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DESIGN FEEDBACK INTERVENTIONS FOR HOUSEHOLD ENERGY CONSUMPTION REDUCTION

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Abstract

Design for Sustainable Behaviour [DfSB] is an emerging research area concerned with the application of design strategies to influence consumer behaviour during the use phase of a product towards more sustainable action. Current DfSB research has primarily focussed on strategy definition and selection within a design process, with surprisingly little research into understanding the actual impact of the behaviour changing interventions yielded through such investigation. Furthermore, the suitability of evaluation methods and the transferability of evaluation results have seldom been discussed. This paper reports on the findings of a three-year research project within the UK social housing sector, research that aimed to reduce energy consumption within the home through behaviour changing intervention, whilst maintaining occupants comfort levels. A behaviour changing prototype was developed through a user-centred design process, resulting in a physical manifestation of one specific DfSB strategy – feedback; a user agentive performance indicator. In order to evaluate this feedback prototype, an evaluation framework was developed, targeted at the three fundamental questions that arise when faced with the evaluation of a DfSB strategy led intervention: (1) Does the produced design solution function for the specified context? (2) Has the user's behaviour changed as a consequence of the design intervention? (3) Is the change in user's behaviour sustainable? Applying these core questions in practice resulted in an evaluation of unparalleled depth. The function and usability of the design were evaluated with users and against extensive feedback design criteria. In addition, behavioural changes in the intentions and habitual processes of the user and their facilitating conditions as well as sustainability changes in energy consumption and comfort were evaluated against pre-intervention state benchmarks. Fitting within the remit of sustainability, the associated ethical dimensions and impact of this DfSB research were also evaluated. Using data collection methods that included focus groups and user trials, the results of this

research project illustrate the success of using this tripartite questioning strategy towards the evaluation of a DfSB strategy led intervention, building a vital knowledge platform for the formalisation of transferable DfSB research and evaluation methods.

Keywords

Design; Sustainability; User Behaviour; Energy; Feedback

1. Introduction

As part of our moral responsibility to maintain the ecological, social and economic base for present day society and future generations (Bhamra and Lofthouse, 2007), environmental targets have been ratified by the Parliament of the United Kingdom (2008, 2009), enshrined within the Climate Change Act 2008. The environmental predicament that both the UK and global communities are in, which has necessitated such legislative action, has been propagated, in part, by energy consumed within the domestic sphere and the greenhouse gases that are produced as a consequence (Department of Energy and Climate Change, 2008). Prior research has illustrated that more efficient technological solutions may not be the solution (Darby, 2006; Mintel, 2009) and that, as many authors have argued, it is the behaviour of the user that should be the target of intervention, focussing on how the user defines and enacts comfort behaviour with the home (Chappells and Shove, 2004, 2005; Cole et al., 2008; Shove, 2008; Steg and Vlek, 2009). In order to promote a change in domestic energy use, it is critical, therefore, to understand and diagnose the problem as well as the underlying factors that lead to their realisation (Abrahamse et al., 2005).

A project that explored such issues was the Carbon, Control and Comfort [CCC]: User-centred control systems for comfort, carbon saving and energy management project, a project funded through the E.ON and Engineering and Physical Sciences Research Council Energy Efficiency panel (EPSRC, 2010). The CCC project was a three year, interdisciplinary UK project that attempted to reduce domestic energy use by 20% in social housing, through the user-centred design of feedback interventions to change behaviour whilst maintaining the tenants comfort levels. To define the context, social housing within the UK can be defined as *"housing that is let at low rents and on a secure basis to people in housing need"* (Shelter, 2012).

The aim of this paper is to present the findings from one aspect of Loughborough University's contribution to this extensive project; an investigation into how DfSB models and strategies can be implemented within a structured design process towards the reduction of domestic energy consumption within social housing properties. This paper focuses

specifically on the evaluation phase of this design process, the development of evaluation criteria and the evaluation of a feedback intervention prototype through focus groups and user trials.

2. Feedback, Design for Sustainable Behaviour and the Design Intervention Process

The factors that influence the individual's attitude and behaviour towards interaction with energy consuming domestic products are complicated. Although, as Darby emphasises, energy is a *"basic human need"* (2000, P.2), studies have shown its consideration by the individual to be very low with minimal interest (Burgess and Nye, 2008; Fischer, 2008). In addition, it has been recognised that the mental frameworks of energy that the individual develops are formed through levels of indirect consumption, dependant on interaction with products and an interpretation of the associated benefits (Fischer, 2008; Steg, 2008), emphasising that the study of energy use is intrinsically linked to the use of products. In order to understand energy consumption, it is, therefore, important to understand the complex behavioural processes that underpin and drive the cognitive structures that form these interactions with energy consuming products.

Although there are multiple models available to provide disparate psychological or sociological perspectives into the underlying structures that form behaviour or practice (an on-going debate outside of the scope of this paper), the Theory of Interpersonal Behaviour (Jackson, 2005), augmented with Verplanken's definition of habit (Verplanken, 2006) will be the model referenced throughout this paper. This psychological approach to behaviour, once augmented, provides a defined model of behavioural understanding with a robust history of application in the field of psychology, in addition to sharing an ontology and terminology aligned to the core of present design thinking (centred on the individual/user, attitudes, goals, habits etc.). Within this approach, the individual is central to a rational decision-making process, with behavioural action influenced by internal and external prompts that interact with the intentions (attitudes, social factors and emotions), habits and facilitating conditions unique to the individual and their context (Chatterton, 2011; Jackson, 2005). With a model identified, the energy consuming actions of the individual and their behavioural processes studied can be put into relative context with the strategies available that seek to change or influence this behaviour.

Broadly speaking, intervention types are split into two categories, antecedent interventions and consequence interventions, of which feedback strategies fit into this latter category. Antecedent interventions, such as commitment, goal setting, informational and structural strategies, aim to influence or change the antecedents of behaviour, namely intentions,

habits and facilitating conditions, prior to the enactment of the behavioural action (Abrahamse et al., 2005). Antecedent interventions thus attempt to focus, motivate, educate, facilitate or constrain the individual towards making a desired behavioural action. Consequence interventions, including the use of reward and feedback strategies, take an alternative approach, shifting focus towards the consequences of behaviour, framing the positive or negative resulting impact that behaviour has in relation to the antecedents that motivated that action (Abrahamse et al., 2005).

