Chapter 8

Performance

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Abstract The Chapter will include an introduction to the context of the performance of buildings in use – changing energy and environmental targets and the development of new designs, materials, and technologies to meet these targets. The questions that emerges is, are these successful? Are the targets being met and if not why not? And are there related effects on performance – do improvements in one area lead to deficiencies in others?

In effect the construction industry is conducting a series of experiments and it is important that we go back and check the results, and more importantly, learn from these. However, this type of activity is not standard practice in the construction industry. This chapter describes a series of projects that have developed and undertaken building performance evaluation (BPE). These include the development of tools, examples of BPE projects, and case studies of the type of insights that can be gained from such projects; and will conclude with a summary how these can inform both clients and designers.

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8.1 Introduction

This Chapter describes research and knowledge exchange activities supported by CIC Start Online that address a fundamental research question that lies at the heart of all the initiatives, designs, technologies and interventions that have been discussed thus far. It is this: do they work as intended?

It seems extraordinary given the level of investment in buildings and their importance both to contemporary objectives of climate change and sustainability, but also the everyday lives of people who use them in terms of comfort, health and satisfaction, that the performance of construction is hardly ever evaluated. For the vast majority of buildings, the answer to the question posed above is that we do not know. What is an increasing cause for concern is that in many of the buildings in which the question has been asked through some form of post construction review, it would appear that they frequently do not work as intended. Research has shown that there is a substantial performance gap emerging between the design intentions and measured performance of both new and refurbished buildings in the UK, with some sectors producing more than twice their predicted carbon emissions (Pegg 2007, CarbonBuzz 2010). In housing, energy and water use can vary by 3–14 times (Gill et al. 2011, Grams-Hanssen 2010, Pilkington et al. 2011). This gap could preclude achieving the carbon reduction milestones and timelines set forth by public policy (UK Government 2008), as buildings' operational energy demands account for nearly half of carbon emissions in the UK (DEFRA 2005).

This gap in performance inevitably leads to a line of enquiry that asks, why is this occurring? Most regulatory requirements used by designers and builders are based around energy design targets, for example Standard Assessment Procedure (SAP) for energy rating of dwellings or Simplified Building Energy Model (SBEM) for estimating energy consumption of non-domestic buildings. However, these tools do not provide evidence to both the regulator or client of what level of performance has actually been achieved in reality. Currently there are no requirements for proof that new build homes have achieved their planned energy performance in reality (GHA 2011).

Furthermore, questions are arising about the environmental performance of new buildings, particularly housing. In some cases there are conflicting goals; for example energy reduction strategies seek to reduce ventilation rates, whilst those concerned with indoor air quality (IAQ) wish to increase them. Research has highlighted concerns about the possible consequences on indoor air quality of the greater airtightness (Davis and Harvey 2008, Crump et al. 2009), and has identified the urgent need for further research in this area. As health and well-being are likely to remain as significant agendas for building occupants and landlords, there is a significant risk for the energy reduction agenda if low energy homes become associated with problems of discomfort or health.

This raises an important issue. Irrespective of the industry, policy and legislative drivers for BPE, there are also ethical dimensions that are rarely considered. BPE frequently refers to effects of occupancy on performance, sometimes characterised as ‘bad’ behaviour. However, a converse view is that people live in these innovative buildings, and so are, in effect, the subjects of these experiments. So the resulting question is: what are the effects of buildings *on* occupants? There is clearly a moral, ethical and ultimately a professional responsibility to those who produce these buildings, as clients, designers and contractors to ensure that they function well and that there are no unintended negative consequences.

Building performance evaluation (BPE) is an absolutely key requirement in this area. It is the one process that can generate the intelligence needed to learn lessons from buildings in order to make the required changes to improve future design. BPE is the missing link in a feedback loop that can foster evidence informed design. With rapidly changing standards, leading to innovations in materials, technologies and construction, it seems reasonable to say that all new buildings are some form of experiment. However, if we do not evaluate the results of these experiments, how can we ever learn from them?

