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ABSTRACT

Raymond J. Cole's body of work, spanning sustainable design, system complexity and human agency, has encouraged researchers to reconceptualize the notions of comfort and building performance. However, methods for predicting energy use and assessing environmental performance have remained predominantly within a reductionist approach common to physics and engineering. The recognition that building performance is characterized by interactive adaptivity and co-evolution of the physical with the social has not been matched by the generation of new methods. Although social practice theories that articulate the socio-technical nature of the built environment have been increasingly appropriated to understand occupants' role in performance, the challenge of studying buildings as complex socio-technical systems remains. This methodological paper discusses the application of the case study method (CSM) to the study of 10 retrofit projects selected from the Retrofit for the Future (RfF) Programme in UK between 2011 and 2012. Guided by Greene's framework for methodological discourse, the epistemic regime is articulated under four headings: philosophical assumptions, investigative logics, guidelines for practice and contribution to system perspective. The discussion of these domains highlights the fecundity of CSM in providing a more nuanced understanding of the interaction between social and technical systems in performance.

KEYWORDS

building performance; case study; post-occupancy evaluation (POE); research methods; retrofit; socio-technical

Introduction

The next best thing to being wise oneself is to live in a circle of those who are. (C. S. Lewis)

Raymond J. Cole's work on the built environment in general, and on the environmental assessment and evaluation of buildings in particular, can be traced back to the early 1990s (Cole, 1992; Cole & Rousseau, 1991). His vision traverses topics from sustainable design and system complexity to human agency. Cole, Robinson, Brown, and O'Shea (2008) suggested that improving environmental performance requires moving away from the concerns of conventional design practice, which emphasizes the choice and performance of mechanical and electrical systems in buildings, to paying attention to the dynamic interaction between the building and its inhabitants. In particular, the notion of 'interactive adaptivity' was introduced to suggest how building performance could be reconceptualized to take account of context and human agency. Interactive adaptivity is

both an inevitable part of the interaction between people and buildings, and a desired outcome in sustainable buildings as the culmination of a dialogic participatory process between occupants and designers that occurs through all stages of design, construction and occupancy. Cole et al. (2008, p. 333) recognized that the concept of 'interactive adaptivity' and their goal of linking it with high performance in green buildings came with many challenges. One of these is an imperative 'to [develop] innovative methods and applications for communicating both the new context and the need for assertions of agency and responsibility of inhabitants'. Cole's own response was to research inhabitants' interaction with the building controls, sensing and monitoring systems via performance information at the Centre for Interactive Research on Sustainability (Cole et al., 2008). The present paper responds to his challenge by exploring the application of the case study method (CSM) to the study of building performance from a socio-technical perspective.

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Methods in evaluating energy and environmental performance

The year 1990 saw the publication of the Building Research Establishment Environmental Assessment Method (BREEAM), the first environmental performance assessment method (EPAM) for buildings (Baldwin, Leach, Duggart, & Attenborough, 1990). The method was intended to ‘promote the design and construction of buildings which [were] friendlier to the environment’ (Prior, 1991, p. 237). In operating exclusively at the design stage, and in bringing together 16 separate metrics under three headings – global, neighbourhood and indoor effects – into a single index of predicted performance, BREEAM displayed the key features and problems of all subsequent EPAMs:¹

- a focus on the design stage with little or no emphasis on the performance of the building as eventually built and occupied²
- a reliance on an assumption that the overall performance of the building, as built, can be safely predicted from a list of design features³
- a presumption that designers should be allowed to trade-off performance under the three main headings of global, neighbourhood and indoor effects

Developments over the subsequent eight years included:

- attempts to build life-cycle assessment methods into EPAMs (Anink & Boonstra, 1996; Kortman, van Ewijk, Mak, Anink, & Knaphen, 1998; Lowe, 2000)
- attempts to place weightings between categories of impact on a firmer methodological footing (Dickie & Howard, 2000)
- the emergence of at least 15 potential alternatives to BREEAM in almost as many countries (Haapio & Viitanieni, 2008)⁴

Build performance assessment: designers’ perspective

One consequence of this flowering of activity around EPAMs was a need to take stock. This challenge was taken up by Cole and Nils Larsson, who developed the Green Building Tool (GBTTool):

as a ‘second-generation’ assessment method that built on the limitations of existing methods, and confronted areas of building performance assessment that were previously either ignored or poorly defined. (Cole, 1999, p. 231; see also Cole, 2005)

The tool involved an expanded set of impact categories:

- resource consumption
- environmental loadings
- indoor environment
- longevity
- process (design and construction; building operations planning)
- contextual factors (*i.e.* location and transportation, and loadings on immediate surroundings)

The assessment framework and default weightings incorporated into GBTTool were the products of an open, consensus-based review process beginning with GBC ’98 (Cole, 1999; Cole & Larsson, 1999; Larsson, 1999; Larsson & Cole, 2001).

In considering how best to assess performance, the complexity and difficulties in setting target performance levels, the need for benchmarking against reference buildings, and the desirability of normalizing metrics were highlighted. Most importantly, the difference between potential and actual performance was explicitly acknowledged. Hence, evaluation of both ‘potential’ and ‘actual performance’ was seen as crucial to improvement of EPAMs and a reduction in the environmental impacts of buildings (Cole, 1999, p. 237).

The performance gap is most clearly visible with respect to energy. In this context, Cole (1999, p. 237) drew attention to ‘idiosyncratic operational factors’ as a key driver. In other words, variation in performance was seen mainly in terms of occupants’ behaviours and/or with their operation of the building, while the design–build reality was held constant. This *laid the foundation for viewing the behaviours of occupants as legitimate concerns of build performance*, but had the effect of artificially separating the effects of *physical features* of buildings from impacts of *occupants’ behaviours*.

