SYMPOSIUM: BUILDING PERFORMANCE LIVE! (3 papers)

Embedding Post-Occupancy Evaluation into Architectural Education: from Specialism to Mainstream

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Introduction

This paper describes a unique student-centred teaching and learning approach adopted in a flagship postgraduate taught (PGT) module entitled 'post-occupancy evaluation (POE) of buildings' run at Oxford Brookes University for over 10 years. The paper also explores ways by which a light-touch version of the POE module can be embedded into undergraduate teaching and MArch studios, to engage students with actual performance of buildings in-use from a socio-technical perspective so as to reduce the gap between design specifications and actual outcomes.

Why building performance matters?

The beginning of the 21st century was heralded by a significant body of evidence indicating the importance, and urgency of acting upon climate change and reducing CO_2 emissions at a global scale[i]. The building sector has been identified to play a key role in the carbon reduction challenge as energy use in buildings accounts for approximately a third of global CO_2 emissions, while in developed countries such as UK, the proportion is even higher, rising to nearly 50%. This is why rapid and step change improvements in the sustainability of buildings are needed, both for new-build and existing building stock. Building designers are therefore increasingly required (by legislation) to deliver buildings which maintain comfort while reducing their dependence on fossil fuels to provide energy services. However research into building performance has revealed that even the best buildings (domestic and non-domestic) often fail to perform as anticipated[ii iii]. Often the causes of this performance gap between design expectations and actual performance are due to complex interactions between building fabric, mechanical services and the behaviours of occupants which occur throughout the design, construction and use of a building.

This growing need to evaluate the in-use performance of (low energy) buildings has led to the evolution of Post Occupancy Evaluation (POE), a process that historically takes place after the building completion, as a diagnostic assessment of the building's actual performance. Technically POE is defined as systematic collection and evaluation of information related to energy use, environmental conditions, fabric performance and occupant feedback, so as to fine-tune the building and inform future practices. POE is also called building performance evaluation (BPE) when undertaken at any stage of a building's life cycle.

The first round of practical research into building performance evaluation was conducted in the 1990s with the PROBE (Post Occupancy Review of Buildings and their Engineering) studies contracted by the Department of the Environment[ii]. Since then, the Carbon Trust has run a research project on Low Carbon Building Performance in the noughties, while the Technology Strategy Board (TSB) is just coming to the end of an £8 million national research programme on building performance evaluation. Although findings from all these research efforts have exposed the performance gap, these studies have also highlighted the importance of creating feedback loops for architects and engineers to understand consequences of their design decisions on actual performance and avoid repetitive errors in the design of buildings.

It is within this context that over the last 10 years, a flagship POE module has been developed and taught (by the author) as part of a specialist MSc programme in Sustainable Building to postgraduate architecture students at Oxford Brookes University[iv]. The module aims to equip future architects with the knowledge and skills to not only understand and evaluate building performance but also design buildings that perform as intended. The student-centred 'learning-by-doing' teaching and learning approach of the module is based on experiential learning principles. It allows students to undertake rigorous real-world research and also develop deeper understanding of in-use energy and environmental performance of buildings, cross-related with occupant satisfaction, perception and interaction; and how these elements affect overall building performance.

Overview of the POE module

Typically the POE module runs in semester 1 over 12 weeks (and more recently 8 weeks) and is delivered through 12 sessions of 3 hours (36 hours contact time and 20 credits), combining lectures and seminars with the POE investigation of a real case study building (domestic or non-domestic) to understand the cause and effect of both hard and soft issues on building performance. Students in groups of three or four conduct POE of a building, thereby developing skills in team-work and collaboration. The strategic questions addressed by the module include:
-*How is the building working*(from multiple perspectives)?
-*Is this what was intended* (as per design intent and client brief)?
-*How can it be improved* (for the building)?
-*What can we learn from it* (more generally)?

