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Title: Service controls interfaces in housing: usability and engagement tool development

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Abstract:

Domestic buildings are increasingly complex; saturated with services that need coherent control if design and inhabitants' goals are to be achieved. The evidenced inappropriate use of controls linked with performance gap suggests that effective methods for assessing the inhabitant relationship with control interfaces for services are needed within building performance evaluation and practice studies. The development of a bespoke domestic usability tool over two iterations is presented, demonstrating new insights into the relationship between design and inhabitant engagement with controls. Deep contextual development came from trialling the tool in four UK domestic case studies. Understanding the purpose of a control interface and inhabitant role was found to be a fundamental diagnostic for inhabitant engagement. The tool became a prompt for immediate action or further information seeking for a quarter of households involved in its application. However affordances and physical issues identified could not be addressed without major physical changes, which should have been picked up at the design and construction stage. Organisational learning based on the tool findings was triggered in one of four developers involved. The challenges for developing usability studies are discussed with recommendations provided for different actors in the housing and construction industry on how to progress these.

Keywords: building controls, building evaluation, building performance**,** building services ergonomics, feedback, housing; inhabitants, usability

Introduction

Background

In 2016 the domestic building sector accounted for 29% of final total energy consumption in the UK. This represented the second highest out of five sectors analysed (DBEIS, 2017, p.9). However in order to meet the targets set out in the Climate Change Act 2008, the UK Government highlights housing as the sector expected to achieve the greatest energy and carbon savings as a result of its policies (NEEAP, 2017; Climate Change Act 2008). The UK building regulations are setting increasingly ambitious energy targets for new and retrofit housing and are seen a driver for the biggest predicted energy savings (NEEAP, 2017, p.4). However, as the UK Committee on Climate Change points out in its assessment of the UK government's Clean Growth Strategy: 'It is vital that the performance gap between design and actual performance is addressed in order to realise energy savings and deliver high-quality homes' (CCC, 2018, p. 20).

Numerous field studies have demonstrated that the gap between the modelled (i.e. predicted) and the measured energy use observed in housing can be as high as ten-fold in energy use per m^2 per annum, which is clearly linked to user control of the internal environment (Palmer et al., 2016). Typically, low energy and technically more complex homes consume more energy than predicted, whereas the less complex and supposedly less energy efficient homes actually use less (Majcen et al., 2013). This is important because the two key areas of household energy consumption in the UK are space heating which accounts for (on average) 69% and 80% when combined with hot water (DECC, 2017, DBEIS, 2017; p22).

A clear link exists between the underperformance of technically advanced homes and the unforeseen use of services controls (Pritoni et al., 2015). A review of a UK national building performance evaluation (BPE) programme covering over 100 projects noted: 'There is a tendency to make controls for mechanical and electrical services too complicated. This alienates occupants and can mean the building defaults to high energy use.' (Palmer et al., 2016, p.4). This suggests a normalised problem in the UK with the usability of these controls (Combe et al., 2011). The ISO 9241-11 standard (ISO, 2017) defines usability as: 'the extent to which a product can be used by specified users to achieve specified goals, with effectiveness, efficiency and satisfaction in a specified context of use.' BPE studies have repeatedly found that effective use of services control interfaces by the user is key to better building performance and improved user satisfaction (Raja et al., 2001; Bordass et al., 2007). Service controls as defined here include all the mechanical and electric systems interfaces in a home as installed by the house builder as well as other features such as taps or window handles designed for inhabitant interaction to control their home environment. It does not include additional control items introduced by the inhabitant, such as free-standing electric fans or personal de-humidifiers.

Usability studies do not always account for the lack of use or inappropriate use of controls by inhabitants. Inhabitants may be unaware, or lack the knowledge or confidence to interact with new controls presented to them in their home. In a 'real world' trial of programmable heating system thermostats carried out by Sachs et al. (2012) the authors found that while the introduction of usable thermostatic controls on heating systems increased the ability of inhabitants to interact, educational interventions or other incentives were needed to release the potential for a successful interaction. In this trial, the high usability of a control itself was not enough to trigger interaction in the real world domestic situation. This finding fits with Stern's (2000) questioning of efforts to understand change in environmentally significant behaviour (such as home heating) within a single variable, such as new programmable thermostats. Stern (2000) highlights four casual variables that affect environmentally significant behaviour: attitudinal factors, contextual forces, personal capabilities, and breaking habits and routines. Equally, poor control design can also be an issue for inhabitants (Stevenson et al., 2013).

As a contextual force, a well-designed and well-located home control may diminish the physical difficulty of using it, minimise constraints and maximise capabilities of inhabitant interaction. However it may not break a well-established habit or routine, and cannot necessarily engender new capabilities, if these are a pre-requisite. Equally, a particular attitude can pre-determine whether or not an inhabitant engages with a control in the first place. In some cases, working with inhabitants to re-orientate them towards energy efficient practices can unlock the energy savings expected in the models but is often unrealised in reality (Oliveira et al., 2017). Without these changes in practices and routines there has only been a limited degree of success in energy efficiency real world trials, which tend to bring smaller savings then expected (Tsang et al., 2012; Buchanan et al., 2018). In terms of safety and security, the available evidence also indicates performance issues caused by lack of interaction (NFPA, 2015). Attempts to tackle this issue tend to involve consultants fixing any problems identified with the targeted controls as well as providing guidance to inhabitants (Tannous et al., 2017). The present authors are not aware of any projects, however, that have attempted to systematically diagnose the actual quality of inhabitant interaction with all the service control interfaces installed in a home related to systems regulating the internal environment e.g. windows, ventilation, heating, lighting, energy but also security, water or emergency control systems. Addressing this usability gap is urgent due to interdependencies between these technologies that all need some degree of maintenance and engagement, which also affects energy performance (Fazli et al., 2015).

The research gap

BPE studies aim to close the overall performance gap through evidence-based diagnosis and feedback (Preiser & Vischer, 2005). Nevertheless, a systematic assessment of inhabitants' actual use of service controls, as defined above, in a home is not part of UK domestic BPE programmes to date despite the increased capacity of these controls to help improve housing performance and evidence for this capacity being underexploited (TSB, 2012; Derbez et al., 2014). Usability studies within BPE tend to be subsumed within the study of commissioning processes, informal walkthroughs, short general questionnaires or interviews (Parkinson et al., 2018; Gupta & Gregg, 2016). Addressing the evidence for long term negative impacts of poor usability on key building performance indices (Peffer et al., 2011) is a particular challenge due to the disconnection between practice, research and housing industry actors (Samuel, 2017). The key question arising from the above is: How can the evaluation of usability and use of service controls be incorporated more effectively within BPE studies?

This paper addresses the need to understand how inhabitants interact with service controls and how BPE can systematically capture that. It describes the evolution of a new domestic usability tool aiming to:

- provide a revised framework for understanding usability
- incorporate usability evaluations as a routine part of BPE

- ascertain inhabitant understanding, skills and satisfaction with the controls interfaces provided
- help develop the inhabitant education process, and
- improve the design and installation of products in buildings.

The paper is structured as follows. The next section describes the theoretical positioning which has informed the development of the tool. Then, the methods section introduces the first version of the tool as it was developed and tested in two housing case studies. It then describes the revisions made to the tool, following feedback from the first trial, and a second application trialled on two further housing case studies. The impact of the tool on an individual and organisational level is identified for each version of the tool. The subsequent section discusses the questionnaire format of the tool and the key barriers and opportunities for its application within BPE studies. The need to build the audience for usability studies is also explored with a focus on controls, the future of usability studies and inhabitant-control interaction with the increasingly automated services. The conclusion sets out recommendations for different audiences regarding the application and development of the tool.

