POST OCCUPANCY EVALUATION (POE): A BREEAM EXCELLENT CASE STUDY

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Despite many challenges, building industry stakeholders of the early 21st century could be viewed by future generations as pioneers for sustainable development and construction. That is, this industrial chapter may be remembered as one in which the demand for heat and power in buildings and associated carbon emissions ceased to be on an upward trajectory. In addition to the concept of a low carbon, low energy built environment, this period may also be acknowledged as one in which the comfort, health and wellbeing of building occupants is fully included. This honourable legacy is arguably within reach due to clearly-stated national and international policies on climate change, energy consumption, safety and end-user comfort. Post-occupancy evaluation (POE) is an important mechanism for the construction industry to objectively measure building performance against policy targets. A function of POE is to capture the value of 'in-use' demand in comparison with theoretical performance. The information gathered can be collated to underline performance outcomes in building energy usage, carbon emissions, wider environmental impacts and end-user satisfaction, thus providing (1) a benchmark for building operation and (2) a route map for future developments and initiatives. This paper draws upon a case study to explore the value of POE of a BREEAM Excellent building. Opened in 2011, the five year occupancy timescale will disclose key performance data. Findings from the POE study will be drawn upon to investigate potential performance gaps that may exist between BREEAM model predictions and actual results for three key parameters: 1) energy (electricity and gas), 2) water (supply and waste) and 3) social performance (comfort, health and wellbeing). Whilst the design of low carbon, low energy buildings is commendable, recording and interpreting actual building performance is a fundamental step in the continuous improvement of sustainable construction outcomes.

Keywords: sustainability, BREEAM, post-occupancy evaluation

INTRODUCTION

"Post-Occupancy Evaluation (POE) is a structured process of evaluating the performance of a building after it has been built and occupied" (Menezes *et al*., 2012 p.357). For many years there has been considerable debate on the performance of buildings, both domestic and non-domestic especially when comparing design performance versus operational performance. Industry critics have long suspected that building performance in operation most notably in the area of energy consumption has consistently failed to meet predicted outcomes. In the wake of the Innovate UK publication 'Building Performance Evaluation Programme: Findings

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from non-domestic projects (2016), the reality of this ‘performance gap’ has been laid bare. Reviewing the apparent scale of the problem (Knutt, 2016), the ‘performance gap’ challenge facing UK construction is likely to occupy the minds of industry stakeholders for the foreseeable future.

Given the findings published by Innovate UK (2016), the role and future significance of POE has undoubtedly increased. Actual building performance clearly requires to be evaluated against predicted design benchmarks; only through a process of in-use evaluation can lessons be learned that can inform future design. This is the first step in continuous performance improvement towards the goal of a low carbon, low energy built environment. According to Atkins and Emmanuel (2014 p.12), the dual benefits of a robust POE protocol is; first it provides a mechanism to improve energy use and end-user comfort and secondly, understanding gained through POE experience will contribute to "the development of improved standard assessment methodologies". This necessity for POE refinement is arguably a reflection of a nascent practice.

The realization that many newly certified low carbon, low energy buildings significantly exceed their pre-occupied design estimates is sobering, raising numerous questions about design, construction and operability. The problem is undoubtedly complex. In addition to any disparity between the original building design and predicted energy consumption / performance (fabric performance) there is also the question of economics (industry profitability) and social desire (market enthusiasm) for low carbon low energy buildings. Whilst the focus of this research is POE of a BREEAM excellent facility and the building performance after a five year occupancy period, other ‘dimensions’ of the performance gap equation require to be acknowledged (Tierney and Tennant, 2015). Indeed, future discussion of POE and by extension building performance strategy will in all likelihood blur the lines between energy consumption, industry accountability and wider societal attitudes towards a low carbon low energy built environment.