Like the PROBE studies, the methodology of the module (as shown in figure 1) involves a *systematic energy assessment* of the building using metered data combined with forensic energy (walk around) surveys; *continuous physical monitoring of environmental conditions* (indoor temperature, relative humidity, lighting and CO_2 levels) as well as gaining quantitative and qualitative *feedback from occupants* on their satisfaction, perception and interactions with the building. User feedback also provides deeper insight into patterns of building use and its effect on energy use, something usually overlooked by design-level assessments and simulations. Data collected can include measured information such as energy use, temperatures, lighting levels, acoustic performance and survey data from the perspective of the occupants regarding issues such as comfort, aesthetics, occupant satisfaction, management and usability of controls. Such an assessment of building performance, from both a technical and social perspective, brings real world experience and knowledge to architecture students, and allows them to learn from the experiences of real occupants in real buildings.

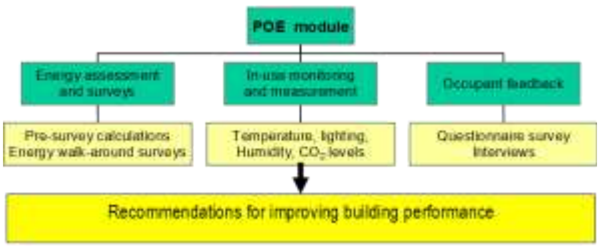

Fig. 1. Key study elements of the POE module

Recommendations are suggested by the students to improve the case study building performance in terms of its energy and environmental impact and occupant satisfaction; these are often sub-divided into no-cost, low, medium and high cost measures for ease of implementation along with an indication of their simple payback periods and life-cycle costs. Wider lessons are also drawn for future building design, specification and performance.

To engage with the various stakeholders especially those who designed and built the building as well as the client, occupants and operators; findings from the POE studies are presented through multiple disseminations routes which include: *oral presentations* by each group to which building designers, owners, operators and users are invited; and written *reports* that capture the POE methodology, findings and strategic conclusions from individual results. These outputs not only provide feedback to the stakeholders but also test the oral and written communication skills of the students, and also provide them with a *mini-dissertation* report that becomes a key component of the postgraduate portfolio.

Study Elements of the POE Module

Before any POE study is undertaken, fundamental information about the case study building (related to building type, size, drawings, and energy use by fuel as shown in Table 1) is gathered by the tutor in co-operation with the building designer or owner. This is called as *initial screening* and helps to address the question *whether the building is worth bothering?*

Assess size/ type of site Single building Multi-building Multi-site	**Building use**
Building drawings Floor areas (gross/ net) Serviced / unserviced areas Building form & orientation	**Occupied hours**
Building Location Local weather conditions: degree days Surrounding environmental features Local infrastructure	**Energy/fuel data** At least 1 year data from fuel bills(actual) or meter readings or energy monitoring system

Fig. 2. Initial screening: data required before POE is undertaken

Availability of this information is almost a pre-requisite for any POE study and it reduces student time spent in gathering background information, although the availability of good-quality information about buildings is raised with students through seminars. Initial assessment of the background building information also helps students to address questions such as: *What have we got? What does it mean? And what can we learn from it?* Addressing these questions progressively builds student understanding of building performance. *The study elements of the POE module* are based on the principle that we need the stories as well as the data to know not just the 'what', but the 'why' and the 'how' of building performance[v]*, as explained below:*

Energy assessment and energy survey

A key aspect of understanding building performance is to assess and benchmark energy use of the case study buildings (*energy audit*), followed by a detailed *energy survey*. Whilst the *energy audit* establishes the quantity and cost of each form of energy input to a building, *energy survey* involves site investigation to assess the end uses of energy (such as lighting, appliances and equipment) including any on-site generation, to understand where and how this energy is used in the building[vi]. A desktop-based analysis is conducted to compare the building energy use and generation (by fuel type) with industry benchmarks (and respective peers), using area-weighted metrics of annual energy use (kWh/m^2/year) and CO_2 emissions (kgCO_2/m^2/year). This initial comparison of energy use helps students to understand the overall energy performance of the case study buildings and identifies priority areas for action and improvement. Comparison of energy use of similar types of case study buildings (e.g. schools located in the same city) prompts students to investigate the reasons for the significant variation in energy use of these buildings, designed to similar sustainability standards (Figure 3).