Usability: some theoretical perspectives

Technology acceptance and ergonomics

One prominent theory guiding research supporting the implementation of new technologies is the Technology Acceptance Model (TAM) (Davis, 1989). This suggests that the intention to accept a technology is determined by its perceived usefulness and perceived ease of use which both determine the extent of actual use. The perceived usefulness depends upon recognition of the benefits that arise from engaging with the new technology. Ease of use is related to physical and mental effort involved in the interaction as well as the perceived effort of learning to use the technology. However '...perceived ease of use may be an antecedent to perceived usefulness...' (Davis, 1989; p.334). Thus, ease of use is particularly important during the initial inhabitant interaction with a product:

> 'Usability is likely to be a key driver for enhanced use of central heating controls for domestic consumers. Where consumers have problems using programmable timers, they may use these devices as simple on/off switches.'

(Munton et al., 2014, p.56).

Ergonomics, also known as human factors (HF), is focused on sustaining interaction between people and technologies, optimising it towards wellbeing and system performance. HF is concerned with understanding the interaction happening in a specific physical and organisational context taking into account the 'needs, abilities and limitations of people' including ease of use (Karwowski, 2012). Ergonomics contributes to product design guidance, as well as the development of the learning supporting the use of technology. HR's inherent positivistic assumption is that any specified interaction examined is needed and beneficial, and all that is needed is for products to be designed and installed according to user physical and mental capabilities in order to encourage 'appropriate user behaviour' (Revell & Stanton, 2018; Caird & Roy, 2008; Meier et al., 2011). However, this does not explain the inappropriate use of a specific control in a domestic context due to other factors e.g. inhabitant habits (Marechal, 2010) preferences (Brown & Gorgolewski, 2015) and the assumptions made by professionals when evaluating people's use of buildings and their controls (Janda, 2011; Tweed, 2013; Tweed & Zapata-Lancaster, 2017; Wade et al., 2018). Practice theory as developed by Schatzki (2001) is useful to explore these and other related factors.

The Practice Turn

There are a variety of definitions for the theoretical term 'practice' (Schatzki, 2001; Reckwitz, 2002; Shove et al., 2012). The definition developed by Gram-Hanssen (2010) and adopted here is that a 'practice' consists of: a technology, human know-how and habits, institutional knowledge and explicit rules, and human engagement. Practice theory helpfully embodies learning, as the development of competencies through enacting a practice (Nicolini, 2017), and the individually different ways of 'knowing-in-practice' that can manifest through the enactment of a practice (Ingold, 2000). Recent practice-based research also considers the context surrounding specific inhabitant perspectives on environmental controls (Gram-Hanssen, 2010; Vaslova & Gram-Hanssen, 2014) and domestication (Hargreaves, 2017). Practice is understood here within a rich data context of 'real world' research methods (Robson, 2011) related to the performance of buildings and technologies as artifacts which already have a physical relationship to human cognitive and sensory perception prior to any developed practice. A broader BPE approach combining quantitative and qualitative methods (Leaman et al., 2010) provides the opportunity to 'ground' practice analysis within the detailed analysis of a physical context and offers a base-line physical context against which to evaluate the outcome of inhabitant practices (Foulds et al., 2013).

Without a more detailed understanding and evaluation of whether or not designed technologies are interacting effectively with inhabitants at the level of basic ergonomic requirements (sensory and cognitive alignment) and in accordance with design intentions, it is hard for designers to practically re-evaluate and physically change their actual designs in response to any practices identified. This is where the theories of affordance and cognitive fit are worth revisiting - in order to unpack the practices associated with services control interfaces.

Affordances and cognitive fit

'Affordances' are latent physical properties of the real environment which provide potential action possibilities (Gibson, 1979; You & Chen, 2007). These are only realised when a person has the intuitive capacity to enact them, which depends on their past experience, knowledge and the manner in which this possibility is conveyed to them (Norman, 1998). Affordances are in this way, '...properties of the real environment as directly perceived by an agent in the context of practical action' (Ingold, 1992: 46), which aligns affordance within practice theory. The theory of affordance is helpful in relating human perception and actions to technologies, but does not set out any guidance. The physical aspect of ergonomics can be helpful here in terms of setting out clear anthropometric criteria and parameters against which to evaluate the affordances offered by service controls.

Providing there are appropriate affordances and a good ergonomic fit, early interaction with control interfaces can utilise trial and error techniques to develop inhabitant understanding and engagement (Baborska-Narozny et al., 2016b). At this problem-solving stage the Cognitive Fit theory (Vessey, 1991) states that good design facilitates understanding the functionality of a control. The identification of a clear purpose and user role as part of the control interface can help to verify whether the inhabitant's mental model for each control is the same or differs from the designer's understanding of what this control does (Norman, 1998; Karjalainen, 2007). Inhabitants can also interact with a control despite misconceptions about what it does exactly (Kempton, 1987), but having a basic understanding about what a control interface does is a prerequisite of intentional repeated engagement, according to the TAM model. This functional purpose also needs to be grasped by the inhabitant before he or she can express an opinion about the 'usefulness' or 'utility' such an interface. For this reason, TAM alone is not particularly useful for understanding how well domestic control interfaces are working, as inhabitants may not know the purpose of a control interface in the first place. Thus the tool developed here aims to explore the material aspects of practice in relation to control interfaces in the home without any presumption about the extent to which a person believes they are useful, or the degree of their basic knowledge.

Methods

Development of the tool

The first version of the tool was developed in 2011 in the UK as part of a BPE case study (Stevenson et al, 2013). The criteria for evaluating domestic mechanical and electrical control interfaces were based on previous usability guidance for the design of controls for end users (Bordass et al., 2007). The six criteria were:

- clarity of purpose (cognition)
- intuitive switching (affordance)
- labelling and annotation (cognition)
- ease of use (physical ergonomics),
- indication of system response (cognition)
- degree of fine control (physical ergonomics).

A comprehensive digital questionnaire captured all the interface controls used in one home, with the aim to eventually capture quantitative data across case studies nationally.

A digital list of all the controls in the home was created from the design specifications. The controls were then grouped under seven categories typically used in the construction industry: heating and water, mechanical ventilation, electric equipment, kitchen appliances, fabric, water services and miscellaneous. A matrix table was then developed to rate each control against each of the above-mentioned criteria, within an overall Excel spreadsheet. A five point rating scale was set out in a colour coded 'traffic light' bar chart, ranging from green ('excellent') to red ('poor'), to aid visual understanding (Figure 1). The matrix table for each control had a photo of the control for ease of reference, and a comment box to record any on-site observations and recommendations related to the criteria. A further text box enabled comments relating to the overall usability of controls as a system (e.g. Mechanical Ventilation controls).

