A Student-Centred POE Approach to Provide Evidence-Based Feedback on the Sustainability Performance of Buildings

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ABSTRACT: This paper describes the learning and teaching approach adopted in a postgraduate post-occupancy evaluation (POE) module run at Oxford Brookes University (Oxford, UK) to examine and assess the technical and functional performance of, and occupants' thermal comfort in, recently-built seven sustainable buildings in the UK, designed by Penoyre and Prasad architects. The case studies include a wide range of buildings covering a mix of educational, health and one housing development. Typically the POE module runs over 12 weeks (autumn semester) for post-graduate architecture students, and uses the experiential learning-by-doing approach to assess both hard and soft issues of building performance. The methodology involves an energy and environmental audit of the building as well as a thermal comfort assessment of its occupants. Finally recommendations are suggested to improve the building performance. The findings from the study provide valuable feedback to both architectural and building services firms to inform their subsequent building designs, specifications and performance. With the continuing need for new, sustainable buildings having minimal impact on the environment, it is imperative for current architectural practices to recognise the need for creating feedback loops to evaluate sustainability-related design aims of their buildings. Importantly this study provides one such opportunity to bring together both academia and industry to work towards developing evidence-based sustainable building design and performance. In this process it also educates and equips students of architecture (future architects) to learn from the design mistakes of current sustainable buildings.
Keywords: Post occupancy evaluation, sustainable buildings, carbon emissions, thermal comfort, monitoring

INTRODUCTION

Post Occupancy Evaluation (POE) studies involve systematic collection and evaluation of information about the performance of a building in use, to bridge the credibility gap between design expectations and outcomes. In the UK, the PROBE (Post Occupancy Review of Buildings and their Engineering) [1] studies established a methodology for carrying out POE and highlighted the importance of creating feedback loops for architects and design engineers, to identify opportunities and avoid repetitive errors in the design of new buildings.

Assessing the buildings' performance in use benefits not only the architects but improves the building for the occupants, and for the environment. The current stress on environmentally sustainable building design to minimise and counter the threat posed by climate change caused by greenhouse gas emissions in the environment, means that, building designers are increasingly asked to deliver buildings which maintain comfort while reducing their dependence on fossil fuels to heat and light. Therefore clients, architects, engineers and surveyors are now expected to build in accurate and effective POE of building performance in achieving real low carbon buildings-but there is uncertainty as to which methods and techniques to use.

The unique POE module at Oxford Brookes University for postgraduate architecture students addresses this need by equipping future architects with the skills and methods to conduct POE studies. The 'learning-by-doing' approach of the module based on experiential learning principles, allows students to develop a first hand knowledge of understanding occupant interaction with the buildings and how it affects the overall building performance, to inform future building designs [2,3]. It also demonstrates how the design process can positively benefit from POE.

The module has over the past five years evaluated a large number of public buildings of Oxford City Council

[3]. In the current academic year (2008), seven recently built, sustainable buildings designed by Penoyre and Prasad architects were evaluated. This provides an opportunity for both architects and academia to come together to create 'information and feedback loop' for continuous improvement of sustainability-related design aims to achieve evidence-based sustainable building design and performance.

OVERVIEW OF THE MODULE

Typically the POE module runs over 12 weeks (autumn semester) for post-graduate architecture students, and uses the experiential learning-by-doing approach to assess both hard and soft issues of building performance. Students, in groups of four or five, assess the performance of a case study building.

The methodology involves an energy and environmental audit of the building as well as a thermal comfort assessment of its occupants, supported by 'hard' quantitative data such as energy consumption data by fuel bills, measurements of internal temperature, indoor air quality (CO_2 levels) as well as lighting and humidity levels within spaces. Since occupant satisfaction with the space and usability of controls affects productivity, it is assessed through thermal comfort questionnaires. User feedback also provides an insight into patterns of building use and its effect on energy use, something usually overlooked by design-level assessments and simulations.

Finally recommendations are suggested to improve the 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.

