Occupant interactions with low energy architecture: exploring usability issues[1]

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Introduction

Dwellings are becoming more complicated as designers seek to cut heat losses through the building envelope, wring the last drop of efficiency out of the heating system and eliminate unintended air flow between outside and inside. However, advances in technical design on their own do not guarantee reductions in energy consumption or carbon dioxide emissions resulting from the operation of the building. To achieve a high level of performance, occupants will need to operate buildings in very specific ways. Future homes, therefore, may be less like machines for living in, and more like complex systems of interconnected equipment that place significant cognitive, physical and psychological demands on those who inhabit them. Adapting to low carbon technologies will require changes to existing practices, new skills, and will offer new experiences—both good and bad—that will influence or even determine their adoption by users. The purpose of this paper is to consider how designers of low carbon buildings can increase their understanding of how occupants might interact with these buildings. The paper will draw parallels with the co-evolution of technology and users in the computing industry during the 1980s and examine the changing attitudes to 'the user' and the methods developed through usability studies to offer a better interactive experience. In fact, a description of the relations between designers, the computers they produce and the users who use them would not look out of place in a discussion about architects, buildings and occupants:

"… insiders know the machine, whereas users have a configured relationship to it, such that only certain forms of access/use are encouraged. This never guarantees that some users will not find unexpected and uninvited uses for the machine. But such behaviour will be categorised as bizarre, foreign, perhaps typical of mere users." (Woolgar 1991, 89)

The development of the computing industry in the 1990s suggests a move away from the "stupid user" attitude—which attributes all system failures to the ignorance of users (Kuutti 2001)—towards recognising the validity of multiple, different perspectives on technology (Winograd and Flores 1987, Nielsen 2001). Users are viewed less as passive recipients who should instantly adjust their lives to follow the dictates of the new technology and more like active individuals with legitimate goals, aspirations, needs and emotions. As in product design and computing, it is no longer acceptable to place all of the blame for malfunction on users. The example of a contemporary approach to washing 'efficiency' shown in Figure 1 reminds us that system designers can get it wrong too. So, it is misleading to blame occupants for all failures in the energy performance of buildings if the interface between people and buildings, and the systems they contain, has been poorly conceived and executed. Furthermore, meanings of designed artefacts also depend on their physical, temporal, geospatial and social contexts. Many user activities only make sense against the backdrop of specific situations.

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Figure 1: automatic for the people? On/off and temperature control has been removed from users, so that a simple tap now needs warnings.

The paper has three main objectives:

- To review the advances in technical systems developed to reduce carbon dioxide emissions in dwellings.
- To briefly review previous studies of people's interaction with energy systems in dwellings.
- To summarise some methods and models emerging from usability studies that might fruitfully be applied to architecture

The paper begins by considering new technologies that are being installed in low carbon and *Passivhaus* designs in the UK. This is followed by a discussion of some issues emerging from previous studies of occupants' interaction with heating systems and controls. The paper then shifts its attention to usability studies and a discussion of some concepts that have been used to characterise and explain users' interactions with devices and computer systems. Finally, the paper introduces the concept of affordance and argues that it can help us understand how to design dwellings and systems that will achieve a better fit between occupants' comfort goals and carbon emissions reduction targets.

The technology of low carbon buildings

Global, European and national targets have established ambitious timescales for reducing carbon dioxide emissions resulting from the operation of buildings. To meet these there are essentially two broad strategies: either decarbonise the energy supply; or reduce the demand for energy to the point where it is negligible or capable of being met by current carbon neutral technologies. Built environment professionals are focusing on the latter, seeking to design buildings that minimise energy demands for heating, cooling, lighting and power by preventing unwanted heat losses (and summer heat gains) through high levels of insulation, low ventilation rates and heat recovery. Existing approaches, however, have tended to treat the problem of reducing demand in buildings as a straightforward engineering exercise with well-defined inputs and outputs. The resulting designs, however, in seeking to advertise their green credentials may be far removed from what is familiar to many people, as shown in Figure 2.

Figure 2: The Stewart Milne Group's Sigma Home at the BRE Innovation Park, Garston—low energy design introduces new appearances and ways of operating a home.