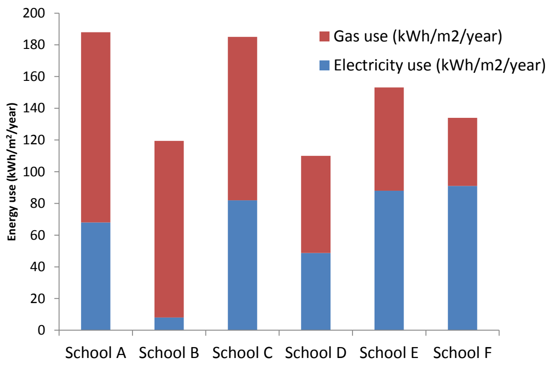

Fig. 3.Comparison of energy use of sustainable schools in London

To determine how energy use of a building is related to weather, degree-days are used as a measure of the variation of outside temperature. In the UK, heating degree-days which quantify the severity and duration of cold weather are used; the colder the weather in a given month, the higher the degree-day value. Degree-days are used to understand seasonal variations of the space heating system by plotting energy use data against degree-days to identify time periods when the building is not performing in the predicted manner. A regression analysis is done to determine how responsive the heating system is to changes in outside temperature. This helps to reveal overall trends in energy performance.

This is followed by an on-site survey of energy end uses (*Energy Survey*) drawing from the established CIBSE TM22 methodology[vii], which involves measurement, analysis or direct assessment of energy use to indicate proportions attributable to heating, lighting, cooling etc. By conducting an *energy survey*, the student is able to relate and understand where energy is being used and/or wasted in the building, and identify opportunities for energy savings. A survey does not necessarily cover all energy uses, but the principal sectors are usually included, which are: space heating- boiler plant & hot water system; air conditioning and ventilation; electrical lighting; as well as equipment and appliances. For example, during the lighting audit of school buildings, excessive usage of electrical lights was discovered during the weekdays and even weekends, despite good daylight levels due to complex controls. The design lighting load was also found to be over specified resulting in excessive electricity consumption.

Physical monitoring of environmental conditions

To gain a deeper understanding of comfort and indoor air quality in the building, students physically monitor the buildings using data loggers such as hobos, i-buttons and lux-meters, so as to measure and record internal and external temperature and relative humidity; indoor lighting and CO_2 levels at regular intervals (15 minutes or 30 minutes) over 4-8 weeks. For instance when studying typical community centre buildings in Oxford, it was found that internal temperatures in almost all buildings were inconsistent, with some spaces as cold as 17^{o}C whilst others heated to over 25^{o}C. Considerable savings were achieved by zone controls and re-adjusting the demand temperature as per external temperature, occupation density and the type of activity happening in a particular space.

Occupant feedback

This physical monitoring data is cross-related with quantitative social science data gathered through *occupant satisfaction survey* and *qualitative semi-structured interviews* of the building manager, owner and occupants, supplemented by occupant *thermal comfort diaries*, to understand the *why* and the *how* of building performance. Over the last five years, the module has been able to use the domestic and non-domestic version of the industry standard Building Use Survey (BUS) questionnaire which assesses occupants' reported levels of comfort and satisfaction with the dwellings design and internal conditions (summer and winter), and also evaluates the degree to which occupants perceive their needs are being met by the building. The results are compared against a rolling BUS benchmark of 50 buildings. Since 2009, about 470 respondents have completed BUS survey across 33 buildings evaluated in the POE module. This level of objective feedback on occupants' perception contextualises the performance of the building from occupants' perspective.