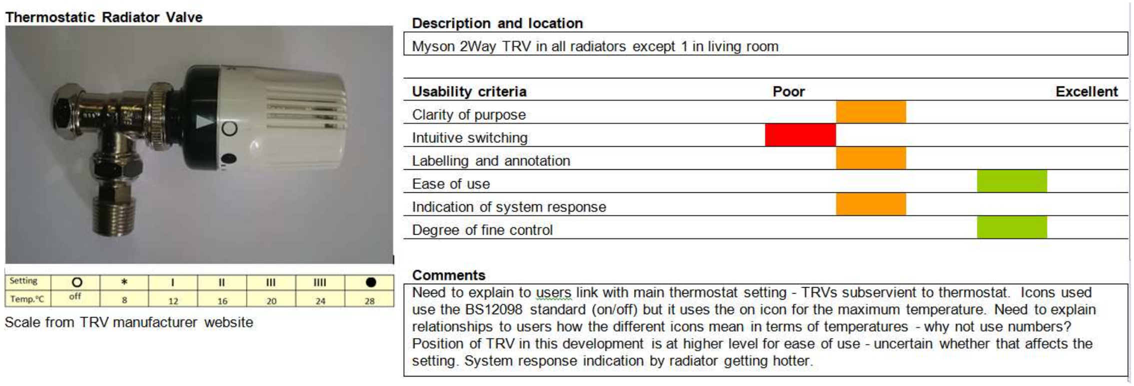


Figure 1. Version 1 of the tool – control interface matrix

The questionnaire was designed to be completed in two to four hours on-site with a detailed examination of the selected controls in a home by a single consultant/researcher with design and socio-technical research skills. It was preceded by a typical BPE drawing and specification audit, to identify any gaps between design intentions and the as built context for the controls, which might inform the results of the usability questionnaire. The BPE study also included semi-structured interviews with the inhabitants of the 40 homes studied in detail, the developer and design team, as well as a review of the installation and commissioning of services and systems, a general Building Use Studies questionnaire[1] for all the inhabitants in the development, and a review of handover procedures and guidance for the inhabitants (Stevenson et al., 2013). The usability questionnaire assessments were designed to be cross-related to the relevant findings which emerged from these other BPE methods (Leaman et al., 2010).

Case study criteria

The case study method provides an excellent means for interrogating problems in depth (Yin, 2009) and is particularly suitable in relation to evaluating the complexity of building performance (Lowe et al., 2017). In order to trial the tool, two different case studies were selected (Table 1), representing two ‘extreme’ scenarios according to recommendations for obtaining maximum variance to create a ‘paradigmatic’ case study (Flyvbjerg, 2006). Due to the predicted difference in capabilities between small and large house builders the aim was to see how well the tool would work for small house builders (i.e. those building up to 100 homes a year), who make up 12% of new housing development in the UK (House of Commons CLGC, 2017) compared to large house builders (2000+homes a year) who make up 59% of the market share[i] (ibid), when both are engaged with new technologies for the first time. It was also to ascertain how the tool would be received by inhabitants in very different sizes of developments, in terms of discussion with them during the BPE process or in response to receiving the BPE findings. A ‘typical’ terraced home was selected within each case study for testing the tool to enable comparison across the two cases. Both case studies were situated in the South of England, to provide similar climate conditions.

[1] https://www.busmethodology.org.uk/

Case study Characteristics	Large Home Builder A	Small Home Builder B	Co-housing C	Medium Home Builder D
Location	Kent, SE England	Somerset, SW England	Yorkshire N England	Yorkshire N England
No. of dwellings in development	150	5	20	over 200
No. of dwellings in BPE case study	42 (1 end terrace house for usability study)	3 (1 terraced house for usability study)	20	20
Typologies considered in case study	Detached, semi-detached, terraced houses, apartments.	detached, terraced houses.	semi-detached, terraced houses, apartments	apartments
Date of completion	2010	2009	2013	2011
Contractual arrangement	Design and Build. 60K house competition winner. Developer has own subcontractors. Architects only employed until end of detailed drawings stage.	Joint development between landowner and developer. Project Manager. Architects employed until end of contract.	Design and Build. Architects only employed until end of detailed drawings stage.	Joint Contracts Tribunal. Architects employed until end of contract
Key services evaluated per dwelling	Mechanical ventilation with heat recovery, condensing boiler, water taps, electricity and lighting high performance doors and windows, solar roof lantern.	Photovoltaic panels, solar thermal panels, mechanical extract ventilation, rainwater harvesting system, wood pellet boiler, unvented hot water cylinder with immersion heater, high performance doors and windows.	Photovoltaic panels, mechanical ventilation with heat recovery, high performance doors and windows gas combi-boiler (apartments only), gas combi-boiler, solar thermal panels + unvented hot water cylinder with immersion heater, (houses only)	Mechanical extract ventilation system, electrical panel heaters, unvented domestic hot water cylinder with immersion heater, access and safety controls, high performance doors and windows.
Tool version applied	1		2	
No. of controls evaluated	29	31	33	23
Eco-standards achieved	Eco Homes ‘Excellent’	Code for Sustainable Homes Level 5	Code for Sustainable Homes Level 4	Eco Homes ‘Very good’

Table 1. Key case study characteristics.

Application of tool and feedback

Comprehensive findings of this usability study have been previously published (Stevenson et al., 2013)). These suggested that the tool needed to continue to cover the wide spectrum of service controls in its future iterations. It was also quickly apparent that while the tool had effectively assessed the basic usability of the controls, the six criteria used were insufficient to diagnose why the controls were performing poorly for the inhabitants, beyond the presenting affordance, ergonomic and cognitive issues. This is where the cross-evaluation of the usability findings with the findings of all the other BPE methods of investigation proved invaluable in terms of generating deeper insights related to the complex practices surrounding the use of these controls (ibid.). The researchers found the tool easy enough to use in the time allocated for carrying out the initial survey (about half a day per home).

Both the small and large house builder in the case study were impressed by the detailed findings. They found the usability reports generated by the tool easy to digest and clear to understand (ibid.). The large house builder (A) immediately targeted a forthcoming development, with similar control specifications, for a review of all control specifications and committed to providing feedback from the findings to its key suppliers. This house builder also pro-actively considered ways in which they could improve inhabitant understanding of the mechanical ventilation system in particular, as the least usable set of control interfaces evaluated. The study spurred them on to interrogate the usability of environmental controls in more depth in a far larger £6.4m research and development project (Cartwright & Gaze, 2013). It was not possible to ascertain how much impact the usability findings had on the inhabitants, if any, as the developer did not present these findings to them, and there was no control study.

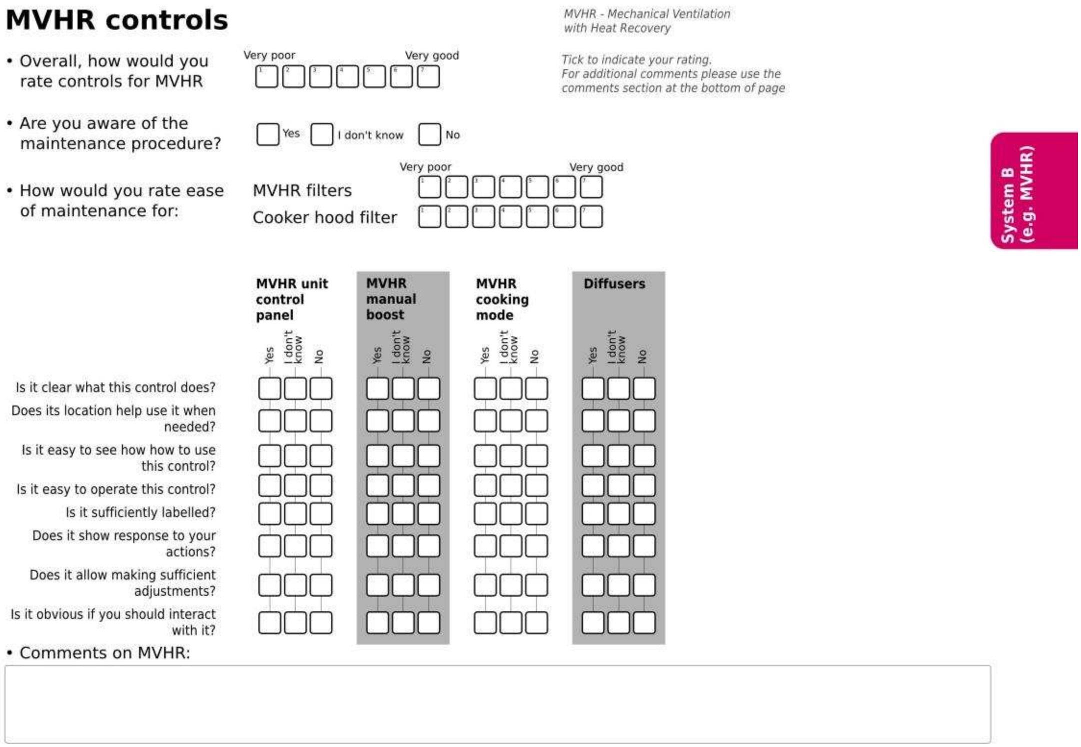
The small house builder (B) was unable to take advantage of the usability findings, having gone bankrupt shortly afterwards, and did not have the personnel capacity to respond to the findings. Nevertheless, the inhabitants in this small development were able to discuss the nature of the findings with other inhabitants, as they all knew each other. The tool also created learning on site between the inhabitants and researchers concerning how various control systems were operating. This first version of the tool provided a relatively in depth analysis of the usability of the controls, but was nevertheless based on the researchers experience and understanding rather than the inhabitants.

