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Designing for comfort – usability barriers in low carbon housing

Authors: Fionn Stevenson[1], Isabel Carmona-Andreu[2], Mary Hancock[3]
[1] University of Sheffield, UK [2] CA Sustainable Architecture, Newbury, UK [3]Oxford Brookes University, UK

Abstract
Recent research into occupant behaviour in low carbon housing indicates that for the same type of house, energy and water use can vary by up to fourteen times between different households. This paper assesses the usability of 'touchpoint' controls in two contrasting building performance evaluation case studies. It situates the discussion within socio-technical theories of habit, practice, and emergent properties in products which facilitate easy and rewarding learning and thus durability. Key findings reveal poor design features and occupant lack of understanding including specific aspects of centralised mechanical heating and ventilation systems and some windows. Lessons learnt and recommendations are highlighted for design guidance and policy consideration, including a more user-centred approach to design and testing of products and key areas of focus in relation to delivering low carbon homes that are more controllable and therefore more comfortable.

Keywords: low carbon housing usability controls

Introduction

All new-build housing in the UK is required to be 'zero-carbon' by 2016 (DCLG, 2007) meaning all regulated carbon emissions, associated with heating, ventilation and lighting, must be minimised and offset if necessary. For the same type of low carbon house, regulated and unregulated energy and water use can vary by three to fourteen times between different households (Gill 2011, Pilkington et al, 2011). Research approaches tend to focus on occupant motivation, behaviour and practices (Crosbie 2010) or building performance evaluation (BPE) which measures user responses (Firth et al, 2008). Usability design factors in relation to the design of the home are often overlooked in BPE (Blakstad et al 2008) even though there is a long history of research on human/control interfaces in industrial design studies (Dix, 2010).

Recent reviews on the use of thermostats in homes, for example, point to usability issues but generally fail to engage in depth with the various design factors involved (Meier et al, 2011, Shipworth et al, 2010). Getting the design for usability right is a prior requisite to changing human behaviour because communicating a 'clear design intent' is critical to user's understanding of the meaning and function of building features and systems (Leaman and Bordass, 2007). Equally, many user actions become habitual as a strategy for efficient information processing to protect against information overload (Jackson, 2005). These habits can effectively bypass thoughts about values and motivation and are highly dependent on the usability of controls.

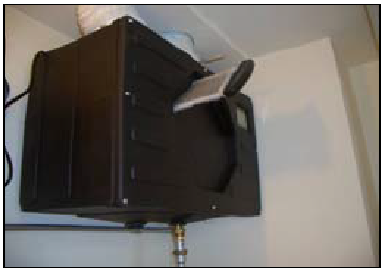
This paper assesses the usability of 'touchpoint' controls in two new build housing case studies. The wider aim of this paper is to explore the role that usability studies play in the evaluation of low carbon housing performance, which 'touchpoints' are critical and what the relationship is between usability and user behaviour and practice.

Evaluating usability

To evaluate the usability of products and systems in low carbon homes a multi-modal method is required (Yin, 1994). The multi-modal method used to evaluate the case studies in this paper combines evaluation of the functional design of controls for end users (Bordass et al, 2007) with typical building BPE methods including: a design and construction audit which reviews all drawings and specifications, 45 minute semi-structured interviews and walkthroughs separately with the occupants, representatives from the developer and the design team, a review of installation and commissioning of services and systems including measurement of mechanical ventilation flow rates, Building Use Studies occupant questionnaires (Cohen et al, 2001), an evaluation of written and procedural handover guidance for occupants and an evaluation of the usability of all user control 'touchpoints' – discussed in detail next.

A functional usability assessment matrix was developed which visually rated critical control features (Figure 1) and issues related to them, drawing on six functional design criteria (Bordass et al, 2007).

2.3 MVHR Filters



Description and location

Greenwood Filters within MVHR unit

Usability criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Labelling and annotation					
Ease of use					
Indication of system response					
Degree of fine control					

Comments

No labelling whatsoever - so if you are not familiar with the unit you don't know they are there. The filters are easy enough to take out and clean (in some units more than others as we have seen them clashing with the door frames). Other than experience there is little indication of when they are getting clogged up - a warning light might be useful? The need to position the unit carefully is clear - the manual also explains that the whole front panel comes out to access the heat exchanger filter every two years - this operation in some units on site is very difficult due to clashes with doorframes and very poor location of units high up in narrow spaces.