The paper is presented in a standard format. Following a brief synopsis of POE, the BREEAM model is reviewed and the research case study outlined. Thereafter findings and analysis from the POE study will be drawn upon to investigate potential performance gaps that may exist between as-designed model predictions and actual results for three key parameters: 1) energy (electricity and gas), 2) water (supply and waste) and 3) social performance (comfort, health and wellbeing). The discussion explores pre-occupied certification with actual performance outcomes and discloses potential challenges in achieving meaningful and comparable evaluations. In contrast to the pessimistic overtones associated with recent findings (see Innovate UK, 2016), it is suggested that recording and understanding actual building performance is a positive and fundamental step in the continuous improvement of a sustainable construction strategy. The paper concludes with some reflections.

BUILDING PERFORMANCE EVALUATION

Objectively measuring the quality of the construction process has been enshrined in the building practice(s) of many countries for centuries. For example, rule 229 of 282 in the Code of Hammurabi in ancient Mesopotamia is around 3700 years old and included the following declaration addressing issues of structural integrity; “if a builder build a house for a man and do not make its construction firm and the house which he has built shall collapse and cause the death of the owner of the house, that builder shall be put to death (taken from Prince, 1904 p.607). Whilst the ‘event’ and ‘consequence’ in this building code is extreme, the inference that builders retain accountability for a period after handover for the services and products they offer is arguably pertinent.

As European cities developed in both size and scale in the middle ages and problems associated with access, land encroachment, fire safety and, of course, structural integrity started to emerge for civic authorities, building standards evolved accordingly. In addition to progressive and increasingly prescriptive ‘Technical Standards’, interest in the systematic evaluation of building performance as a discrete practice has its origins in the 1960’s (BSRIA, 2011). Whilst early interpretations of building performance largely overlooked in-use energy consumption, occupant feedback and empirical evidence of operational efficiency, management systems for improved analysis and mechanisms for meaningful feedback began to develop. In 1975, the Post Occupancy Review of Buildings and their Engineering (PROBE) studies represented a significant development in building performance understanding and arguably remains an industry yardstick for subsequent performance studies of multiple building types (BSRIA, 2011).

To date, the most significant aspect of building performance evaluation is in the area of sustainability. In 1990 the UK government published ‘This Common Inheritance, Britain’s Environmental Strategy’ (DOE), which set out for the first time UK Government policy to address environmental concerns. A key driver has been the UK Government’s commitment to reduce carbon dioxide emissions by 80% by 2050 when compared with 1990 levels (Menezes *et al*., 2012). Coincidentally, in 1990 the Building Research Establishment published its first Environmental Assessment Method (BREEAM). Since first launched, BREEAM has continued to grow in popularity and it is estimated to have been used to evaluate and certify the environmental performance of more than 540,800 buildings in over 75 countries (BREEAM, 2016). For many construction professionals, BREEAM is now a familiar design and construction environmental assessment tool (Schweber and Haroglu, 2014).

More recently, the UK Government introduced an initiative called ‘soft landings’. With its origins in the PROBE studies (BSRIA, 2011) which date back to 1975, soft landings is focused on the notion of 'building aftercare’ with the objective to promote designers, contractors and service engineers help new clients understand how their building(s) operate and maximize the efficiency of the building management systems in place. Although beyond the scope of this case study, Government Soft Landings (GSL) is a pillar of BIM level 2 adoption (Adams, 2016) and an important component of an embryonic and overarching building performance evaluation strategy.

BREEAM ACCREDITATION

BREEAM is a credit-based environmental assessment system addressing key categories of a building specification: energy use, health and wellbeing, innovation, land use and ecology, materials, management, pollution, transport, waste and water. A building design is assessed against the maximum number of credits available in each category and rated accordingly. An overall percentage score is awarded and a BREEAM rating of 'unclassified' (<25%), 'pass' (≥25 - <40%), 'good' (≥40 - <55%), 'very good' (≥55 - <70%) or 'excellent' (≥70%) can then be applied. It should be noted that these figures are for BREEAM Bespoke 2006. A further summary classification of 'outstanding' (≥85%) is now awarded in BREEAM but was not part of the BREEAM Bespoke 2006 procedure and the requirements for 'pass' and 'good' are now ≥30 - <45% and ≥45 - <55% respectively.