Build performance: technologists’ perspective

Rather than grappling with the full breadth of sustainability, building technologists have tended to focus their concerns on improving building energy efficiency through the study of technical, and in particular energy, performance. Technical underperformance, or ‘the performance gap’ in dwellings was first highlighted by the Twin Rivers Programme (Socolow, 1978) in the US, and subsequently by the Post-occupancy Review of Buildings and their Engineering (Probe) projects in the UK (Bordass, Leaman, & Ruyssevelt, 2001; Cohen, Standeven, Bordass, & Leaman, 2001). The performance gap is defined in terms of

the difference between matched measurements and predictions of energy use. Reported differences between design and operational performance in buildings and building elements are persistently in the order of a factor of two (Laurent et al., 2013; Lowe, Wingfield, Bell, & Bell, 2007). However, measuring energy use and ensuring that models match the situation in the field are both profoundly problematic. For example, problems with predictions of energy use are exacerbated by using models and associated databases that are designed for demonstrating regulatory compliance, rather than for generating unbiased predictions of energy end-use under real operating conditions (Menezes, Cripps, Bouchlaghem, & Buswell, 2012). This has led some to argue for the need for better estimates of real operating conditions in modelling (Lomas & Eppel, 1992; Macdonald, Clarke, & Strachan, 1999), while others have suggested scenario testing and sensitivity analysis based on field visits to determine factors influencing end use (Demanele, Tweddell, & Davies, 2010). The problems with both these are that they attempt to understand the phenomenon in the absence of a socio-technical perspective and without appropriate theoretical and methodological tools to explore it empirically.

System perspective and gaps in method

The building performance literature has displayed a progressively increasing sophistication in the conceptualization of buildings as complex technical systems, with change seen as taking place continuously through processes of adaptation, refurbishment, (re)construction and demolition, at all levels from the individual building to national building stocks (du Plessis & Cole, 2011). But there has until recently been a parallel tendency to see occupants and other human actors as sources of uncertainty, rather than as full participants in the complexity (e.g. Guckenheimer & Ottino, 2008, p. 6). Methods for understanding and assessing performance have remained reductionistic, with occupants' behaviours represented in energy-use audits with little understanding of the possible drivers of change, and much less about interactive adaptivity.

The significance of Cole et al. (2008), through their recognition of the phenomenon of interactive adaptivity, lay in pointing to the way to a richer conceptualization of complexity, characterized by close coupling of social and technical subsystems,⁵ each forming the context for the other, and together constituting a socio-technical regime.⁶ If one accepts this conceptualization, research aimed at achieving an empirical understanding of performance requires theories and

methods that account not only for the technical but also the social, and interactions between them, in the context of design, construction and commissioning processes as well as occupation. The present paper attempts to show how this can be done through a methodological discourse on the application of the CSM in the context of deep retrofit.⁷

Research context: the FLASH project

The overarching aim of the FLASH project (Chiu, Lowe, Raslan, Altamirano-Medina, & Wingfield, 2014; Lowe, Chiu, Raslan, & Altamirano, 2012, 2013) was to understand the variability of retrofit processes and performance outcomes for dwellings retrofitted through the Technology Strategy Board's (TSB) Retrofit for the Future (RfF) Programme (TSB with SE², 2013).⁸ Underpinned by a socio-technical perspective, the methodological aim was formally to apply CSM to conventional post-occupancy evaluation (POE), so as to explore the interaction between social and technical processes. While the actual process of designing and conducting case study research should be systematic (Smith, 1997; Stake, 1994, 2006; Yin, 2009), it is both complex and often poorly understood (Flyvbjerg, 2006). Within a case study itself, methods can be multilayered and creative, supporting Johnson and Onwuegbuzie's (2004, p. 20) assertion of mixed methods as 'an expansive and creative form of research'.

The presentation of this paper adopts the style of methodological discourse amongst social researchers (e.g. Greene, 2006), and will focus on the discussion in four domains that are relevant to the development of socio-technical methods:

- philosophical assumptions and theoretical stances
- investigative logics – when, where and why
- guidelines for practice
- contributions to system perspective

Applying the socio-technical case study method

Philosophical assumptions and theoretical stances

The Probe project (Bordass et al., 2001; Cohen et al., 2001) pioneered POE as a method of studying energy performance in buildings, with occupants' comfort and satisfaction among its metrics of performance. Although a well-established method and used widely in the field, its links to academic discourses around theory and methods have remained mostly implicit. As a result, its

scope for further methodological development has been restricted.

The development of social practice theory (SPT) is rooted in the tradition of sociology and its concern to transcend the duality of ‘agency & structure’ (e.g. Bourdieu, 1992; Giddens, 1984). Guy and Shove (2000), Shove, Pantzar, and Watson (2012); Wilhite (2009), Gram-Hanssen (2010) and Foulds, Powell, and Seyfang (2013), among others, have applied SPT to the study of the influence of human factors on energy use in buildings. While all appear to derive their brand of SPT from Schatzki (1996), the respective accounts differ significantly. For example, Wilhite emphasizes routines/habits, while Shove et al. hold that practices consist of materiality, competence and meanings. Gram-Hanssen’s version, which recognizes four components of social practices (know-how, institutional knowledge, engagement and technologies), comes closest to that of Schatzki’s.

Drawing on the work of Wittgensten, Schatzki (1996) asserted that human actions embody both agency and structure. This means that while habitual actions, e.g. cooking, voting, industrial, religious and banking practices (Schatzki, 1996, p. 89, 2002, pp. 70–72), are products of societal structures, these actions have agentic potential with the power to shape and reshape society (Reckwitz, 2002). For Schatzki, social practices refer not only to routinized behaviours/habits but also are constituted by four conceptual components that reflect the architecture of meanings and actions: practical understanding, rules/institutionalized knowledge, tele-effective structures and technologies. He postulated that the basic structure of practice is ‘an organised constellation of actions’ where actions are ‘bodily doings and sayings’ which can be observed in a multitude of different ways, in disparate locations and at varying times. Practice, then, is conceived in terms of the shared commonalities of these actions (Schatzki, 2002, p. 71).

What distinguishes Schatzki’s theory from others’ is that social practices are processes with trajectories.

They are temporally and spatially prefigured and conditioned inherently by material and social arrangements, where ‘arrangement’ is the ‘hanging together of entities in which they relate to each other, occupy positions, and have meaning’ (p. 20). Schatzki’s account of the Shakers’ production of medicinal herbs is a classic example. Their practices have to be seen not only in terms of the activities of collecting, chopping and drying of herbs but also of the intertwining of these activities with both the physical arrangement of the Shaker villages and the social order of Shaker society, including their religious convictions and strong sense of community. The *persistency and change* of these activities has the effect of maintaining, shaping or reshaping practices (Schatzki, 2002). In the same way, retrofit practice can also be observed as a socio-technical phenomenon that is co-constituted through material arrangements, actions and meanings (Figure 1).