BPE has previously been defined as “the act of evaluating buildings in a systemic and rigorous manner after they have been built and occupied for some time” (Preiser and Vischer 2005). Early BPE methods include the gathering of both quantitative data through monitoring and qualitative data though surveys (Markus and Building Performance Research Unit 1972), but more recently the methodology for this has been developed by studies such as PROBE (Leaman and Bordass 2001). In housing, a range of methods and parameters have been developed to capture data (Stevenson and Hom 2010), and a comprehensive set of criteria for BPE has been set out by the Technology Strategy Board (TSB) Building Performance Evaluation programme (TSB 2010).

However, undertaking BPE is not necessarily a straightforward process. There are a variety of methodologies and approaches, some of which are still developing. There are a range of building types, tenures and types of occupants to consider, and monitoring is also a rapidly developing area, with continuing advances in sensor technology and data acquisition.

CIC Start Online has been active in promoting, developing and undertaking BPE and other related forms of performance testing of materials and buildings throughout the project. A range of institutions are developing methodologies and reporting findings from innovations, and the examples in this chapter evidence this quite clearly. These studies involve collaborations with a range of stakeholders including architects, housing associations contractors and manufacturers.

This chapter reviews the CIC Start Online contributions to the field of building performance. These are broadly characterised by a series of themes, which address the barriers to BPE. Although by no means mutually exclusive, with several studies contributing to multiple strands, the themes nevertheless represent an approximate taxonomy for characterisation. They include:

- Performance Gaps
- Methods and Tools
- Occupancy
- Existing Buildings
- Focussed Studies
- Design Integration.

8.2 Performance Gaps

The nature of the performance gap between design and build in Scotland was examined in a study by the Scottish Energy Centre, Edinburgh Napier University, in collaboration with the Morrison Partnership entitled 'The Gap between Design & Build: Construction compliance towards 2020 in Scotland' (Bros -Williamson 2012a, Bros -Williamson and Purdie 2013).

It is becoming increasingly apparent that many buildings are not achieving the energy reductions that were anticipated and this study provides a thorough overview of the issues leading to performance gaps. As well as identifying some key literature sources in this field the study undertook a review of compliance requirements and gave concrete examples of performance gaps that occur at design, construction and occupation stages, in both new-build and renovation projects. It reviewed possible causes at design stages, including tools, aspirations and specification; at construction stages in terms of workmanship and communication; it identified the role of occupancy post completion; and a clear recommendation from this work was the need for more BPE. It also proposed a more progressive building design and construction model (Fig. 8.1).

(Fig. 8.1)

A review of BPE was also provided in the 2011 online Conference 'Resilience of Buildings, Neighbourhoods and Cities' in a presentation entitled 'Resilience to Occupancy: Findings from recent Post Occupancy Evaluation projects' (Sharpe 2011). The presentation outlined the changing context of contemporary housing in Scotland, including reducing volumes and window sizes, increasing airtightness, as well as energy and carbon reductions demands which are driving many of the design innovations discussed in previous chapters. The presentation described a range of research projects undertaken by Mackintosh Environmental Architecture Research Unit (MEARU) that had undertaken forms of post occupancy evaluation of constructed buildings. These included the Priesthill project (Sharpe and Porteous 2001) and the SAP+ study for Scottish Homes (Kondratenko et al. 2004).

The Priesthill study validated the energy performance of the project, which was higher than predicted, but still a significant improvement in overall terms. The shortfall was found to be higher than predicted ventilation rates, and this was further explored in the SAP+ study, which found both liberal window opening during the day leading to high ventilation losses, but very low ventilation rates at night leading to very high relative humidity (RH) levels. These studies clearly identified the differences between design prediction, legislative targets and real life.

The performance gap in non-domestic buildings has also been identified in other work, for example the article on school design in Innovation Review 10 by Renate Powell from the Carbon Trust (Powell 2012). This highlighted performance issues in new school design, including poor comfort, poor balance between daylighting, ventilation and temperature, and inadequate environmental sustainability.

In reviewing this context it seems ironic that meeting building standards in terms of energy use and ventilation *is* a requirement, but proof that the building achieves these standards is not. The Sullivan report, which has led to changes in legislation in terms of energy efficiency and carbon reduction had as its first recommendation:

> "Monitoring of recent private and public sector low carbon domestic and non-domestic buildings in Scotland including behavioural and occupier lifestyle monitoring as well as energy efficiency, carbon footprint, temperature, ventilation etc. built both with public funding and by the private sector." (Sullivan 2007).