The German *Passivhaus* standard is emerging as a popular standard for new low energy buildings and is attracting much interest in the UK and elsewhere. While *Passivhaus* is, strictly speaking, not necessarily a low carbon standard—it is oblivious to the source of the energy it requires—it is seen as a fruitful starting point for low carbon design, on the assumption that a suitably decarbonised energy supply can be found to meet the residual energy demand. *Passivhaus* is interesting because it is derived from the fundamental principle that it should be possible to meet the heating requirement from the air required to satisfy fresh air requirements alone. The incoming air, therefore, is heated to the temperature needed to meet the demand, which places an upper limit on the peak heating load, since there is a practical maximum temperature for the incoming air, for comfort and safety reasons. More formally, *Passivhaus* establishes two main requirements:

- the total energy demand for space heating and cooling should be less than 15 kWh/m^2/yr of treated floor area; and
- the total primary energy use for all appliances, domestic hot water and space heating and cooling should be less than 120 kWh/m^2/yr

As noted above, there is a further requirement: the peak heating demand must not exceed 10 W/m^2 if the temperature of the incoming air is to kept below a practical maximum of 40°C.To meet these requirements, a building typically must achieve wall U-values of 0.15 W/m^2 K or lower. Window U-values will normally be less than 0.8 W/m^2

K, although there is some evidence to suggest that this figure may be relaxed upwards in milder climates (Tweed and McLeod 2008). With this level of super-insulation, is safe to say the high temperature, point heat source which has been part of domestic interiors for many years is likely to disappear in the *Passivhaus* dwelling as it would always supply too much heat. More critically for this discussion, the building must achieve high levels of air tightness and rely on controlled mechanical ventilation with heat recovery (MVHR). Whilst technically desirable, the absence of 'unwanted' air leakage around openings, as indicated in Figure 3, will represent a new experience for many occupants and will require adjustment. The *Passivhaus* standard is roughly equivalent to the energy requirements of Level 4 of the Code for Sustainable Homes. Levels 5 (zero energy for heating, cooling, and lighting) and 6 (like 5 but including zero energy for appliances) are likely to require even greater sophistication. On paper, these measures are unremarkable, but they suggest quite a different thermal environment for the home, introducing significant technological perturbations to existing systems and practices for achieving thermal comfort. These changes are also likely to impinge on other aspects of life in the home. Unfortunately, the everyday operation of these systems is rarely considered, mainly because those who advocate their use are 'converts' who have the expertise, skills and motivation to operate them to achieve optimal energy performance. However, there is strong evidence to suggest that the interpretation of even such simple devices as the room thermostat is not obvious, as we shall see in the following section.

Figure 3: testing uncontrolled air leakage around a door frame using a smoke pencil. The strict control of air movement into and out of a dwelling represents a new experience for many builders and occupants, and is not always seen as a self-evident gain.

Occupant interactions with energy systems in dwellings

Interest in how people use buildings, and especially how that correlates with energy consumption, is growing. Until recently, studies of buildings in use were rare and, when they have been carried out, they are often a form of post-occupancy evaluation, which rarely aims to inform future design. Longitudinal studies carried out over years, months or even a complete heating season are less common. However, there are a few important studies that lay the groundwork for more detailed investigation.

The Abertridwr monitoring project

The Welsh School of Architecture carried out one of the earliest detailed studies of occupant behaviour and energy consumption in the early 1980s (O'Sullivan and McGeevor 1982, Jones et al 1980). Although others had carried out detailed physical monitoring of unoccupied buildings, this three-year study of 39 houses in Abertridwr, South Wales, combined social and physical monitoring and paid careful attention to the impact that occupant behaviour had on internal environmental conditions and energy consumption.

In a paper based on analysis of how people actively pursue thermal comfort, McGeevor (1982) contrasts results from laboratory based, climate-controlled studies with *in situ* observations of how people create and judge the quality of their thermal environments. The paper notes that the three components of an implicit theory of human action embedded in energy policy of the time were that the goal of human action in this context was to achieve thermal comfort as determined by laboratory studies, that comfort had an economic cost which obeyed the normal 'laws' of economics and that to achieve comfort economically the individual needs information and knowledge. The paper subsequently questions all three of these assumptions about human action and suggests how they might be revised.

Firstly, thermal conditions measured in the field were often widely different from those suggested by laboratory studies and by existing theory. A key observation is that people judged thermal environments relative to their habitual experience of thermal conditions such that overheating was considered acceptable because it exceeded the crucial requirement of keeping warm during the cold British winter. One individual judged his heating system to be "marvellous" because it was capable of creating "sweltering" conditions (McGeevor 1982, 104). Second, the influence of the cost of energy on consumption in these homes was complex. Although residents were generally keen to reduce their fuel bills, in some cases, cost was ignored in favour of creating conditions that were in excess of what would normally be predicted as comfortable. This is explained by "short term hedonism and passive acceptance of fate" which suggests pricing of fuel to deter wastage and reduce consumption may not work. Finally, the study revealed an acute lack of understanding of how heating systems and controls worked but a well-developed body of folk wisdom about heating and fuel bills constructed and maintained by a local social network.