Through an understanding of feedback strategies within these terms and boundaries, feedback can be defined as an educational tool, used to frame energy-consuming issues and problems caused through behavioural action in order to generate cognitive reflection upon and within the intentional, habitual and conditional antecedent structure of the individual. Whichever categorisation one takes of feedback strategies, however, the key behaviour change mechanism of importance is that of information provision, as information is central to the concept of feedback as an educational tool. Without information, the bridging cognitive connections between action and effect are weakened, as the impact of the action is not linked by the individual to the behavioural antecedents that precipitated that action, negating any form of reflection or increase in awareness (Darby, 2008, 2010; Fischer, 2008).

The ability of information to motivate the individual is not only dependant on its content, but also its delivery method, as this helps to frame the information presented to the individual. The key points to conclude from extensive (but by no means exhaustive) prior work in the field are that the information provided by the feedback device needs to be accurate and frequent enough, depending on the context of use, in order to strengthen this cognitive bridge between action and effect (Abrahamse et al., 2005; Darby, 2006; Fischer, 2008; Fitzpatrick and Smith, 2009; Hargreaves, 2010; Wood and Newborough, 2007). Furthermore, the information presented needs to be comprehensible, undemanding, and easy to cognitively process (Anderson and White, 2009; Burgess and Nye, 2008; Fischer, 2008; Fitzpatrick and Smith, 2009; Hargreaves, 2010; Wood and Newborough, 2007), with ambience features easy to map cognitively for implicit evaluation (Ham et al., 2009; Löfström and Palm, 2008; Maan et al., 2011). In addition, the use of historic or normative comparisons depends on the motivations and intentions of the individual (Abrahamse et al., 2005; Fischer, 2008; Fitzpatrick and Smith, 2009; Hargreaves, 2010; Wood and Newborough, 2007). Given this myriad of requirements, it is imperative that a feedback intervention is tailored to the intentions, capabilities and expectations of the individual, failure

to do so may lead to potentially damaging rebound effects. Clearly, the process by which these mechanisms are designed needs to consider these requirements (Wilson et al., 2010).

DfSB is a branch of sustainable design theory that offers such processes and mechanisms, presenting a catalogue of design-led strategies concerned with influencing user behaviour, during the use phase of a product, towards more sustainable action (Lilley, 2009b). It has been recognised by the majority of researchers working in this field that there exists an axis along which these strategies are positioned, determined by the control or power in decision-making. At one end of this axis are technologically agentive solutions such as intelligent, automatic technologies, whilst the other end of the axis represents user agentive technologies, such as feedback (Elias, 2011; Lidman et al., 2011; Lilley, 2009b; Lockton and Harrison, 2012; Tang and Bhamra, 2011; Wever et al., 2008; Zachrisson and Boks, 2012). However, as one would expect from a field that is growing rapidly with researchers investigating various facets and definitions of this axis concurrently, there are disagreements on the terminology and classification of these strategies, making future research attempts and cross-research discussions difficult without clear and common agreement (Boks, 2011).

Whilst a design process model is gradually emerging through consensus (Selvefors et al., 2011; Tang and Bhamra, 2011; Zachrisson et al., 2011), the exact relationship between the phases is yet to become standardised. It is clear, however, that user-centred design research techniques are required prior to the selection of an intervention strategy in order to understand the intervention context, the behavioural antecedents and the corresponding action and effect. This information is then used to select, frame and bound the behaviour in order to focus the selection of the behaviour changing strategy. Concepts are generated within the defined remit of the strategy or strategies selected, evaluated against the behavioural antecedents through longitudinal study. The lack of DfSB case studies at present makes it difficult to judge the effectiveness of the design processes proposed as well as the appropriateness of both the targeted behaviour and the selected DfSB strategy. Because of the lack of case studies coupled with the short duration of many of the implemented design processes identified, which tend to focus on the early, front end of the design process model and the selection or defining or DfSB strategies, how a DfSB device should be evaluated is relatively undetermined. Consideration of the evaluation phase of the design process and development of appropriate assessment criteria is, for the most part, absent, leaving a considerable gap in knowledge that this paper addresses.

Rather than implement an embryonic model that is currently under debate, for the purposes of this research it was more appropriate to frame the design process around an already

established design process, specifically one that revolves around the techniques implicit in DfSB anchored design schemes; the User-Centred Design [UCD] process. A UCD process, such as the ISO standard for Human-centred design for interactive systems (British Standards Institution, 2010), typically follows a cyclical, iterative structure, beginning with the exploration, understanding and specifying of the context of use and the users' needs and requirements. Although presented as disparate phases within the ISO standard to emphasise their relative importance, in reality, the user and the context are inextricably linked and this understanding and specifying of their features and criteria may be established concurrently (IDEO, 1999; McClelland and Suri, 2005). If the aim of DfSB is to change the behaviour of a user, composed of intention, habits and facilitating conditions, then clearly this stage is vital to developing an understanding on which to base, inform, and evaluate future design decisions to reach this goal. A second phase discussed in UCD literature (IDEO, 1999; McClelland and Suri, 2005) but not explicit in the ISO model concerns the identifying of design opportunities, a point of synthesis, turning the qualitative data gathered in the preceding phase into forward facing statements of design direction. Opportunities from a DfSB perspective could be related to identifying specific behaviours and actions to target or strategies to implement. Returning to the ISO standard, the next phase concerns the production of design solutions, a formalising of design knowledge into concepts that address the opportunities identified and that are in line with the understanding and expectations of the user and context (British Standards Institution, 2010). DfSB solutions that respond to the ill-defined problems and opportunities identified can be explored and iterated from a large number of initial concepts to an eventual convergence on a single concept (Cross, 2007; Pugh, 1990). The next phase is a user-centred evaluation, an evaluation of the concept (and assumptions made) with real world users (British Standards Institution, 2010; McClelland and Suri, 2005). A DfSB evaluation specifically concerns the evaluation of the design, sustainability and behavioural aspects benchmarked against the user and context as identified in the initial understand and specify phase as developed through the course of the design process. This phase may not be the last as the evaluation may uncover or illuminate a need for further information or redefinition of the user, context or opportunity (an iteration back to the understanding and specifying or intervention opportunities phases), or may also illustrate design weaknesses that require improvement (an iteration back to the intervention design phase). For the purposes of this paper, the definition of the UCD process, or the Design Intervention Process, can be visualised as the following diagram, Figure 1.
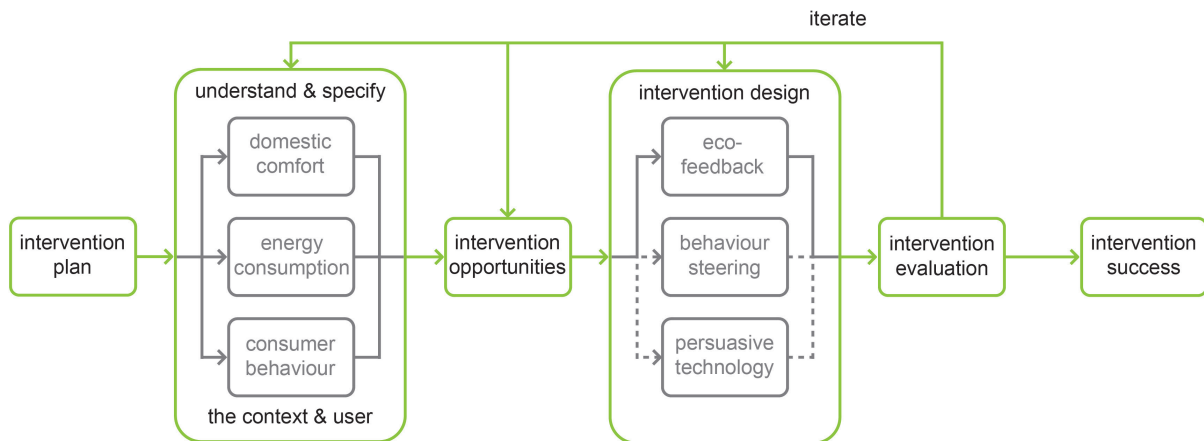
Figure 1: The Design Intervention Process