However, this has yet to be implemented. Research indicates that it is unlikely that voluntary measures on their own will deliver significant change as experience has shown that developers respond most pro-actively to legislation (Osmani and O'Reilly 2009). To this end, getting the message about the importance of BPE out to building clients and policymakers is a critical strategy, and has been a continuing theme across several CIC Start conferences and seminars, including CIC Start online conferences 'Resilience of Buildings, Neighbourhoods and Cities' (CIC Start Online 2011); 'Build Tight – Ventilate Right?' (CIC Start Online 2012), and 'Building Performance Evaluation - Why and How? (CIC Start Online 2013). These conferences have included presentations from a range of individuals and organisations both from the UK and internationally, which have provided clear examples of problems and challenges emerging as a result of performance gaps. The 'Build Tight – Ventilate Right?' (CIC Start Online 2012) conference in particular highlighted tensions in respect of seemingly mutually exclusive requirements of reducing ventilation rates for energy conservation versus improving ventilation rates for indoor air quality and health.

8.3 Methods and Tools

There are considerable barriers to undertaking BPE. As well as a lack of acceptance and understanding in some areas there is also a need to develop robust and deliverable methodologies that are both effective and affordable. The Technology Strategy Board (TSB) is currently undertaking a 4-year, £8m programme of BPE with over 120 projects across the UK with the intention of developing BPE capacity and knowledge. The 'Building Performance Evaluation - Why and How?' (CIC Start Online 2013) conference brought together domestic TSB projects in Scotland to discuss this area and share knowledge about the various projects.

Studies funded by the TSB BPE programme lasting 2 years are typically £40-60k, and few, if any housing projects have this element built into the cost plan, particularly as it is not a legislative requirement. As a result, those clients and organisations wishing to undertake BPE need to make a justification of the cost, but the financial model for housing provides very little room for manoeuvre. To those familiar with this area it seems self-evident that the expenditure of perhaps 0.5% of construction on checking that the building works as intended is a good investment, particularly where such work may lead to improved energy efficiency, reduced running costs and better comfort and health.

However, the rapidly emerging performance gap between design and reality defines a clear need for in-use feedback of building performance on shorter timelines, and with practical methodologies. In the domestic sector gaining access to houses to undertake BPE can be a considerable challenge. In its most comprehensive form it can be disruptive to occupants, requiring several visits to fit monitoring and metering equipment, undertake surveys, filling in diaries, and survey fatigue is not uncommon. Whilst in non-domestic buildings occupants are more accessible, in housing there are both ethical and practical barriers that need to be addressed.

Finding ways to minimise disruption is therefore critical, and several CIC Start studies have investigated forms of BPE, which undertake shorter, more intense studies. Whilst these clearly do not provide a holistic view of use throughout the year, or a comprehensive evaluation of a building, they nevertheless provide extremely valuable insights into patterns of occupancy and the energy and environmental performance in these periods. Such studies are also more affordable and may present a thin end of a wedge that can bring BPE into the public and industry consciousness, and also lead to working relationships with SMEs that can then lead to larger studies; examples of these are discussed below.

Stimulating demand through ‘light-touch’ approaches was addressed in a study “Development of Post Occupancy Evaluation for evaluation of innovative low carbon social housing projects”, (Menon et al. 2010), undertaken in conjunction with John Gilbert Architects (JGA), which was also presented at a webinar in April 2011 (Sharpe et al. 2011). The aim of the feasibility study was to explore the potential for the development of a cost effective Post Occupancy Evaluation (POE) methodology (with a particular sustainability focus) that could be used to gather both quantitative and qualitative information regarding energy and environmental performance of housing.

The study investigated a ‘light touch’ approach to POE, in which a snapshot of performance could be undertaken through monitoring houses for a short period, in this case two-week periods. This would include both quantitative measurement of environmental conditions, but also gathering of qualitative data through interviews, surveys and observations.