Figure 1: Extract from Usability Assessment Matrix

The matrix utilises a five point scale 'traffic light' assessment code combined with textual evaluation and a 'telling' photo of the product concerned. The user control 'touchpoints' represent everything in the home that the user physically touches in order to provide environmental and comfort control. The 'touchpoints' are divided into 7 categories:

1. Heating and water controls
2. Mechanical ventilation controls
3. Electrical equipment controls
4. Kitchen appliances
5. External skin touchpoints
6. Water services controls
7. Miscelleneous controls

Each 'touchpoint' control product is initially evaluated by an expert researcher. The category as whole is then evaluated in terms of functional relationships between the components in that category. These functional assessments are then cross-related to the wider practice-related and emergent issues identified through user and design team interviews/walkthroughs which deliberately consider the same control issues. A fresh 'expert eye' is often used in BPE studies to carry out initial troubleshooting (Leaman et al, 2010) because inexperienced researchers can miss vital clues and users may have adapted to the control problem or forgotten about it. By cross-relating expert research analysis with subsequent user evaluation, a richer picture is formed based on Real World research (Robson, 2011). This method also reveals contradictions between experts and users, providing useful reflective learning for both and is illustrated in the case study evaluation which follows next.

The housing developments

The two chosen case studies reflect the extreme scales of development and types of private housing developer. This makes them 'paradigmatic' case studies which can be generalised from (Flyvbjerg, 2006). The characteristics of the two case studies are described briefly below:

- *Large developer - Crest Nicholson*
  Operating nationally, their case study development in Kent was conceived and designed in 2006 and completed in early 2011. It was based on the winning design entry for an *Affordable £60K Home* in the UK government's *Design for Manufacture* competition and designed to achieve an Eco-Homes Excellent level[1]. The low carbon technologies deployed included a roof lantern, mechanical ventilation with heat recovery (MVHR) system and condensing boiler. The BPE project evaluated one end terrace house in depth together with further evaluations related to the development process including questionnaire responses from 42 homes out of 150 on the site, four household interviews and walkthroughs, and one home demonstration evaluation.

- *Small developer - Ecos Homes*
  Based in the South West of England, their case study development in a small Somerset village was substantially completed in 2009. It involved a substantial number of low carbon technologies deployed on two detached houses and three terraced homes situated around a courtyard. It was the first CSH Level 5 private housing development to be completed in the UK. The low carbon technologies deployed included a 2 kWp photovoltaic system, solar thermal panels, a 11.3 kW wood pellet boiler, an indirect, unvented 250 litre domestic hot water cylinder with immersion heater, a mechanical extract ventilation (MEV) system and rainwater harvesting system. The BPE project evaluated one terraced house in depth together with further evaluations related to the development process including questionnaire responses from the three occupied houses on the site, three household interviews and walkthroughs, and one home demonstration evaluation.

Functional use of control products

The best scoring control products for functional use in the small development were the bathroom taps, shower temperature control, electric oven, and consumer unit (Figure 2). The worst scoring products in the small development were the MEV extract terminals, MEV control panel, woodstove boiler fuel storage area and clothes drier, with the hot and heating system controls not far behind. In the large development, the various MVHR control products performed worst together with the boiler unit controls and the television sockets.

Comparing the functional usability in the two developments revealed that the heating and ventilation controls performed worst overall on average by a significant margin in both cases. The rest of the controls for the small development indicate a good overall score in most cases, except for the miscellaneous controls which only achieved a fair score. In the case of the large development, the rest of the controls also scored a good response overall except for the external fabric controls.

[1] Eco-Homes was the precursor to the CSH standard.