Occupants understanding of room thermostats

Drawing on this work and supplementing it with his own observations and measurements, Kempton (1986) suggests two folk theories of room thermostat behaviour that people rely on when operating their heating systems. The first is the feedback theory, which is largely consistent with the engineering definition of thermostatic control, in which the thermostat shuts down the heat supply when the monitored room temperature reaches a value (the set point) indicated by the thermostat setting (though not necessarily identical to it) and switches it on again when the temperature drops below a lower specified temperature.

The second folk theory describing thermostat behaviour is the valve theory, which assumes that the thermostat controls the flow of heat from the boiler by narrowing and widening an opening in the heat supply pipes or ducts. The valve theory is the more interesting precisely because it is at odds with the internal workings of the heating system which is only capable of supplying heat at a constant flow rate. The valve theory leads occupants to adjust the thermostat setting frequently to respond to changing conditions and requirements. Occupants, for example, will often turn the thermostat down before going to bed, thereby providing their own night setback for the heating system. However, when coupled with observations of operations normally performed in the home to control heating, the valve theory may be most effective for occupants because it offers the flexibility of a warmer than 'normal' house for people coming in from the cold outdoors, which a house at a uniform temperature would not. So, while the valve theory may be 'wrong' from the designers point of view, from the occupants' it can be more efficacious (and possibly energy efficient): "A theory that is useful for designing thermostats is not guaranteed to be a good theory for using them." (Kempton 1986, 87).

The study at Abertridwr was mainly concerned with occupants' operation of and understanding of room thermostats and thermostatic radiator valves (TRVs). Similarly, Kempton's work focuses on the lowly thermostat, which is still a vital component of any heating system. Since then, there have been significant increases in the level of technology used in buildings to monitor and control heating and ventilation systems, buoyed by a strong belief in the ability of technology to alleviate environmental problems.

Mechanical ventilation and heat recovery (MVHR)

As noted above, the exacting constraints of minimising heat loss through uncontrolled air infiltration and excessive ventilation is usually addressed using mechanical ventilation and heat recovery (MVHR). However, the novelty of this technology causes confusion about how it should be operated, even among those with a keen interest in low carbon design, as the following entry on the Green Building web-based forum suggests:

"HRV is best used in the heating season and in hot summer weather. In the spring and autumn opening the windows is better as no energy is used. During the summer in a well insulated building keeping the doors and windows closed for as long as possible and using HRV for ventilation is a viable strategy as it will improve thermal comfort. It should be cooler inside than outside and you want to keep it this way. Many come with a summer bypass but you don't really want this as during the summer you want to cool the incoming air as the internal temperature should be lower than the external air temperature." (GreenBuildingForum 2007).

Furthermore, there is anecdotal evidence to suggest occupants do not always accept MVHR technology. Occupants have been known to switch off 'unnecessary' fans and block air vents. It is important to emphasise that these components of the low energy house are part of a much larger network of equipment that occupants must grapple with in the pursuit of their comfort and other goals. Any analysis of occupant-component interaction, therefore, should look beyond the immediate interface between an individual and the device to follow the connections to other parts of the building. For example, occupants will also need to get accustomed to unfamiliar heat distribution networks and appliances from using heat pumps and underfloor heating instead of high temperature boilers. New forms of metering and monitoring, as shown in Figure 4, will inevitably change the way people operate their homes in unpredictable ways.

Figure 4: new types of 'smart' electricity and gas meters are intended to give occupants greater information about their consumption and thus encourage them to adjust their usage accordingly. (Source: PRI, www.pri.co.uk. All rights reserved.)

Thermostats and other electro-mechanical components of the heating and ventilating system in buildings are obvious candidates for studying human-technology interactions. But in principle, occupants may choose to operate any easily configured part of a building to effect changes to the internal environment, and there is renewed interest in making more of the building fabric configurable. Figure 5 shows traditional and contemporary versions of shutters. In the second example, the 'simple' window offers four separate control elements: curtains, shutter, blinds and opening light. These operable elements and their possible configuration by occupants open up new areas for study and underline the assertion that buildings can be seen as equipment rather than as static objects.

(a) (b)

Figure 5: traditional shutter over a window in Venice; contemporary example of a window at BRE Innovation Park.

Even for such seemingly intuitive devices there is abundant evidence that occupants entertain very different ideas about how these should be operated. This can be confirmed by counting the number of occupied rooms in dwellings in which the curtains are open long after dark during the winter. Similarly, occupants frequently open windows during daytime on hot days to try to cool the building and close them at night, when the building could benefit from the cooler night time temperatures.