This methodology is less intrusive on the resident and is cost effective for the housing association. The study found that this approach could give valuable insights into the nature of the occupancy, levels of energy consumption and the resultant environmental conditions. It clearly identified performance gaps between SAP calculations and actual consumption, but also highlighted examples of good practice. The work illustrated the benefits of BPE to the housing associations, two of which have gone on to undertake further BPE studies on their properties and one of the participants, Hanover Scotland Housing Association (HSHA) has subsequently collaborated with MEARU on larger TSB funded projects at Bloom Court, Livingston and Murray Place in Barrhead.

The broad methodology that was piloted in this study was further developed and utilized in a subsequent CIC Start academic consultancy “9-11 Gilmour’s close - performance evaluation” (Sharpe and Shearer 2012). This study was undertaken in conjunction with Assist Architects. The study looked at the performance of a Category B listed tenement refurbishment that had incorporated low energy principles to the design in the form of ground source heating, passive solar strategies, mechanical ventilation with heat recovery (MVHR) and upgrade of the fabric’s thermal performance by internal lining. This had been previously described in an article by Andy Jack in Innovation Review (Jack 2009).

There had been anecdotal evidence of overheating leading to widespread window opening. Given the low energy intentions of the building, this was a cause of concern and was the subject of the study. This project assessed the performance of this development in terms of energy use and user experience, through a 3-week monitoring process and subsequent analysis of the small office space and 5 individual dwellings.

Although a short study, the snapshot revealed significant amount of data for the architects and landlords, highlighting underperformances in the MVHR and heating systems that explained the observed occupant behaviour. The study provided a series of recommendations for future design improvements for new proposals; building alteration/ upgrade for Gilmour’s Close; occupant support; and areas for further study. The landlord of this development is currently undertaking some of the recommended interventions and it is hoped that a further study will be undertaken to verify their effectiveness.

Both these studies were successful on at least three levels. Firstly, they were able to develop and implement a light-touch methodology that was minimally invasive for the occupants and able to provide a rich dataset within the time and cost constraint of the feasibility study. Secondly, they were also able to generate useful knowledge about the actual performance of these buildings, and recommendations for actions to improve performance, both in the subject buildings, but also in design. Thirdly, they revealed to the client organisations the benefits and insights of BPE, and this has led to further projects and investigations.

As well as these studies, several articles in Innovation Review have identified methodologies and tools that are used for BPE. Park (2012) described the core principles of the Soft Landing approach, which requires a 'cradle to occupation' process for the handover of a building and extends the duties of the team during handover and the first three years of occupation. Stages include: inception and briefing enabling, design development and review, pre-handover, initial aftercare and extended after care and POE.

Information on the use of some commonly used tools has also been identified and disseminated. Park (2011) described the requirements and standards for airtightness testing introduced under the 2010 Building Standards. As well as general methodologies for BPE, some studies examined the nature of equipment used for environmental monitoring. Glasgow Caledonian University undertook a study for AppleGreen Homes on the 'Application of an innovative energy consumption monitoring system' (Barrie 2012). The project investigated the application of a wireless sensor network (WSN) infrastructure to support monitoring of an energy-efficient built environment, specifically a mass-market affordable home created by Scottish company Applegreen Homes. The work includes the creation of a feature-set specification for a monitoring system, the development of hardware and software to provide the necessary functionality and an evaluation within a built environment.

One particular area of deficiency that BPE has consistent identified is the management and handover of design and construction information. An important development in this field is likely to be the use of Building Information Management (BIM). This was investigated in the study 'Sustainable BIM-driven post-occupancy evaluation for buildings' by Heriot Watt University in collaboration with Wylie Shanks Architects (Motawa and Corrigan 2012). The study explored the need to facilitate this sharing of information among the stakeholders and supply chain at both procurement and operation stages through interviews with key stakeholders. The study identified the key operational and carbon performance variables for Scottish public buildings, which are required to adopt BIM approach as a means of better informing the stakeholders on the performance. If implemented this could help to develop a smarter procurement strategy based on consistent information to be shared by all stakeholders.