POE case studies in 2008: building descriptions

Seven sustainable buildings were evaluated for POE in this academic semester (September-December). All buildings are designed by Penoyre and Prasad architects, UK and a few have been awarded in their respective segments. The case studies include a wide range of buildings covering a mix of educational, health and one housing development. In particular this architectural firm specialises in healthcare and educational buildings. They were awarded the Building Design (BD) 'Health building architect of the year' award in 2007 and the BD 'Education architect of the year' award in 2008. Therefore, about three healthcare projects form a part of this study, located in and around London. These projects vary in size from 2000m^2 of primary and social care services in Green Wrythe Lane centre to the largest primary care facility (9000m^2) in Britain, located in Hounslow, London. The third building- Gracefield Gardens Health Centre, Streatham, is a mid-sized facility (4000m^2) comprising of primary care and specialised units.

The study also includes three educational buildings, designed with a range of sustainable features. The 13000m^2 Minster School, in Nottingham has been designed to achieve a BREAAM very good rating and provides specialist facilities for 1600 pupils in music and humanities. The Ashburton Living Village in Croydon, London provides 12000m^2 of integrated learning, leisure and sports facilities for increasing community participation. Some of the sustainability features include passive environmental controls, rainwater harvesting and PV panels. Ousedale School, in Milton Keynes is a smaller project providing learning space for secondary students in an annexe to the existing school and includes sports, assembly halls and music and drama spaces. The only housing project for the study, Colliers Gardens, in North Bristol, comprises of 50, one and two-bedroom flats with some shared community facilities. In 2006 it was awarded as the best affordable housing and an exemplary retirement development.

Notably, all case study buildings have been recently completed over the last 2-3 years and have been occupied since then. The study provides the architects an opportunity to revisit their buildings once they have been completed and assess the effect of their design interventions in reality.

A *multi-modal* POE method is used for gathering information about the case studies, involving desktop research to establish basic background information, preparing technical data pro-forma to establish construction as well as predicted and actual building performance, data-logging temperature and humidity, alongside questionnaire surveys and semi-structured interviews with key actors using open-ended prompts to gauge occupant satisfaction and thermal comfort.

ENERGY AUDIT

The foremost aspect of the POE is assessing the energy use within the buildings. Primarily, energy audit comprises of a pre-survey analysis from fuel bills, allowing a comparison of the building's energy use against benchmarks. It is followed by an on-site energy survey of end uses such as lighting, appliances and equipment, building control systems etc to understand where and how this energy is used in the building. The energy audit, hence, accounts for both, the supply (gas and electricity) and the demand side (end uses) of energy use in the buildings.

Preliminary audit The preliminary audit is a desktop-based analysis of the fuel bills with the climatic data (degree days), of the building. Degree-days are a measure of the variation of outside temperature, which enables building designers and users to determine how the energy consumption of a building is related to the weather. In the UK, heating degree-days are used. They quantify the severity and duration of cold weather, the colder the weather in a given month, the higher the degree-day value.

Degree-days are used in the preliminary stage of energy auditing to understand seasonal variations of the space heating system. This is done by plotting the energy use data against the 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 system is to changes in outside temperature. This analysis helps in revealing the overall trends in the building's energy performance.

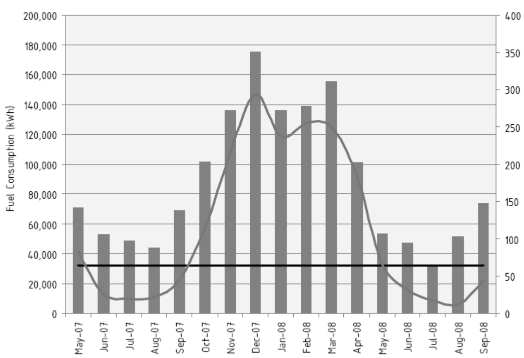

Figure 1: Monthly gas fuel consumption and degree days for Hounslow health centre (Source: Daniela Skarica, student, 2008)

Another important aspect of the preliminary audit is to compare the building energy use with benchmarks by calculating Normalised Performance Indicator (NPI). NPI is a government-accredited scheme, used as 'yardstick' to state area-weighted annual energy consumption (kWh/m^2/yr) of a building allowing for weather, exposure and occupancy patterns of the building. NPI is widely used to compare energy performances of buildings to benchmarks (kWh/m^2/year or kgCO_2/m^2/yr), thereby providing an indication of the potential for improvements. While the 'typical' benchmark is the median level of performance of all the buildings in the category, 'good practice' represents the top quartile performance. Such comparisons at an initial stage of POE assess the standard of energy efficiency in the case study buildings, and identify priority areas for action. The NPI's for the seven buildings and their comparison with associated benchmarks are listed below.