The term ‘socio-technical’, coined by scholars of the Tavistock Institute, London, in the context of studies of industrial organization (Emery, 1959), is often associated with SPT and energy and buildings research, but the meaning of the term is often unclear. And despite the fact that technology/materiality is a component part of a number of articulations of SPT, it is seldom adequately conceptualized or operationalized in empirical investigations (e.g. Gram-Hanssen, 2011; Karvonen, 2013; Vlasova & Gram-Hanssen, 2014).⁹ While social theorists claim that ‘social practice studies [have deepened] the understanding of key socio-technical issues’ (Tweed, 2013, p. 553), it is unclear how the performance gap can be addressed by simply understanding occupants’ responses and lived experience without understanding technical systems that *co-constitute* them. The occupants’ doings and sayings both make sense within, and impact on, the physical context; the two must therefore be understood together.

Post-humanist social theorists (e.g. Latour, 1999; Pickering, 2001) have asserted the importance of non-human entities, e.g. artefacts, machines and technology

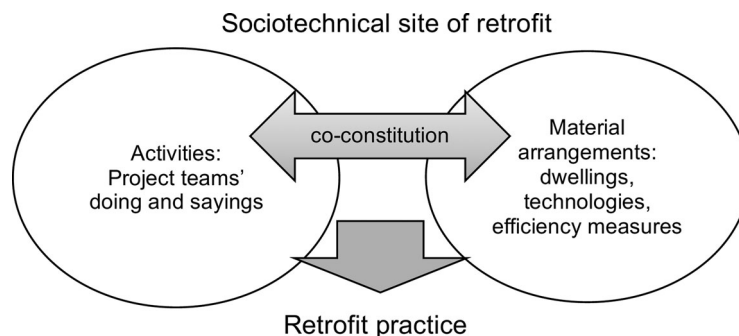


Figure 1. Retrofit practice as a socio-technical phenomenon: co-constitution and co-evolution.

in social life and social practices (Schatzki, 2002, p. 11). Latour (1999) used the term ‘black boxing’ to describe how certain technological artefacts, by virtue of their success in the real world, can easily be ignored by sociologists and others. Thus, in the built environment, the inner workings and interactions of technological systems such as heat pumps, mechanical ventilation heat recovery (MVHR) systems or of large-scale infrastructure such as district heating, are rarely made visible (Chiu et al., 2014). Their existence is taken for granted and their adequacy, sufficiency and efficiency are not well understood by researchers. Moreover, amongst some empirical social researchers, the black box has been prematurely shut by an ill-conceived notion that building scientists have ‘perfected energy-efficiency technologies’ (Guy, 2006, p. 646).

Prematurely black-boxing technology in a socio-technical system may lead to the generation of partial knowledge about performance, and weaken the potential of SPT as an effective heuristic device to explore socio-technical phenomena. Most importantly, it is inconsistent with the premise that social and technical systems are co-constituted and co-evolve across time and space (e.g. Pickering, 2001).¹⁰

Accepting that building performance is a socio-technical phenomenon carries implications for methods of enquiry and the nature of knowledge.¹¹ To allow the integration of both physical and social knowledge, the FLASH research team comprised a physicist, a social scientist, an architect and two engineers (Chiu et al., 2014).¹² The team then had to confront the fact that researchers from different disciplines carry with them different mental models (Phillips, 1996; Smith, 1997). These include value commitments, perspectives and core constructs. For example, while the laws and concepts of thermodynamics are key constructs and units of analysis for building engineers, SPT and its aforementioned components are the preferred units of analysis among social researchers. By combining such different paradigms in one project, it became clear that SPT alone was insufficient to sustain the investigative approach.

To set aside (but not to suppress) some of the scepticisms and doubts about the validity or ‘truth’ of knowledge generated through the socio-technical frame with its associated mix of methods and perspectives, the pragmatist philosophy espoused by James, Dewey and Peirce (Simpson, 2009), was adopted to provide an epistemological stance that might defuse disciplinary conflict. With the emphasis on ‘problem solving’ (a familiar concept among engineers), pragmatism provides a link between human experiences and the technologies that support and transform human lives. The pragmatists’

epistemological perspective is that knowledge is processual, derived from both practice and experience, and warranted to the extent that it is useful (Baert, 2005, p. 8; Dewey, 1938). James’ (1978, p. 32) notion that ‘theories become thus instruments, not answers to enigmas, in which we can rest’ can serve as a reminder to an interdisciplinary research team that the purpose of their study is to produce practical knowledge to improve building performance rather than to build abstract theoretical knowledge (e.g. Foulds et al., 2013). The convergence of SPT and the philosophy of pragmatism (Bourdieu & Wacquant, 1992, p. 122) can support the cultivation of ‘a quality of mind’ that will help both physical and social researchers to loosen their respective, in part, imagined scientific straitjackets and come together to investigate a problem with the aim of resolving it through new investigative logics and greater flexibility in methods.

Investigative logics

The FLASH project set out to investigate the strategies, mechanisms and processes that influence the outcomes of low-energy retrofit in social housing.

The research objectives formulated were:

- to explore the retrofit strategies adopted by project teams (PTs) by carrying out focus-group meetings
- to capture occupants’ experiences of the retrofit process and their response to the outcomes by conducting modified post-occupancy interviews
- to investigate physical outcomes of retrofit interventions by analysing physical monitoring data
- to identify and understand the factors and mechanisms that affect outcomes by carrying out an integrated analysis of all the above data

CSM as holder for mixed methods

While many researchers have recognized buildings as complex socio-technical systems (Guckenheimer & Ottino, 2008, p. 6; du Plessis & Cole, 2011), they are often overwhelmed by system complexity and seemingly have no investigative strategy with which to respond (Bordass, Leaman, & Cohen, 2002).¹³ With the pragmatist philosophy embedded in the socio-technical conceptual framework, the view that emerged within the FLASH team was that not only is building physics a necessary knowledge component, but also it plays a key role in providing a boundary and structure for the selection of social components that are relevant to the problem at hand – understanding performance.

Thus, the authors embraced a mixed-methodology approach capable of capturing the breadth and depth

that no single method could do (Mertens, 2010). It was understood that methodological decisions needed to start with investigation of the physical (dwellings) and social (occupants) context in which retrofit technology was to apply.

CSM and multiple case studies

As Stake (1994, p. 236) asserts, ‘Case Study is not a methodological choice, but a choice of object to be studied’; the study object can be simple or complex, and the methods applied can be quantitative and/or qualitative.

