Developing a new framework to bring consistency and flexibility in evaluating actual building performance

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Abstract:

Building performance evaluation (BPE) is becoming an important tool for the improvement of building design and operations globally. However, with low energy buildings becoming more complex and clients increasing their interest in the evaluation of the impact of design and technologies on indoor environments, occupant health and productivity, gaps are often found between design expectations and actual performance. Often the causes are not just a result of one factor but 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. Although a few BPE techniques such as the Building Use studies (BUS) questionnaire survey are beginning to be used internationally to evaluate user perception and satisfaction, largely BPE forms a fragmented whole with tools and methods that are not widely applicable.

This paper develops and demonstrates a novel BPE framework to bring consistency and flexibility in evaluating actual building performance. The paper critically reviews and evaluates existing BPE methods and techniques (derived from BPE studies undertaken in UK and elsewhere) and situates them in different building life stages. Using a hierarchical approach, a 'BPE framework' is devised for new and existing buildings as well as refurbishments. The framework is designed to have four graduated levels starting at the 'basic' level and developing incrementally to 'core', 'comprehensive' and 'advanced' levels. The working of the BPE framework is demonstrated by applying it to four discreet BPE studies to enable cross-comparison of different BPE approaches based on their stage of application, depth and duration of BPE investigations. Such a graduated and flexible framework helps to bring consistency in evaluating building performance in an otherwise fragmented field, to help minimise the performance gap between design intent and actual outcomes and improve building performance.

Keywords: Building performance evaluation, Soft Landings, Performance gap, Low energy buildings, Passive House, Post-occupancy evaluation

Purpose:

The field of Building performance evaluation (BPE) forms a fragmented whole with tools and methods that are not widely applicable. In response, this paper develops and demonstrates a novel BPE framework to bring consistency and flexibility in evaluating actual building performance.

Design/methodology/approach:

The paper critically reviews and evaluates existing BPE methods and techniques and situates them in different building life stages. Using a hierarchical approach, a 'BPE framework' is devised for new and existing buildings as well as refurbishments. The working of the BPE framework is demonstrated by applying it to four discreet BPE studies to enable cross-comparison of different BPE approaches based on their stage of application, depth and duration of BPE investigations.

Findings:

The framework is designed to have four graduated levels starting at the 'basic' level and developing incrementally to 'core', 'comprehensive' and 'advanced' levels, thereby focussing on 'need to know' rather than 'nice to have'. The framework also offers a mechanism to map different types of BPE studies with varying scope and content.

Practical implications:

As we enter a world of smart meters and smart buildings, we are transitioning into a new future of understanding building performance. The study helps to better understand which BPE method can be used to study what aspect of building performance and in what building life cycle stage, against time, cost and user expertise.

Originality/value:

The graduated and flexible framework helps to bring consistency in evaluating building performance in an otherwise fragmented field, to help improve building performance.

1. Introduction

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 (IPCC, 2007). The building sector has been identified to play a key role in the carbon reduction challenge as it accounts for approximately one-third of the total CO_2 emissions and offers the largest low-cost reduction potential at a sectorial level (Metz *et al.*, 2007) while contributing to sustainable development. To address this issue governments worldwide have put a lot of effort into improving energy and construction standards in existing & new buildings, and in energy performance assessment tools such as Building Research Establishment Environmental Assessment Method (BREEAM) (UK), Leadership in Energy and Environmental Design (LEED) (USA) and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) (Japan).

As a result, a series of new build and retrofitted low energy and low carbon buildings have emerged. However, with more complex low energy buildings and clients increasing their interest in the evaluation of the impact of design and technologies on indoor environments, occupant health and productivity, gaps are often found between design expectations and actual performance. This performance gap between the predicted (energy) performance of a building (domestic or non-domestic), or a specific technology, and its measured performance has been demonstrated for over a decade (Bordass and Leaman, 2005; Lowe *et al.*, 2007; Gill *et al.*, 2010; Stevenson and Leaman, 2010; Williamson *et al.*, 2010; Wingfield *et al.*, 2010; Gleeson and Lowe, 2013; Johnston *et al.*, 2013; Gupta *et al.*, 2015; McElroy and Rosenow, 2019; Shi *et al.*, 2019). As an example, data from Innovate UK's Building Performance Evaluation (BPE) programme (Palmer *et al.*, 2016a; Palmer *et al.*, 2016b) are shown in figures 1 (domestic) and 2 (non-domestic).

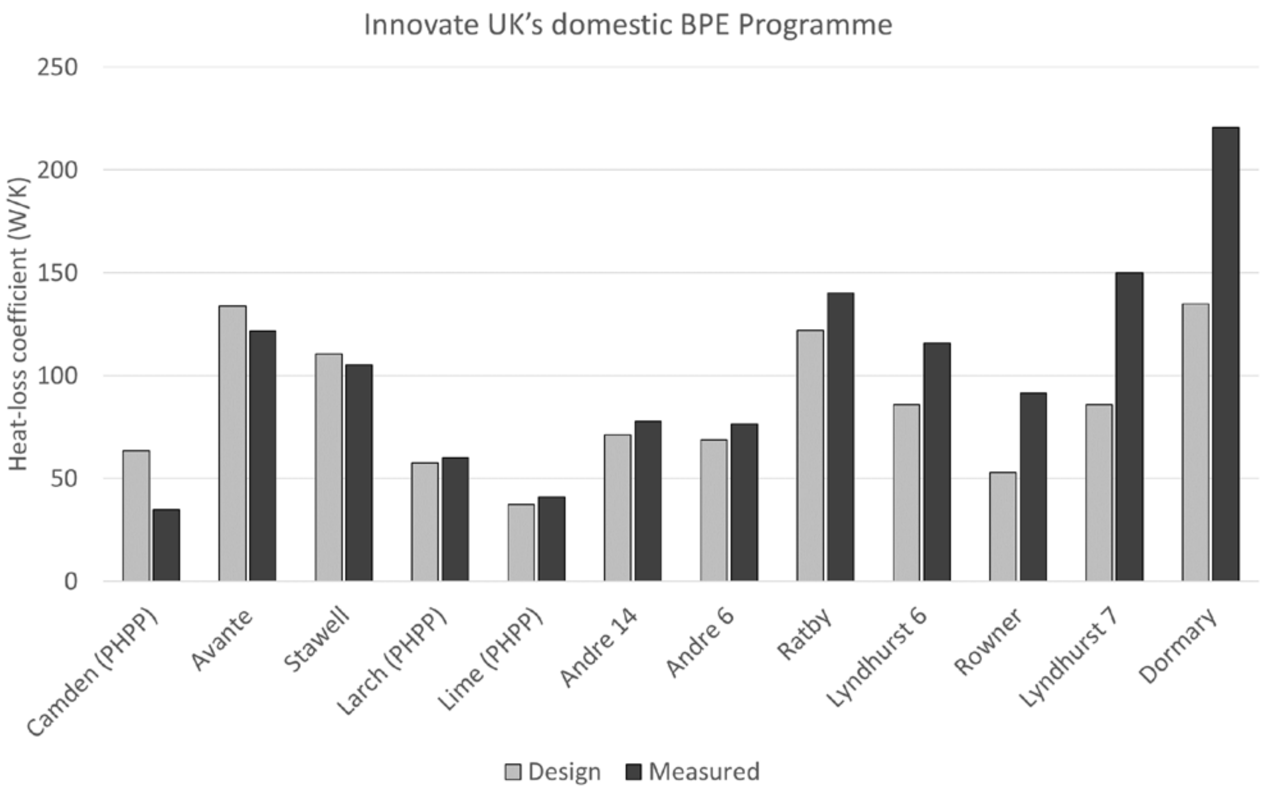

Figure 1. SAP predicted calculations as compared to co-heating test results (data source: (Palmer *et al.*, 2016a)). Note PHPP refers to where the Passive House Planning Package was used for calculation in lieu of SAP (Standard Assessment Procedure)