Revisions to the tool

In the next tool version developed in 2014, the technique was revised to provide a much swifter paper and pencil questionnaire (Figure 2 and questionnaire in the supplementary online data) to be handed to an inhabitant about a year into their occupancy and completed by them in about 20 minutes. The aim was to explore whether the inhabitants had moved beyond the uncertainties of the early occupancy stage toward gaining a sense of clarity of purpose of each control interface and their interaction role. The first page of the questionnaire now asked for background information about the respondent, his/her occupancy profile and dwelling typology. Four new questions sought evaluations of the home handover and home user manual and their role in facilitating home operation and maintenance on a seven point Likert scale (very poor-very good) (Fowler, 2014) to capture the long term inhabitant perceived impact of the induction process which has not been included in BPE methods to date. The aim was to identify any patterns in relation to inhabitants' cognitive understanding of control interfaces and their own role in engaging with them. A seven point scale was now deployed to evaluate perceived skills in using technical devices (very low-very high) in order to better interpret the ratings for different control interfaces. An open comment box was provided for an inhabitant to indicate any circumstances that influenced their ability to use these interfaces in general. This enabled an exploration of perceived capability compared to ratings for each control as a diagnostic for developing individual user learning needs. Each system category was now contained within a single page for ease of use and clarity, covering all the services installed. For each system an overall 'satisfaction with controls' question was included using a seven point scale (very poor-very good) to compare the general system and detailed control evaluations, as previously. General questions about awareness of the maintenance procedures for each system were added, given that usability issues concerning maintenance were found important in version 1 findings (Stevenson et al., 2013).

For each system, the survey was organised into a repetitive matrix with the revised criteria as rows and particular controls as a columns (Figure 2). Based on the analysis of the first trial two further criteria were added. The first focused on location.

‘Location’ issues had previously been subsumed within the ‘ease of use’ criterion but were constantly named in the comment box by the researchers during the first tool deployment, suggesting that location should be a separate criterion to understand whether poor ‘ease of use’ reflected poor ergonomics of the control interface or a problem with its positioning. Similarly, the original ‘intuitive switching’ criterion was now split to cover affordance (‘Is it easy to see how to use this control?’) and cognition (‘Is it obvious if you should interact with it?’). This requirement emerged after the mechanical and electrical systems handover demonstration in one of the revised tool case study developments failed to clarify to the inhabitants their role in controlling ventilation despite explicit questions raised by them (Baborska-Narożny et al., 2016b).


MVHR controls
MVHR - Mechanical Ventilation with Heat Recovery
• Overall, how would you rate controls for MVHR — Very poor … Very good
Tick to indicate your rating. For additional comments please use the comments section at the bottom of page
• Are you aware of the maintenance procedure? — Yes / I don't know / No
• How would you rate ease of maintenance for: MVHR filters; Cooker hood filter — Very poor … Very good
System B (e.g. MVHR)

	MVHR unit control panel	MVHR manual boost	MVHR cooking mode	Diffusers
	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No
Is it clear what this control does?				
Does its location help use it when needed?				
Is it easy to see how how to use this control?				
Is it easy to operate this control?				
Is it sufficiently labelled?				
Does it show response to your actions?				
Does it allow making sufficient adjustments?				
Is it obvious if you should interact with it?				

• Comments on MVHR:

Figure 2. Usability tool version 2 – sample page of user feedback questionnaire.

The revised questionnaire provided three response options for each question (‘Yes’, ‘No’, or ‘I don’t know’) instead of the original five point scale to save space and make the questionnaire easier to fill in, given that the survey now had eight questions for each control. Importantly, the ‘I don’t know’ response is usually not plausible in survey design (Fowler, 1985, p.164), however it can be a valid indicator of lack of confidence to suggest a limited interaction with a control interface. In a few cases the ‘I don’t know’ answer also allowed the respondent to indicate whether or not they were able to rate the control at all in relation to a specific criterion. The revised response option addressed the issue of ‘I don’t know’ in version 1 findings which also emerged in relation to single instances at pilot stage of the revised tool. The revised questionnaire had no photos of the control interfaces, just the technical names, to keep it succinct.

Case study criteria

The second iterated version of the tool was applied in two contrasting housing developments from the first two case studies, in order to provide maximum differentiation across all four case studies, as recommended by Flyvjeberg (2006) and Yin (2009) (Table 1). A medium size new build collective housing development (C) was selected alongside a large and deep retrofit development (D), providing two additional housing development types. The tool was again part of an in-depth BPE evaluation in each case (Baborska-Narożny et al., 2016a). Both developments were this time situated in the north of England.

Application of tool

The tool was applied in 40 homes a year into occupancy, to ascertain the learning and established habits related to the service control interfaces over four seasons. The researcher already knew the targeted 40 households as part of the broader BPE project (Baborska-Narożny et al., 2016b, Stevenson et al., 2016, Baborska-Narożny et al., 2017). This good relationship between the research team and the inhabitants might help explain the 100% return rate of the completed survey. The vast majority of respondents invited the researcher into their homes to shadow their completion of the questionnaire. The researcher intervened only to clarify the questions if needed, and took notes of the process and what was unclear to the respondent, to avoid influencing the results. Interestingly, during the process of filling in the questionnaire a quarter of the respondents visited the control interfaces they were hesitating to rate in order to remind themselves how operate them and answer the survey questions. A total of 80% of the respondents also developed a learning dialogue with the researcher immediately after the survey as a result of their confusion about the control interfaces. A short time was deliberately left for this as part of the revised technique and provided excellent insight into inhabitant understanding of systems and control interfaces, highlighting their major misconceptions (Baborska-Narożny et al., 2017). In three cases the immediate issues raised were followed up by an email exchange between the inhabitant and researcher, providing further clarification. The survey itself thus unexpectedly served as action research (Stringer, 2014) triggering inhabitant learning focused on control interfaces.

Analysis and findings related to tool revision

The overall findings mirrored much of what had been discovered in the first trial in terms of affordance and physical ergonomics. The key added value came from revising the questionnaire to gain inhabitants understanding of the control interfaces rather than the researcher's understanding. The revised survey questions also prevented respondents guessing answers to the affordance and ergonomics questions because to answer 'Yes' or 'No' they needed to have had some experience of interacting with the control interfaces. The survey results now revealed the control interfaces that were least used or even unknown to respondents, helping to indicate their learning needs. (Figure 3, Figure 4). The verbal dialogue between the researcher and respondent helped both of them to elicit and highlight the lack of use of very simple and usable controls resulting from a typical vicious circle: the inhabitant's lack of understanding of their purpose due to poor service performance (e.g. broken fan components meaning that the purpose of an unlabelled fan switch was unknown) caused by lack of service maintenance.