An example that illustrates this is provided by the study on the socio-technical challenges influencing heat demand of a district-heated council block in London (Morgenstern, Lowe, & Chiu, 2014). This started from the recognition that heat demand measured by heat meters is influenced by both the physical characteristics of the dwelling and social characteristics of the occupants. Understanding heat demand therefore required a combination of quantitative and qualitative methods applied to collecting both physical, *i.e.* physical characteristics of the building; temperature and relative humidity data collected at 10-minute intervals; and social data, *i.e.* qualitative observational and interview data. Analysis of these datasets made it possible to draw inferences about the potential impact of heat-meter installation on the fair allocation of heating costs and billing methods not only for the case itself but also for similar but better-performing apartment blocks controlled by the same social landlord.

While Morgenstern et al. (2014) focused on a particular case, the FLASH project was a study of 10 cases. Retrofit dwellings were purposefully selected to capture maximum variation (MV) (Patton, 2002) across dwelling types, occupant compositions and PTs. More importantly, the selected cases represented a bounded system, within which (1) practical understanding, (2) rules/institutionalized knowledge, (3) teleo-effective structures and (4) technologies (Schatzki, 2002) formed the constituents of the project’s conceptual framework. The function of the conceptual framework was to help

to determine the initial set of ‘variables of interest’ for the investigation by focusing not only on the routine collection of quantitative data concerning ‘comfort’ as previously defined in most POE studies, but also on the meanings and experiences of occupants as their homes underwent retrofit. To capture these data, new instruments were needed:

- a new semi-structured interview guide for interviewing occupants, created by modifying and extending the Building Use Studies (BUS) survey
- an interview guide for focus group interviews with PTs

Finally, a follow-up interview guide for individual PT members was prepared, based upon the results of field observations and data analysis of interviews obtained from both instruments.¹⁴

Quantitative data collected through the first instrument above included the number of occupants, income, hours of occupation and thermostat settings; categorical data included comfort and satisfaction; qualitative data included occupants’ perceptions and narratives around comfort and experiences before, during and after retrofit, as well as data from PT focus groups. Apart from quantitative monitoring data,¹⁵ other data collected for each case were field observation notes, and in-depth interviews of occupants and PTs. Occupants were also asked to complete diaries recording patterns of appliance use over a two-week period. These were sent to occupants before, and collected at the end of each interview.

Multiple case studies design

To implement the CSM approach from conception to analysis, the research team proposed a parallel design (Table 1). The plan was to select a sample of 10 cases as the socio-technical site. There were three investigative aspects of each case: the physical aspects of the dwelling and retrofit measures applied; the PTs who designed and implemented the retrofits; and the occupants.

Table 1. Matrix of units and subunits of analysis against aspects of investigation within a socio-technical system.

| Units and subunits of analysis | Project teams (7) | Dwellings (10) | Occupants (10 households) |
|--------------------------------|--|--|---|
| Socio-technical components | Practical understanding and institutional knowledge, engagement with occupants | Energy-efficient technologies | Engagement with the project team |
| Data categories and contents | Composition: retrofit strategies and learning | Type: configuration and reconfiguration Retrofit measures employed | Perception and experiences of retrofit process and outcomes |
| Methods | Focus group and follow-up individual interviews | Plans, architectural and construction drawings, photographs, monitoring data | Semi-structured interviews with ‘walk throughs’ |

Guidelines for practice

A pilot

A pilot visit to a designated site was carried out by the social researcher and an independent researcher from Databuild,¹⁶ to test the boundaries of the project's investigation and the fecundity of the proposed procedure and instruments. The pilot adopted and modified the POE model established, primarily for commercial buildings, through Probe, primarily for commercial buildings. In the resulting modified model, inspection of building services such as the fabric, heating and ventilation systems was carried out and observational data that affect occupants' comfort and indoor environmental quality (IEQ) were collected through the semi-structured interview guide mentioned above. The results of the pilot suggested that observational data should be collected by photographing the energy-efficiency measures installed and the potential physical consequences of retrofit (*e.g.* internal and external reconfiguration, mould growth observed inside the dwellings). Other visual data in the form of architectural plans and drawings were also subsequently included in the dataset.

Sampling strategy

As noted, the types of dwelling, composition of occupants and of the PT associated with each dwelling were three main aspects that defined each case. The use of MV sampling strategy (Patton, 2002) aimed to capture within the 86 cases that participated in the RfF programme the typological diversity, *e.g.* terrace, detached, semi-detached, age of dwelling – with and without heritage value – of the existing housing stock in UK, and the demographic/composition of the occupants, *e.g.* single (by gender and age), couples, families with adult children, with young children, and ethnicity. Primary qualitative data were collected during the visit to each sample dwelling. These included occupant interviews, visual records of retrofit measures and occupants' responses to these measures. The final layer of selection was to ensure PTs in the sample were not dominated by any single organization.¹⁷ Each PT normally comprised an architect, an energy consultant, a social housing landlord, constructors and installers (the PT of case G did not have an architect). A focus group interview was conducted with each PT. This sampling strategy reflected

Table 2. Alignment of sampling strategies in relation to theoretical concepts and categories.

| Case | A | B1–B3 | C | D | E | F | G | H |
|--|---------------------------------|----------------------------------|---|--------------------------------|-------------------------------|---|--------------------------------------|---|
| Physical arrangements | | | | | | | | |
| Dwelling type and approximate year of construction | Three-bed terraced, 1992 | Three-bed terrace, 1945–80 | Three-bed terrace, modernized with central heating two years ago, Victorian | Four-bed mid-terrace, 1940–50s | Two-bed mid-terrace, pre-1919 | Four-bed semi-detached, 1960s | Four-bed end-terrace, late Victorian | Three-bed semi-detached (originally built as detached), in a conservation area, early 1900s |
| Area (m ²) | 83.7 | 95 | 87.4 | 100 | 80 | 130 | 76.8 | 83.6 |
| Fabric | Brick cavity wall | | Solid brick wall | Solid brick rendered wall | Solid brick wall | Brick cavity wall | Solid brick wall | Solid brick wall |
| Floor | Suspended timber floor | Solid concrete floor | Suspended timber floor | | | Suspended timber floor with a solid floor extension | | Suspended timber floor |
| Glazing | Single | Double | | | | Single | | |
| Social arrangements | | | | | | | | |
| Team structure | Architect led | SRL led | SRL led | Architect led | SRL led | SRL led | SRL led | Architect led |
| Household composition | Single mother with two children | Families of four, four and three | Single elderly woman | BME family of eight | Single man | Family of seven | BME family of five | Elderly couple |
| Communication between the project team and occupants | Liaison officer | | Through the occupant's son | Liaison officer | | None – vacant possession on completion of retrofit | | Liaison officer |

Note: BME = black and minority ethnic; SRL = social registered landlord.

the theoretical concepts of physical and social arrangements in Schatzki's formulation of SPT (Table 2).