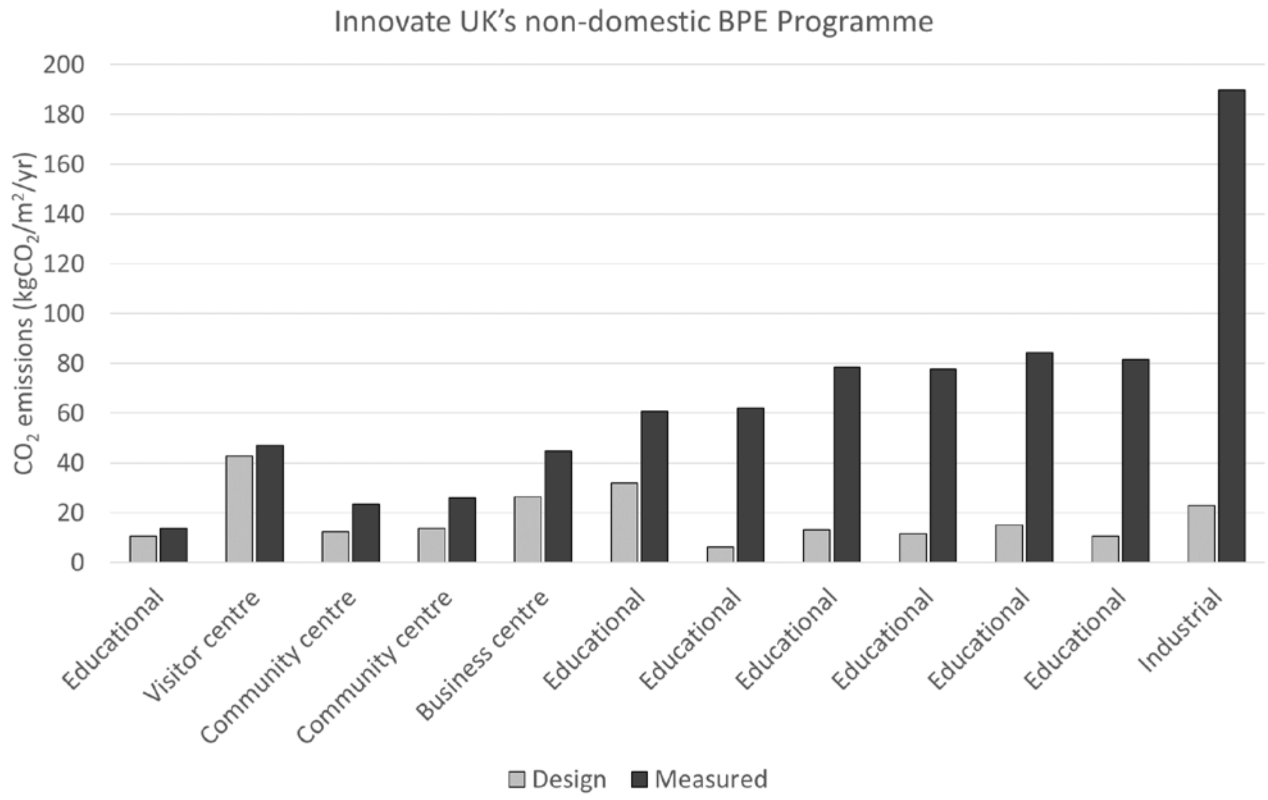

Figure 2. Non-domestic performance gap in CO_2 emissions (data source: (Palmer *et al.*, 2016b)).

The gap can vary widely between domestic and non-domestic and within sub-sectors. A common finding with highly efficient dwellings (commonly passive House dwellings) has been that the gap is much smaller (Palmer *et al.*, 2016a; Johnston *et al.*, 2016; Gorse, 2016), suggesting that high levels of design detail and quality control throughout the entire design and build process may be helpful in bridging the gap. Gorse *et al.* (2017) also demonstrate positive outcomes from the retrofit efforts during the National Green Deal implementation phase in the UK. Clearly, however, national policy targets for carbon reduction cannot be met without understanding, quantifying and minimising this performance gap.

The reasons for the performance gap can generally be attributed to the discrepancies that arise from the design and modelling tools used to design the building, through build-ability, build process and build quality ('as-designed' and 'as-constructed'), systems integration and commissioning, handover and operation ('as-constructed' and 'in-use'), to the understanding, comfort and behaviour of the occupants ('as designed' and 'in use') (Wingfield *et al.*, 2008; Gorse *et al.*, 2017). In fact, occupant behavioural patterns (which can be positive, e.g. wearing warmer clothes in addition to heating during the winter or negative, e.g. leaving windows open when the heating is switched on) can impact energy consumption by a factor of 2-3 in physically identical homes (Steemers and Yun, 2009; Gram-Hanssen, 2010). The need to evaluate the in-use performance of low energy buildings has led to the evolution of BPE, which involves feedback and evaluation reviews at every phase of the building delivery, from strategic planning to occupancy, adoptive reuse and recycling (Preiser and Vischer, 2005). BPE is a systematic collection and analysis of information related to energy performance, environmental conditions, fabric performance; qualitative feedback from occupants, building owners, managers, design & construction team, FM managers, and occupants to fine-tune the building and inform future practices.

BPE can be used, as a hindsight tool for learning and fine tuning after the project is complete; a foresight tool for comparison and evaluation of existing situations before a new project is started; and as an insight tool for reality checking and managing expectations during the project (Bordass and Leaman, 2005). The potential impact of any BPE feedback is dependent on the lifecycle stage at which it is undertaken. This impact is highest when BPE can influence the early stages of the building lifecycle where major decisions contributing to a large portion of the performance gap originate. *Though BPE can be used to describe the evaluation of any or all stages of a building's lifecycle, this paper will focus on the as-designed review through in-use stages.*

Many BPE programs were developed and adopted in the US by federal agencies proposing a balanced approach to suit each case (Federal Facilities Council, 2002). In Australia BPE was considered as an important parameter of the post-implementation review in several health buildings allowing for feedback into future projects (Carthey, 2006). Another attempt to engage a coordinated common approach (focussed on measuring and reporting energy use and greenhouse gas emissions from building operations) at an international level was made by the United Nations Environment Programme (UNEP). However, the fragmentation of the building sector, lack of baseline references, and economic incentive has hindered its effectiveness (Cheng *et al.*, 2008).

Despite the growing interest in BPE and the development of a series of evaluation methods at an international level, the existing agenda forms a fragmented whole lacking a systematic approach or a regulatory framework for feedback as part of the construction process (Bordass and Leaman, 2005; Stevenson, 2009). The lessons learnt are not always adequately communicated or used for the purposes intended because of the lack of a commonly agreed methodology. Harmonisation and rationalisation of the existing BPE techniques is needed for the findings to be applied widely.

Within this context, this paper critically reviews BPE studies undertaken within and outside the UK, along with their scope and ownership (Government, academia, industry or non-governmental organisation (NGO)) to unravel a suite of techniques and methods that are being adopted for evaluating the actual performance of different building types, at different building stages, and for various stakeholders. These techniques are evaluated against a set of established criteria (cost, ease of implementation, stakeholder engagement etc.) and categorised according to building stages, to develop a holistic BPE framework in order to:

- Provide consistency, independence and impartiality in the evaluation of building performance;
- Reduce the performance gap between 'as designed', 'as built' and 'in-use' stages;
- Create a robust and credible methodology from a bottom-up analysis of actual case studies and BPE programmes;
- Distinguish 'need to know' factors from 'nice to know' factors so as to avoid the risk of over evaluation and survey fatigue amongst occupants; and
- Assess the depth and scope of BPE investigations undertaken for different building types / stages.

The working of the BPE framework is demonstrated by applying it to four different BPE studies across different building lifecycle stages.

2. Review of existing BPE studies in UK and globally

Early BPEs started in the 1960s as one-off case study post-occupancy evaluations, focusing on the residential environment of many urban renewal projects that took place in North America and Western Europe, to investigate and resolve many unexpected architectural and social problems like the sick building syndrome (Preiser and Vischer, 2005). In the years to follow, BPE studies were related to a variety of building types including educational and health institutions, prisons, offices and other commercial buildings (Preiser *et al.*, 1988). Table 1 summarises different BPE studies and approaches from the UK (where the bulk of the authors' experience lies) undertaken in domestic and non-domestic buildings, retrofit and new build. A review of international literature is also summarised in Table 2.