8.4 Occupancy

An element of building performance that is attracting increasing attention is that of occupant behaviour. This is often characterised as misuse, but it is becoming apparent that many buildings are not designed for contemporary patterns of use, with limited environmental strategies often dictated by legislative requirements, and inadequate controls. Occupants, like designers and clients, frequently have little access to information that might affect their energy consumption and environmental performance.

One of the elements explored by the study with John Gilbert Architects (Menon et al. 2010) was to develop a sample on-line POE tool and template documentation, which could be applied to future POE exercises, carried out by Housing Associations. This examined ways of communicating information to the landlord and occupants, including innovative ways of representing data. In this case a 'weather map' tool was developed, which showed, through colour change, varying environmental conditions in the dwelling. This issue of feedback and communication to occupants is very important.

(Fig. 8.2)

As the behaviour of building occupants affects the energy and environmental performance, the ways in which users of a building are given guidance on how to use their buildings, particularly when these include novel or unfamiliar technologies, is crucial. This particular problem was addressed by a study "Developing a Template for a 'Quick Start' User Guide for New Home Owners" (Sharpe et al. 2012), undertaken in collaboration with the Home Logbook Company (HLB) that developed guidance for occupants of low energy homes.

Scottish Government Building Standards Directorate had previously commissioned MEARU in conjunction with 55 North Architecture to develop occupant guides as part of the Building Regulations new Section 7 'Sustainability'. This section outlines optional standards for sustainability for new housing - the higher levels include the need for straightforward user information for homes including a 'quick start guide' to the building fabric, mechanical systems, ventilation strategies and other sustainability features (Sharpe and Bridgestock 2011, Menon et al. 2012).

This project was a chance to put this into practice. The HLB Company together with MEARU developed a bespoke 'quick start' guide for housing, including the aspects addressed in the new building standards in Scotland. The aim was to identify the most effective process of gathering this information and to propose a simple template which could be replicated by housing providers to meet the Section 7 criteria for new homes.

(Fig. 8.3)

The 'pilot' guide was tested with a range of new house owners and tenants in both the public and private sectors. Feedback on the guide was obtained from residents and survey results were overwhelmingly positive. 100% of the residents said that they found it easy to read and that the diagrams were easy to understand, and 94% said that they feel more informed about how to use the house in a more energy efficient manner. There was less confidence about whether the guide helps residents to understand the controls – the guide identifies where information about controls could be found, but in many cases the controls themselves were found to be confusing. Both this study and other research in this area (Stevenson et al. 2012) have identified that users' knowledge of how to use low energy homes is a significant barrier.

On a related theme HLB Ltd also examined home owners' attitudes to water consumption in the study 'Communication strategies to minimise water consumption in social housing' with Heriot-Watt University (Gul and Menzies 2012). It found that there was a significant lack of awareness regarding water conservation amongst social housing tenants, and explored a variety of ways in which this could be improved through information campaigns with different user groups.

User engagement with energy and resource consumption was investigated in several studies. The use of energy monitoring was an important component of the study 'A Tool to Calibrate Cost Effectiveness of Energy Efficiency' by MEARU and University of Sheffield in collaboration with NRGSTYLE Ltd (Noguchi et al. 2012). During the design stages for a low-energy refurbishment, the existing energy consumption was monitored using an EWGECO energy monitor, and the findings used to help define design options. The novel EWGEKO smart meter was also the subject of webinar 39 - Integrating Energy Monitoring Systems for Smarter Homes (Stinson and McCorkindale 2013) which outlined the benefits and development of a smart meter system

The effectiveness of a new system for occupant control of heating systems was the focus of a study "Ecotrip Heating Control Field Trial" (Russell 2013) by Glasgow Caledonian University for Corrour Concepts which investigated technology for a domestic central heating control. The feasibility study undertook a field trial of the unit to investigate its ease of use and potential energy savings.

8.5 BPE in existing buildings

Refurbishment of existing buildings to reduce energy consumption whilst maintaining the fabric of the building presents a series of very unique challenges and a number of studies have focussed on existing buildings. BPE is equally important in these buildings types, if not more so, as existing conditions may restrict the choice of solutions that can be applied. This was found to be the case in the study at Gilmour's Close, where fire safety measures compromised the performance of the MVHR system (Sharpe and Shearer 2012).