For the study sample, the available physical monitoring data were held on a dedicated Energy Saving Trust (EST) database. Focus group interviews with PTs took place in parallel with occupant interviews. Individual interviews with members of PTs were carried out as follow-ups to questions arising from the analyses of focus group and occupant interviews. Table 3 summarizes the retrofit approaches and strategies taken by the PTs in relation to dwellings and the composition of occupants' households.

Data analysis in multiple case study design

Social and technical features and characteristics of the 10 sample dwellings were observed and described in a master matrix held by Databuild. Physical monitoring data for the sample cases were downloaded from the EST database. Verbatim focus group transcripts were also produced to provide a description of each PT's retrofit strategy, the measures employed, and their reflection on their experiences and 'learnings' (Lowe et al., 2013). In parallel, verbatim transcripts of occupants' interviews were also produced to provide individual case profiles for analysis.

Co-verification

This array of datasets, together with all photographic data, plans and drawings of each dwelling, were then subjected to co-verification. The general purpose of the co-verification process was to reduce methodological artefacts that might have emanated from any particular method (Johnson, Onwuegbuzie, & Turner, 2007). The co-verification process was essential to ascertain data quality and integrity as well as to note and resolve queries arising from the array of data in each individual case. For example, case A was originally recorded in the RfF database as a dwelling with single-brick (*i.e.* solid) wall construction, with an MVHR system. However, field observation identified the dwelling as being of cavity-wall construction, with no MVHR. Instead, the house had been equipped with a combined mechanical extract and stack ventilation system. External and internal photographs were taken. Field researchers held meetings with other members of the researcher team to co-verify what had been observed and what had been recorded with the support of photographic evidence and architectural plans and drawings of each dwelling. Supported by the building physicist and the architect in the team, the cavity-wall construction was confirmed. Independent verification of the construction was provided by an analysis of the transcripts in which related events were told by both the PT and the occupants. Also, the

occupant's account of their wish to avoid being identified by neighbours as one of households chosen by the RfF programme helped to explain why the original fabric strategy (using external insulation at front and back of this mid-terrace dwelling) had been abandoned in favour of a mixed strategy of insulating the front internally with nanogel to preserve the facade and applying external insulation only to the back of the dwelling.

Another example of co-verification is provided by cases B1–B3, three dwellings in a terrace of four. To determine the configuration of the heating and ventilation systems in these dwellings and how these systems interacted with other measures installed in the dwellings and their occupants after retrofit, the research team had to conceptually reconstruct the unusual configuration of a communal heating system with independent MVHR units installed in the individual dwellings by using photographic data and descriptions of the systems from both the PT and the occupants, a task that could not have been tackled by the social researcher alone. The co-verification process thus played a vital role in establishing how physical and technical systems were configured. Co-verification was an essential precondition for triangulation, which in turn allowed investigators to make sense of actions and trajectories towards retrofit outcomes.

Analytic strategy: concurrent triangulation of qualitative and quantitative data

Supported by the social researcher, the engineer on the team took the lead in analysing the qualitative data from focus group interviews with the purpose of understanding the retrofit strategies adopted by PTs, their experiences of the retrofit process when confronted with their respective dwellings, and their learning as they reflected subsequently upon the process (Lowe et al., 2013). The initial results of the focus group analysis produced a preliminary description of the retrofit practices (doings and sayings) associated with each case. This description included: principles and approaches articulated; their relationships with occupants; and micro-actions such as communication, handover procedures, sequencing of construction, and other crucial social and contractual relationships that had the potential to influence the implementation of retrofit processes. These included mechanisms for communication between PTs and occupants (*e.g.* liaison officers from the social housing landlord, family members, occupants' neighbours); lessons learned from the choices of new materials and technologies such as the application of energy-efficiency products, *e.g.* nanogel, insulation methods, new ventilation technologies such as MVHR; sourcing and supply chain issues; and the kinds of

Table 3. Retrofit strategies, approaches and measures in relation to households and project teams.

| Case | A | B1 | B2 | B3 | C | D | E | F | G | H |
|--|---|---|----------------|-----------------|------------------------|---------------------|--------------|--|------------------------------------|--|
| Team structure | Architect led | HA led | | | LA led | LA led | LA/HA led | Architect led | HA led | Architect led |
| Composition of the household | Single mother, two children | Family of four | Family of four | Family of three | Elderly woman | BME family of eight | Single man | Family of seven | BME family of five | Elderly couple |
| Stated retrofit approach | Whole house | Fabric first | | | Insulate then generate | Fabric first | Fabric first | Passivhaus | Modified Passivhaus | Passivhaus |
| Summary of the fabric and ventilation strategies | HWI, intermediate leakage, HV (natural + individual MVHR) | EWI, AC, CHS, low leakage, whole-house MVHR | | | HPCF, PIV | EWI low leakage | HWI | EWI, AC, low leakage, whole-house MVHR | HWI, MEV + HP intermediate leakage | EWI, AC, low leakage, whole-house MVHR |

Note: AC = airtight construction; BME = Black and minority ethnic; CHS = communal heating system; EWI = external wall insulation; HA = housing association; HPCF = high-performance cavity fill; HV = hybrid ventilation; HWI = hybrid wall insulation, e.g. external at the back, internal at the front; LA = local authority; MEV + HP = continuous extract ventilation with exhaust air-heat recovery to hot water; MVHR = mechanical ventilation heat recovery; PIV = positive-input ventilation.