For this POE case study, BREEAM Bespoke 2006 was used to evaluate energy and transport combined, materials and waste combined, health and wellbeing, land use and ecology, management, pollution and water. The overall percentage awarded in February 2008 was 71.38%. This environmental evaluation (≥70%) equated to a BREEAM rating of 'excellent'. The aim of this case study is to review the pre-occupancy predictions made for energy, water management and health and wellbeing at the 5-year post-occupancy juncture. Three key categories of the BREEAM Excellent rating from February 2008 have been selected for PO analysis in 2016: (1) energy use and associated carbon emissions; (2) water usage and the pollution aspects associated with site surface water and flood risk reduction and (3) health and wellbeing of building users. Note, the criteria for credits awarded in 2016 (five year POE) relate to evaluation guidelines set out in BREEAM Bespoke 2006.

RESEARCH STRATEGY

The objective of this POE case study of a BREEAM Excellent facility is to add to the body of work reviewing the performance of pre-occupied certified sustainable building projects. The primary research data is taken from energy meters located onsite and accessed via a central data base. This is augmented by secondary data including a literature review of recent publications including research articles, books and magazine editorials. Anecdotal evidence from meetings with in-house Facilities Management (FM) personnel is also drawn upon to support findings and discussion.

There are two related research questions. First, do the case study findings correlate design intention with post-construction reality in terms of energy use, site water management, including flood risk reduction and occupant health and wellbeing (satisfaction)? And, second, if there is any discrepancy between the predicted and actual performance is this because (a) the prediction methodology was flawed, (b) the construction process was unsatisfactory or (c) a combination of both?

The case study is a POE of a BREEAM Bespoke 2006 'Excellent' award made in February 2008 for a university campus building located in South-West Scotland. Building use, occupancy and resources is shared by two higher education institutions. The original outline business case (OBC) for the shared campus began in 2006 with funding approved in 2007. The construction phase commenced in October 2008 with handover in May 2011. In 2012, the building received the Green Gown Award: Modernization - effectiveness and efficiency in the estate. This award recognizes enhanced sustainability without compromising core business objective of 'value for money'. BRE was commissioned to undertake a POE - operational review, this was initially scheduled to take place within 3 - 6 months of handover however due to funding delays, the timeframe slipped to 12 months.

The research is site-specific in its analysis, but anticipated that outcomes can inform industry-wide understanding of post-occupancy building performance. There are a number of limitations and assumptions. A case study is unique and may have contextual constraints that inhibit like for like comparison (Leaman *et al*., 2010). To mitigate potential differences, the POE draws on performance criteria used at the design stage and set out in BREEAM bespoke 2006. In addition, definition and measurement of building performance may also be contested. Any deviations in performance measurement may skew final interpretations. Despite these caveats, performance measurement is an important starting point and whilst industry-wide generalizations come with a ‘health warning’, assimilation with recent publications (see Innovate UK, 2016) provides a valuable, interesting and ongoing contribution to the 'performance gap' conversation.

RESULTS, ANALYSIS AND DISCUSSION

(1) Primary energy demand and reduction of CO2 emissions (Credit E1)

The results disclose a key post occupancy adjustment. A notable outcome of the POE is the reduction of 2 credits (7 credits in 2016) for E1 (Reduction of CO2 emissions). For this case study, the original award of 9 credits in 2008 implied an 18% improvement over and above the building regulations (2006) requirement of a minimum 23% improvement on the notional Building Emission Rate (BER) value (119 kg CO_2/m^2) for naturally ventilated office buildings. In other words, a 41% (18% + 23%) improvement on 119 kg CO_2/m^2, this equates to 70 kg CO_2/m^2. The case study gross floor area is 18000 m^2, which equates to an as-designed annual CO2 emissions rate for the facility equal to 1260000 kg CO2. The framework for comparative credit awards to be made in 2016 based upon actual energy usage data from the metering records for the facility is shown in Table 1.