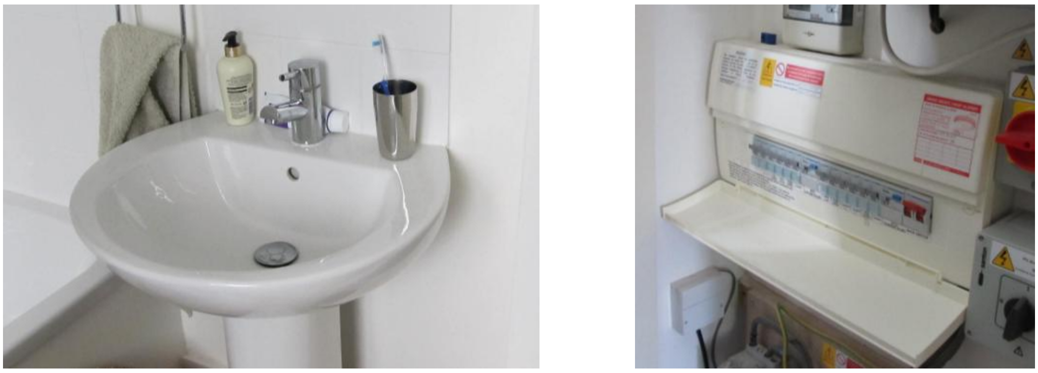


Figure 2: Bathroom taps and consumer units proved highly usable

There are a number of user, developer, design and construction factors which are all contributing to the usability issues above in an interrelated way, as identified from the associated findings in the case studies. Two key areas are focused on next in terms of emergent practice issues.

Mechanical ventilation

In the large development occupants reported opening windows for ventilation and getting frustrated when they could not get adequate cool air or hot air from the MVHR system. They did not understand the MVHR system and expected it to heat the house, which it could not. In one of the dwelling interviews the occupant complained about cold air from the vent in the dining area; an inspection revealed the boost switch was on without the occupant being aware of what it was meant for. The boost switches were placed inaccessibly high up on the rear wall of the MVHR cupboard (Figure 3) when they should have been installed near the cooker or bathroom to facilitate user response related to these areas.

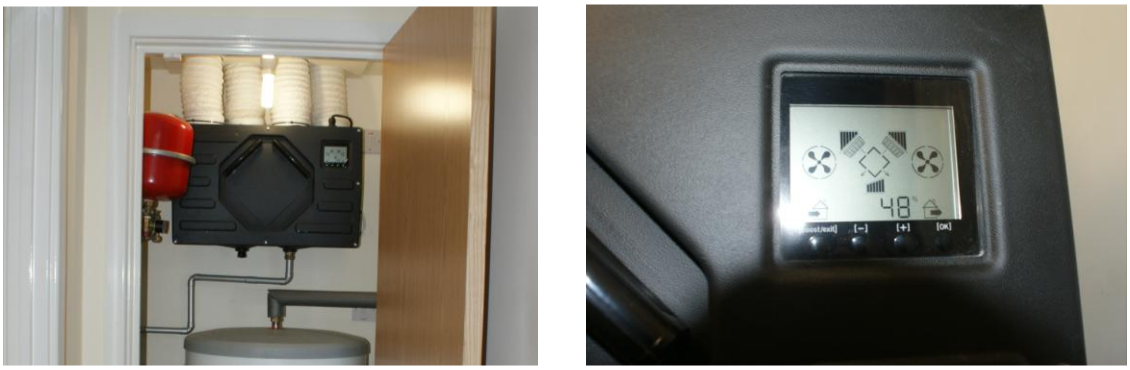


Figure 3: Boost switch and controls on right at top of MVHR Unit

The occupants also tended to fill the MVHR cupboards with shelves and use them as storage making access to the boost switch difficult. Although the MVHR unit displayed a regulated warning symbol to indicate that the heat exchanger filter should be cleaned at fixed intervals the occupants did not necessarily know this or how to carry out the task leading to filters left clogged up (Figure 4).

The MEV system in the small development required trickle ventilators to introduce fresh air. However, this cooled the house down in a way that one household found unsatisfactory because it lowered room temperatures by 1.5 deg.C and so they closed these. At the same time trickle ventilators were erroneously installed in rooms containing MEV extract terminals.