Table 4. Initial matrix of construction strategies in relation to other case variables.

| Case | A | B1 | B2 | B3 | C | D | E | F | G | H |
|--|---|--|----------------|-----------------|---|---|--|--|--|---|
| Team structure | Architect led | HA led | | | LA led | Architect led | LA/HA led | HA led | HA led | Architect led |
| Composition of the household | Single mother, two children | Family of four | Family of four | Family of three | Elderly woman | BME family of eight | Single man | Family of seven | BME family of five | Elderly couple |
| Construction strategy in relation to dwelling occupation | <i>In situ</i> | <i>In situ</i> | | | Decanted | <i>In situ</i> | Semi-decanted | Void | Void | <i>In situ</i> |
| Reasons for the above strategy | Explicitly stated occupant-centred approach | Testing the feasibility of performing a retrofit with occupants <i>in situ</i> , as decanting would increase costs | | | Occupant was too old to endure the disruption | Engaging occupants in the retrofit (did not stated) | Strategy to decant occupants was foiled due to a significant delay of the schedule | Improving 'void' dwelling in the housing stock | Improving 'void' dwelling in the housing stock | Occupants were not decanted for reasons of ill-health |

Note: BME = Black and minority ethnic; HA = housing association; LA = local authority.

contracting practices that facilitated or impeded effective retrofit (Lowe et al., 2013).

Contemporaneously, the social researcher led on the analysis of the qualitative data from occupant interviews with the purpose of understanding how occupants were recruited onto and engaged in the RfF project, their experiences, their perceptions of comfort and satisfaction or otherwise with the changes made in their homes. In exploring the contribution of retrofit strategies to the effectiveness of achieving the goals of the RfF programme, researchers began to see the entanglement of the material, physical and social arrangements that manifested themselves in PT practices and specific adaptive practices (heating and cooling) of occupants.

Experience of disruption of daily life was one of the main themes that emerged from occupants' experiences. The corresponding themes that emanated from the PTs' discussions were about the impacts of strategies of 'decanting' or 'working with occupants *in situ*'¹⁸ during the retrofit process, on learning, economics and economies of scale.

The process of analysis was supported by matrices and submatrices (Miles & Huberman, 1994) constructed from data held in the master matrix, and from additional field data collected by the FLASH team. These matrices were very large and cannot practically be included in this paper. However, Table 4 shows a simplified example of a matrix used to support specific operations through which insights from cross-case analysis were generated.

Comparing the PTs' discussion of issues related to strategies of 'decanting' or 'working with occupants *in situ*' (motivation and action) and the different experiences of disruption articulated by occupants during retrofitting (reactions) led to an insight into the conditions for resistance (cases A and B) and acceptance (cases D and H) of specific ventilation technologies such as MVHR (Chiu et al., 2014, pp. 580–581). Table 5 presents a simplified illustration of the analytical procedure.

Upon noting the patterns of occupants' reactions to MVHR and PTs' responses or non-responses, further dynamic matrices and submatrices were then developed to link variables and outcomes across cases. For example, Table 6 shows a simplified version of a matrix used to explore the relationship between 'occupants' awareness' and 'communication', linked with '*in-situ*/decanting strategies', 'retrofit strategy change' (e.g. with respect to MVHR), 'occupant adaptation' (i.e. their ability to control comfort through the systems interface(s) provided), and outcome variables such as 'overall satisfaction' and 'satisfaction with the retrofit process'.

The above examples highlight one of the analytical techniques in CSM. When confronting a vast amount

of data (both quantitative and qualitative) generated from the field, the analyst must return to the conceptual framework that helped to define the analytical boundary of the system to avoid drowning in system complexity. In a multiple case study, while there might be times that a certain phenomenon requires an exploratory approach using inductive logic, deductive logic is also necessary to confirm or reject hypotheses arising from exploration. However, this direction of travel may also be reversed. For example, in the FLASH project, patterns that emerged through recognizing certain practices, e.g. 'decanting' and '*in-situ*' retrofit, were then explored further in terms of their meanings for both PTs and occupants through the events they recalled. As in a criminal investigation, the process of progressively focusing and funnelling cases through a set of questions produced converging evidence that together added up to a clearer and fuller picture of the potential motivations, decisions and trajectories of the retrofit strategy that the PT adopted. These questions included:

- What did 'decanting occupants' mean to PTs and occupants for cases C and E?
- What were the implications for PTs of deciding to retrofit dwellings with occupants '*in situ*'?
- What were the benefits and costs of decanting for different actors in the retrofit process and how were these distributed?
- How might the meaning of 'decanting' in the interests of 'operational convenience' for the PT be interpreted differently by occupants?

A similar line of questioning was used to explore the possible meanings of '*in situ*' in relation to codes¹⁹ generated, such as *operational inconvenience*, *real-world learning*, *reduction of costs* for PTs; as against *disruption of everyday life*, *security and safety of possessions*, *cognizance of the impact of process*, and *opportunity for resistance, negotiation, acceptance and adaptation* on the part of the occupants (Chiu, Lowe, Altamirano, & Raslan, 2013, pp. 17–18; Lowe et al., 2012, p. 14).

Furthermore, by constructing other dynamic matrices (e.g. the number of cases with target variables, with meanings coded for each case) within and across cases and sets of cases, and exploring the relationship with other categories of experiences such as 'reported awareness of occupants' level of engagement', a critical insight was generated: that 'engaging with the occupants, with day-to-day communication and dialogue' throughout the process was a crucial factor in mediating occupants' acceptance of, adaptation to, and satisfaction with retrofit technology (Chiu et al., 2013, p. 48).

Table 5. Dynamic matrix in relation to the design, implementation and adaptation of ventilation strategy in four cases.