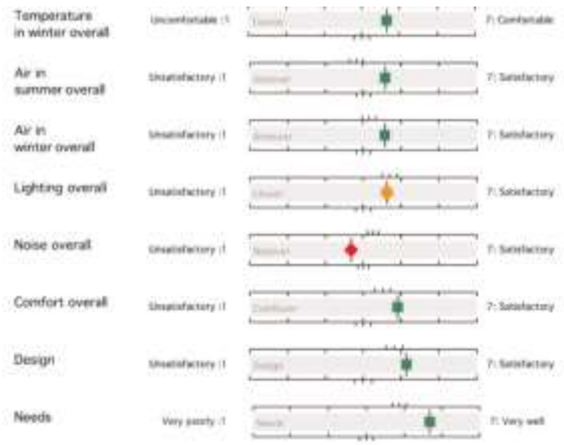

Fig. 4. BUS summary results from 35 respondents of a relatively new University building (BUS survey undertaken in 2011)

Case Studies

The POE module also provides a platform for collaboration between academia, practice and policy-making to foster evidence-based sustainable building design and performance. Over the last 10 years 80 domestic and non-domestic buildings across the UK have been evaluated, covering a whole range of building types as shown in figure 5. Dwellings and civic buildings form half the total number of buildings, followed by University and School buildings.

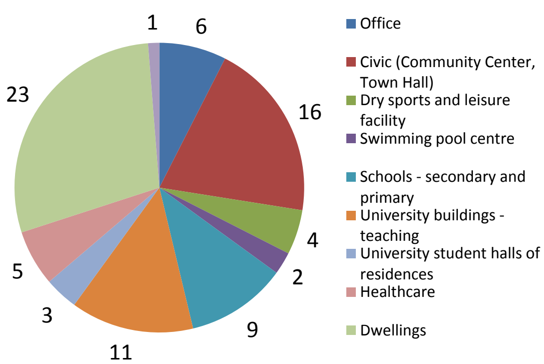

Fig. 5. Breakdown of building types evaluated in the POE module

While half the buildings were designed using sustainability standards by reputed architectural practices (Penoyre and Prasad LLP, PRP Architects, Ridge), the other half represent conventional buildings owned by the University and local authority (Oxford City Council). So far 15 sustainable school and healthcare buildings designed by Penoyre and Prasad, and five housing projects designed by PRP architects have been evaluated. Strategic findings from the studies have been fed back to the design teams, through student-led workshops and seminars run at the architectural practices.

Findings from 19 POE studies of local authority-owned community, leisure and sports facilities showed that potentially about 30% of CO_2 emissions could be reduced cost-effectively using a combination of 'no-cost' (good house-keeping) and 'low-cost' measures (better controls, energy management), whilst above 50% emissions were technically-possible by upgrading the building fabric. Some of the measures proposed by the POE studies were adopted in the refurbishment of these buildings.

In recent years students have studied the performance of 14 University buildings on their own University campus, which has led to: introduction of building level metering and sub-metering; adjustments to demand temperatures depending up the type of activity taking place; as well as informed future briefing, design and specification of new University buildings. This has meant that the University campus is being used as a teaching and learning tool as part of a wider aim of developing a University Living Lab.

Linking POE with Design Studio Teaching

Knowledge gained from the POE module can help to inform the design briefs of the design studio projects through learning gained from the direct experience of studying buildings in-use. This is why the POE module runs in semester 1 before the design studio (semester 2), so that students can systemically study similar buildings (to what they are going to design in the following semester) and transfer the learning from POE into their design projects. Seeing for themselves the consequences of design interventions through a forensic lens (and from occupants' perspective) tends to open students' minds to the relationship between design and performance.

This is also in line with the feedback loop promoted by Bordass[viii] (Fig 6), wherein POE feedback can be collected at any stage in the life cycle of a building.