The focus of this paper, as previously stated, is the evaluation phase of this process, specifically entitled within the Design Intervention Process as the Intervention Evaluation phase. The next section of this paper defines the evaluation criterion that needs to be considered and assessed within this phase.

3. Feedback Interventions: Evaluation Criteria

The purpose of a user-centred evaluation is twofold; to feed back positive and negative information into the design process in order to better meet (or understand and redefine) the user's requirements, as well as to understand if the design produced meets those specified user requirements (British Standards Institution, 2010; Maguire, 2001). IDEO succinctly elaborates upon this, stating *"the point...is to change the solutions, not to prove that they are perfect"* (IDEO, 1999, P.77). The criterion against which a design is evaluated is developed from an understanding of the contextual research study and through a cyclic design process. Although the users' exact requirements will change depending on the aim and function of a design, three fundamental questions arise when faced with the evaluation of a DfSB strategy led intervention:

- *Did the produced design solution function for the specified context?*
- *Has the user's behaviour changed as a consequence of the design intervention?*
- *Is the change in user's behaviour sustainable?*

3.1.   Did the Produced Design Solution Function for the Specified Context?

This question pertains to an evaluation of the designs usability and function. Is the usability of the design in line with the user's requirements and expectations, and do the design functions operate as the designer intended? Clearly different DfSB strategies have different criteria against which to assess usability and function. Taking the three points of Lilley's (2009b) strategies as an example, eco-feedback, behaviour steering and persuasive technology, there may be a common target such as reducing resource consumption, for example, but the methods employed vary drastically. Eco-feedback may seek to reduce consumption through the provision of information, which has its own framing questions between itself and the user. Behaviour steering devices may rely on affordances and constraints to encourage a reduction in consumption, and thus semantics and ergonomics may be of focus. Persuasive technologies in negating the user to enforce a change may be assessed against the technical support to install and maintain the technology and to monitor the technology's effects.

As feedback intervention was the primary focus of this research investigation, the question as to whether the produced design solution functions for the specified context should be viewed through a feedback evaluation lens. Drawn from an extensive review of literature, as previously touched upon, concerning the categories and considerations of feedback, the following function and usability aspects need to be evaluated to provide a thorough feedback intervention evaluation (Table 1).

How frequently and what is the duration of the feedback information that is fed back to the user, and what is the effect this has on the user's cognitive bridging between action and effect?
How accurate is the feedback information presented, and how does this help to associate or dissociate a user with their actions?
How does the selection of the contents and metrics resonate with the user's individual norms and motives?
Is the feedback information presented a granulation from a larger system, and how does it help or hinder a user's understanding of this information within that system?
How does the medium of presentation affect a user's ability to engage with the feedback information?
How does the selection of presentation mode affect the user's comprehension of the feedback information provided?
How does the user interpret ambient features, and to what extent are they cognitively mapped by the user and in line with the designer's intent?
How does the location of the device affect the ways in which the user interacts with the feedback information?

Does the user have any technical expectations of the feedback intervention, and have these been met?
Does the feedback information rely on the use of comparisons to further information groups, and does this inhibit or stimulate consumption?
Has any additional information been provided or goals or reward schemes activated to supplement the feedback information?
Are there any user led challenges that may inhibit or counter the designer's intention for the feedback intervention?

Table 1: Function and Usability - Evaluation Questions

3.2. Has the User's Behaviour Changed as a Consequence of the Design Intervention?

One of the primary objectives of a DfSB intervention should be the changing of a user's behaviour towards long-term sustainable ends, not the short term changing of a user's action for immediate ecological/social/economic gratification. Therefore, this second question relates to the DfSB interventions ability to change the behaviour of the user. In order to determine if the user's behaviour has changed due to the design intervention, it is imperative to understand the antecedents of that behaviour targeted for change. Only then can it become possible to recognise and fully evaluate any change in the behaviour attributed to that intervention. The following questions, anchored by a psychological approach to behaviour, the Theory of Interpersonal Behaviour (Jackson, 2005), aim to determine and understand the changes in context and intentions between the prior and post design intervention states, (Table 2).

What was/is the user's knowledge and perception of environmental matters, morality, resource consumption and comfort, both prior and post to the introduction of the design intervention?
What was/is the user's value weighting of environmental matters, morality, resource consumption and comfort benefit, against expected cost, prior/post to the introduction of the design intervention?
What was/is the user's conceptualisation of social rules and actions relating to environmental matters, morality, resource consumption and comfort both prior and post to the introduction of the design intervention?
What was/is the user's categorisation of social and group roles in terms of environmental matters, morality, resource consumption and comfort, both prior and post to the introduction of the design intervention?
What was/is the user's perception of their self and what do they deem to be appropriate goals and actions in terms of environmental matters, morality, resource consumption and comfort, both prior and post to the introduction of the design intervention?
What are the positive and negative emotional responses associated with actions related to environmental matters, morality, resource consumption and comfort, both prior and post to the introduction of the design intervention?

What were/are the facilitating conditions (capabilities, situational context, public policy, economic variables etc.) that influenced/s the user's action, prior/post to the introduction of the design intervention?
How did/does the facilitating conditions constrain or afford options, prior/post to the introduction of the design intervention?
How did/does the contextual infrastructure moderate or influence between intention and habitual factors, prior/post to the introduction of the design intervention?