Table 1: Case study year-5 credit assessment for Energy

BREEAM reference	Credits available in BREEAM Bespoke 2006	Credits awarded in BREEAM Bespoke 2006	POE survey credits awarded 2016 (change)
E1 Reduction of CO2 emissions	15	9	7 (-2)
E2 Sub-metering of substantial energy uses	1	1	1 (0)
E3 Sub-metering of areas / tenancy	1	0	0 (0)
E4 External lighting	1	1	1 (0)
E21 Energy efficient fume cupboards	1	1	1 (0)
E (Eco) 4 Provision of energy efficient white goods - fridges / freezers	1	1	1 (0)

To facilitate predicted versus actual energy performance, annual energy consumption for 2011-12 reveals that 1903 MWh (gas), 1924 MWh (electricity) and 1959 MWh (biofuel) were used. The total actual Building Emissions Rate (BER) for 2011-12 was 68kg CO_2/m^2 (<70 kg CO_2/m^2). In 2012, the two biofuel boilers were replaced by gas boilers. This was a decision based primarily on economics although it was noted that the burners proved to be less reliable than previously expected. Given the excessive price of biodiesel in comparison with fossil fuel (gas) coupled with poor reliability, it became financially problematical to justify the operation of an alternative low carbon energy source. Subsequent meter readings for 2014-15 were 2979 MWh (gas) and 1910 MWh (electricity), which means that the total actual Building Emissions Rate (BER) for 2014-15 increased to 77kg CO_2/m^2 (>70 kg CO_2/m^2).

From the figures, the predicted BER in June 2007 can be seen to have been very accurate and, if anything, slightly cautious on energy consumption when gas, electricity and biofuel were all used in 2011-12. The nine credits awarded in BREEAM category E1 are therefore valid at that point in time. The removal of the biofuel from the heating and hot water strategy meant that the actual BER in 2014-15 increased to 77kgCO_2/m^2 from the predicted 70kg CO_2/m^2, this means that the nine credits awarded would be seven retrospectively. The loss of two credits in the E1 category has the effect of reducing the overall BREEAM rating from 71.38% to

69.96%. The overall BREEAM rating would be compounded further with the replacement of the biofuel boilers, resulting in the loss of a further three credits in the Pollution section (P11 category). The loss of three P11 credits means that the overall BREEAM rating for the POE 2016 reduces from 71.38% to 67.15% and therefore downgrading the facility from BREEAM 'Excellent' to BREEAM 'Very Good'.

Despite the apparent re-classification, it is important to note that the inferred carbon emissions target of 70kgCO2/m² per year is a specific targeted improvement on the 'notional' building emissions rate (BER) of 119kgCO2/m² for a naturally ventilated office building as per case study documentation dated June 2007. Given the case study building is only partially naturally ventilated, the BER for mixed mode ventilation (natural and mechanical) is likely to be higher than the documented 119kgCO2/m².

Important prescriptive aspects of BREEAM Bespoke 2006

This section of the POE explores BREEAM credits awarded largely on the basis of a building specification checklist. In contrast to the potential variance in performance frequently associated with energy demand and CO2 emissions, there are key aspects of building design and construction where the POE is relatively constant. Key aspects selected for discussion are; (2) Water and Pollution categories: minimising flood risk (P7), renewable and low emission energy technology (P11), potable water consumption (W1); and, (3) Health and Wellbeing category: day lighting and window views to outside (HW1 and HW2), artificial lighting (HW3 - HW7), internal air pollution (HW9) and ventilation rates (HW11).

(2) Water (building water usage, surface water run-off and flood risk)

Three credits were awarded for the design approach to surface water run-off and flood risk in the campus environment (P7). The importance of this aspect of a sustainable built environment has become very well known to many communities in the UK in recent years. The strategy for this building design was to take all the rainfall from the estate surfaces including car parks and other hard landscaping to a sustainable urban drainage system (SUDS) pond, which has an attenuation capacity of approximately 4000 cubic metres. The POE survey has noted that the SUDS pond has worked effectively as a flood risk reduction feature both at the site and by mitigating any additional pressure to the local sewer pipe work on heavy rainfall days.

The BREEAM category that aims to minimise the consumption of potable water (W1) in buildings awards up to three credits for compliance. In this case study, two credits were awarded for specifying dual flush WCs to reduce flush volumes from 6 litres (full flush) to four litres (partial flush) and, secondly, for specifying waterless urinals. Aspects of W1 that were not specified in the case study included electronic sensor, spray or aerating taps or timed push taps. Interestingly, the last of these (timed push taps) are installed in many locations throughout the building. The framework for comparative awards to be made for water management and pollution risks in the year-5 POE in 2016 is shown in Table 2.