Studies of human-technology relations

There is an established body of literature addressing spatial and topological aspects of human interaction with and experience of architecture and the built environment—most notably in the field of environmental psychology (Lee 1976), but also in critical and phenomenological studies of architecture (Rasmussen 1962, Bachelard 1964, Pallasmaa 1996). However, in these the occupant or observer is treated mainly as a passive receptor of sensor information and so there is very little research that considers buildings and their systems as operable equipment with which occupants interact to modify internal conditions, apart from the work on thermostats discussed above. There are interesting accounts of thermal comfort as a social and cultural phenomenon and how technologies help to disrupt established comfort practices and thereby define new ones (Shove 2003). Such studies reveal a rich history of social and technological change and provide an important perspective on many of the contemporary issues designers and technology developers currently face. What is missing, however, is the detailed understanding of how individuals perceive and operate devices, components and systems as part of a nexus of equipment that constitutes the modern home. Thus, while edifying, these accounts of historical social trends rarely delve into individuals' experiences of using these technologies and as McCarthy and Wright suggest: "the individual experiencing subject has largely been lost. As a consequence, the dialectical tension is minimized and the social reified to the point where individual experience is rendered irrelevant. … in traditional theorizing about practice the richness and messiness of experience becomes subordinated to the technical in both technology and theory." (McCarthy and Wright 2004, 46). There can be little doubt that an individual's interaction with a technology is in large measure shaped by social and cultural forces, but to omit his or her direct experience from the account leaves many questions about the nature of the technology unanswered.

The absence of detailed studies of individuals' interactions with built environment technologies may be mitigated by research on usability aimed at improving user experience of manufactured goods, consumer devices and software. Over the past twenty years there has been much research into how people perceive and interact with computer systems and other forms of technology. There are possibilities for transferring methods and results developed in these areas and applying these to architecture. For example, the field of human-computer interaction highlights the need for extensive testing of designs with potential users during the development of a software system (Landauer 1987). This has given rise to novel methodologies such as the Wizard-of-Oz method, in which the computer is simulated by a hidden person, and "synthesis by analysis" which uses three methods to inform the design process:

- failure analysis: systematic observations of where the technology or people "go wrong;" individual difference analysis: characteristics of people who find various systems or features easy and hard to learn or use are investigated;
- time profiling: measuring the parts of tasks to which people devote the most time may reveal difficulties.

Failure analysis in particular looks as though it could be developed to understand what happens when interaction between people and buildings breakdown. Possible directions emerge from studying similar accounts of breakdown in Heidegger, Leontev and Dewey (Koschmann et al 1998). This will be investigated in a future paper.

There is a wealth of experience in developing methods and tools with which to investigate users' experiences with software, hardware and related technologies—for example, between designing systems that are easy-to-learn and those that are easy-to-use. Too much to summarise here. However, there is one key concept that can offer a useful approach to designing for multiple, diverse users: J.J. Gibson's concept of affordance.

Affordances

Donald Norman, one of the pioneers of usability studies, popularised the concept of affordance in usability studies (Norman 1988) but it was introduced by the ecological psychologist, J.J. Gibson:

"An affordance is neither an objective property nor a subjective property. It is both. An affordance cuts across the subjective-objective dichotomy and in doing so highlights the inadequacy of this dualistic thinking. It is equally a fact of the environment and a fact of nature. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer." (Gibson, 1979, 129)

The concept has subsequently been developed to describe an organism's skill acquisition by Dreyfus (1996) and Ingold (2000). Briefly, an affordance is an emergent property of interactions between organisms and their environments. The concept recognises that the potential uses of an object or tool are not independent of its different users or the context in which it is to be used. An example provided by Dreyfus (1996) may clarify this: a chair 'affords' sitting because "we have the sort of bodies that get tired and that bend backwards at the knees … [and because] Western Europeans are brought up in a culture where one sits on chairs."

Gibson was adamant that his ideas could benefit the discipline of architecture and he lamented the lack of any serious attempt to develop this or similar ideas in architecture:"… a glass wall affords seeing through but not walking through, whereas a cloth curtain affords going through but not seeing through. Architects and designers know such facts, but they lack a theory of affordances to encompass them in a system." (Gibson, 1979, p.137)The potential for developing such a theory is hinted at by Ingold in his discussion of affordance, perception and skills. Ingold (2000) argues that it requires specific skills to release affordances from an environment. Thus the relational links between an organism and its environment are reinforced. The affordances afforded by an environment can only be released to an organism which possesses the knowledge and skills to be able to exploit them. Again, this is less intuitive at the scale of environments but more so when we consider devices or tools.