Table 2: Intentions and Facilitating Conditions - Evaluation Questions

With the contextual aspects and intentions identified in the prior and post design intervention states, the third variable that needs evaluating is the one that governs the user's action, their level of cognitive reasoning, or conversely, their level of cognitive automaticity. In order to determine the habitual strength of behaviour the following questions have been derived from Verplanken's definition of habit (Verplanken, 2006), (Table 3).

How frequently was/is the behavioural act enacted, prior/post to the introduction of the design intervention?
Did/Does the user exhibit a lack of awareness of how they act in terms of conscious decision making or delegation of control of the behavioural act to contextual cues, prior/post to the introduction of the design intervention?
Did/Does the user have free mental capacity to do other things, or exhibit efficiency through expectation filters, prior/post to the introduction of the design intervention?
Did/Does the user have difficulty in controlling their behaviour in relation to this act, with trouble in deliberate thinking or planning, prior/post to the introduction of the design intervention?
Did/Does the behavioural action represent a sense of personal identity to the user, prior/post to the introduction of the design intervention?

Table 3: Habit – Evaluation Questions

3.3.   Is the Change in the User's Behaviour Sustainable?

This third category of inquiry relates to the impact of the changed user behaviour, in respect of being ecologically, socially and economically sustainable. Through an understanding and measurement of the change in these sustainability metrics, the success of the DfSB design intervention can be put into perspective against the interventions function and ability to change the user's behaviour. In the context of this paper, two specific sustainability metrics of interest are domestic energy consumption and domestic comfort. The following items evaluate the states both prior and post the introduction of the design intervention (Table 4).

What was/is the domiciles domestic energy consumption prior/post to the introduction of the design intervention?
What was/is the domestic energy consumption by inhabitant/appliance/room/temporality prior/post to the introduction of the design intervention?
What were/are the inhabitant's expectations and actual levels of physical (lighting/acoustical/air/thermal) comfort, prior/post to the introduction of the design intervention?
What was/is the domestic comfort level by inhabitant/room/temporality prior/post to the introduction of the design intervention?
Can the effect of contextual infrastructure (such as building fabric, situational context and economic variables such as cost per unit of energy etc.) upon energy use and comfort, both prior and post to the introduction of the design intervention, be quantified?
Does the ecological, economic and social benefit from the change in behaviour outweigh the ecological, economic and social impact of intervention provision?

Table 4: Sustainability – Evaluation Questions

The question of ethics in design, as Albrechtslund (2007, p.66) states, *"is not optional"*, as technology has ethical connotations whether prescribed towards sustainable ends or not by the designer, therefore also requiring evaluation. Considering DfSB specifically, the issue of ethics is intensified, as the expected behavioural change prescribed through the design intervention by the designer in order to reduce energy consumption, may not be in line with the expectations and values of the user (Pettersen and Boks, 2008). The designer, however, is ideally positioned within the design process as a solver of ill-structured problems, a definition within which ethical design clearly resides (Dorst and Royakkers, 2006; Vries, 2006).

The following questions (drawn from an extensive review of literature concerning ethics in design (Albrechtslund, 2007; Berdichevsky and Neuenschwander, 1999; Fogg, 2003; Gowri, 2004; Lilley and Lofthouse, 2010; Pettersen and Boks, 2008; Verbeek, 2006)) evaluate the ethics of the user's changed behaviour, as well as the ethics of the process through which the design intervention was created (Table 5). The ethical measure of an intervention is not only calculated by the behaviour changed, but is also is an ethical measure of the designer and design process itself.

Was the designer's original intent for designing a behaviour intervention ethical?
Was the designer's original motivation for designing a behaviour intervention ethical?
Are the intervention methods employed by the designer, in order to change the user's behaviour, ethical?
Has the designer/user/purchaser taken moral responsibility for the design intervention?
To what extent is the user in control of the design intervention?
Is the level of user control over the design intervention acceptably weighted against the intent and motivation of the designer?
Have the democratic decision making rights of all stakeholders been accounted for in the design process?
Have the values and morals of all stakeholders been accounted for in the design process?
Have the values of the stakeholder been evaluated against a robust ethical framework?
Are the intended outcomes of the design intervention ethical?
Have unintended interactions between the user and the design intervention been predicted and are ethical?
Have unintended use contexts involving the user and the design intervention been predicted and are ethical?

Table 5: Ethics – Evaluation Questions

With the criteria for the evaluation of a feedback intervention defined, the next section of this paper illustrate a case study in which these probing and examining questions were applied in the evaluation of a feedback intervention with social housing tenants.

4. Feedback Interventions: Evaluation Case Study

To effectively evaluate a feedback intervention that has been designed through DfSB processes and strategies, it stands to reason that such a behaviour changing mechanism must be initially developed and produced. Although a detailed description of the design process in its entirety is outside of the remit of this paper, a brief description and mapping of how the Design Intervention Process was enacted during this case study will help in establishing the general context leading towards the intervention evaluation phase.

In order to design and understand the efficacy of a feedback intervention that seeks to reduce domestic energy consumption it is imperative that both the individual and the operating context are investigated and understood. This initial phase, to *'understand and specify the context and user'*, involved a study in the town of Merthyr Tydfil, South Wales, an area of the UK with significant unemployment and low levels of education and life

expectancy (Office for National Statistics, 2010, 2012). Seven social housing tenements with several dimensions of variability such as household composition, the built form and age of the property, as well as variations in terms of heating system and meter or tariff type participated in this initial user/context study. For each household, two data collection techniques were used; semi-structured contextual interviews (the context defined as being within the home) and semi-structured guided tours. A guided tour is an observational method in which the participant explains and reflects upon artefacts, actions and experiences within this environment whilst the researcher attempts to capture with audio-visual methods the phenomenological results and interpretations of these interactions (IDEO, 2003; Lilley, 2009a; McClelland and Suri, 2005; Pink, 2007). These guided tour focussed on how the tenants defined and constructed their most and least comfortable spaces in their home. This combination of techniques formed the initial understanding of the user and context.

The second phase, *'intervention opportunities'*, concerned the generating of areas of opportunity; the reframing of a theme or insight based on empathic qualitative research, into future facing opportunities for design investigation. With areas of opportunity determined, they were then used to direct the ensuing design effort and to refocus the original problem (IDEO, 1999). Derived from the initial understanding of the user and context, the brief was reframed as:

> *"Recognising that the pursuit of 'fresh air' can have an effect on the efficiency of a heating system, explore mechanisms through which to convey to the tenant the consequences of their fresh air attainment. By feeding back the consequences of choice on the heating system, reduce the tenants' domestic energy consumption whilst allowing for the maintaining of comfort standards".*

The next phase of the Design Intervention Process was *'intervention design'*; the point in the design process in which the designer creatively frames and explores the solution space, rapidly generating and converging a breadth of concepts in response to an ill-defined problem (the brief) (Cross, 2007, 2010). Four elements comprise this phase of the Design Intervention Process, expanding the context and user understanding, the generation of solutions, the selection and development of solutions, and finally the prototyping of a solution.