A particular problem in existing buildings is the retrofitting of insulation to achieve a required level of performance, particularly in older stone properties. Moses Jenkins, Senior Technical Officer at Historic Scotland describes in-situ measurement of U-values of materials used in historic building refurbishment (Jenkins 2010) and a feasibility study entitled "Monitoring building fabric and internal environmental behaviour of a recently insulated historic building" (Bennadji and Turner 2011) was undertaken by Robert Gordon University in conjunction with Kishorn Developments that monitored the before and after performance of an additional insulation applied to the wall of a traditional stone building. It compared the measured results with CFD simulation. It found some differences; the measured value of relative humidity of insulated wall fell within the range of relative humidity values calculated for the air gap in the simulation 29% of the time.

This problem was also explored in a feasibility study undertaken by Edinburgh Napier University in collaboration with BCA insulation (Bros-Williamson 2012b) 'Thermal and condensation analysis of a typical solid wall following a refurbishment intervention'. This study undertook thermographic imaging and in-situ testing of U-values of a masonry wall that had partial installation of phenolic intern insulation - upper parts of the wall had been left un-insulated for aesthetic reasons to avoid hiding the original cornicing. As well as illustrating differences been predicted and measured U-values, it clearly demonstrated the thermal improvement of the insulated elements, but also highlighted risks of the residual cold spots and interstitial condensation (Fig. 8.4).

(Fig. 8.4)

An alternative solution was assessed in the study 'Testing of a method for insulation of masonry and lath walls, by Robert Gordon in collaboration with Craigie Levie (Bennadji 2012, Bennadji and Levie 2012). This study examined the performance of a water-blown foam insulation, Icynene, placed behind a traditional plaster and lath wall. In this instance the installation performance was the main focus of the study, which highlighted a number of operational problems that need to be resolved when installing insulation into this type of cavity, but demonstrated that the technique is viable (Fig. 8.5).

(Fig. 8.5)

More specific experimental tests have been conducted in existing buildings. A feasibility study by Glasgow Caledonian University in collaboration with Locate Architects 'Co-heating test for Alternative Refurbishment Strategy on Hard to treat House on Uist' (Baker 2013) undertook 'real-world' testing of two different improvement strategies – a conventional internal insulation approach, and an alternative that improved air-tightness, reduced thermal bridging, improved external waterproofing and retaining exposed thermal mass. The study used a 'Co-heating' test coupled with results of air-tightness testing on a typical single storey two bedroom stone walled croft house with a floor area of about 40m2 in Daliburgh, South Uist. The study identified specific benefits of both approaches, but concluded that elements of both strategies are needed.

8.6 Focussed studies

In some cases, investigations focus on specific issues. An example of the value of real life assessment of performance was presented in the article by Professor Colin Porteous of MEARU in the article in the Innovation Review. This article summarised the approach and findings of multi-disciplinary, 3-year research project funded by the Engineering and Physical Sciences Research Council (EPSRC) (Porteous et al. 2012). MEARU led the project in conjunction with two other research units – Research on Indoor Climate and Health (RICH) at Glasgow Caledonian University and Energy Systems Research Unit (ESRU) at the University of Strathclyde. This involved a large scale Post Occupancy study undertaking survey and monitoring of housing in Glasgow, investigating the health and energy implication of domestic laundry practices. In this case, the monitoring then fed back into laboratory testing and computer simulation, a reversal of the normal direction of knowledge flow in construction. The monitoring looked closely at moisture, which has implications for indoor air quality (IAQ) and health, due principally to mould spores, dust mites and chemicals (used in laundering and released from materials and furnishings). IAQ in turn relates to energy consumption for space heating, with control of ventilation playing an increasingly crucial role in limiting fossil fuel consumption and carbon emissions. It also introduced 'Healthy Low Energy Home Laundering', Design Guide which is a key publication arising from the study and now available free-online at www.homelaundrystudy.net (Porteous et al. 2012).