| Case | A | B3 | D | H |
|---|--|--|---|---|
| Ventilation strategy, implementation and adaptation | Original design with MVHR rejected. Radical redesign included a solar ventilation chimney with skylight, and louvered side vents beside the windows. | Original design implemented – communal heating system with individual MVHR. | Design implemented with rerouted ductwork following negotiation. | Design implemented with adaptation to physical constraints driven by the PT. |
| Social conditions (the doings and sayings of PTs and occupants) | Occupant observed that the MVHR installed in the kitchen looked like a 'tumble dryer [...] it was huge, it sounded like an aeroplane taking off [...]'. She asked that the MVHR be removed despite being made aware of its advantages in terms of energy saving and provision of fresh air. She insisted on having a normal cooker hood installed instead. The replacement took some time to arrive. | At the time of the interview, the occupant had been distressed with the installation since it had never worked. He described it: 'No, I am [not satisfied]. With the work they have done, I don't. They have put in these new systems. They put it on first, and they tried it out. All it did is, it blew out cold air in, so they came and turned it off. And it hasn't been on since.' 'Yes, I have no heating at all. It doesn't work, after they have put it in, they can't work it.' | Occupants were shown the plans and told about how the system was supposed to work. The interviewee did not entirely understand the implications until the work started. He recalled, 'I thought it was going to be something like a simple vent [...] we were quite upset because they were making holes in all the floors, to put in all the ducts [...] it took quite a lot of space and we didn't realize it would take so much space. [...] We had to stop them. They had a lot of meetings with us [...]'. The occupants demanded a rerouting of ductwork. | The liaison officer stated on behalf of the occupants: 'it was literally a case of [...] learning as we went. For example, installing high performance windows as bay windows the builders had to build the two storey bay out to take their weight. This had implications for the loft, so they had to extend the roof out around 18 inches all round. And then there were solar panels up on the roof and MVHR equipment in the loft etc.' The overall result of the structural alterations was sufficient space in the attic to accommodate the MVHR system. |
| Engagement and communication | There was regular contact between the occupants and the architect throughout the process. However, the occupants did not foresee the eventual scale of the retrofit. | The occupants could not communicate with the workmen, who spoke no English. | Helpfulness of the project manager and architect enabled them to cope. | The occupants described the day-to-day interaction between themselves and the workmen as 'just like one big family'. They said that the project and construction were brilliant and could not praise the PT highly enough. |
| Resistance/acceptance | Resist–redesign–accept. | Resist–dysfunction–cope. | Negotiate–redesign–adapt–accept. | Acceptance despite disruption due to retrofit. |

Notes: For detail of physical and social conditions, see Table 2.
MVHR = mechanical ventilation heat recovery; PT = project team.

Contribution to system perspective

A clear example of a contribution to the system perspective emerged from a hypothetico-deductive exploration of variations in internal temperature. Patterns of high internal temperature (21–24°C) after retrofitting or in the context of highly insulated new dwellings have been reported in the literature since the 1970s (e.g. Socolow, 1978; Haas, Auer, & Biermayr, 1998; Oreszczyn, Ridley, Hong, & Wilkinson, 2006; Schnieders & Hermelink, 2006; Hong, Gilbertson, Oreszczyn, Green, & Ridley, 2009), and have typically been interpreted as evidence of rebound. Led by the physicist and supported by the social researcher, five *a priori* socio-technical hypotheses (H1–H5) for variations in internal temperature were generated (Chiu et al., 2014):

H1: Poorly designed control interfaces (technical), which make it difficult for occupants to control (social and behavioural) their heating system (technical).

H2: Compensation by occupants (social and behavioural) for variations in internal temperature (physical) caused

by variations in fabric performance (technical) or poorly balanced heating systems (physical).

H3: Physical consequences of intermittent or partial heating (physical).

H4: The larger impact of [poorly controlled] incidental heat gains (e.g. solar etc.) in highly insulated dwellings (physical and technical).

H5: Active decision on the part of occupants to take advantage of retrofit by raising heating system set-points (behavioural).

Internal temperatures ranging from 15 to 26°C were observed amongst the 10 case study dwellings. Careful triangulation of both physical (dwelling configuration, energy-efficiency measures installed, monitoring data) and social (PTs' focus group and occupants' interviewing data), demonstrated that aspects of all five hypotheses were at work within the 10 cases. An overarching interpretation is that internal temperature emerges from complex interactions between occupants' heating/cooling practices (thermal preferences, competence in

Table 6. Submatrices constructed to analyse the disruption experienced by occupants with respect to a specific construction strategy, measures (e.g. MVHR), and satisfaction.

| Case | A | B ₁ , B ₂ , B ₃ | C | D | E | F | G | H |
|--|---|---|----------------------------|--|---|--|--|--|
| Occupants' awareness | Unaware | Unaware | Unaware | Not fully aware | Aware | n.a. | n.a. | Not fully aware |
| ventilation strategies | MVHR changed to natural + individual MEV | Communal heating system + MVHR | PIV | MVHR | HWI, mechanically assisted PSV | Whole-house PSV | HWI, MEV | MVHR |
| Construction strategy in relation to dwelling occupation | <i>In situ</i> | <i>In situ</i> | Decanted | <i>In situ</i> | Semi-decanted | Void | Void | <i>In situ</i> |
| Disruption | Distress, resistance and change of strategy, adaptation | Distress, no resistance, no change, poor installation and, commissioning and little evidence for adaptation | No distress | Disruption endured, observation led to resistance, then to dialogue and change | Distress as a result of witnessing a chaotic construction process and lack of communication | Allocation of housing after the construction process had finished. No distress | Allocation of housing after the construction process had finished. No distress | Good communication, dialogue throughout had lessened distress and increased satisfaction as a result |
| Communication between the PT and occupants | | Liaison officer | Through the occupant's son | | Liaison officer | | Vacant possession on completion of retrofit | Liaison officer |
| Satisfaction with installation process | DS | VDS, VDS, VDS [respectively] | VS | VDS | VDS | n.a. | n.a. | VS |
| Overall Satisfaction | VS | VDS, DS, VDS [respectively] | S | VS | S | S | VS | VS |

Note: DS = dissatisfied; HWI = hybrid wall insulation, e.g. external at the back, internal at the front; MEV = mechanical extract ventilation; MVHR = mechanical ventilation heat recovery; n.a., not applicable; PIV = positive-input ventilation; PSV = passive stack ventilation; PT = project team; S = satisfied; VDS = very dissatisfied.

control of interfaces, use of secondary heating) lifestyles (laundry and cooking practices), and the varied thermal environments created after retrofitting, and there is a need to consider a wider range of explanations for high mean internal temperatures than rebound alone (Chiu et al., 2013, 2014).

The above analyses of disruption, and variations in internal temperature demonstrate how the social and the physical are intertwined to produce building performance. In the case of disruption, social meanings assigned by PTs and occupants to practices of ‘decanting’ versus ‘*in situ*’ influenced the pathway and outcomes of each retrofit project. The careful observation and triangulation of different datasets confirmed that all five of a set of socio-technical hypotheses relating to internal temperature were in play, demonstrating that internal temperature is not merely a physical phenomenon but a socio-technical one.