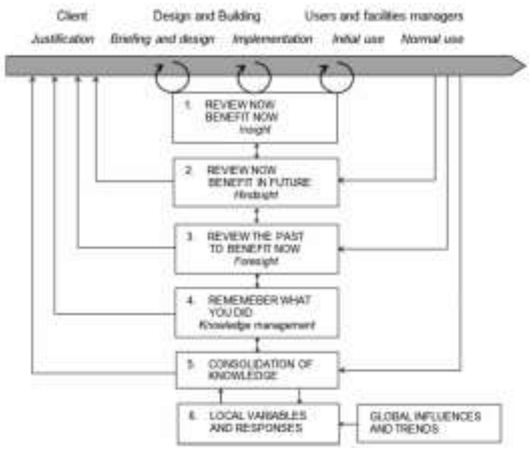

Fig. 6. Layers of feedback in relation to building life-cycle

The POE module falls into the *foresight* category wherein feedback is collected by studying the existing situation and analogues (POE module) before a new building design is done (Design studio). As a result of exposure to POE, some students even develop *insight* during their design project by reality checking and managing expectations of the building users and stakeholders. The POE module itself provides *hindsight* to the case study buildings through learning and fine tuning.

This linkage of POE with design teaching helps students to link consequences of design decisions and specifications with actual outcomes. Students also realise the significance of setting operational performance as design targets to encourage effective collaboration between architects and other consultants. In the long term, POE studies help to inculcate a culture of continuous learning amongst students to inform future projects.

Developing a Light Version of POE Module

Given the growing concern about the gap between designed and actual performance of buildings, it is vital that every architecture student and design tutor recognises the need for creating feedback loops to evaluate sustainability-related design aims of their buildings. To achieve this paradigm shift in architectural education, POE (BPE) teaching itself has to move from a niche specialist Masters programme to mainstream undergraduate and postgraduate (MArch) architectural education. For this a light-touch version of the POE module can be developed comprising of a simple *energy assessment*, *walk-around survey* and *occupant feedback survey* (using a BUS type approach), so as to engage students with actual performance of buildings in-use from a socio-technical perspective. This light-touch version of POE can either be integrated within technology teaching or run as a stand-alone *POE-lite module*.

Such an approach will also align with practice-based and live design projects that are being increasingly undertaken in both undergraduate and postgraduate studios. Students can be trained in defining design concepts which are based on operational outcomes rather than design specifications only. For instance, simple to use tools such as the RIBA-CIBSE *CarbonBuzz* platform can help students in setting up appropriate performance targets, as it compares design energy data of a range of buildings (and building types) with actual performance data disaggregated by end use.

Concluding Discussion

It is becoming clear that POE studies are a useful tool in generating the evidence and feedback needed for learning lessons from buildings in order to develop evidence-based sustainable building design solutions. Particularly for students of architecture, it also provides a valuable specialist skill in understanding and evaluating building performance, in relation to their own design and that of others. By strategically aligning the POE teaching with design studio teaching, it provides an opportunity to address the performance gap that occurs between design intent and actual reality.

POE studies of University buildings have also triggered the development of a University Living Lab initiative, which would transform the University campus as a living lab site for applied teaching and research around sustainability and low carbon development. It would also enable collaboration between students, academics, practice, and the Directorate of Estates and Facilities Management to deploy and monitor new technologies and services in real world settings.

Looking into the future, it is vital to link POE (BPE) teaching with Building Information Modelling (BIM), so that performance outcomes are embedded with design specifications through a digital environment. This also fits in within an overall *Soft Landings* framework that advocates a focus on outcomes from inception and into operation. Such experiential learning approaches will enable students to avoid inadvertent pitfalls when designing buildings.

Bordass and Leaman (2013) have called for a *new professionalism* amongst built environment professionals, which is based on a shared vision of concentrating on outcomes and developing greater knowledge about building performance in use[ix]. Direct experience and learning about building performance through POE at the undergraduate and postgraduate levels can help architecture students in embracing this ethos earlier on in their professional lives.

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