In some cases, very specific investigations have been made into the performance of particular systems or technologies. For example, in the study 'Assessing the energy impact of different strategies of integrating PV/Thermal Heat Recovery systems in Scottish homes' (Noguchi 2011) undertaken by MEARU in collaboration with RobertRyan Timber Engineering, the project undertook in-situ monitoring of the performance of a full-scale mock-up of a PVT/HR system in Sweden. The observation helped identify the performance of PV/T modules in question — particularly, the ventilated PV/T mock-up, under snowy winter conditions. Although results were not positive in this condition, the real life observation helped to identify the negative impact of snow on PV cells leading to an ice dam if the system is not integrated with building envelope (i.e. roof) properly. This type of insight would not be possible in modelling or simulation.

Effects of airtightness and ventilation were also described in the article 'Seal Tight, Ventilate Right' by Donald Shearer of MEARU in CIC Start Online Innovation Review (Shearer 2011). This article described a detailed BPE program being undertaken on the Glasgow House, the design intentions of which had been introduced by Stuart Carr from PRP Architects in 'The Glasgow House: A 'low-tech' approach to the problem of fuel poverty' (Carr 2010). The study is conducting a number of detailed evaluations of the prototype housing using occupant scenarios to test the relative performance of two construction types. This article identified some shortfalls in performance of the MVHR system in relation to requirements for IAQ.

8.7 Design Integration

A further barrier exists in the reluctance of those involved in the design and construction of buildings to engage with BPE, perhaps most simply characterised as a fear of 'bad news'. There is an aphorism that "doctors bury their mistakes – architects have to live with them". In fact, quite the opposite is true. The medical profession takes considerable pains to learn from its mistakes to ensure they are not repeated, the same cannot be said of the construction industry.

As there is currently little verification of performance there is consequently less litigation for non-compliance, but there is a concern in the industry that BPE will reveal deficiencies that would not otherwise have been seen. However, it has become apparent that these fears are unfounded. BPE can reveal positive messages and, in cases where problems are encountered, analysis of these will lead to learning. BPE findings can inform the construction industry, policy and government.

There are considerable advantages for architects to be involved in BPE as a way of increasing knowledge about the implications of design decisions and developing an understanding of how buildings are being used. In recent years architects have had far less control over the design and construction process. More specialists in the design and construction industries are now involved, but without an overview that links design intention to end product, there is a risk of a fragmentation in the process. BPE can be a way for architects to reclaim some of this territory if it can lead to an improvement in the services provided, what Bordass and Leaman refer to as a 'new professionalism' (Bordass and Leaman 2013).

BPE thus presents opportunities for the profession as the driver of the design agenda, but implicit within this is the notion that designs actually perform well. To verify this, it must be tested. Forms of POE are now included in the RIBA 2013 Plan of Work. Whilst this has received something of a lukewarm reception by the profession who characterise it as one more task they have to do within the same fee, it could be developed as a more comprehensive service, which not only provides additional work, but also informs design practice. As the demand for BPE increases, the service will be provided, but it is clear that architects not only have a professional and ethical duty to learn from the designs, but are also best placed to feed this back into design.

As evidenced by these studies, this is a rapid changing area. Architects are seeing that the benefits of BPE in terms of knowledge gained far outweigh any negative aspects. In any event, BPE should be seen as a learning, rather than judgemental activity. Once the participants understand this, a far more fruitful dialogue can occur. This is evidenced in the article 'Passive solar PassivHaus paradigm for Scotland in zero-carbon quest? Lessons from study tour in Switzerland and Germany' by Prof. Colin Porteous (Porteous 2010). The articles describes a series of innovative low energy buildings in Switzerland and Germany, but crucially also provides substantiation, through monitoring projects, of their performance.

A number of articles on design intentions include information on performance. In her article 'Affordable Low Allergy Housing' Prof. Sandy Halliday of Gaia Research describes monitored performance of low allergy housing (Halliday 2010) as evidence of its effectiveness and in the article 'Plummerswood Active House', she shares the early performance (Fig. 8.6) of the Plummerswood house by Gaia which is undertaking a TSB funded 2-year BPE study (Halliday 2012).