Adding the question 'Is it obvious if you should interact' in the revised tool proved invaluable. Even when the inhabitants were aware of a system and had some understanding of how it worked, they were confused about their role in controlling it and whether they should interact with the related interfaces.

Sometimes it was hard to understand whether the respondent was actually responsible for controlling and maintaining the systems identified, or whether this was voluntarily assigned to other member of the household or an external organisation, e.g. changing mechanical ventilation with heat recovery filters. This suggests the importance of identifying organisational roles and responsibilities in relation to the use of control interfaces either prior to carrying out the survey or through follow up dialogue in order to avoid this confusion.

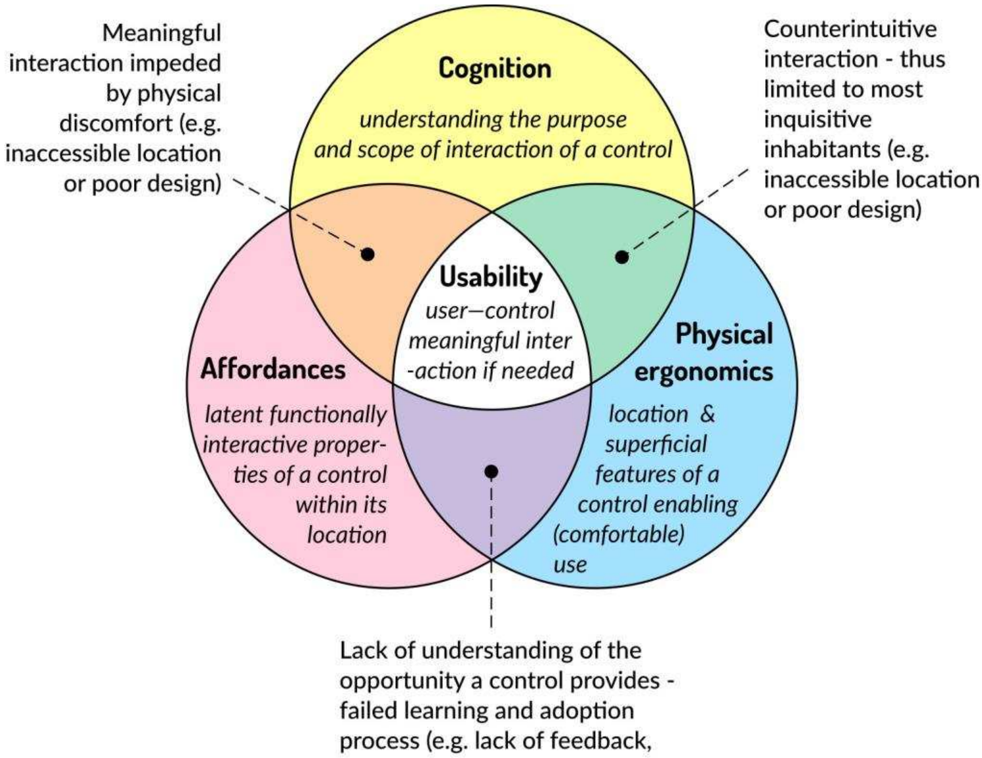


Figure 3. Usability of controls in buildings against theoretical background.

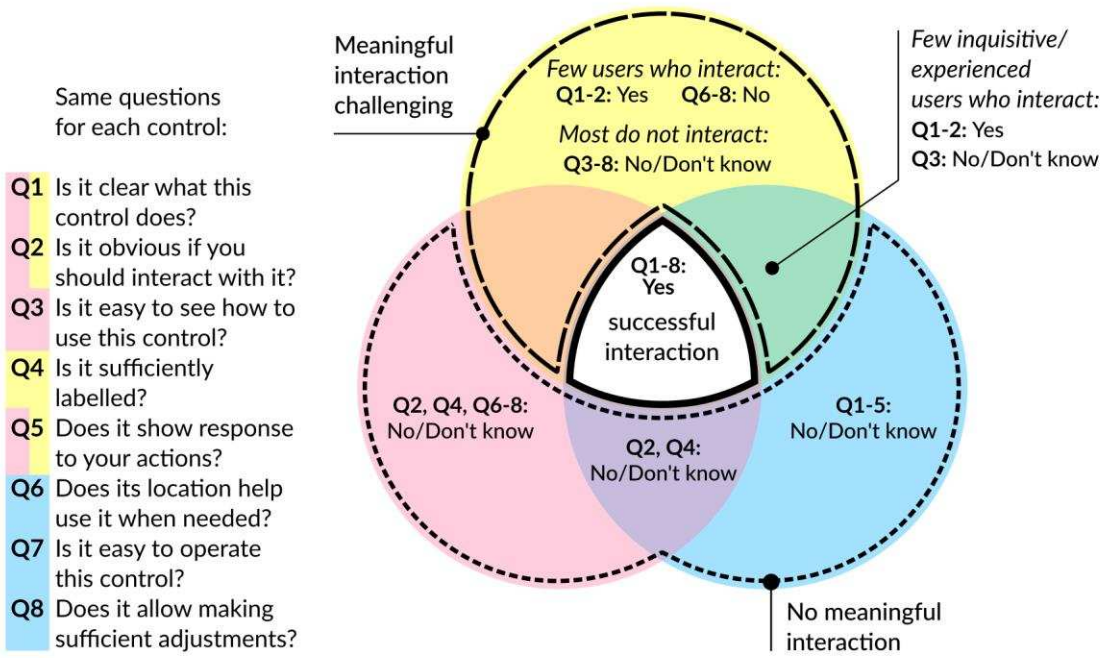


Figure 4. Usability questions and mapped responses interpretation

Impact

In Case C, the presentation of findings to all the inhabitants prompted the co-housing task team responsible for maintenance and repairs to develop and issue a 'Maintenance handbook', identifying responsibilities in relation to specific systems control interfaces, e.g. MVHR filter changing was now prompted by the maintenance team but delegated to inhabitants. Unfortunately the overall findings were never presented to the architect, contractor, or relevant sub-contractors who did not engage with the BPE project, despite efforts to involve them. In Case D the findings were presented to a senior director in the house builder organisation which entered into a serious financial crisis during the BPE project and sold all its assets in the development. This diminished their engagement, with no recommendations followed up. They also failed to recognise an opportunity to feedforward key lessons to other projects as the company was more focussed on delivering bespoke solutions which seemingly prevented them from taking on board BPE lessons from project to project.

The tool and findings were perceived as a valuable individual learning experience by the respondents with the questionnaire becoming a prompt for immediate action or information seeking and triggered eleven households to take positive action, such as correcting faulty labelling or conducting necessary maintenance. However the ergonomics and affordance issues identified could not be addressed without major physical changes, which should have been picked up at the design stage.

The long term impact of the tool application was also significant. One year after the completion of the survey, four of the participating households (D) disseminated their knowledge obtained from participating in the survey to of the rest of the inhabitants via a closed residents' Facebook group (removed for reviewing stage).

Discussion

Questionnaire: qualitative or quantitative?