Table 1. Existing UK BPE approaches categorized by leading organisation

	Organisation	Methods used

Government	**PROBE: (Post Occupancy Review of Buildings and their Engineering)**	Approach based on the combination of a 'snapshot' energy assessment and occupancy evaluation; established techniques such as the use of a Pre-visit Questionnaire for the facilities manager, airtightness testing and TM22 energy assessment tool (Cohen *et al.*, 1999; Bordass and Leaman, 2004).
	TSB: Technology Strategy Board – BPE competition	£8m allocated to fund the evaluation of new built domestic and non-domestic buildings during their construction, initial occupation and in-use phase towards investigating the widening performance gap and creating performance-based standards. All studies will be required to use specified approaches, tools and techniques to capture data in a comparable form (TSB, 2010).
	TSB/ EST - RfF: Retrofit for the Future competition	Developed a whole house performance evaluation approach to determine how design features–enhanced airtightness, improved fabric insulation levels, renewable energy-contribute to the energy performance of refurbished houses. Their standardised approach for refurbishments and new build is based on a combination of short term 'one-time' fabric tests and long-term evaluation/ monitoring (EST, 2008).
	HCA: Homes and Communities Agency - Monitoring guide for carbon emissions, energy and water use	A 'closed loop' approach where feedback from separate building life cycle stages links back to the concept, briefing and design of subsequent projects. Oxford Institute for Sustainable Development (OISD) developed guidance on monitoring of user perception, behaviour and physical building performance when in use. The post completion monitoring stage emphasises evaluating the interaction between social and physical aspects of building performance during occupancy (HCA, 2010).
Industry	**BSRIA**	Provides methods and services for air permeability testing, measurement of U-values in construction elements such as walls, thermography and whole house co-heating tests (BSRIA & MBE KTN, 2011).
	Soft Landings Framework by Usable Building Trust / BSRIA	Methods like documentation tendering and design review, commissioning and handover process observation, comprehensive aftercare schedule followed by extended recording of the building's operation and performance; evaluation stages are complimentary to RIBA stages of work and aimed towards extending the commitment of the design and construction team beyond the handover of a building (Usable Buildings Trust, 2009).
NGO / Non-profit	**UBT: Usable Building Trust - Feedback Portfolio**	POE methodologies are categorized into four groups: procurement – process, design quality; technical – fabric, services, space; people- occupants, workplace assessment; and sustainability- environment & energy, social & economic (Bordass *et al.*, 2006).
	BRE: Building Research Establishment	Variety of post-occupancy evaluation methods offered including monitoring of environmental conditions, assessment of design quality using Design Quality Method (DQM) tool, sustainability and utility audits (BRE, no date), Post-occupancy Evaluation in the First Year of Occupancy.
	GHA: Good Homes Alliance	A four-level hierarchical performance evaluation approach based on EST's monitoring approach. Level 1- monitoring the energy use; Level 2-indoor conditions monitoring and an annual occupants' questionnaire; Level 3- weekly logging and seasonal questionnaires and Level 4 -bespoke whole house monitoring approach, equipment performance and the behaviour of the occupants (OISD: LCBG, 2010).
Academia	**Leeds Beckett University**	Development of a unique method for establishing the actual fabric heat loss in housing compared to the predicted heat loss and the reasons for the difference, known as a co-heating test (Wingfield *et al.*, 2010; Stafford *et al.*, 2014).
	University of Nottingham	Series of domestic POE studies in university based experimental eco houses. POE techniques include environmental monitoring, energy assessment and analysis of the occupancy patterns and space use with the use of a Real-Time Location System (Spataru *et al.*, 2010).
	Oxford Brookes University	Customized performance evaluation approach for Indian green buildings - An exploratory investigation to develop and test a customized building performance evaluation (BPE) approach (I-BPE framework) for the Indian context. The I-BPE approach is tested in a case study building to gain insights for refining the underlying methods and processes for conducting further BPE studies in the context of India (Gupta *et al.*, 2019).

	Glasgow School of Art	The Mackintosh Environmental Architecture Research Unit (MEARU) was engaged by the Glasgow Housing Association (GHA) to provide design advice on 'The Glasgow House'. This was a prototype for low energy, flexible, affordable housing that would be a solution for both social and private rented sectors, and housing for sale. It included a range of low energy strategies including sun-spaces, mechanical ventilation with heat recovery (MVHR), a clay block construction system to provide a highly insulated envelope with thermal mass, etc (Sharpe, 2013).
	University of Sheffield	Proposal of a theoretical and ethical framework for 'Live' BPE: assessing the different methods that are currently available for fitness of purpose in an educational setting and introduces new individual and collective evaluation methods. Also explores the barriers and opportunities for staff and students wishing to evaluate BPE at all stages in the current architectural studio in the UK and beyond. Additional methods: usability studies, video evaluation, and social learning (Stevenson, 2014).
	University College London	Application of the case study method (CSM) to conventional post-occupancy evaluation (POE), so as to explore the interaction between social and technical processes. socio-technical methods explored: philosophical assumptions and theoretical stances; investigative logics – when, where and why; guidelines for practice; contributions to system perspective (Lowe *et al.*, 2018).

Table 2. Review of international POE / BPE case-studies and their methodologies

	Case study	**Methods used**
Japan	**International BPE (IBPE) research group: Case study of office tower in Nagoya, Japan (Kato *et al.*, 2005).**	Extensive investigation of employee activity and communication within the workplace has been at the core of building performance evaluation in Japan. A POE of an office tower was conducted by the IBPE research group to investigate the effectiveness, applicability of innovative workplace planning and design strategies. The specific techniques used were activity mapping, activity duration mapping, movement mapping and communication mapping. Implementation and analysis of workplace mapping is time intensive but provides insight into the culture of the organization and can be utilized in the design briefing and in-use occupancy stages of POE.
Netherlands	**Evaluation of innovative workplace design in Netherlands (Mallory-Hill *et al.*, 2005).**	Performance Evaluations throughout the lifecycle of the building are unusual in the Netherlands context. Relatively high-quality work environments are the norm and regulations are very strict. The building design review process involves a review of effectiveness, programme and design. Changes in organizational trends have increased the demand for innovative office solutions, but stakeholders need assurances that these proposals will work before investing. Therefore, the objective of POE in Netherlands is to test whether clients' goals are achieved and improve the understanding between facilities management, employee satisfaction and organisational needs. The focus is on user satisfaction and organisational performance while facility costs and technical aspects such as environmental systems are only evaluated if there are particular issues. Full scale mock-ups of innovative systems are evaluated before installation, thus informing client decisions at the design and briefing stage.
Brazil	**Assessing Brazilian workplace performance (Ornstein *et al.*, 2005)**	The Brazilian office real estate industry is characterised by a lack of commitment between builders and occupants; leading to a situation where building exteriors often take priority over other design features. 'Space per person' is the only standard applied to Brazil's commercial buildings. The Sao Paolo University research team carried out systematic assessments of office building performance. The evaluation procedures used were categorized as 'observations', 'perceptions', and 'measurements' and included review of design and construction drawings, walkthroughs, unstructured interviews, questionnaires and measurement of environmental conditions.

USA	**Case study of Kresge Foundation office complex (Goins, 2011).**	The research at the Center for the Built Environment in the University of California, Berkeley has developed various methodologies for building performance evaluation under 5 categories: Indoor Environmental Quality (IEQ), Building HVAC Systems, Building Envelope Systems, Human Interactions, and Sustainability & Whole Building Energy. Their case study on the Kresge Foundation office complex compares its performance against industry standard design and operations performance criteria. Performance was evaluated in the 20 areas of human factors; indoor water use; storm water management; landscape performance (water use and biodiversity); acoustics; lighting; indoor air quality (IAQ); thermal comfort; energy performance; and life cycle, operational costs. These performance criteria are derived from CBE's occupant satisfaction database; ASHRAE - Performance Measurement Protocols (PMP); LEED-NC Version 2.1 and others.
	Vital Signs Project – 1992 to 1998 – Center for Environmental Design Research at the University of California, Berkeley (Project, 1998).	The project was aimed at increasing the awareness of architecture students on how design decisions affect building performance. A series of flexible, modular "Resource Packages" were developed to provide protocols for the evaluation of existing buildings. The methodology and techniques recommended by the resource packages are organized at three different levels to cater to varying expertise, objectives and time. The packages contain information on primary physics principles, their impacts on design decision making, applicable standards/practices and protocols for field observations/ evaluation. The resource package is applied to case studies in the following format: background, inquiry, questions & hypothesis, building evaluation & analysis, synthesis & design implications.
	Agents of change project, 2000-2005, U.S. Department of Education (AOC, 2005).	The program used intensive training sessions and toolkit loans to prepare students to assume their roles as teachers, architects and stewards of the built environment. The Vital signs methodology (questions and hypothesis are used to create methods of investigation) was applied to case studies in workshops and the results were made publically available through the website. Participants had access to both equipment and teaching toolkits.
Australia	**Post-occupancy Evaluation Methodologies for Healthcare projects in Australia (Carthey, 2006).**	Carthey reviewed current POE processes used in Healthcare projects in Australia to find that although POE plays an important role in feeding back lessons from the evaluation of existing buildings into the planning of future health projects in Australia, problems like the lack of commonly agreed methodology for conducting evaluations have hindered the effective communication of lessons. Inconsistencies in data collection (type and format), analysis and reporting impact of these studies and are the result of the lack of standardisation.
India	**Learn-BPE project 2018 – 2019 (learn-bpe.org/)**	Four project workstreams: Customising UK based BPE methods and tools for India; Testing customised BPE methods in domestic and non-domestic Indian case studies (specifically certified green buildings); Embedding BPE through mandatory and elective coursework; Dissemination and knowledge exchange – development of a building performance network for India.