(Fig. 8.6)

The need for BPE to feed back into design is a crucial component. This was the subject of a study Embedding Simplified Post Occupancy Evaluation (Nugent et al. 2010, Clarke et al. 2011) within the design process by the University of Strathclyde Glasgow with Page and Park (P/P). This project developed prototype software (POET) for gathering information on the on-going energy consumption of buildings designed by Page and Park. For a given building, energy use data is recorded and stored in POET over a one to two year period following occupancy. These figures can then be displayed in the form of graphs and compared with the benchmark performance data within the program. In addition to the quantitative data, a questionnaire-based building performance evaluation is undertaken by the facility manager (or equivalent) and the outcomes stored in POET. The intention of these evaluations is to capture the building users' consensus view of performance and record how this changes over time. Observational walkthroughs can also be used to corroborate evidence gained. They can be used to record whether people are using the building as intended; where they relax, how they use quiet spaces and what they do to counteract negative environmental features. The study has parallels with the previous projects in that it seeks to develop a more responsive, lighter touch approach than currently exists in industry standard tools such as TM22 and the BUS. Page and Park are utilising the tool in two of their current projects.

The role of BPE in design was also the subject of the study 'Embedding Post Occupation Evaluation into Practice (Shearer et al. 2012, Newlands et al. 2013), undertaken by Kraft Architecture in collaboration with MEARU. This study had addressed three issues, how can POE be made more affordable and accessible and made a valued routine practice. The study undertook a review of current BPE state of the art and discussed the challenges and possible solutions that may be required, including a review of techniques and solutions that can be applied. Whilst the study was not conceived of as a 'how to' of POE, it provides insights for the construction industry on how to 'mainstream' POE practice and its benefits.

It is evident from the studies presented in previous chapters that forward thinking architects have become more aware of the need to undertake BPE in order to make better buildings and inform their design practice. Chapter 4 has described a series of diverse approaches to sustainable design practice and it is interesting to note the emphasis being placed on post occupancy studies. Over 14 articles in Innovation Review specifically described intentions to monitor the buildings and innovations being proposed.

4.7 Conclusions

It is clear that the performance gap between design intention and actual performance needs to be closed, not just to meet energy targets, but also to provide sustainable, liveable buildings. Without robust assessment of performance, we cannot understand how buildings perform, how they are used, nor how we can make them better.

Research into, and through BPE, reveals new knowledge about the performance of buildings, their technologies, and also their occupants. The ability for this knowledge to inform design practice is invaluable. Early chapters evidenced a range of innovations in design and construction and have identified the pressing need to take a more holistic approach to design that extends throughout the lifecycle of buildings, and that develops methodologies that can close the loops and feed user experiences and building performance back to design stages.

The knowledge generation and dissemination initiated by CIC Start Online has developed and extended the knowledge and practice of BPE and provided insights into the real-life performance of design, materials and technologies. These studies have enabled significant knowledge exchange between architects, building owners, occupants and academics about where performance gaps may be arising, how they might addressed, and how this knowledge can be fed back into the design, procurement and construction processes.

It is evident that significant innovation is required to meet the challenges set down by climate changes and the need for sustainability, but what these studies have demonstrated is that although technology is important it is not a solution in its own right and simple fabric first approaches to building orientation, form, and construction; and a concern for the users and occupants of buildings continue to be fundamental tools for the design and production of environmental architecture.

The need to support BPE is clearly evidenced, both in terms of legislation, but also capacity and skills in the construction industry. The studies have met, and also stimulated, an increasing demand for BPE in the construction industry in Scotland. In many aspects this research and innovation is leading the UK.

Figures' captions

Fig. 8.1 A Progressive building design/construction model (Bros-Williamson 2012)

Fig. 8.2 Innovative communication methods (Menon et al. 2010)

Fig. 8.3 Excerpt from a 'Quick-Start' guide (Sharpe and Bridgestock 2011)

Fig. 8.4 Graph showing the Glaser method results against in-situ results (Bros-Williamson 2012b)

Fig. 8.5 Test installation of Icynene (Bennadji and Levie 2012)

Fig. 8.6. Thermographic Imaging, Plummerswood Active House (Photo S. Haliday, W. Butler)

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