The aim of the final developed concept in this case study was to feedback to the tenant the status of their heating system in tandem with the status of their windows, so to convey directly the energy consequences of their behaviour. Two input variables are monitored; the

radiators status (surface temperature) as well as windows status (open or closed). Feedback is provided in the form of two output mechanisms: light (colour) and sound (click). As the surface temperature of the radiator increases from cold, the light located within the base of the radiator activates, changing colour depending on the temperature. As the light moves between temperature categories, the feedback device also clicks to indicate a change of state (replicating the sound of a gas central heating boiler turning on). If a window is opened in tandem with a detected increase in radiator surface temperature, the light colour corresponding to temperature immediately displays a warning light, to indicate waste. If the window is closed, the scales immediately return to the pre-open window state. If the radiator begins to cool, the status of the light also begins to regress. If a window is opened with no initial surface temperature activation, then no feedback is required or provided, as there is no conflict in energy usage. The following table, Table 6, summarises the operating conditions and associated feedback response.

Information	Window Status	Radiator Status	Intervention Light Status
The radiator is cold	Closed	<25°C	Not active
The radiator is warm	Closed	25-43°C	White*
The radiator is hot (burn hazard)	Closed	43°C >	Orange*
The radiator is cold	Open	<25°C	Not active
There is an energy conflict (waste)	Open	25-43°C	Red*
There is an energy conflict (waste)	Open	43°C >	Red*
*An audible click denotes a change between status			

Table 6: Feedback Intervention Prototype Statuses

The developed prototype took the form of a low-fidelity part prototype (Buchenau and Suri, 2000; McClelland and Suri, 2005), Figure 2, which registered the temperature of the radiator using a self-adhesive thermocouple and the status of the window with a magnetic reed switch (the magnet to make/break the circuit was attached the window, with the sensor attached to the window frame).
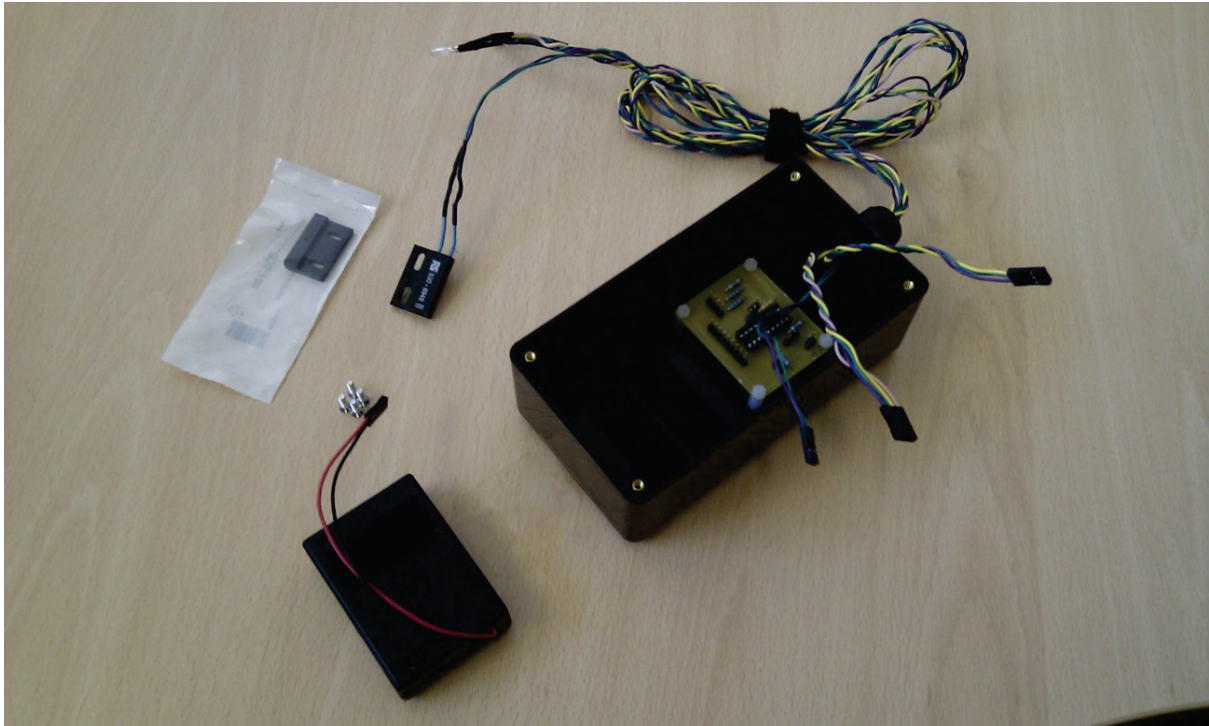
Figure 2: Intervention Prototype

The information was fed back via three LEDs attached to the lower front of the radiator and through a piezo buzzer located within the main body of the prototype. The prototype was literally a black box device on rubber feet designed to run on batteries, requiring no complicated maintenance or retrofitting. An information magnet was also produced as part of the prototype, fixed to the radiator to remind the tenant of the meaning of the different light statuses. In order to evaluate the feedback intervention prototype in the *'intervention evaluation'* phase, two data collection methods were employed, namely semi-structured focus group interviews and user trials.

In brief, two semi-structured focus group interviews were run in Loughborough and Manchester (UK) with a total of 10 social housing tenants. In the context of this research study, the focus was on the feedback intervention prototype. As stated by Nielsen (1997, P.94-95), *"the proper role of focus groups is not to assess interaction styles or design usability, but to discover what users want from the system"*. Focus groups therefore can be considered for exploratory purposes, uncovering opinions, experiences and motivations rather than validating or quantifying design characteristics (Bruseberg and McDonagh-Philp, 2002). Both focus groups consisted of questions centred on two scenario videos and the physical prototype.

The first video depicted a typical scenario of occupant behaviour captured within the initial study to understand and specify the context and user. In this scenario, the individual within

their living room experiences thermal and air quality discomfort and seeks to address this. The individual becomes cold and physically touches the radiator to determine the heating systems status. Deciding that the heating system is not active, the individual turns the thermostat up and then monitors the change in radiator temperature over time through physical contact with the radiator, until the radiator becomes too hot to touch. After a long period the individual experiences air quality discomfort and decides to open a window to air out the room, forgetting that the heating system is active. The window is then left open and the energy waste conflict between window and heating system is never considered. The purpose of the video was to introduce to the participant the research study in a relatable and tangible way, as well as to focus discussion towards the required topics and issues (McClelland and Suri, 2005). The second video introduced the intervention into the established context and played through an expected typical use scenario (Figure 3).