Table 3. Global review of methods and protocols used in BPE / POE (HCA, 2010).
*These sources also employ mapping as a strategy
**Main funding / organisation sector: A = academia, G = government, I = industry, N = NGO

No.	Building type	Org. Sector**	Key sources	Methods used				
				Tech. eval. / physical monitoring	Question-naire	Interviews/ Focus groups	Walk-through/ observation	Video/ photo analysis
1	Offices	I	CIBSE TM22 (CIBSE, 1999)	x			x	
2		G/N	PROBE (Bordass and Leaman, 2004)	x	x	x	x	
3		I	Mallory-Hill *et al.* (2005)	x	x	x	x	
4		A	Ornstein *et al.* (2005)	x	x	x	x	
5		G	OGC (2005)	x	x			
6		N	BCO (2008)	x	x	x		

7		I	Soft Landings (Usable Buildings Trust, 2009)	x	x	x	x	
8	**Healthcare**	G	AEDET evolution (DH & NHS, no date)		x	x		
9		A	Burt-O'Dea (2005)		x	x	x	x
10		G	Carthey (2006)	x	x	x		
11		A	Stevenson and Humphris (2007)	x	x	x	x	
12	**Education**	G/N	Sanoff *et al.* (2001)		x	x	x	x
13		G/I	Watson and Thomson (2005)			x	x	
14		G	DfES (2006)	x	x		x	
15		G	HEFCE (2006)	x	x	x	x	
16		A	Pegg (2007)	x		x	x	
17	**Housing**	G	EHCS (DCLG, 2001-2008)	x		x	x	
18		N	EDG (2005)	x		x	x	
19		A	CarB (Crosbie, 2006)	x	x			
20		A	Gillott *et al.* (2006)*	x			x	
21		A	Stevenson and Williams (2007)	x	x	x	x	
22		G	EST CE298 (2008)	x				x
23		A	Stevenson and Rijal (2008)	x		x	x	x
24		G	TSB/ EST – Retrofit for Future (2008)	x	x	x	x	x
25		A	Hormazabal *et al.* (2009)	x		x	x	
26		G	DCLG (Wingfield *et al.*, 2011)	x	x		x	x
27		G	Gorse *et al.* (2017)	x	x	x	x	x
28	**Cross-type mix**	I	BRE (no date)	x				
29		N	UBT Feedback Portfolio (Bordass *et al.*, 2006)	x	x	x	x	x
30		A	Dou and Steemers (2007)*	x				x
31		G	Gupta and Chandiwala (2009)	x	x	x	x	x
32		N	GHA (OISD: LCBG, 2010)	x	x	x	x	x
33		G	HCA (2010)	x	x	x	x	x
34		G/I	TSB – BPE Programme (2010)	x	x	x	x	x
35		G	Wingfield *et al.* (2010)	x				
36		I	BSRIA & MBE KTN (2011)	x				
37		A	Gupta *et al.* (2019); (Abraham, 2013)	x	x	x	x	x

Traditionally the evaluation of dwellings consisted either of quantitative physical monitoring or qualitative occupancy satisfaction questionnaires, but it was very rare to find those two feedback methods combined since they respectively spanned across building and social science. A review of assessment techniques adopted by various recent BPE studies (in UK and globally) for different building types (housing, offices, schools etc.) reveals that they tend to comprise of qualitative and/or quantitative methods (Table 3), but with a diverse set of tools and methods that do not seem to be widely applicable, thereby forming a fragmented whole. Although a few BPE techniques such as the Building Use studies (BUS) questionnaire are beginning to be used internationally (Brown *et al.*, 2010; Best and Purdey, 2012; Deng *et al.*, 2017) to evaluate user perception and satisfaction, there seems to be a general lack of a commonly agreed methodology for conducting evaluations, leading to inconsistencies in data collection, data analysis, reporting and communication of findings.

This is further reinforced by the fact that most of these BPE studies are led by government or academia to bring rigour and independence, in the absence of a widely-agreed BPE framework. Also, most of the BPE work seems to have focussed on new-build domestic and non-domestic buildings designed to have a low environmental impact, with considerably limited investigations on existing buildings and refurbishments, which form the majority of the building stock in any country. This reinforces the need for developing a harmonised BPE framework that can be applied to all types of buildings (new build and existing) and across different building stages.

3. Aligning BPE methods with building life cycle stages

Although there is increasing interest in building performance, the people who procure, design and construct buildings seldom engage with the performance of buildings during the procurement process and in-use stage (Bordass and Leaman, 2005). However, it is recognised that BPE needs to run in parallel with building lifecycle stages in order to create a comprehensive, on-going evaluation approach for continuous improvement. One such example is the Soft Landings framework, initially developed by the Usable Buildings Trust and Mark Wray (and currently implemented by BSRIA) which sets out a series of stage specific BPE techniques and checklists to set design targets against outcomes, create a continuous feedback loop for improvement and help to manage user expectations (Usable Buildings Trust, 2009). By breaking down the once rigid separation between construction and operation, such an approach ensures that the commitment of all stakeholders spans before, during and for the first three years after handover to fine-tune the performance of the building and identify opportunities for future projects (Way and Bordass, 2005). Table 4 outlines the Soft Landings stages and aligns them with the Royal Institute of British Architects (RIBA) building lifecycle stages and BPE elements that could be used during the process to tackle the performance gap. The Soft Landings approach handles the various performance gaps at their source, leading to an increased possibility of identifying and rectifying performance issues. For example, the performance gap between the ‘as-designed’ and ‘as-built’ is evaluated at the pre-handover stage of the Soft Landings framework.

Table 4. Scope, elements of Soft Landings stages

RIBA Stage	Soft Landing Stage	Scope of service	Corresponding BPE Elements	Addressing the performance ga	
Preparation	**1. Inception and briefing** *Identify all actions needed to support the procurement*	Clarify the duties of members of the client, design and building teams during critical stages, and help set and manage expectations for performance ‘in use’.	**Define targets / outline BPE methodology** o Set performance targets for energy, sustainability and carbon	Prepare to tackle the performance gap	
Design	**2. Design development and review** *Support the design as it evolves*	Applying the procedures established in the briefing stage, reviewing the likely performance against the original expectations and achieving specific outcomes.	**Design and model checks** o Model and analyse design towards meeting energy and carbon targets	Gap between as-designed and as-built	Gap between as-designed and in-use

Construction	**3. Pre-handover** *Prepare for building readiness and provide technical guidance*	Greater involvement of designers, builders, operators and commissioning and controls specialists, in order to strengthen the operational readiness of the building.	**Pre-occupancy evaluation** o Fabric testing o Installing monitoring equipment o Review consistency between as designed and as-built and adjust performance expectations. o Review of commissioning processes and control interfaces. o Evaluation of the handover documents o Walkthrough with construction and design team		
Use & *aftercare*	**4. Initial Aftercare** *Support in the first few weeks of occupation*	Resident representative or team on site during the users' settling-in period to help pass on knowledge, respond to queries, and react to problems.	**Handover evaluation** o Review of handover process o Walkthrough with occupants o Spot checks and occupant feedback interview	Gap between as-built and in-use	
	5. Years 1 - 3 extended Aftercare and POE *Monitoring review, fine-tuning and feedback*	Periodic monitoring and review of building performance.	**In-use evaluation (often referred to as POE)** o Assessment of annual energy use o In-use monitoring of environmental conditions and equipment usage o Walkthrough with occupants o Occupant feedback survey		

For BPE to become a tool for continuous improvement of building performance during the building lifecycle, it is helpful to situate each BPE method or technique (derived from BPE studies discussed in previous sections) within the different stages of the Soft Landings framework, so as to address the performance gap. To better understand the scope and level of application of each BPE method, the portfolio of methods are evaluated against the following criteria (using a scale of High, Medium and Low), using authors' experiences and a review of relevant BPE studies (table 5).

- **Cost:** Cost of the equipment (purchase and installation) and human resources needed: e.g. Co-heating tests require specialist equipment; an unoccupied but heated building etc. and therefore incurs a higher cost compared to a walkthrough survey which needs only the time and experiences of the occupant/manager and the evaluator.
- **Ease of implementation:** Complexity of each method depending on the level of competency and specialist experience needed for its implementation, the quantity and size of the equipment and the duration of the investigation: e.g. monitoring the performance of renewable technologies requires qualified electricians for installation, while the overall energy consumption can be easily obtained from meter readings/ bills etc.
- **Engagement with the stakeholders:** The scale of involvement and approval required by various stakeholders, to implement a certain technique, can dictate whether or how often these techniques take place: e.g. 'Design review meetings with clients, developer and management' require input from a range of stakeholders and are more difficult to arrange; ' interviews with the facilities manager' involve only the manager and the evaluator and could take place after/before the walkthrough.
- **Time duration:** The time taken to implement any measure or technique (both installation and analysis): e.g. the design and construction audit which involves a detailed review of drawings and onsite visits is time intensive, while thermal imaging can be done in less than an hour, if the conditions are suitable.