Typically a questionnaire elicits quantitative data for statistical analysis, with the studied sample reflecting patterns occurring in wider populations (Fowler, 2014). Our questionnaire was applied in relatively small samples and it quickly became clear that the key strength proved to be its embedding within an in-depth BPE case study approach, which allowed the usability findings to be cross-related to other practice aspects. Version 2 thus became an inhabitant centred diagnostic tool, to reveal 'unknown unknowns' and exposed inhabitant misconceptions about their environmental control systems/misuse of control interfaces which proved to be a major cause of their lack of engagement. The findings demonstrate the limited applicability of asking the inhabitants about the usefulness of specific control interfaces (as the positivistic TAM model suggests) if inhabitants do not know whether they should interact with the control interfaces. The tool, when applied with other BPE methods, helped to expose barriers which prevent earlier engagement in learning, and more importantly, why this was happening. Simply presenting standardised information to inhabitants generally has disappointingly low impact (Stern, 2000; Powel, 2009; Burchel et al., 2016). Engaging people with the tool can trigger a process of co-constructing design (Pink et al, 2017) following mutual learning and feedback between inhabitants, researchers, design teams and house builders.

Relationship with BPE studies

Both versions of the tool were deliberately situated within in-depth BPE socio-technical case studies involving both inhabitants and housing industry organisations. Such BPE studies are limited in number due to the expertise, time and cost involved (Buswell et al., 2017). Despite this, their role in explaining the complex drivers underpinning the performance gap in the domestic sector is unique and telling (Lowe et al., 2017). Situating the revised tool within BPE adds a systematic and detailed assessment of service control interfaces from the inhabitants' perspective. Creating a case study, recruiting participants, conducting initial design and energy audits, undertaking photo surveys, and walkthroughs, must inform the tool preparation stage. The tool builds on the findings from these initial BPE methods and provides insights which can then shape the subsequent methods e.g. inhabitant interviews, broader inhabitant questionnaire prompts, and monitoring diagnostics. A BPE study feedback meeting to present and discuss the findings from the specific usability study to the inhabitants is a vital part of any planned collective co-learning. However in version 2 it was the one-to-one home visits that proved to be the key learning experience for individual inhabitants. Designers, developers, contractors and manufacturers could ideally feed the emerging recommendations from such a study into their practice and development. This becomes an opportunity for 'fast-track' organisational learning in relation to usability issues, through the incorporation of the tool into architectural practice-based research during the occupancy stage of projects with the findings fed back into subsequent design practice (RIBA, 2013; Samuel, 2017). This type of learning, however, needs support from built environment professional bodies in the UK who recognise the importance of BPE (RIBA et al., 2016).

Building an audience for usability studies

The above learning opportunity will only materialise if the focus of the tool (i.e. affordances, ergonomics and inhabitants' cognition of controls) is of interest to the actors in the housing industry. The experience of using the tool in the four case studies presented is mixed, revealing both positive opportunities and significant barriers for successful learning at an organisational level. Only the large house builder (A) acted on the feedback provided by the tool, leading to significant changes in their other on-going projects and processes. In the three other cases the usability study results did not trigger any action because:

- feedback was never delivered to the relevant parties
- financial difficulties resulted in a lack of organisational capacity to act and limited engagement,
- feeding the lessons forward was not considered applicable to 'unique solution' projects

This lack of feedback was partially due to lack of interest from the professional actors and the fragmented process of specifying controls specifications undertaken by different subcontractors for separate systems, leading to a resultant lack of responsibility on behalf of the designers and housing developer.

A key financial barrier preventing an audience for usability is that these issues do not necessarily have an immediate commercial impact upon the many building delivery stages stakeholders. This is due to the disconnection that exists between those groups who are responsible for product development and deployment (manufacturers, clients, designers and contractors) and those who are responsible for and interested in maintaining building performance (facility managers, inhabitants, building owners) (Leaman et al., 2010; Zimmerman & Martin, 2001). Without the provision of feedback, industry actors are unable to recognise common patterns of problems and poor performance related to control interfaces. As a result, the pressure to improve the usability and inhabitant understanding of control interfaces tends to be research rather than market driven, as revealed in the aims of AIMC4, a major housing industry-led research programme involving three of the largest housing developers in the UK (Cartwright & Gaze, 2013). A fundamental step toward creating an audience for usability would be the introduction of usability issues into professional education and continuing professional development (CPD) related to the design, construction, maintenance and inhabitation of housing. A rethink of manufacturing policies and protocols to focus on the usability of specific products for whole home environments and their inhabitants could also help reorient the perception of the wider construction industry.

Another key challenge relates to individual inhabitant interest in how the provided control interfaces might help them achieve their energy and comfort goals. The revised tool provoked inhabitants to reflect on their interaction with control interfaces. Eight months into occupancy many still did not know what purpose specific controls actually served, suggesting they had probably never located or used them. The tool established a positive engagement through actual testing of the ergonomics and the affordance of the controls. Well-evidenced inappropriate or lack of use of service controls in the domestic environment has also prompted the industry to seek alternative technical solutions. These alternatives exclude the need for inhabitant interaction with controls altogether where possible by relying on intelligent automation (Strengers, 2016).

Even in this scenario, however, future home technologies will still need maintenance and calibration. Therefore the need remains for inhabitants to understand the purpose of the technologies in order to engage with their maintenance and calibration either in terms of doing it themselves or paying someone to do it. Designing home technologies which communicate maintenance requirements (including signalling when the system is faulty, performing non-optimally or simply broken altogether) and alert inhabitants to this need through feedback is essential and goes in close collaboration with designing control interfaces which keep the inhabitant aware of them, understanding their purpose and convincing them about the benefits of controlling, maintaining, repairing or even replacing the technology. Future development of the usability tool could assist with evaluating and designing this new area of interactive home technology.

Conclusions

This paper has introduced the usability tool and situated its development as a state of the art, as used in association within BPE studies. The tool provides a robust method and technique for revealing the usability of control interfaces. When used in conjunction with other BPE methods, it reveals the wider usability implications for the effective control of home service systems. A clear benefit is that the tool provides actionable feedback for inhabitants and industry actors. The usability questionnaire was initially utilised to establish a quantitative assessment of the quality of interaction provided by all key control interfaces available to an inhabitant within their home allowing key problem areas to be identified. However it was rapidly realised that the tool is best developed on a bespoke basis for heuristic and diagnostic purposes. In this way, it can be used to facilitate a co-learning process for all involved in a housing development. At the same time, one limitation of the current version and approach to using the tool is the inability to broadly validate usability levels across projects using control studies which draw on large amounts of quantitative data based on the same control specifications. Further work is needed to develop such an approach which could also demonstrate the impact of improved usability specifically in terms of closing the energy performance gap.

Although the analysis of affordance and physical ergonomics are important elements for understanding inhabitant practices, a key finding from this study is that the inhabitants' cognitive recognition of purpose and their own role in relation to interacting with service controls is fundamental for engagement and learning. Without it, a control interface and the service system associated with it tends to be ignored by the inhabitant. Significantly, success depends on combining a range of carefully designed and integrated elements and activities to facilitate inhabitants' essential cognitive learning in housing developments: clear user guidance, active learning support, adequate labelling and interaction feedback provided by control interfaces.

Another significant aspect impacting on usability lies in the process of selection and procurement of controls. This is beyond the scope of this paper, but deserves further investigation to help prevent poor controls from being re-specified. Meanwhile, designers need to focus on usability at the design stage by specifying well-designed control interfaces and securing an ergonomically suitable location in the first place, as it is unlikely that affordance and physical ergonomic issues can be easily addressed during the post-occupancy period. This raises the wider question of how to structure a co-learning process, based on inhabitant feedback, into the design of control interfaces for homes. This could happen if the assessment and evaluation of the usability of control interfaces in the home became routine in post-occupancy evaluation and feedback into the product design as well as housing design process. However, it is recognised that there are still wider fundamental challenges to this which need to be overcome in terms of: the fragmented nature of the housing industry; financial disconnections between product development and building performance evaluation; and the 'bespoke' nature of housing development which can preclude thinking about learning from previous housing BPE and usability studies.