Figure 3: Capture from the Intervention Scenario Video

Repeating the same scenario as before, the individual becomes thermally uncomfortable and following being informed by the intervention as to the heating systems off status, turns the thermostat up. The effect of this action is then visually monitored over time by the individual observing the intervention. Again, after a long period the individual decides to air

out the room due to unacceptable air quality parameters and so opens a window. This time, the intervention informs the individual as to the conflict between window and heating system use and appropriate action is taken. Following the scenario videos, the physical prototype was introduced to the focus group participants to capture and provoke any further reactions to features that may not have been possible through the video format (McClelland and Suri, 2005).

Focus groups interviews were not the only data collection method employed during the course of this research. A user trial involves taking a representation or embodiment of one or all aspects of a research study outcome and allowing a participant to interact with it within an experimental control or real world environment. The purpose of such a trial is to explore physical and cognitive impact, measure performance and to investigate contextual factors (British Standards Institution, 2010; Lilley, 2009a; Maguire, 2001; McClelland and Suri, 2005). The purpose of this evaluation was to measure the performance of the feedback intervention prototype and to provide new insights back into the research process. As such, user trials were undertaken with two participant households that formed the cohort for the initial user/context study. CA02 and CA05 were selected as they both exhibited frequent use of windows for the control and circulation of fresh air and controlled the heating on an ad hoc basis, often leading to energy conflicts with their window actions or to a comfort conflict with other tenants. A pre-intervention qualitative baseline was established using a semi-structured contextual interview, focused on establishing a baseline of our understanding of the participants' knowledge and normative structures, as well as the context in which they operate, followed by the installation of the intervention prototypes.

The prototypes were installed into the living room of CA02 (Figure 4), and into the kitchen of CA05. These locations were chosen for installation as they were self-designated by the participants as their most comfortable space in the initial user/context study. The intervention prototypes were uninstalled after four months of installation. It was envisaged that this timeframe would provide a compromise between the research study duration and the allowing of any change in habitual behaviour to take shape (Lally et al., 2009).

Figure 4: CA02 Living Room with Prototype (Active)

Following removal, both CA02 and CA05 participated in a final semi-structured contextual interview, in order to provide a qualitative comparison to the pre-installation baseline and the initial user/context study. The post-intervention questions were split into understanding if there had been any change in the participant's experience of comfort and how they attain it and secondly, questions relating to the functions of the prototype itself.

Information gathered through focus groups and user trials with contextual interviews needs to be classified and interpreted. Through these analytical processes, the structure and consequences of user behaviour and action within this research context and the impact of the feedback intervention are understood. As such, the data analysis technique of thematic analysis was used; a technique used to develop a rich and think description and understanding of the research (Braun and Clarke, 2006). The results of this analysis are discussed in the following section.

5. Feedback Interventions: Evaluation Results and Discussion

In order to determine if the intervention was a success, the findings of the focus groups and user trials need to be put into context against the three fundamental questions posed.

Furthermore, it is also important to consider and discuss the suitability of the evaluation methods employed, to determine if these methods are the most appropriate for evaluating a DfSB strategy led intervention. This section of the paper summarises and discusses these findings.

5.1.   Did the Produced Design Solution Function for the Specified Context?

A focus group interview is not an ideal mechanism through which to validate and quantify design decisions, due to the discursive and dynamic nature of the method. It is, however, an ideal platform through which the produced design, a culmination of contextual research into an issue or *'problem'*, can be discussed with users in order to ascertain whether the designers understanding of the issues of concern are correct, and furthermore, that this technological manifestation of the *'solution'* is what the user actually wanted (Bruseberg and McDonagh-Philp, 2002; McClelland and Suri, 2005; Nielsen, 1997). The findings from the focus group interviews support this use of the methodology, illustrating multiple discussion points concerning the need for feedback and information, and issues with how the feedback was generally interpreted and acted upon.

The findings indicated that whilst the use of scenario videos helped in aiding discussion and framing the context and issues of interest, the participants generally did not understand or see the need for information concerning how they manage their home energy heating systems. The discussions concluded that feedback on window opening in particular would be of little benefit to them but that feedback may be of educational value to children. The majority of the participants relied on the physical sensation of comfort as a feedback mechanism that arises from the use of these heating systems, including, for example, the touching of radiators to determine if the heating system was active. Such mechanisms, however, are not ideal as they rely on discomfort to indicate a change of state. Without this information, systems would be left unaltered, potentially at great financial cost to the tenant.

> *FG06   I just leave mine set on twenty all the time, and when it goes below twenty it'll just kick on and take the chill out the air.*
> *GTW   Do you find sometimes that you can't tell if it's turned on or off?*
> *FG06   Yeah, you can't tell unless you feel the radiators.*
> *GTW   So you could spend the whole week with the heating on and not realise?*
> *FG05   Just until your gas goes!*

Concerning the design of the feedback intervention itself, the use of ambience was generally well understood and accepted by the focus group interview participants, demonstrating in

part the success of using scenario videos and the physical prototype as part of the methodology. The concept of having a red light for *'waste'*, however, was an issue as the majority of participants believed it to represent a *'hotter'* radiator temperature, indicating that the majority of participants did not fully understand how their heating systems actually worked.

The advantage of using user trials over focus group interviews was that it was possible to understand how the user engaged and interacted with an intervention in a real use context over time. Changes in perception and interaction could be mapped over the installation period in situ. What the findings of the user trials illustrated, was that the frequency, duration and accuracy of the information fed back to the participant had the desired consequence in effectively helping the participant to understand both how the action of opening a window with the heating on and how the heating system actually worked. Through the provision of rapid and accurate information, the participants could see any instantaneous effect that their actions would have on the heating system, either intentional or unintentional such as opening a window or changing the thermostat.

> *CA02 My son-in-law would open the window…and you could see the colour changes straightaway. It does make you more aware of the temperatures in the room…you could understand how the heat could go out of the room so quick and come back on…you can see the difference when you opened the window how your energy is flying out of the window…in fact you can think well, why put the heating on if I'm going to open the windows, because it's just flying out of the window like, isn't it?*

This encouraged a period of investigation and optimisation, particularly during the initial period of installation, although towards the end of the four month installation period the participant's receptiveness to the information seemed to decrease. This was attributable to the participant's actions becoming optimised as far as they believed possible, therefore no longer requiring the information.