Table 5. Evaluation of BPE methods and techniques

BPE study elements	Techniques		Evaluation criteria: Cost	Evaluation criteria: Engagement across stakeholder group	Evaluation criteria: Complexity of implementation	Evaluation criteria: Time required	Soft Landings Stages: 1. Briefing	Soft Landings Stages: 2. Design development	Soft Landings Stages: 3. Pre-handover	Soft Landings Stages: 4. Initial aftercare	Soft Landings Stages: 5. Years 1 to 3 aftercare
Inception and briefing	Initial induction with design team & client: specification, roles, and procedures finalised		L	M	M	L	■				
	Review of analogues (best practice)		L	M	M	M	■				
	Set in-use performance targets (energy, CO_2)		L	H	H	M		■			
	Review design compliance with standards (CSH, passivhouse, etc.)		L	L	M	M		■			
Design and construction audits	Review: energy calculations, drawings to compare 'as designed' & 'as built'		L	L	M	M			■		
	Developer diaries including photographic diary		L	M	L	M			■		
	Review of metering and sub-metering strategy		L	M	M	M			■		
	Semi-structured interviews with occupants (within 3-6 months)		L	H	M	L				■	
	Semi-structured interviews with design team (within 3-6 months)		M	H	M	L				■	
	Walkthroughs with design team, client and developer (within 3-6 months)		M	H	M	L				■	
	Photographic survey and analysis		L	L	L	L				■	
Review of the commissioning process and handover	Review of systems commissioning and installation		L	L	M	M			■		
	Review of monitoring/data recording equipment		L	L	M	M			■		
	Review of arrangements for aftercare, maintenance, operation		L	L	M	M			■		
	Evaluation of handover data (Home User Guide, O&M manuals, logbook)		L	L	M	L			■		
	Observation of building induction and handover to users		M	M	M	L			■		
Fabric Testing	Air permeability test		L	M	M	L			■		
	Air leakage identification		L	M	M	L			■		
	Co-heating (whole house heat loss) test	These methods produce better results if they are undertaken simultaneously	H	H	H	H			■		
	Tracer gas test		M	M	H	H			■		
	Infra-red thermography		L	L	H	L			■		
	In situ U-value measurement		M	M	H	M			■		
	Party wall by-pass test		M	M	H	H			■		
	Wall moisture content		M	M	H	H			■		
	Diagnostic investigations of specific aspects (e.g. thermal bridging)		M	M	H	M			■		

Assessment of energy use	Walkthrough energy (forensic) survey and photographic survey	L	L	L	L					
	Services performance testing and evaluation	M	M	H	M					
	Smart metering of utilities	M	M	H	M					
	Sub-metering of individual electricity circuits	H	M	H	M					
	Electrical appliances energy use assessment using a true power-meter	L	L	M	L					
	Energy assessment and reporting - Preliminary audit	L	L	L	L					
	Energy assessment and reporting - Detailed audit	L	L	M	M					
	Data from monitoring BMS system	L	M	M	H					
	Energy use and performance of Mechanical Ventilation systems	M	M	M	M					
	Performance of microgeneration technologies	H	M	H	H					
Monitoring & Evaluation of Environmental conditions	Spot checks and recording measurements (Temp, RH, CO2, light, sound)	L	L	L	L					
	Continuous monitoring of internal environmental conditions (Temp, RH, CO2)	H	M	H	H					
	Continuous monitoring of external environmental conditions (Temp, RH)	M	M	M	H					
	Monitoring of use of windows, doors and other openings by occupants	H	M	H	H					
	Occupancy levels using Passive Infrared (PIR) Detector	M	M	M	H					
	Occupancy patterns and space use using Radio Frequency technology	H	M	H	H					
	Continuous monitoring of external climatic conditions (weather station)	H	M	H	H					
	Measurement of indoor Air Quality (VOCs, NOx, etc.)	H	M	H	H					
	Ventilation check (effectiveness of mechanical ventilation air flow rates)	M	M	H	H					
Occupant Feedback	Occupant satisfaction questionnaire	L	L	L	L					
	Interviews with occupants/staff (12-24 month)	L	M	M	L					
	Structured interviews with management (usability, maintenance, etc.)	L	M	M	L					
	Walkthroughs with occupants/staff	L	M	M	L					
	Occupant text diaries	L	H	L	M					
	Occupant normalisation sheets (with interviews)	L	H	L	M					
	Photographic audits by occupant	L	H	L	M					
	Video audits by occupant	M	H	L	M					
	Focus groups with stakeholders	M	H	M	M					

The methods and techniques in Table 5 are categorised under the following study elements, which are aligned with the different life stages of a building.

- Design and construction audits
- Evaluation of handover and commissioning processes
- Post construction fabric testing
- Energy assessment and benchmarking
- In-use monitoring of internal and external environmental parameters
- Occupancy evaluation on behaviour, perceptions, comfort and satisfaction levels

The study elements such as d*esign and construction audit* and *review of handover process and commissioning* help to identify the gap between 'as-designed' and 'as-built' performance. This is done by capturing the 'as-built' performance of the building envelope and installed equipment and how occupants react to it including the effectiveness of the handover process. The following text describes in more detail how the BPE study elements may be aligned with the Soft Landings framework.

Inception and briefing: Stage of preparing, evaluating precedents, and preparing the plan to avoid the performance gap at every following stage.

Design and construction audit: The most common methods used in this stage are the review of 'as-designed' versus 'as-built' drawings and energy performance calculations, followed by a forensic photographic survey. To compare design intentions with final performance, qualitative semi-structured interviews and walkthroughs are undertaken with the design team, occupants and building owners at the early occupation stage. Design and construction audit techniques can be applied at the design development, pre-handover and initial aftercare stages of the Soft Landings framework.

Review of commissioning and handover: The main purpose of a commissioning review is to review the system design, installation and commissioning checks of all services (mechanical and electrical) and systems (lighting, heating, cooling and ventilation) provided to the building, including measurement of the performance and energy use of any mechanical ventilation system. This ensures that the operational strategy is likely to deliver the desired performance and comfort for the occupants. The effectiveness of the handover process (introduction of occupants/users to the equipment and functioning of the building by the design and building team) is evaluated through available data (user guides, building logbooks etc.) and also directly observed. The handover process is usually evaluated in terms of clarity, communication and user engagement. These techniques can be implemented soon after the construction is complete and in the initial stages of handover and occupation (Pre-handover stage).

Fabric Testing: Measuring the performance of the building fabric 'as-built' is vital in quantifying the performance gap. A portfolio of diagnostic techniques is available for fabric testing which measure air tightness, insulation performance and occurrence of thermal bridging, given that thermal bridges can represent more than 30% of heat loss in a well-insulated building (Wingfield *et al.*, 2011). Infra-red thermography provides an infra-red image which gives an indication of surface temperatures and can enable thermal anomalies in construction to be identified. The technique is particularly effective in combination with other techniques, for example during an air permeability test, by directing the use of smoke test to specific areas of the building, focusing attention on construction details that may be performing poorly.

The following evaluation categories of 'assessment of annual energy use', 'in use monitoring' and 'occupancy evaluation' occur in the Soft Landings stage of Initial Aftercare and Year 1-3 Aftercare.

Assessment of annual energy use: The assessment of energy use, a key objective in many BPE studies, can be carried out for any building after one year of occupation. The authors found that quantitative techniques such as monitoring utility consumption and renewable performance were far more prevalent than techniques like spot checks, walk through surveys and energy assessment of electrical appliances. Quantitative measures reveal the 'what' without revealing the 'why'; cost effective techniques like walk through surveys with key stakeholders play an important role in revealing the cause behind consumption patterns and in fine tuning performance. The combination of these measures should be included in all BPE studies.

In-Use monitoring: These methods can range from monitoring basic internal and external environmental conditions – temperature, relative humidity and CO_2 levels to complex and expensive monitoring of indoor air quality, MVHR performance, fenestration usage and occupancy detection. The techniques adopted for a specific BPE study are dependent on the specific focus of the study; equipment and installation limitations; resources to analyse and compare monitored data. It was found that intensive monitoring methods are more common in domestic approaches. This may be due to the fact that most large scale non-domestic buildings have Building Management Systems (BMS) which have inbuilt monitoring capabilities.

Occupant Feedback: Qualitative feedback from occupants is crucial to any BPE study and could take place through a variety of techniques at any time after initial occupation. However, it was found that some techniques like building survey questionnaires and interviews far outweigh intensive techniques like logbooks, video diaries or focus groups. The intensity of time and expertise needed to correlate logbooks with monitoring data, along with the high levels of occupant commitment required for collecting such data explains the apparent unpopularity of these techniques. They may be best reserved for studying specific behaviours or systems.

Overall the most predominant techniques were building questionnaires, metered utilities, interviews with occupants, monitoring of internal and external environmental conditions, performance of MVHR and micro generation technologies, air permeability testing, review of building demonstration and systems commissioning. The prevalence of some techniques over others is often attributable to the ease of use and available experience at both the data collection and analysis stages. Techniques where standardised approaches for implementation and analysis exist, like Building User Survey Questionnaires for occupant feedback, are more likely to be widely used. Effective techniques like spot checks and walkthroughs which are vital to understanding the reasons behind a certain performance are not adequately explored, perhaps due to the level of expertise required for such on-site analysis.

