice everywhere, and you can't, obviously we'll start, we'll put the thermostats lower in rooms we're not in and that kind of stuff, and that would be limiting, in a sense it is limiting you know, but what else you can do other than that I'm not sure."*

There is evidence of adaptation to unforeseen circumstances as for example in the case of an occupant who suffers an illness that temporarily changes thermal needs and the way that rooms are heated in the house:

> *I've turned [the heating] up in our bedroom for example, that sort of thing, and spent more time in here because this room's always warm. But that's partly because I've spent more time sitting watching television. I'm more or less back to normal now, but for a couple of weeks I couldn't do an awful lot and didn't feel that brilliant. So I was in here quite a lot and this is a nice warm room to be in if you're not feeling great ... it is important when you don't feel great, warmth is really important.*

This flexibility in operation is not available in current smart systems, and it is difficult to see how it could be incorporated.

Discussion and conclusions

In this brief paper it is difficult to argue a conclusive case for the efficacy (or not) of occupant engagement with their dwellings. However, there are signs that some occupants accept that they need to learn how the building works for them to achieve the desired thermal conditions. The field data suggest the following key points:

- People have developed sensitivity to thermal environments and have acquired some understanding about the factors that affect the thermal conditions, i.e. natural environment (orientation, climate conditions) and built environment factors (building fabric, configuration of spaces).

- People hold some level of understanding of the thermal environments and how their home works and they are willing and able to operate their homes to achieve the desired thermal experiences; for example, by operating windows and doors; by using curtain, draught excluders and other elements that are not traditionally considered components of the environmental system; by carrying small interventions i.e. building additional barriers to prevent heat gains/losses (porch, layer on attic).

- Occupants' skilful operation of their homes relies as on engagement with their surroundings through the body.

- When occupants' access to heat and controls is restricted, they may supplement the system using additional devices and appliances that could lead to additional energy usage, such as in the use of portable heaters and fans.

- Dwellings offer more capabilities than black box and automated controls: seasonal heating schedules, operation of a wide range of elements of the built environment (curtains, windows, internal doors), consideration of climatic conditions and natural environment characteristics to inform the control settings.

- While occupants refer to energy consequences of their actions, concerns about energy consumption and associated costs are often subservient to achieving desired thermal conditions.

Given that some occupants demonstrate skill and interest in operating their homes, the question to be asked is what is the acceptable balance between the ability of intelligent occupants (agency, ability and willingness of house occupants to modify the environment) and automated controls?

Systems that automatically control are often based on 'ideal' users and standardised routines of home living. However, these may embed simplistic models of how people operate their homes, their expectations of thermal conditions at home, and the variable patterns of home living. Even smart controls that claim to learn from routines of use need to be critically examined in the light of the complexities of home living: routines change in unexpected ways, different house users have different expectations—whose routine is it adjusted to?

The question of agency arises. Who should be in control? There are many ways to approach this question: from a perspective of authority and power – who has 'the remote'? From a perspective of competence – who can deliver the required conditions most efficiently? And from a perspective of cost – who can provide the most cost-effective solution?

The answers to these are unlikely to lead to a single solution. There is immense variety in the attitudes and behaviours and competences of occupants that influence the degree to which they want to engage with the systems in their homes. Some will want a 'fit and forget' solution whereas others may seek to continuously tinker with settings in ways that allow them to feel in command. And there will be hybrids, such as an 'off only' thermostat that requires no user interaction to switch the heating off but does not switch it back on automatically.

In conclusion, there is scope to develop smart systems that distribute their 'intelligence' between people and systems in much the same way that computers and other consumer appliances have learned to cede control to users if that is the best place for it to rest.

Further work

The observations drawn from the above suggest areas for further study. In many of the examples of behaviour cited it is not clear whether the occupants' actions led to improved thermal conditions or savings in energy consumption. This needs to be examined in greater depth. As a corollary of this, interviews imply complex chains of reasoning by occupants that suggest the existence of mental models

among them about how their homes and energy systems work physically. If we are to tap into users' expertise it would be fruitful to know more about how they understand the world.

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