Table 1: Comparison of NPI's with benchmarks

Energy use (Gas + Electricity) (kWh/m2/yr)					
Building type	Actual energy	NPI	TM46 (2008)	CIBSE Guide F	
			Typical	Typical Practice	Good Practice
Educational buildings			*Schools*	*Secondary schools*	
Minster	201	185	190	177	133
Ashburton (estimated)	119	143	190	177	133
Ousedale	110	174.1	190	177	133
Health centres			*Clinics*		
Hounslow	263	219.8	270	-	-
Green Wrythe Lane	306	294.6	270	-	-
Gracefields	224	193.9	270	-	-
Housing (for elderly)			*Long term residential*	*Sheltered housing*	
Colliers Gardens	213	64	485	500	360

The table shows that almost all buildings perform well with respect to the typical benchmarks, and have a lower energy use. The Green Wrythe Lane centre is the only building, which performs, worse both in terms of actual energy use and NPI.

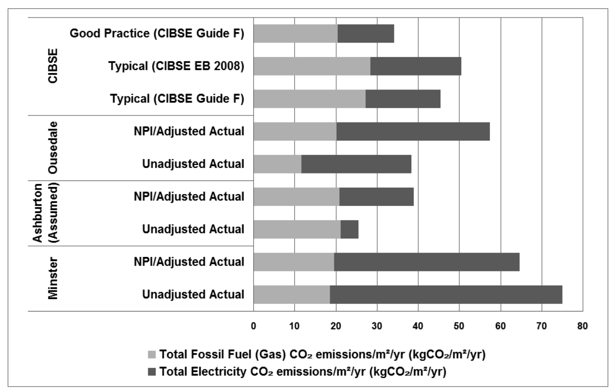

Figure 2: Schools-CO_2 emissions (kgCO_2/m^2/yr)

The carbon emissions graph (figure 2) compares the gas and electricity related CO_2 emissions with the benchmarks. Unlike the energy use table, where all the schools performed better, the carbon emissions' comparison depicts a different scenario. While the gas related emissions have considerably reduced in all buildings and are lesser than the good practice benchmark, probably, due to an efficient building fabric, the electricity use is much higher than the benchmarks. The actual electricity use for Minster school is almost four times the good practice benchmark while Ousedale schools' is almost twice the good practice benchmark.

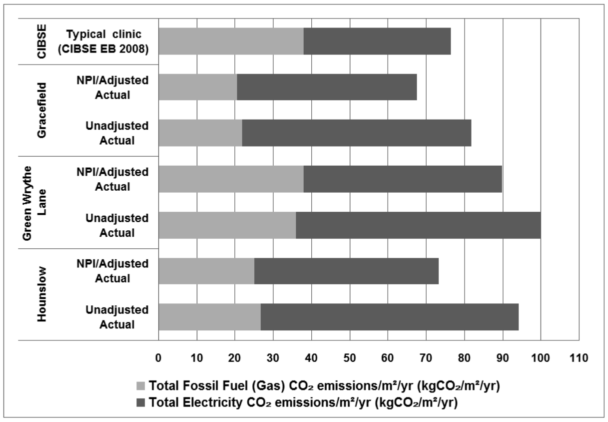

Figure 3: Health centres- CO_2 emissions ($kgCO_2/m^2/yr$)

The health buildings show a similar trend with respect to increase in carbon emissions related to electricity, though, the increase is not as much as the educational buildings. For Green Wrythe lane, an increase in gas-related emissions is in accordance with the higher than average energy use (Table 1).

Energy survey The preliminary audit assesses the overall building energy use and is followed by an on-site survey of energy end uses, to correlate the demand and supply side of fuel consumption and find probable reasons for any anomalies found in the preliminary audit. The process normally involves measurement, analysis or direct assessment of energy consumption 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; building fabric, space heating- boiler plant & hot water system, air conditioning and ventilation, power- equipment and appliances and lighting: natural and artificial.

Assessing all the major energy end uses allows a further breakdown of how fossil fuel and electricity is being is being used in the building. For example, during the lighting audit of the schools, unnecessary usage of electrical lights was found during the weekdays and sometimes even weekends, despite good daylight levels. There were also problems with more than required design lighting load.