Table 2: Case study year-5 credit assessment for Water and Pollution

BREEAM reference	Credits available in BREEAM Bespoke 2006	Credits awarded in BREEAM Bespoke 2006	POE credits awarded 2016 (change)
W1 Water consumption	3	2	2 (0)
W2 Water meter	1	1	1 (0)
W3 Major leak detection	1	1	1 (0)
W4 Sanitary supply shut off	1	1	1 (0)
W5 Water recycling	1	0	0 (0)
W6 Irrigation systems	1	1	1 (0)
P7 Flood risk / water run off	3	3	3 (0)
P8 Minimising water course pollution	1	1	1 (0)
P11 Renewable and Low Emission Energy	3	3	0 (-3)

(3) Health and wellbeing of building users (occupant comfort, safety and satisfaction)

The Health and Wellbeing section of BREEAM Bespoke 2006 applied more categories than any other in this case study (18 in total) and clearly signals that the comfort and health of building occupants is a significant consideration for a BREEAM sustainable building design (and construction) audit. BREEAM reference HW1, HW2-7, HW9 and HW11 have been highlighted here for their general importance to building occupant well-being and because of specific interesting observations made during the POE case study.

HW1 awards one credit where at least 80% of the occupied building floor area has adequate daylight provision (glazing area being the key influence), aiming at an average daylight factor (DF) of 2%, measured as the ratio of internal to external illuminance, expressed as a percentage. The DF of 2% is not an onerous minimum requirement and most commentaries emphasise the potential gain in health and wellbeing. In this POE of a BREEAM Excellent building, the credit was not awarded. The initial evaluation included an observational survey of the staff offices and found it necessary for the artificial lighting to be on for most days during the observational period.

This category of the POE focuses upon the award of credits for the expected health and wellbeing of building occupants. The year-5 case study addresses these matters by determining the credits achieved in an observational verification survey in 2016 (see Table 3). A summary point of this survey finding is as follows: the atrium and south façade offices and classrooms are very well served by natural daylight but the north façade and courtyard orientated offices are not. The primary reason for this is the importance placed upon the super-insulated wall fabric, which inevitably reduces the glazing surface areas.

HW2 awards one credit for the provision of a view to the outside for all occupants. This was not used in all parts of the building assessment, but the credit was awarded where applicable and was verified in the POE observational survey work. HW3-7 are all associated with credits to be awarded for visual comfort in the building and all of these were awarded: glare control from internal or external blinds (HW3), high frequency fluorescent lighting to avoid a flickering perception that can be evident with low frequency fluorescent light fittings (HW4), appropriate illuminance (lux) levels for all parts of the building (inside and outside) (HW5), the provision of separate lighting zones to allow variation control in the building (HW6) and switching arrangements that allow easy light settings control (HW7).

Table 3: Case study year-5 credit assessment for Health and Wellbeing

BREEAM reference	Credits available in BREEAM Bespoke 2006	Credits awarded in BREEAM Bespoke 2006	POE credits awarded 2016 (change)
HW1 Daylighting	1	0	0 (0)
HW2 View out	1	1	1 (0)
HW3 Glare control	1	1	1 (0)
HW4 High frequency lighting	1	1	1 (0)
HW5 Internal and external lighting levels	1	1	1 (0)
HW6 Lighting zones	1	1	1 (0)
HW7 Lighting controls	1	1	1 (0)
HW8 Potential for natural ventilation	1	0	0 (0)
HW9 Internal air pollution	1	0	1 (+1)
HW11 Ventilation rates	1	0	1 (+1)
HW14 Thermal comfort	1	1	1 (0)
HW15 Thermal zoning	1	0	0 (0)
HW16 Microbial contamination	1	1	1 (0)
HW17 Acoustic performance (ambient noise levels)	1	0	0 (0)
HW17 Acoustic performance (room reverberation time)	1	1	1 (0)
HW19 Safer parking	1	1	1 (0)
HW25 Laboratory fume cupboards	2	2	2 (0)
HW26 Containment Level 2 & 3 laboratory areas	3	2	2 (0)