4. Developing the BPE framework

As shown in Table 5, although there is a growing portfolio of BPE methods and techniques available to address the performance gap in different building stages, there is a lack of consistency and consensus on which method is to be used, and when. This brings about confusion in data collection, analysis and reporting of findings, making BPE a fragmented whole. To ensure wider applicability and consistency and tackle requirements of different BPE studies, a series of ‘BPE frameworks’ (consisting of suitable BPE methods) need to be developed, adopting a hierarchal approach in the form of a framework following the principle of ‘need to know’ versus ‘nice to have’. Such a ‘BPE framework’ also needs to be multi-dimensional and align with different stages within a building life cycle (with different technical and design complexities) to enable continuous evaluation and improvement, as shown in Figure 3.

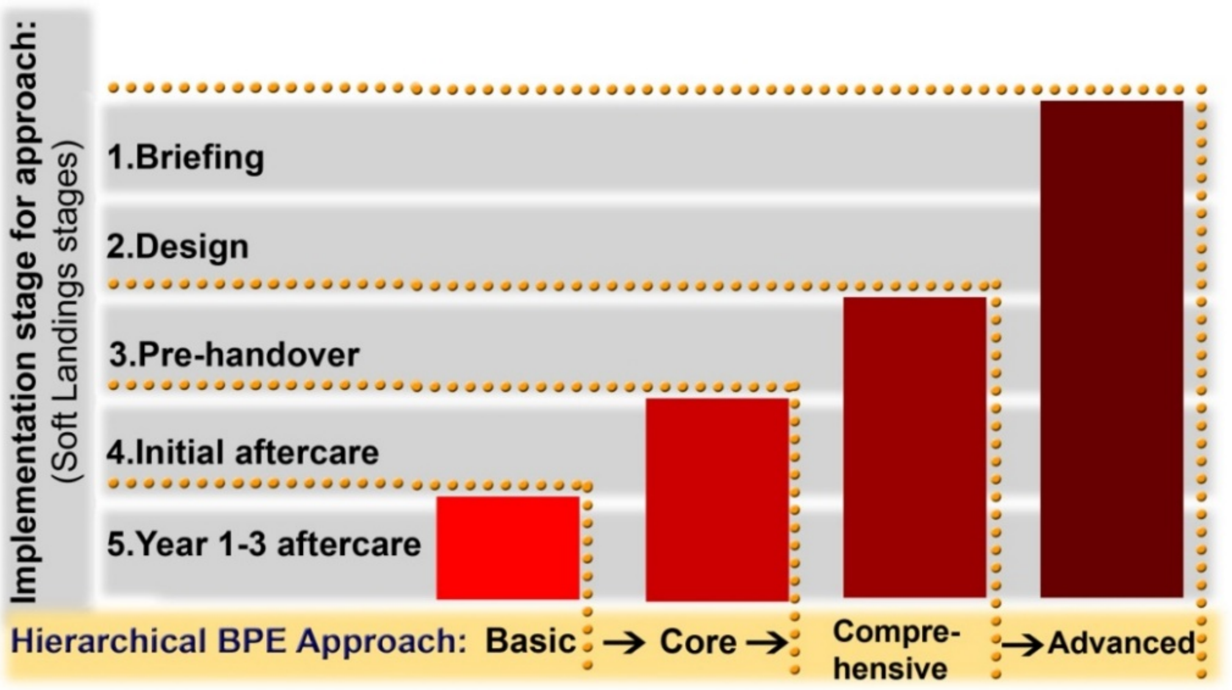

Figure 3. BPE framework aligned with Soft Landings stages

The proposed BPE framework is applicable to new-build, refurbishments and existing buildings (Figure 4). However, the study elements, *design and construction audit* and *review of handover process*, are only applicable to new-build and refurbishments, as reflected in Figure 4. The framework adopts a graduated approach comprising Levels 1-4, progressing from *basic* to *core, comprehensive* and *advanced* levels of investigation, dependent on the building lifecycle stage, depth and duration of BPE investigation and the resources available (cost of equipment and personnel, and technical expertise required).

A series of established and robust BPE methods and techniques are suggested for each level across teh different BPE study elements (Figure 4).

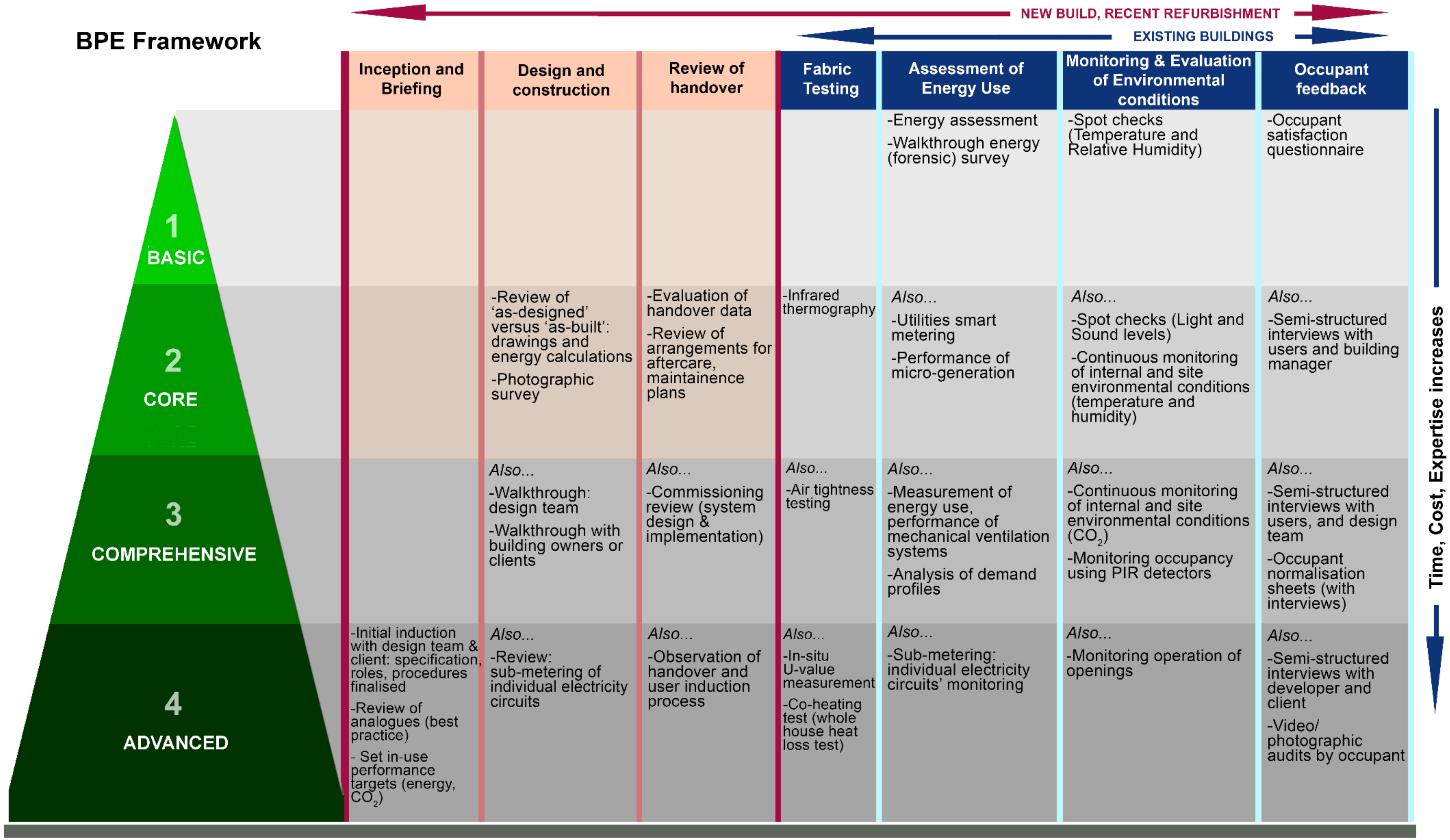

Figure 4. BPE framework showing the hierarchical approach and methods.

Level 1 - Basic level (typical BPE): involves the three most popular BPE techniques usually applied at the in-use stage: energy assessment using meter readings, walkthrough (forensic) survey, and an occupant satisfaction questionnaire. This indicative level of investigation establishes the overall performance of a building and requires minimum cost, time and expertise. It is also suitable for quick evaluations in large scale developments. This approach may be used as a preliminary step whose results reveal whether an in-depth evaluation will follow. The indicative time required for this approach is one season - cooling or heating season depending on which season is more energy intensive in the local climate.

Level 2 - Core level: is an investigative level usually implemented immediately after occupation of the building (for new builds and refurbishments). This level (for new build, refurbishments and existing buildings) also includes thermography to assess the fabric performance, smart metering of utilities and continuous monitoring of internal (and external) environmental conditions (temperature, and relative humidity), and semi-structured interviews with the design team, building manager and users. In addition, for new-build and refurbishments, design & construction review, photographic survey, review of handover data (logbooks, user manuals) and review of arrangements for aftercare and maintenance, are also included. This level requires monitoring kit (data loggers, hobos) to be installed in the building. The core level is usually undertaken over a year to include one heating and cooling season; studies spanning more than a year tend to provide insights into building performance caused by external conditions like weather.