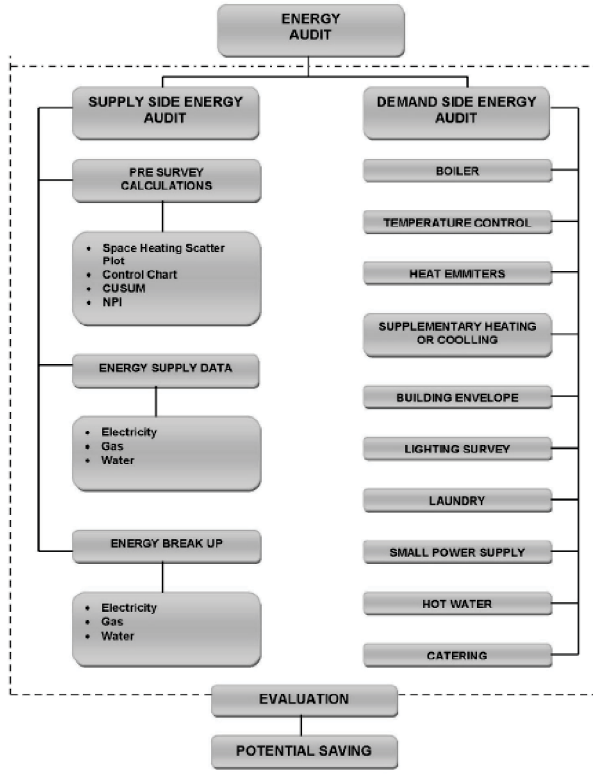

Figure 4:Flow chart showing an action plan for energy survey in Colliers Gardens (Source: Ashley Burns, student 2008)

ENVIRONMENTAL AUDIT

The environmental audit focuses on quantitative and qualitative analysis of broader ‘sustainability’ related criteria such as air quality, comfort, water consumption, waste management and other ecological issues such as biodiversity in design. These aspects are classified as indoor, local and global impacts, depending on their spheres of influence.

The environmental impact of the building is represented as a credit-based system similar to the commercially available BREEAM package for assessing the environmental impact of the buildings. The credits and the categories are decided by students based on their specific projects. The indoor impacts assessment is supported by measuring hard, quantitative data from data loggers for indoor temperature, lighting levels, humidity, noise and air quality (CO_2). The figure shows the global and local issues considered for one such environmental report card.

Global	Comment	Score
Energy & Resource Consuption		
Annual CO_2 emissions from electricity	Benchmarks	-1
Annual CO_2 emissions from gas		2
Water		1
	Total score	2
Environmental Policy		
Management systems	BMS	1
Purchasing		-1
Manuals		-1
	Total score	-1

Local	Comment	Score
Water Consumption		
Waste water treatment		0
Grey water treatment	system broken	0
Water saving devices	Poor	-1
Storm water treatment		0
	Total score	-1
Waste & Recycling		
Recyclable waste management	Poor	1
Reused materials		0
	Total score	1
Transportation		
Provision of cycle storage		2
Public transport	Poor	0
	Total score	2
Ecology		
Land pollution		1
Vegetation		2
	Total score	3

Figure 6: Environmental report card for Ousedale School, (Source: Simon Chung, Student, 2008)

OCCUPANT SATISFACTION

The occupant satisfaction assessment is carried out through a questionnaire for the building users focussing on issues of primarily thermal comfort within the spaces, air quality, ventilation, usability of building controls and environmental awareness. The survey method varies from face to face interviews, drop and collect or electronic questionnaires sent via e-mail. Key findings from the survey for the seven buildings are described in table 2.

Table 2: Findings from the occupant satisfaction surveys

Building type	Number of respondents	Main findings
Educational buildings		
Minster school	Staff- 45 Students-94	Mostly comfortable internal temperatures; Air quality responses varied from stuffy to draughty highlighting individual preferences; 90% Staff and students positive about the building
Ashburton	31	Concerns about lack of control within the space; Prefer warmer temperatures, in winter; Overall satisfaction is rated above average
Ousedale	Staff-21 Students-77	Positive levels of comfort across a range of criteria; Temperature found to be warmer than required.
Health centres		
Hounslow	Staff-46 Visitors-32	Concerns with mechanical ventilation system and inability to open windows; Low lighting levels in rooms facing atrium; Overall satisfaction levels high
Green Wrythe lane	Staff-4 Visitors-27	Lack of natural light in some areas; Concerns with limited control over artificial lighting and noise from outside; High forgiveness factor with average satisfaction levels.
Grace fields	Staff – 36 Visitors 31	Mostly comfortable internal temperatures, warm in some areas; Overall experience satisfactory
Sheltered Housing		
Colliers Gardens	Staff-5 Residents-12	High satisfaction levels with the building; Warm in some areas.