The risk of internal air pollution is assessed in HW9 and refers to the location of fresh air intakes in the ventilation system and specifically that they must be away from sources of external air pollution such as car parks and roads. In the BREEAM analysis carried out in 2007, this credit is not awarded, but this position is certainly worth reviewing given the car park and roadways around the campus building are substantially more than the required 20m distance from openable windows and ventilation system intakes. Also worth reviewing is the credit considered in HW11 for providing minimum building ventilation rates. In spite of being a mandatory building control requirement, the credit was not awarded in 2007. The reason being, that HW11 is directly linked to HW8, which requires all external façade windows to be openable. The case study building has some external windows that do not open and perhaps, therefore, suffers an unfair 'double jeopardy' penalty. Two extra HW credits would take the overall BREEAM rating from 67.15% to 69.38%, which is very close to the 2007 BREEAM 'Excellent' rating.

POE: Benchmarking performance

The POE results for this case study are essentially positive and therefore contrast recent findings in the Innovate UK report (2016). However, reservations remain regarding the operational ease of PO measurements of building performance and their frequency. Many of the POE credits awarded adhere to a checklist of design and built requirements as opposed to 'actual' building performance. Indeed, the calculation of BER was one of the few areas where actual building performance in terms of energy consumption was measured against as-designed calculations. Reviewing this case study, it is very important to highlight the definite need to connect initial design aspirations with a range of post-occupancy building performance analyses.

Drawing on both Menezes *et al*., (2012) and Atkins and Emmanuel (2014) there is a requirement for environmental performance modelling to be objectively verified for accuracy and for POE to be interpreted as a process, not just an event. There are arguably two rational approaches to building performance measurement; a prescriptive based approach or alternatively a performance based approach. The prescriptive based approach, not dissimilar to the assessment discipline adopted by BREEAM would set out clear guidelines which if satisfied would support the award / rating of an environmental performance. Alternatively, a performance based approach could be adopted where resultant performance standards are established but crucially no recommended route to achieving these standards is specified. A performance based approach would also ratify the idea of staged ‘environmental’ building classification. At design / handover (year zero) a ‘predicted’ award would be made, at handover plus one year (year zero + 1) a ‘provisional’ award would be made based on a 12 month POE and at three years (year zero + 3) a 'full' award would be presented. Throughout the design, build, operate process, the environmental classification may alter dependent upon actual, post-occupancy performance outcomes.

Adoption of a performance based and staged approach (predicted / provisional / full award) for the environmental classification of buildings would also endorse the notion of mandatory post occupancy evaluation. Although not a new concept (Heffernan *et al*., 2012), in the UK objective post occupancy evaluation of actual energy efficiency remains a largely unorthodox practice. Given Government targets for CO2 reductions, the measurement and evaluation of actual energy consumption needs to become a cornerstone of a viable and sustainable low carbon, low energy construction strategy.

CONCLUSIONS

POE in building design, construction and operation is fundamental. Without objective review, analysis and comparison between predicted and actual performance future opportunities for improvement in building design, construction and operability may be missed. Repeated industry inability to capture and reflect on 'live' data sets may inadvertently facilitate ongoing sub-standard performance.

This case study makes two notable contributions to the performance gap debate. First, currency, the positive case study PO findings are in contrast to the negative tone reflected in the recent Innovate UK report (Innovate UK, 2016). Second, the analysis and discussion highlight common tensions between finance, efficiency and low carbon design solutions. Given the many challenges associated with POE and achieving meaningful comparison it is suggested that a prescriptive model of assessment is overly cumbersome. Future debate should not only focus on the performance gap per se; the validity, protocol and ease for environmental modelling should also be explored. In addition, case study findings and analysis support the idea that POE needs to become a mandatory element for every new construction project (domestic and non-domestic) if UK carbon emissions reduction targets set by the Energy Performance of Buildings Directive (EPBD) (OJEU, 2010) are to be realised.

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