Level 3 - Comprehensive level: adopts a diagnostic approach and is usually applied at the pre-handover (construction) stage. The additional techniques included in this level is continuous monitoring of internal CO_2 levels (as well as temperature and relative humidity), long-term performance of micro-generation technologies (solar photovoltaics, solar thermal, heat pump, micro-CHP etc) and energy performance of mechanical ventilation systems, as well as studying demand profiles (usually in non-domestic buildings). To contextualise the findings, occupancy monitoring is undertaken using Passive Infrared Device (PID) sensors and activity log sheets are also completed by occupants (in summer and winter). To assess usability and manageability, survey of user controls is also undertaken along with spot checks and measurement of temperature, relative humidity, light and noise levels in different parts of the case study building. Particularly for new-build and refurbishments, walkthroughs are undertaken with the design team and building owner, and metering and sub-metering arrangements are reviewed. Handover and induction processes are also observed and evaluated. This level of investigation requires sophisticated monitoring kit (which is able provide data remotely), and expertise in analysing quantitative and qualitative data. It is typical to undertake a level 3 investigation for at least two years to cover two heating (or cooling) seasons. The level of commitment required from the design & construction team and occupants is higher than level 2.

Level 4 - Advanced level: tends to be used for detailed and longer-term investigation of specific items or inputs especially for pioneering/prototype projects where the lessons learnt are highly likely to feed forward into future projects and processes. In addition to what is done in Level 3, sub-metering of end uses of energy (space heating, hot water, cooling, lighting, plug loads etc) is undertaken to disaggregate usage of energy. Opening and closing of doors and windows is continuously monitored to understand user interaction and user behaviour. To determine the actual U-values, in-situ U-value tests are also undertaken for usually north-facing walls (in the Northern hemisphere) and party walls. Spot checks are undertaken to measure indoor air quality levels using sophisticated equipment. This is also cross related with the continuous measurement of CO_2 levels (which acts as a proxy for indoor air quality) and occupant feedback. To capture specific issues in the building, occupants are requested to make video or photographic diaries. For new-builds and refurbishments, whole building heat loss tests called as co-heating tests are undertaken along with thermography and tracer gas testing. The advanced level involves the most time, expertise and cost, often spanning for up to 3 years (or for the duration of the project). The approach requires a deep commitment from the initial stages of the project from the client, design team, contractors and occupants, but it tends to deliver useful results for everyone.

The BPE framework offers flexibility and customisation for different BPE studies in line with the depth of BPE investigation. It can also be used as a tool for cross-comparison of diverse BPE studies based on their stage of application, type and duration of BPE investigations. This is illustrated in Figure 5, wherein the BPE framework is plotted against the life cycle stage (aligned with Soft Landings) and duration of a BPE study. Potentially studies could even fall between two levels depending up on their scope and content. The BPE framework can also be used as a discussion tool with clients to determine the BPE approach most suitable for a certain building type.

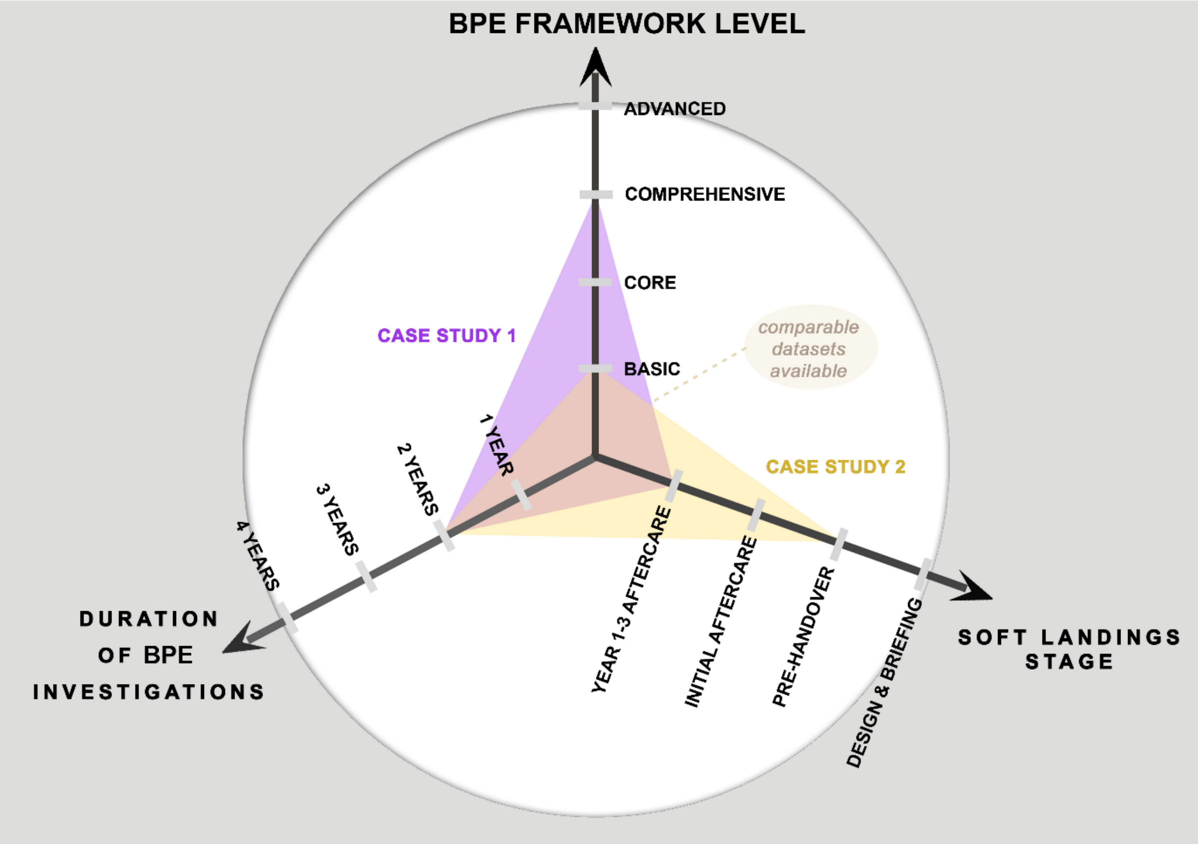

Figure 5. BPE framework tool.

5. Application of the BPE framework to case studies

The working of the BPE framework is demonstrated by applying them to the four published BPE studies by the authors covering domestic and non-domestic, new build and refurbishments, undertaken by the authors.

Project 1: BPE studies of non-domestic buildings as part of a post-graduate teaching module on building performance evaluation at Oxford Brookes University (Gupta, 2007; Gupta and Chandiwala, 2009)

About 50 non-domestic buildings in the UK have been evaluated as part of the BPE post-graduate teaching module taught to Master students at Oxford Brookes University. These studies focus on existing buildings which have been occupied for more than one year; take place over less than three months in the winter; and typically consist of energy assessment, Walkthrough (energy survey) and spot checks, and occupant satisfaction questionnaires. The energy audit is based on energy bills, weekly meter readings and appliance audits; energy consumption is normalised for weather, area and occupancy; and compared to a variety of benchmarks. Internal and external environmental conditions (temperature, relative humidity, CO_2, light and sound levels) are measured through spot checks, and data is assessed against industry benchmarks (CIBSE TM 46). Occupant feedback is collected through BUS questionnaires with occupants and facilities managers. These studies represent the application of a *level 1* or *Basic BPE* where minimal resources – time, equipment, experience is used to conduct an *indicative* evaluation of building performance. The findings include recommendations for improvement categorized by cost and disruption, and reveal issues which need further investigation.

Project 2: BPE study of Angmering Community Centre building, UK (Gupta *et al.*, 2017)

The performance evaluation of the Angmering Community Centre is part of a UK Government Funded program on BPE. The project commenced at initial occupation and ran for two years, covering the review of the handover, assessment of energy use, in-use monitoring, fabric testing, walkthroughs and qualitative feedback. The community centre is heated using Ground Source Heat Pumps which were monitored for their long-term performance. Initial findings included problems with handover, a lack of a defined trouble shooting mechanism and effective communication between stakeholders in the design and briefing stage, all of which have had a significant impact on operations. The Angmering Community Centre BPE is an example of *Level 2* or *Core BPE* which extends beyond the Basic level in the resources and time required for investigation; non-invasive fabric testing techniques like air permeability and thermography are used; the review of the handover process reveals the background of many operational issues.