As is evident from the table, user survey highlights issues with warmer temperatures in some spaces and a lack of sufficient control over building services in two buildings. These can be easily rectified to increase occupant comfort. There are no major issues highlighted related to any of the studied buildings. Overall the forgiveness factor for new buildings is generally very high [4] and shows that people are more accepting of minor discomfort issues if the building is well-designed for the function and provides a reasonable amount of control to the occupants.

RECOMMENDATIONS

Findings from the study inform the recommendations suggested by students to improve the energy and environmental performance of the building. The table below lists key recommendations for each building studied. Some of the most effective no-cost measures include creating awareness about building controls within the building for efficient use.

Table 3: Key recommendations

Building type	Key recommendations
Educational buildings	
Minster school	Time the BMS system to account for low use in holidays and adjust temperature set points; Reduce the over designed lighting load by changing lamps to a lower wattage; Lights need to be manually operable or coupled with daylight sensors in circulation areas
Ashburton	Lack of any fuel data due to the process of building commissioning; Requires investigation of who is billed for energy charges, as recommendations are difficult to be implemented unless ownership is resolved.
Ousedale	Electricity use can be reduced by creating awareness and instigating a culture of turning lights off in classrooms; Occupancy sensors in circulation spaces Wind conditions on site make it viable for a wind turbine assessment

Health centres	
Hounslow	Incorporate the originally planned designated waste recycling area and create awareness about recycling; Sensors for electric lights in circulation areas; Installing dual flush systems and a rainwater harvesting system on site can reduce high water consumption.
Green Wrythe Lane	Time the boilers to account for low space heating use over weekends; Provide staff members control over lighting in their space; Localised switches for lights in circulation areas or sensors
Grace fields	Create awareness about building controls for efficient use; Label lights and controls appropriately
Sheltered Housing	
Colliers Gardens	Reduce heating temperatures by a few degrees to avoid overheating internal spaces; Install motion and daylight sensors for lights which are switched on 24 hours a day; Reinstate the BMS System and connect to various services

Most buildings performed well in space heating use and maintain comfortable temperatures but have higher than typical electricity use, due to inefficient use of artificial lighting, which is switched on for more than what is required. Therefore localised manual switching controls combined with automatic sensors have been commonly recommended to minimise unnecessary wastage.

CONCLUSION

The POE study of seven sustainable designed buildings by Penoyre and Prasad Architects provides a valuable opportunity to assess how buildings perform with respect to design intentions. It is imperative that this feedback is sought and widely reported so that the design team can take any feedback on board for forthcoming projects. In fact day-long seminars by students and module tutor have been set up to share the lessons learnt with the design and engineering teams. In particular, the analysis of the actual, measured performance of a building-in-use against its intended performance and best practice benchmarks, bridges credibility gaps between expectations and outcomes**.**

All the buildings studied were found to be using lesser energy than typical benchmarks except Gracefield Gardens. However, carbon emissions for most buildings were higher overall, due to a much greater percentage of electricity use in the building as compared to benchmarks. Most of the electricity use is due to lighting within the building, and it was found that even well designed buildings with good daylight levels suffered from inefficient and wasteful ways of using electricity for lighting. A few buildings also had a much greater design lighting load than required. Some of the recommendations for this include: replacing lamps with lower wattage lamps combined with provision of better controls and creating awareness amongst users.The occupant satisfaction and comfort levels within all the buildings studied, were found to be higher than average. Lack of building services controls was highlighted in few buildings along with minor issues of higher temperatures in some areas. Overall, most users found the buildings pleasant and rated the buildings positively.

The POE module therefore provides the architecture students an opportunity to learn a valuable skill of assessing buildings in use and draw on findings from occupant use and interaction with the building, to inform their own future designs.

The study also provides an opportunity to bring together industry and academia to work towards developing a continuous stream of information and feedback for benchmarking and evaluating new sustainable buildings. It is recognised, that the study is restricted to a limited duration of time (September – December 2008) and would benefit from a longitudinal study taking into account any or all of the recommendations which were taken on board by the building management team. This would ensure that the continuity of the feedback loop is maintained and the building performance is optimised over its lifetime.

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