The CSM has revealed buildings as complex, dynamic socio-technical system and shown how pathways to performance can be observed in an empirical setting. In particular, it has shown:

- the process of interactive adaptation at work within the retrofit system
- the role of participation in the design process, and engagement and communication during the retrofit process, and
- the association of all the above with occupant satisfaction with the retrofit process and end result

This offers support for Cole et al.’s assertion of the importance of ‘an integrative and participatory process’ with ‘communication and dialogue at all stages of design and occupancy’ that values both adaptive building systems and human agency as drivers of interactive adaptivity (Cole et al., 2008, pp. 330–331).

Conclusions

Cole’s body of work has inspired the authors to present this methodological paper with the aim of demonstrating that CSM, in the hands of an interdisciplinary team and underpinned by a socio-technical approach, provides a way of assessing/evaluating building performance that takes account of the complex interactions between the social and the technical, and allows the role of agency and responsibility of the designer, constructor and occupant to be better understood.

Although not comprehensively or exhaustively, this paper has demonstrated how investigative methods require the underpinning of philosophical assumptions regarding the nature of our world (ontology) and the

nature of warranted socio-technical knowledge (epistemology); and how coherent investigative logics could help to constrain the potentially overwhelming complexity of the phenomenon by carefully choosing and justifying the relevant components under investigation, guiding the choice of relevant data and their respective collection methods.

Practical guidance has been given as to how CSM can be used to study (in this case) retrofit as a complex system, highlighting the value of the co-verification process that helped to improve data quality, and the use of dynamic matrices in combination of both deductive and inductive logic to generate hypotheses (lines of questioning) in an ongoing process of analysis. Examples have also been given of how different types of data collected could be analysed and triangulated, to strengthen the validity of interpretations.

Employing the CSM as described above makes the co-constituted nature of the performance gap evident. The practical implications of accepting buildings as complex dynamic systems within which the technical and social co-evolve are that occupants are central to the successful design, implementation and performance; dialogue and communication between PTs and occupants throughout the retrofit process is key to satisfactory process and outcome.

Designed and applied appropriately, CSM is capable not only of producing primary empirical data to support modelling and design, but also of capturing the contextual complexity that is often required for causal inference – understanding what the performance gap is and also how it arises, and how therefore it might be changed.

The main limitations on the future expansion of socio-technical CSM in this field are the availability of resources, of suitably trained people, and of examples and methodological discourse in the literature.

Notes

1. These include the US Green Building Council’s (USGBC) Leadership in Energy and Environmental Design (LEED), which arrived almost a decade later with the publication of LEED v1 in 1998.
2. I. Cooper, in a personal communication, 2017, states that the importance of actual performance was appreciated from the outset. At the launch of BREEAM at a Society of Chief Architects of Local Authorities (SCALA) conference in 1990, John Duggart (one of BREEAM’s key creators) spelled out three aspirations for BREEAM: first, that it would have a ratchet effect, driving up regulations and then moving on to set increasing higher voluntary performance standards; second, that it would be used iteratively during design; and third, used again, through an ‘in occupation’

- version, to investigate/certificate the extent to which the 'as built' building conformed to the design intentions in use. It is this bridge that has not been built effectively.
3. Such as double envelopes, active solar, photovoltaics and breathing walls.
 4. Of these, only two, BREEAM and LEED, have achieved international commercial significance.
 5. To discuss these meaningfully as separate systems requires that they be functionally independent and observable in isolation. In practice, this is rarely possible.
 6. Smith, Stirling, and Berkhout (2005, p. 1493) define a socio-technical regime as a 'relatively stable configuration of institutions, techniques, and artefacts, as well as rules, practices, and networks that determine the "normal" development and use of technology'. See also Schatzki (2011).
 7. Good CSM requires all the standard procedures applied to rigorous, empirical social research, *i.e.* field notes, transcription validation, member checking and an audit trail throughout. Perceptions of lack of rigour in case studies perhaps, in part, arise from lack of training in these basic procedures, coupled with an unfamiliarity with the relevant methodological literature (*e.g.* Flyvbjerg, 2006).
 8. The TSB was established by the UK government in 2004 as the UK's major funding mechanism to support industrial innovation and collaborative research and development. In 2009, the TSB launched the RfF programme 'To address the challenge of the UK's national CO₂ reduction target of 80% by 2050.' The RfF established 86 exemplar projects in the social housing sector across the UK. The 80% reduction target applied to each project justified the term 'deep retrofit'. The TSB subsequently worked with the European Regional Development Fund (ERDF) to co-fund the Facilitation Learning and Sharing (FLASH) programme.
 9. Such studies have tended to emphasize occupants' behaviours, *i.e.* use of heating/cooling/thermal controls before or after retrofit, rather than practices as an emergent property of the interactions between the physical and the social.
 10. Pickering's work revolved around the development of azo dyes after 1877. He suggested that chemists' tinkering with material was guided by developments in the coupling reaction in chemical theory and had generated an indefinite series of new dyes. The consequences were that a whole host of new social institutions became established and the role of chemists changed from university researchers to industrial scientists.
 11. Or, in other words, ontology carries implications both for epistemology and methodology.
 12. The research team was supported by Databuild, an independent contract research organization commissioned by the Energy Saving Trust (EST) to manage the collection of physical data on the dwellings, and to undertake occupant interviews in all 98 projects.
 13. One of the most eloquent descriptions of this complexity is given by Bordass et al. (2002, p. 64): 'One cannot over-emphasise how difficult buildings are to study properly. They are "complex dynamic open systems", with hundreds of apparently relevant variables.'

14. Copies of all instruments can be obtained from the authors upon request.
15. Physical monitoring data were collected by an independent agency commissioned by the EST.
16. See note 12 above.
17. The final sample consisted of 10 dwellings with seven PTs. One PT was led by a firm of architects that worked for two different social landlords on two separate projects. A second PT undertook the retrofit of a terrace of four dwellings, three of which were included in the FLASH project. All other cases consisted of single dwellings in which retrofits were carried out by individual PTs (Chiu et al., 2014).
18. The term 'decanting' refers to the practice of moving occupants out of the dwelling during the retrofit process; 'in-situ' refers to the opposite practice. The terms emerged from the retrofit teams themselves.
19. Codes are tags for assigning units of meaning to 'chunks' of words, phrases or sentences in the transcripts. They are used in the analytical process to retrieve and organize the chunks and derive possible meanings from them (Miles & Huberman, 1994).

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