Project 3: BPE study of low energy homes in Swindon, UK (Gupta *et al.*, 2018)
The study evaluated two low energy (CSH level 5) homes within a new low energy housing development in Swindon. The project ran for three years starting from the pre-handover stage and was funded by a UK Government programme. The main BPE methods used included design and construction audit, fabric testing, review of commissioning, handover, initial occupant feedback, in-use monitoring, assessment of energy use, fabric testing, walkthrough and occupant feedback questionnaire and interviews (at early occupancy and in-use). Walkthrough interviews were also conducted with the designers, builders and owners (local authority). The design and construction audit revealed significant differences in the fabric standards of different houses within the same development (design targets for air permeability for all homes was 3 $m^3/(h.m^2)$ but post-construction measured values varied from 5.27 $m^3/(h.m^2)$ in House A (depressurisation values) compared to 15.74 $m^3/(h.m^2)$ in House B). The reduced airtightness along with behavioural issues, augmented by a problematic handover, has led to a higher than expected energy consumption. The Swindon homes project is an example of the *Level 3* or *Comprehensive BPE* where a diagnostic framework is used to quantify and locate performance gaps by comparing the design intent with 'as-built' and 'in-use' conditions.

Project 4: BPE study of a deep low carbon domestic refurbishment in Oxford, UK (Gupta and Gregg, 2016)
Level 4 or *Advanced BPE* was applied to a deep and whole-house refurbishment of a Victorian, end-terrace house in Oxford, funded by UK Government's Retrofit for Future program. The project ran for over three years and started at the design and briefing stage with a pre-refurbishment BPE. This initial BPE quantified the actual energy consumption and environmental conditions of the dwelling prior to refurbishment. These findings combined with actual in-use characteristics derived from occupant feedback questionnaire and interview, informed the briefing and design stage, and helped to select appropriate user-centred refurbishment solutions. This also provided a reference for comparing the performance of the dwelling post-refurbishment. At the pre-handover stage, fabric testing (using thermography, air pressure testing) was conducted along with a review of commissioning and design and construction audit. The initial aftercare included a review of handover data, observation of handover and occupant feedback. Subsequently in the in-use stage, a sophisticated whole-house monitoring system was installed to measure environmental conditions (internally and externally), undertake smart metering of utilities and long-term performance of micro-generation systems (solar photovoltaics and solar thermal). A survey of user controls was also undertaken along with regular walkthroughs, interviews and activity log sheets with occupants. The first-year post-refurbishment registered an overall reduction of 68% and 23% in annual gas and electricity consumption respectively. Regular occupant feedback has helped in the detailed analysis of energy profiles and behaviour. This Oxford Retrofit project is an example of the *Advanced level* with feedback starting right from the briefing and design stage itself (pre-refurbishment) itself and running through all stages of a build process through post-refurbishment.

Each of these four BPE projects are mapped onto the *BPE framework* (Figure 6) to cross-compare their scope and illustrate how different studies may choose to cover varying depths of BPE investigations, depending on available resources, time, purpose of the study and sponsorship. The framework offers a useful lever to map different types of BPE studies with varying scope and content. The framework can also help to focus on 'need to know' rather than 'nice to have', thereby helping researchers, clients and building design team to select the appropriate BPE level to be adopted for future projects.

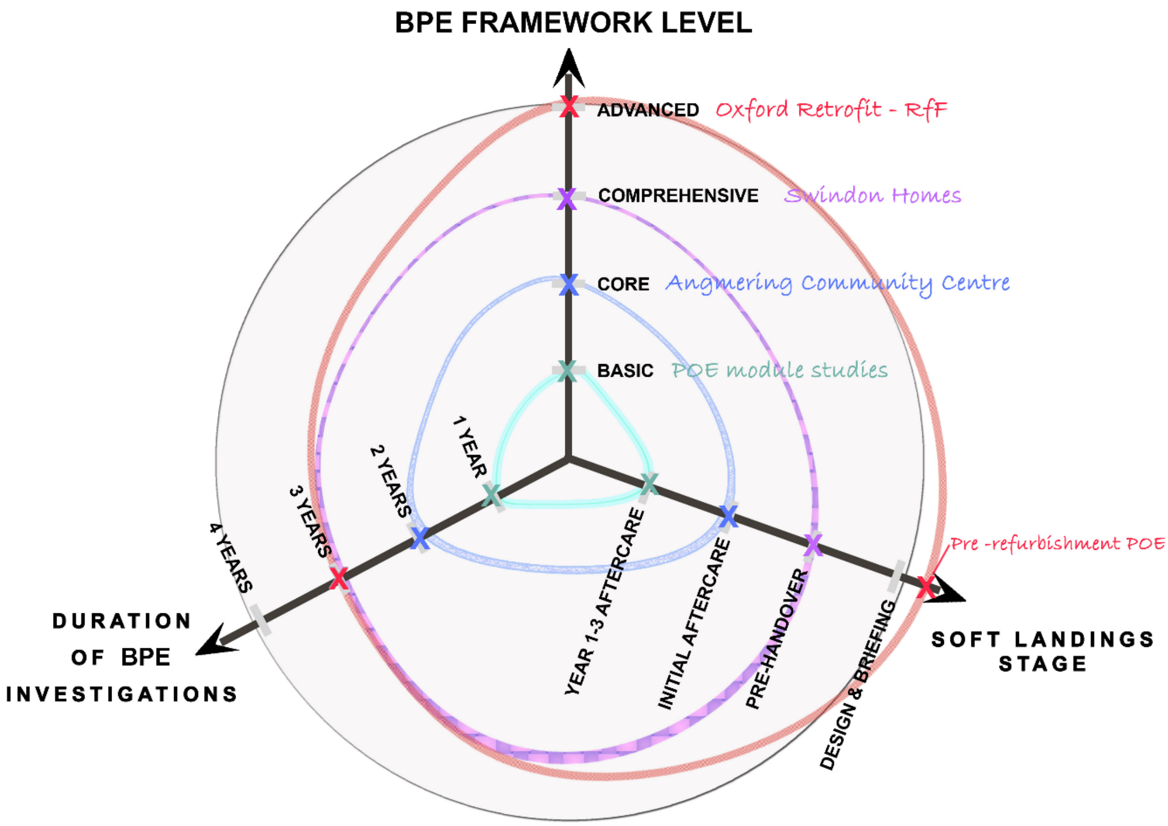

Figure 6. BPE framework tool showing the depth, extent and duration of BPE investigations of the sample BPE projects

6. Conclusion

It is increasingly recognised that the growing performance gaps between 'as-designed', 'as-built' performance and 'in-use' performance of low energy buildings have the potential to undermine national carbon reduction targets. BPE plays an important role in identifying and reducing these gaps for new builds, refurbishments and existing buildings, in order to improve building design, commissioning, maintenance and performance of that building(s) and future building design and performance. Situating the performance gaps within the building lifecycle reveals the importance of the Soft Landings framework which advocates a comprehensive BPE approach across different lifecycle stages of the building. It is clear that an effective BPE approach for new builds and refurbishments needs to span all lifecycle stages and include feedback from all stakeholders – owners, design team, construction & maintenance team, and occupants.

Existing BPE studies in the UK and globally, have been reviewed to reveal a high level of fragmentation within a rapidly growing field. The analysis confirms lack of market demand for BPE given that most of BPE studies are funded by Government and led by academia. Also, most of the focus in BPE has historically been on new-build domestic and non-domestic buildings, with some emerging studies evaluating investigations in refurbishments, and much less work on existing conventional buildings which form most of the stock. Methods and techniques drawn from these BPE studies have been systematically evaluated against cost, engagement with stakeholder group, ease of implementation, time required and corresponding lifecycle stages to understand the rationale behind the most popular and established techniques.

The proposed *BPE framework*, based on a four-level hierarchical but flexible approach can assist building owners, social housing providers, local authorities, private clients, consultants and researchers, across the world, to determine the appropriate level of BPE investigation that needs to be adopted for evaluating building performance in projects, depending on the purpose and resources available. The framework enables cross-comparison and harmonisation of the varying levels of BPE investigations that are being undertaken across the world. This is essential if evaluation of building performance has to be developed as a discipline;

Other benefits of such an approach are:

- Provision of standardised BPE levels facilitating consistency, accountability, transparency, and development of standardised data management tools, faster training for evaluators, reduction of investment risks (since the levels are based on empirical work).
- Mapping of BPE projects within the *BPE framework* will help the building industry identify gaps in the existing knowledge/data base.
- Using a framework will allow cross evaluation across sectors, creating an interlinked knowledge base towards improving overall building performance now, and in the future.
- The hierarchical framework allows BPE studies to be conducted with maximum impact within the existing restrictions and resources by focussing on techniques to collect and analyse 'need to know' variables rather than 'nice to have' variables.

Although the framework has been developed using work mostly done in the UK, the principles of the framework should be applicable to any new-build, refurbishment or existing building. Most importantly the framework offers flexibility and consistency in studying actual performance of buildings to minimise the gap between intent and outcomes.

Acknowledgement

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