> *CA05 The benefit for me was when it was…the radiator was obviously knocking itself off and I didn't realise, you know; so I was wondering why it was. So, it make me then move about to see; I was going in the living room and feeling that one and that would be on, the hall one would be on, and I'd think: oh right, why has that gone off. So, I'd have a fiddle with that. Then I'd see it come back on. And then I'd turn it back down. And I'd be like this then, trying to read the paper and I'd be checking it then; looking at it all the time…But then it just blends in like all the other stuff that's*

around...I think I got into such a routine with the heating, you know, I forgot it was there really…but you just don't notice them; they're just familiar; they just blend in.

The location in which the prototype was installed had a clear effect on the level of information received, as it allowed for the real-time monitoring of the status of the heating system from a position of localised comfort (a favourite chair near the radiator). In terms of the use of ambient features, the use of the *'click'* mechanism also proved to be of particular use as a localised prompt, as this tended to initiate the opening investigation of the status lights on which subsequent actions were placed. The key issues with such a localised information point were twofold. Windows not included within the intervention were not monitored, allowing a window to be open in one room and the heating to be on in another without a *'waste'* warning, and furthermore, additional tenants in these multiple occupancy dwellings did not necessarily have access to this information, and so therefore could not act upon it.

5.2. Has the User's Behaviour Changed as a Consequence of the Design Intervention?

The findings of the focus group interview did not illustrate any changes in behaviour; as such a change is unlikely to be demonstrated from a single focus group interview. One of the constituent parts of habitual behaviour is a frequency of past behaviour (Jackson, 2005; Lally et al., 2009; Polites, 2005; Steg and Vlek, 2009) a change which cannot be established from a single point in time without self-reporting (which brings its own set of problems (Sniehotta and Presseau, 2012)). What a focus group interview does offer, however, is that it allows the researcher to understand if the *'problem'* and intervention context have been understood and appropriately translated into a *'solution'*. In terms of understanding behaviour and potential behaviour change, this manifests itself as an understanding of the antecedents of behaviour and the effects that the intervention may have upon them, primarily the intentions of the individual.

From these focus group interviews, it was clear that the benefit of comfort provided through such actions as opening windows and using the heating system is weighted as being of greater value than any economic or environmental cost. Some participants left their heating system active throughout the year, preferring the year-round thermal balance regardless of cost; something that was especially apparent when discussing the short term use of windows for fresh air and managing the effects of cooking, drying clothes or smoking irrespective of whether the heating system is active or not. These short-term benefits were

perceived as being of greater value than the economic cost of leaving a window open or the cost of effort required to alter the heating system.

> GTW   So does anybody actually open the windows with the heating on?
> FG10   Because to change the air in the mornings [FG09 nods in agreement].

The findings also provided evidence that the participants had a distrust in technological devices and information in general, preferring to defer to their own perception and senses, relying on experiential learning to determine future courses of action.

> FG07   You're still going to touch the radiator...it's just human...you're still going to touch it, still going to check it like that...its human senses...like when you hear the thermostat click, you still touch it to see if it's come on, even though the click has told you that the heating is come on.

Another interesting finding supports the position that those who used a prepayment system or shorter billing term for paying for energy may have had a different model of understanding and associated consumption than those who pay over longer periods. A few participants analogised the use of home energy to being like that of a car, whereby you are only concerned with its consumption towards the end of the period when the cost of its use is again put into the users frame of awareness.

> FG08   ...it's like in a car, isn't it, at the end of the month you drive slower in it than at the start of the month...so at the end of the month...you drive as slow as you can, thinking I need to get to another petrol station, but when you've put a full tank in, the first twenty to fifty miles you're going around like the clappers because you think 'I've got loads of fuel'...but it's the same thing with the heating.

In terms of habitual behaviour, as previously discussed, it is impossible for any such change to be effectively noted or its antecedents understood from a single focus group interview. It is possible, as illustrated, to understand and theorise upon any potential use contexts with the participants, based on the participant's intentions and experiences. Awareness as to when the heating system is put on or turned up, and opening a window was generally high, although after this engagement their awareness of the consequences of this action dropped, with the individual preferring to allow the system to run unabated until extreme discomfort was experienced.

The user trials provided the opportunity to detect a change in behaviour by comparing a baseline taken of the individuals behavioural antecedents prior to the installation of the design intervention, and then comparing that baseline to a point taken after the design intervention had been installed. The advantage of such a methodology was that it allowed the researcher to determine how the individual's intentions, habits and resulting action may have changed over time, providing, in this study, fixed points in time for qualitative comparison (prior and post installation). In addition to understanding the change in action, changes in the facilitating conditions can also be revealed that will influence behaviour, such as any change in the built form of their home, their heating system, economic concerns or the other tenants with whom they reside.

Comparing the baseline data to the post-installation data, it was apparent that the majority of intentions, facilitating conditions and habits stayed the same. From the qualitative data, it was clear that the built form and heating technologies were still the same within these participating properties, with the same tenants occupying the same rooms, performing similar daily tasks and window opening and heating activation routines as recorded in the baseline. Perceptions of the role of one's self as well as perceptions and the value weighting of resource consumption and comfort had not changed between these two recorded states (such as the desire for *'fresh air'* despite being aware of the heating systems activity).

> *CA02 As soon as I get up I'd open the window to allow a bit of air in; unless it's extremely cold – in that case I don't…If it's nice for a few hours; but if it's not very nice just for a half hour or something just to let some fresh air in…My daughter opens her bedroom window as soon as she wakes up in the morning…and the bathroom window's open now; the toilet window – just a little bit…*
> *EDH So, if the heating was on and you were airing out how long would the windows be open for?*
> *CA02 If it's cold only about 20 minutes perhaps…*

What had changed, however, was the knowledge and awareness that the participant had concerning how the heating system worked and when it is active. This change manifested itself with both participants having a deeper understanding of how, when and why their heating system was active or inactive, leading to the exploration and optimisation of its control for both resource consumption and comfort management. Importantly, this awareness occurred prior to extreme discomfort, the mechanism noted in the baseline as being the primary notification of undesired heating system running, therefore, essentially

reducing the time that the heating system was running in its inefficient state, saving energy. Conflicting energy use due to multiple occupancy could also be assessed and corrective actions taken, whereas previously the covert actions of other family members in adjusting the heating system would not be noticed until it became too hot.