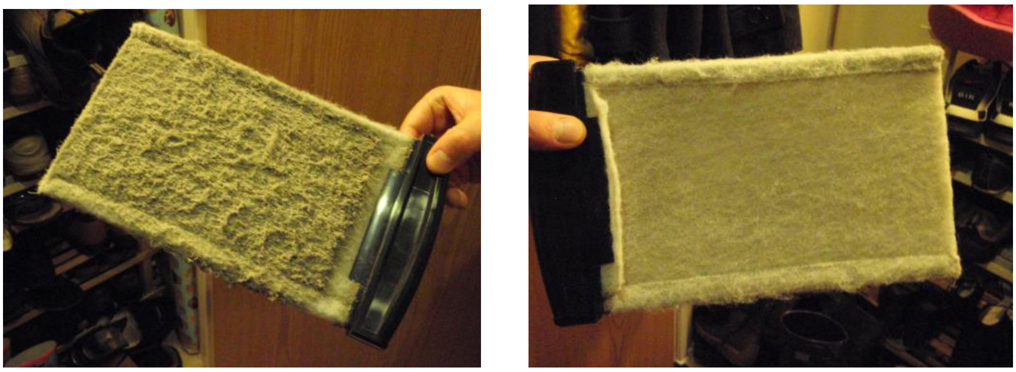


Figure 4: Before and after photos of clogged up MVHR filter following cleaning

Controls were not provided for the MEV system by the developer and adjustment of fan speeds meant re-wiring the fan terminal block located in the roof loft space. The fan speed had been incorrectly set by the installer to level 1, which is the night set back or holiday mode, and is ineffective for general ventilation purposes. The same household found that on rewiring the fan speed to level 2, it was too noisy upstairs as they like to meditate so they reverted to closing the trickle vents and rewiring the extract back to level 1. The ventilation unit would have been less noisy if there had been less use of flexible ducting. The flow rate measurements revealed that the system was delivering only 25% of the required performance due to poor installation practices – something which the occupants had little control over.

Heating and hot water

Both developments had heating and hot water systems that had a number of complex interactive controls. In the large development, the boiler control interacted with the programmer, room thermostat and thermostatic valve controls which were all located in obvious positions. There was relatively little comment on the heating controls and occupants were happy enough with the handover process. By contrast in the small development, the location of heating and hot water controls services related to the solar panels and immersion heater in roof spaces made their adjustment inaccessible (Figure 5). The charging unit for the heating distribution circuit had three pump speed settings and should have activated during firing of the boiler only. Instead, the unit operated continuously and had been set to the highest speed. The occupants in one house believed that this pump on the heating system was intended to run continuously because this was information they had received from the developer. The resulting noise nuisance generated by the charging unit led them to switch the unit off at the mains, even when the pellet boiler was on and despite thinking that this might lead to a system breakdown. The wood pellets for the boiler had to be fetched from private garages next to a communal area as there was no storage provision in the home.

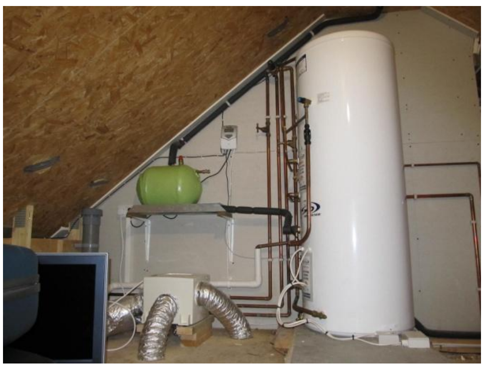


Figure 5: Heating controls in roof

Figure 6: Woodstove

Because the immersion heater was expensive to use to heat the large water tank and had poor controls and access in the small development, the occupants in one house preferred to light the pellet boiler even in summer conditions, if the solar hot water was not sufficiently hot. They felt that the remote display panel indicating solar collector temperatures, hot water cylinder temperatures and the amount of energy generated by the photovoltaic panels did not offer much interactive learning. For these to be useful to them, they would have liked some means of benchmarking the relative performance of each energy input, e.g. the proportion of energy generated by the solar panels vs. the wood pellet boiler. Occupants discovered that there was more maintenance required than expected for the wood pellet stove and adapted to the requirements (Figure 6). The stove needed cleaning two or three times a week– they kept a dedicated vacuum for this purpose.

Three underlying factors have been identified to explain why all these usability barriers exist: habits, guidance, and learning. These are discussed next.

Habits

In the small development, occupants had a habit of keeping the MEV ventilation rate low because of the noise resulting from too much flexible ductwork, despite knowing it was on the wrong rate. They also switched off the charging pump for the heating distribution system, despite expecting this might damage the system, because it was too noisy and they had been told it needed to be on all the time when it didn't, and was in fact incorrectly set to be on continuously by the installer. The domestic installer left the installation/user manual for the cylinder and the Benchmark commissioning log book in the loft adjacent to the cylinder. This institutionalised installer habit did not help the occupant as the cylinder was situated in the relatively inaccessible roof space.