Despite the broader challenges above, trialling the usability tool has shown that it can form an invaluable part of the building performance evaluation (BPE) portfolio of techniques, closing a gap in knowledge related to inhabitants' practice of control interfaces in the domestic sector.

Key recommendations for designers are:

- to perform bespoke usability studies routinely as practice-based research provide feedback from previous usability studies at the strategic design briefing stage for a new project
- to implement a continuous process of revising specifications and design work on basis of routine usability feedback.

Key recommendations for developers are:

- to incorporate costs for usability studies from the start, as part of the overall BPE process. The BPE process needs to be adopted from the outset of a project, i.e. during the strategic briefing stage
- to share relevant findings from usability studies to the supply chain, including manufacturers and installers
- to review specifications and design contexts for technology control interfaces in the home, in the light of usability findings

Key recommendations for institutional and governmental policy-makers are:

- to recognise the value of specific usability analysis as an integral part of POE and incorporate this element into institutional policy and guidance on POE and BPE
- to require the development and provision of specific guidance to raise the standard of usability of control interfaces in housing design
- to promote usability as an important feature for inhabitants to optimize the operation of their homes
- to mandate the inclusion of the usability of control interfaces in the design education curricula
- to develop new architectural pedagogies which integrate usability studies into the design studio.

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References:

Baborska-Narożny, M., Stevenson, F., Chatterton, P. (2016a) Temperature in housing: stratification and contextual factors, Proceedings of the Institution of Civil Engineers - Engineering Sustainability. 169(4), 125-137.

Baborska-Narożny, M., Stevenson, F., Ziyad F.J. (2016b) User learning and emerging practices in relation to innovative technologies: A case study of domestic photovoltaic systems in the UK. Energy Research & Social Science, 13, 24-37.

Baborska-Narożny, M., Stevenson, F., Grudzińska M. (2017) Overheating in retrofitted flats: occupant practices, learning and interventions, Building Research & Information. 45(1-2), 40-59

Bordass, B., Leaman, A., & Bunn, R. (2007). Controls for End Users: a guide for good design and implementation. Bracknell: BSRIA.

Brown, C., & Gorgolewski, Mark. (2015). Understanding the role of inhabitants in innovative mechanical ventilation strategies. Building Research & Information, 43(2), 210-221. https://doi.org/10.1080/09613218.2015.963350

Buchanan, K., Staddon, S., & Van der Horst, D. (2018). Feedback in energy-demand reduction. Building Research & Information, 46(3), 231-237. https://doi.org/10.1080/09613218.2018.1412981

Burchell, K., Rettie, R., & Roberts, T.C. (2016) Time for change?: the hard work of energy demand reduction. Demand Center Conference, Lancaster, 13-15 April 2016. Retrieved from: http://www.psi.org.uk/pdf/2016/burchell_et_al_time_for_change_DEMAND_2016.pdf

Buswell, R., Webb, L., Mitchel, V., & Mackley K.L. (2017). Multidisciplinary research: should effort be the measure of success? Building Research & Information, 45(5), 539-555. https://doi.org/10.1080/09613218.2016.1194601

Caird, S. & Roy, R., (2008). User-centred Improvements to Energy Efficiency Products and Renewable Energy Systems: Research on Household Adoption and Use. International Journal of Innovation Management, 12(3), 327–355.

Cartwright, P. & Gaze, Ch. (2013). Lessons from AIMC4 for cost-effective, fabric-first, low-energy housing: Part 2 Supply chain development. Garston: BRE. Available at: www.aimc4.com

CCC (Committee on Climate Change) (2018). An independent assessment of the UK's Clean Growth Strategy: From ambition to action. Report. Available at: www.theccc.org.uk

Climate Change Act 2008, c.27. Retrieved from http://www.legislation.gov.uk/ukpga/2008/27/contents

Combe, N., Harrison D., Craig, S., Young M.S. (2012) An investigation into usability and exclusivity issues of digital programmable thermostats. Journal of Engineering Design, 23(5), 401-417.

Davis, F.D., (1989). Perceived usefulness, perceived ease of use and user acceptance of information technology. MIS Quarterly, 13: 319-340. DOI: 10.2307/249008

DBEIS (Department for Business, Energy & Industrial Strategy) (2017) Energy Consumption in the UK Report. Retrieved from https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

DECC (Department of Energy and Climate Change) (2017) UK National Energy Efficiency Action Plan and Annual Report. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/uk_neeap_2017.pdf

Derbez, M., Berthineau, B., Cochet, V., Pignon, C., Ribéron, J., Wyart, G., Mandin, C., Kirchner, S. (2014). A 3-year follow-up of indoor air quality and comfort in two energy-efficient houses, Building & Environment, 82, 288-299.

Fazli, T., Yeap, R.Y., Stephens, B. (2015) Modeling the energy and cost impacts of excess static pressure in central forced-air heating and air-conditioning systems in single-family residences in the U.S. Energy and Buildings, 107, 243-253.

Flyvbjerg, B. (2006). Five 'misunderstandings' about case-study research. Qualitative Inquiry, 12, 219-245 doi:10.1177/1077800405284363

Foulds, C., Powell, J. & Seyfang, G. (2013). Investigating the performance of everyday domestic practices using building monitoring. Building Research & Information, 41(6): 622-636. https://doi.org/10.1080/09613218.2013.823537

Fowler, F.J. (2014) Survey Research Methods, Applied Social Research Methods Series Volume 1. 5th ed. Thousand Oaks, CA: SAGE Publications.

Gibson, J. (1979). The Ecological Approach to Visual Perception. Boston: Houghton Mifflin Company.

Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. Building Research & Information, 38(2), 175-186. https://doi.org/10.1080/09613210903541527

Grégoire, D.A., Barr, P.S., & Shepherd, D.A. (2010) Cognitive Processes of Opportunity Recognition: The Role of Structural Alignment. Organization Science 21(2):413-431. http://dx.doi.org/10.1287/orsc.1090.0462

Gupta, R., Gregg, M. (2016) Do deep low carbon domestic retrofits actually work? Energy & Buildings, 129, 330-343.

Hargreaves, T., Wilson, C., & Hauxwell-Baldwin, R. (2018). Learning to live in a smart home. Building Research & Information, 46(1), 127-139. https://doi.org/10.1080/09613218.2017.1286882

House of Commons Communities and Local Government Committee (2017) Capacity in the homebuilding industry. Tenth Report of Sessions 2016-17. London: House of Commons.

Ingold, T. (1992). Culture and the perception of the environment. In E.Croll & D. Parkins (Eds.) Bush base: Forest farm - Culture, environment and development. London: Routledge. pp. 39-56.

Ingold, T. (2000) The perception of the environment: essays on livelihood, dwelling and skill. London: Routledge.

IDF Interaction Design Foundation (2017) The basics of User Experience Design, ebook. www???

ISO 9242-11 (2017) Ergonomics of human-system interaction - Part 11: Usability: Definitions and concepts. ISO Standards.

Janda, K.B. (2011) Buildings don't use energy: people do. Architectural Science Review, 54(1), 15-22.