The use of any tool, therefore, requires a set of skills. Individuals will be more or less adept at using these tools, and their skill level will vary depending with time and, for most, with the training they receive and how much practice they get. Some people will display a 'natural' talent for using specific tools.

The connection between affordance, skill and cultural context is explained by Dreyfus, who enlists support from Merleau-Ponty:

"J.J. Gibson, like Merleau-Ponty, sees that characteristics of the human world, e.g. what affords walking on, squeezing through, reaching, etc. are correlative with our bodily capacities and acquired skills, but he then goes on, in one of his papers, to add that mail boxes afford mailing letters. This kind of affordance calls attention to a third aspect of embodiment. Affords-mailing-letters is clearly not a cross-cultural phenomenon based solely on body structure, nor a body structure plus a skill all normal human beings acquire. It is an affordance that comes from experience with mail boxes and the acquisition of letter-mailing skills. The cultural world is thus also correlative with our body; this time with our acquired cultural skills." (Dreyfus 1996, 8)

Affordances are realised through the *effectivities* of organisms. As noted above, the affordance of providing a seat can only be achieved by organisms who have the capability to exploit the shape of a chair. An effectivity can be a physical property of an organism or a psychological propensity, a skill or even a cultural norm to which a person adheres.

The concept of affordance can be applied to such tools as room thermostats, thermostatic radiator valves, timer controls and even shutters and blinds. Treating a blind, for example, as a set of potential affordances rather than as performing a self-evident function entails the effectivities and competences of those who are seeking to regulate their environments in the blind plays an important but complex part in shading and ventilating enclosed space. Affordance, therefore, reminds us to treat the purpose of buildings and their components more abstractly as offering tools and equipment that occupants appropriate to achieve their goals, comfort-related or otherwise.

Concluding remarks

This paper has addressed the issues surrounding the increasing technical sophistication of buildings, which is set to increase as designers recommend technological solutions to problems of carbon dioxide emissions and energy consumption. It has been argued here that technical solutions alone will not deliver the savings their designers seek unless there is a good fit between the technology and occupants. It is also argued that it is no longer acceptable to place the 'blame' for poor environmental and energy performance on occupants. Just as the computing industry slowly learned to develop a more holistic, research-driven approach to developing hardware and software, so architects and others engaged in designing the next generation of low carbon buildings need to consider and involve the occupants from the outset. The user is not the problem.

The brief review of approaches suggests architecture might fruitfully adopt methods pioneered in human-computer interaction research and in product design. The notion of affordance is of particular relevance to design (Zaff 1995). It encourages designers to adopt a more ecological approach that recognises the multiple perceptions of what an environment affords and the skills and understanding need to liberate the potential of tools and environments. In this view, people are seen as organisms with cultural as well as physical and psychological characters and needs. Buildings become more like habitats in which some people thrive and some, with different effectivities, do not. Designed environments are places where people seek out, perceive and exploit affordances according to their individual effectivities. An ecological approach, therefore, is a reminder to treat architecture as part of a larger whole, recognising that the outer skin of the building envelope is often not the most natural boundary for considering the social life of buildings. The parallels between architecture and computer system design are illuminating but it would be wrong to give the impression that everyone on the computing industry shares the view that system development needs to become more user-focused. Woolgar's record of discussion with technical support in a computer company suggests otherwise:

"It is in this light that we might best understand the occurrence of 'atrocity stories' – tales about the nasty things that users have to done to our machines. Such tales portray nastiness in terms of users' disregard for instructions (violation of the configured relationship users are encouraged to enter into) and their disregard for the case (violation of the machine's boundary)." (Woolgar 1992, 89)

There will always be a core of technical designers who perceive the end-users as obstacles to achieving their goals. History, however, suggests that it is generally less expensive in the long wrong to work with users at an early stage rather than accommodate their unmet needs at a later stage.

It is important to remember too that making systems easier to understand and to use is not the only issue in encouraging users to follow a preferred course of action. As Nielsen notes:

"It is not a question of whether users are capable of overcoming complexity and learning an advanced user interface. It is a question of whether they are willing to do so." Nielsen (2001).

Similar problems are likely to emerge in debates about whether occupants will choose the "right" course of action at critical junctures in operating their homes. This opens up a new area for debate—the extent to which design should seek to encourage or promote particular courses of action, which is highly topical now (Thaler and Sunstein 2008). It is perhaps no coincidence that politicians are showing interest in this new field of behavioural economics (Lewis 2008) as western society enters a new phase in which design is seen as an important tool for the impending massive social change required to meet environmental and energy targets. But that is for another paper.

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