In the large development, the installation engineer inadvertently reduced the supply and extract fan speeds and adjusted terminal valves such that the values, because he expected the display on the commissioning air flow instrument to match the manufacturer's notional design values. He did not check the calibration of his instrument, which happened to be incorrect. Consequently, the design flow rates were set too low on the large development and occupant responses and habits were dictated by this functional flaw. Some occupants habitually did not use the MVHR boost switch or clean the filters because they were not aware of them or could not use them easily.

Guidance

In the large development there was a significant misconception in the handover process about what the MVHR actually did. The Home Demonstrators thought the MVHR would "balance" the heat of the house, when in fact it cannot do this on its own, as supplementary heating is needed. This led occupants to think that the MVHR was a heating source in itself. The fact that the roomstat controls the temperature setting and the TRVs were subservient to it was not fully understood by Home Demonstrators. The demonstration tour did not include an explanation of how to set the boiler programmer. There was no demonstration of how to get into MVHR unit for cleaning the heat exchanger filter and occupants had no hands on experience of any of the heating or ventilation controls. Additionally, the guidance literature on these controls was overly technical and did not facilitate easy learning through bespoke graphical illustrations of equipment situated in the home. Although occupants appeared content with the handover process, it became apparent through research undertaken that afterwards they still did not actually understand some of the environmental control systems in their home.

In the small development there was no mention of an MEV system in the sales brochure, implying that a passivent system was still being deployed when this had in fact been changed during the build process. This caused significant occupant confusion. The developer expected suppliers to carry out their own handover with the occupants. However, tradesmen on the ground were often unfamiliar with the installations they were asked to provide. Occupants claimed that they had not been offered any instruction on the use of the ventilation system and believed that the trickle ventilators were unnecessary, i.e. the mechanical system provided the total ventilation requirement. Therefore, the essential trickle ventilators remained closed, leading to poor air quality. There was no hands-on experience of windows operation and the hot water tank and ventilation system in the loft were not shown due to lack of easy access during the handover. The handover took place on the day they moved in, which was not ideal for occupants as there was too much to think about. As a result, they were not satisfied with the handover process and felt it was not thorough enough. They also felt the information pack was too technical and not aimed at the end user.

Learning

The two case studies demonstrate that the know-how needed in order to engage with low carbon technologies is missing at the design, developer, installer and occupant levels in new build housing development. In the case of small developers, a major challenge lies in the affordability of employing expert consultants on design teams to integrate the complexity of mechanical low carbon technologies. There is also an urgent need for developers to have fully trained customer relations staff who understand the complexities of new low carbon technologies when demonstrating these to occupants, in order to avoid subsequent sub-optimal behaviour.

For occupants to be able co-evolve learning with low carbon technologies (Cole et al, 2008) the products need to be designed with the user context in mind, with designers having a more situated understanding of functional performance. At the same time the increasing creep of added functionality in control products is actually leading to a disengagement from the user who finds products too complicated (Chapman, 2005). Rather than requiring twenty pages of guidance, a boiler programmer should reveal its functionality in a straightforward way to the user. A positive user engagement will also lead the user to value the controls as objects in their own right which are to be maintained, repaired if possible, and appreciated rather than discarded and replaced at the first sign of malfunction (ibid).

Conclusion

It is clear from these paradigmatic case studies that the usability of low carbon housing control products is highly contingent upon a complex interaction between procurement processes, user expectations, understanding, experience, habits and functional ergonomics. Key recommendations include:

1. More robust design and detailed evaluation of environmental ‘touchpoint’ control products for housing to take account of user engagement

2. Clearer labelling for user control points

3. Clearer guidance and handover procedures for occupants with more hands on experience of the heating and ventilation systems

4. An explanation and demonstration for occupants of how to optimally use controls

5. A detailed and co-ordinated specification and layout plan for services which works in tandem with the design process, employing suitable expertise for this. The focus should be on simplicity of use and access.

6. Training for installers, site operatives, and customer care staff to ensure all parties fully understand new technologies being deployed, including how they should be installed, commissioned and maintained.

7. Robust Installation and commissioning procedures with more detailed requirements provided by the developer and design team in the tender documentation.

A key question remains in terms of who will fund all of these recommendations and how they will be delivered in practice. It is unlikely that voluntary measures on their own will deliver significant change, as experience has shown that developers respond most pro-actively to legislation. What is overwhelmingly apparent, however, is the need at all levels to place a much higher value on user-centred design and handover of low carbon control products and systems in housing for the full potential of the benefits of low carbon housing to be realised.

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