> *CA02 …if it was a day like today now and [daughter] wanted that heating on, and I certainly don't see no reason for it to be on...I'd put it on for them but I wouldn't have it on myself...I knew she'd been down then and she'd put the heating on…if I didn't want it on I'd turn it off on the radiator.*

5.3.   Is the Change in the User's Behaviour Sustainable?

The use of a focus group interview was limited as a method in investigating the sustainable effects of the design intervention. Whilst a focus group interview may provide an insight into the intentions of the participant, it can only offer a small amount of predication to its actual impact on comfort and resource consumption. What the focus group interview provided was a discursive opportunity for the researcher and the participants to discuss values, moral and expectations.

During the focus group interview, an example of such discussion arose around the use of windows with the heating system active. From a resource conservation perspective, it would be ideal for the participants to turn their heating off when opening the window.   The majority of the participants, however, did not anticipate doing so even when provided with information from the intervention, potentially choosing to ignore the values inscribed by the designer in order to pursue their own perception of values and benefits. The device potentially allowed the user to choose the action appropriate to them, being afforded democracy in decision-making. In addition, the focus group platform allowed the potential users to discuss any issues they thought might have been of concern arising from the scenario video and envisaged potential use of the device, facilitating the discussion of intentional and unintentional potential outcomes. The focus group interview also provided evidence as to why an intervention was an ethical necessity, with the findings stating that leaving the heating system active for an unintentionally long period may be detrimental to the health of some children.

> *GTW   So how do you know when it's too hot [due to the heating]?*
>
> *FG05 ...when one of my kids starts shaking because they can't breathe because of the air.*

The user trials also allowed for an evaluation of the ethics surrounding the intervention and the design decisions made, based on actual experiences rather than predications. An intentional ethically responsible effect of the device was that it eventually removed the need for the participant to touch the radiator in order to determine the temperature of the radiator. Once the participant had cognitively associated or physically benchmarked the temperature of the radiator with the status indicator LED, the need for the participant to touch the radiator was removed, reducing the chance of the participant burning herself because of this desire for information.

> *CA02 Well, when you got up in the morning of course you put the heating on, and then all of a sudden that would start clicking then. Oh, the radiators getting warm now; and it would click when the radiator was getting warm…if you're just watching telly then the click would be the first thing you notice. But like I said, it wasn't annoying in any way…in the beginning I used to [touch the radiator]; you just get used to it then. Oh, that's getting hotter; or that's not so hot now…*

An unintentional effect of the intervention was that it allowed the participant to realise when they had run out of prepaid gas and the heating system had shut itself off, allowing the participant to hastily reinstate the gas supply without too great a loss in comfort. Whilst this may have in effect increased consumption, the value priority for the participant at this point was comfort, and this intervention helped to facilitate that management.

> *CA02 As I said, the [grandson] was most fascinated; he'd sit by it watching it…waiting. He was amazed by it…and our [grandson] would get up and say: the radiators have gone off. Well, we'd sit here and we didn't know the gas had gone; we'd run out of gas. So, [grandson] knew by that; the gas has gone, he said, because that's off…Because we didn't really know it had gone off like.*

6. Conclusions

This paper has demonstrated that the questions asked by the evaluator of a DfSB intervention can be subdivided into three fundamental questions which can be further disaggregated to give additional resolution concerning:

- *the functionality and usability of the intervention (criteria dependant on the DfSB strategy);*
- *the intentions, habits and facilitating conditions of the user in context – the behavioural antecedents (criteria applicable to all DfSB strategies);*
- *the sustainability impact of the intervention which in this context was considered in terms of energy, comfort (criteria dependant on the intervention context) and ethics (criteria applicable to all DfSB strategies).*

To summarise the answer to the question, did the produced design solution function for the specified context, the answer is yes, potentially. The caveat to this positive answer is that the device clearly needs to be iterated to be made more in line with the participant's cognitive understanding of how *'waste'* is defined or the feedback intervention requires further supplementary information to explain how the heating system actually works and what the cost benefit may be to avoiding such an outcome. In addition, the system of feedback should be expanded to include other rooms within the house so to provide a better picture to the tenant on how their home is heated and cooled as a system, and that other tenants in other rooms within the household may be able to act upon this information. Answering the question has the user's behaviour changed as a consequence of the design intervention, the answer is yes. The provision of information has not altered the motivation or intentions of the participants to act; however, by providing information feedback, it has allowed the participants to act upon these motivations and intentions more efficiently. Although the action and intentions of turning on the heating system is essentially the same as prior to installing the intervention, with no significant change, the feedback mechanism provided has superseded the habit of waiting for extreme discomfort by increasing knowledge and awareness allowing the participant to tailor its control and curb its use. Answering the question, is the change in the user's behaviour sustainable, is in effect a composite question concerning an evaluation of ethics and changes in comfort and domestic energy consumption. Whilst it is clear that the values of the intervention did not always coincide with the values of the participant, the intervention afforded the participant a large degree of flexibility in their response to the information provided, allowing them to democratically choose their own desired course of action. Intentional outcomes had been identified and accounted for, with the few unintentional outcomes that did manifest themselves not resulting in unethical outcomes.

Conclusions drawn from this study, summarised in Table 7, suggest that a focus group interview is ideal when attempting to uncover and gain further discursive insights concerning the individuals' intentions, and how these values and beliefs reside within an ethical

framework. In addition, the functionality of the design can be discussed, not to provide a quantitative assessment but rather to explore if the researcher's original interpretation of the individual's values and intentions was correct, and that the designed intervention was appropriate to the *'problem'* and to further discuss any potential ethical issues that may arise from its uses. A focus group interview, whilst not ideal for summative evaluation, is good for the early formative stages of designing a DfSB strategy led intervention. User trials are well suited to both formative evaluations, to help with the cyclic process of understanding and iterating the design, as well as summative, to draw conclusions as to the change in behaviour and sustainability impact over time. The application of energy consumption and environmental monitoring would have, it is predicted, provided both physical and quantitative evidence for any measurable change in comfort (through environmental proxies) as well as determine if the intervention had actually reduced or increased energy consumption, filling in the evaluative gap left from the user trials.

	Design	Behavioural Antecedents			Sustainability		
	Function	Intention	Facilitating Conditions	Habits	Energy	Comfort	Ethics
Focus Group Interview	■	■					■
User Trials with Contextual Interviews	■	■	■	■		■	■

Table 7: Data Collection Methods Used and the DfSB Data it is Suited to Collect

The research contained within this paper has addressed many of the gaps in knowledge currently present in the field of DfSB through the practical application of a Design Intervention Process. A key contribution to knowledge within this Design Intervention Process was the *'intervention evaluation'* phase. This phase applied and discussed a series of evaluative methods and formulated a tripartite questioning framework targeted specifically at evaluating the constituent parts of DfSB, building a vital knowledge platform for the formalisation of transferable DfSB theory, design and evaluation methods.

Acknowledgements

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