Karwowski, W. (2012). The Discipline of Human Factors and Ergonomics. In Handbook of Human Factors and Ergonomics, G. Salvendy (Ed.). 4^{th} Ed, Wiley. ISBN: 9780470528389

Leaman, A., Stevenson, F. & Bordass B. (2010) Building evaluation: practice and principles, Building Research & Information, 38:5, 564-577, DOI:10.1080/09613218.2010.495217

Lowe, R., Chiu, L.F., & Oreszczyn, T. (2017) Socio-technical case study method in building performance evaluation. Building Research & Information, DOI: 10.1080/09613218.2017.1361275

Marechal, K. (2010) Not irrational but habitual: The importance of "behavioural lock-in" in energy consumption. Ecological Economies, 69(5) 1104-1114.

McCunn, L.J., & Gifford, R. (2013) Environmental Design in Acute Care Settings: A Case Study of a Neurological Rehabilitation Unit. HERD: Health Environments Research & Design Journal, 7(1), 102-113 DOI: 10.1177/193758671300700109

Munton, A.G., Wright, A.J., Mallaburn, P.S, & Boait, P.J. (2014). How heating controls affect domestic energy demand: A Rapid Evidence Assessment. A report to the Department of Energy and Climate Change. DECC, London.

Neisser, U. (1976). Cognition and Reality: Principles and Implications of Cognitive Psychology. New York: WH Freeman and Company.

NFPA (National Fire Protection Agency) (2015) Smoke Alarms in U.S. Home Fires Fact Sheet. Retrieved from www.nfpa.org

Nicolini, D. (2017). Practice Theory as a Package of Theory, Method and Vocabulary: Affordances and Limitations. M. Jonas et al. (eds.), Methodological Reflections on Practice Oriented Theories, pp.19-34. DOI 10.1007/978-3-319-52897-7_2

Norman, D. (1998). The design of everyday things. London: MIT Press.

Palmer, J., Godoy-Shimizu, D., Tillson, A., Mawditt, I. (2016) Building Performance Evaluation Programme: Findings from domestic projects. London: Innovate UK.

Parkinson, A.T., Reid, R., McKerrow H., Wright D. (2018) Evaluating positivist theories of occupant satisfaction: a statistical analysis, Building Research and Information, 46(4), 430-443. https://doi.org/10.1080/09613218.2017.1314148

Peffer, T., Pritoni. M., Meier. A., Aragon. C., & Perry, D. (2011) How people use thermostats in homes: A review. Building and Environment, 46(12), 2529-2541.

Powell, G., (2009). Warming Homes, Cooling the Planet: An Analysis of Socio-Techno-Economic Energy Efficiency Policy and Practice in the UK. PhD Thesis. Department of Geography, Durham University.

Preiser, W.F.E., & Vischer J. (2005) Assessing Building Performance. Oxford: Elsevier.

Pritoni, M., Meier, A.K., Aragon, C., Perry, D., & Peffer, T. (2015) Energy efficiency and the misuse of programmable thermostats: The effectiveness of crowdsourcing for understanding household behaviour. Energy Research & Social Science, 8, 190-197.

Raja I.A., Nicol, F., McCartney K.J., & Humphreys M.A. (2001) Thermal comfort: use of controls in naturally ventilated buildings. Energy & Buildings, 33(3),235-244.

Reckwitz, A. (2002). Toward a theory of social practices. European Journal of Social Theory, 5(2), 243–263.

Revell, K.M.A., Stanton N.A. (2018) Mental model interface design: putting users in control of home heating. Building Research & Information, 46(3), 251-271. https://doi.org/10.1080/09613218.2017.1377518

RIBA and Hay, R., S. Bradbury, D. Dixon, K. Martindale, F. Samuel, A.Tait (2016). Pathways to POE, Value of Architects. University of Reading, RIBA.

Robson, C. (2011). Real World Research. 3rd Edition, Chichester: Wiley and Son,.

Sachs, O., Tiefenbeck, V., Duvier, C., Qin, A., Cheney, K., Akers, C., & Roth K. (2012) Field Evaluation of Programmable Thermostats. US Department of Energy. Availble at: https://www.osti.gov/biblio/1059166

Samuel, F. (2017) Supporting Research in Practice. The Journal of Architecture, 22(1), 4-10 DOI: 10.1080/13602365.2017.1280288

Schatzki, T. (2001). Practice mind-ed orders. In T. Schatzki, K. Knorr Cetina, & E. Von Savigny (Eds.), The practice turn in contemporary theory (pp. 42–55). London: Routledge.

Shove, E., Pantzar, M., & Watson, M. (2012). The dynamics of social practice: Everyday life and how it changes. Thousand Oaks: Sage.

Stern, P. (2000). Toward a Coherent Theory of Environmentally Significant Behavior. Journal of Social Issues, 56(3), 407–424.

Stevenson F., Baborska-Narożny M.,Chatterton P. (2016) Resilience, redundancy and low-carbon living: coproducing individual and community learning. Building Research & Information. 44(7), 789–803

Stevenson, F., Carmona-Andreu I., & Hancock M. (2013). The usability of control interfaces in low-carbon housing. Architectural Science Review, 56(1), 70-82.

Strengers, Y. (2016) Envisioning the smart home: Reimagining a smart energy future. In Digital Materialities, S. Pink, E. Ardevol, D. Lanzeni (Eds.) (pp.61-76). London: Bloomsbury.

Technology Strategy Board (TSB) (2012). Building Performance Evaluation, Domestic

Buildings Guidance for Project Execution, Version 7. Swindon: The Technology Strategy Board.
Tannous, W.C., Whybro, M., Lewis, C. et al. (2017). Home Fire Safety Checks in New South Wales: an economic evaluation of the pilot program. Journal of Risk Research, https://doi.org/10.1080/13669877.2017.1281336
Tsang, F., Burge, P., Chatterton, T., Wilson, C., Diepeveen, S., Drabble, S. & Guerin, B. (2012). What works in changing energy-using behaviours in the home? A rapid evidence assessment. Technical Report. UK Government: Department of Energy and Climate Change. Available from: http://eprints.uwe.ac.uk/29888.
Tweed, C. (2013). Socio-technical issues in dwelling retrofit. Building Research & Information, 41(5), 551-562. https://doi.org/10.1080/09613218.2013.815047
Tweed, C., Zapata-Lancaster, G. (2017). Interdisciplinary perspectives on building thermal performance. Building Research & Information, DOI: 10.1080/09613218.2018.1379815
Vlasova, L., & Gram-Hanssen, K. (2014). Incorporating inhabitants' everyday practices into domestic retrofits. Building Research & Information, 42(4), 512-524. DOI: 10.1080/09613218.2014.907682
Vessey, I. (1991). Cognitive Fit: A Theory-Based Analysis of the Graphs Versus Tables Literature, Decision Sciences, 22(2), 219-240.
Wade, F., Murtagh, N., & Hitchings, R. (2018). Managing professional jurisdiction and domestic energy use, Building Research & Information, 46(1), 42-53. https://doi.org/10.1080/09613218.2017.1324698
Whitfield, D. (1972). Putting ergonomics into standard. Design. 288, 52-53.
Wilson, J.R. (2000). Fundamentals of ergonomics in theory and practice, Applied Ergonomics, 31(6), 557-567.
Yin, R.K. (2009). Case study research: Design and method. 2nd ed. London: Sage.

You, H., & Chen, K. (2007) Applications of affordance and semantics in product design. Design Studies, 28(1), 23-38.
Zimmerman A., & Martin, M. (2001). Post-occupancy evaluation: benefits and barriers. Building Research & Information, 21(2), 168-174. https://doi.org/10.1080/09613210010016857

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[i] Medium builders are defined as delivering 101-2000 homes a year and make up the remaining 29% of the market share.