Standard Protocols for Data Collection and Knowledge Acquisition

V4.0

By Roderic Bunn and Ian Orme

02 April 2014
Standard Protocols for Data Collection and Knowledge Acquisition

Carried out for: Construction Industry Council
26 Store Street
London
WC1E 7BT

Contract: Report Number 57264

Issued by: BSRIA Limited
Old Bracknell Lane West, Bracknell
Berkshire RG12 7AH UK

Telephone: +44 (0) 1344 465600
Fax: +44 (0) 1344 465626

Email: bsris@bsria.co.uk
Website: www.bsria.co.uk

QUALITY ASSURANCE

<table>
<thead>
<tr>
<th>Issue</th>
<th>Date</th>
<th>Prepared by:</th>
<th>Checked by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final</td>
<td>24/01/2014</td>
<td>Roderic Bunn</td>
<td>Ian Orme</td>
</tr>
<tr>
<td>Draft 2</td>
<td>08/11/2013</td>
<td>Roderic Bunn</td>
<td>Ian Orme</td>
</tr>
<tr>
<td>Draft 1</td>
<td>29/08/2013</td>
<td>Roderic Bunn</td>
<td>Ian Orme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Building Performance</td>
<td>Head of Consultancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analyst</td>
<td>&amp; Research</td>
</tr>
</tbody>
</table>

DISCLAIMER

This report must not be reproduced except in full without the written approval of an executive director of BSRIA. It is only intended to be used within the context described in the text.

This report has been prepared by BSRIA Limited, with reasonable skill, care and diligence in accordance with BSRIA’s Quality Assurance and within the scope of our Terms and Conditions of Business.

This report is confidential to the client and we accept no responsibility of whatsoever nature to third parties to whom this report, or any part thereof, is made known. Any such party relies on the report at its own risk.
EXECUTIVE SUMMARY

BSRIA has undertaken a desk study on behalf of the Green Construction Board (GCB) to identify the currently available standard protocols for data collection and knowledge acquisition. The study has reviewed available literature and sought input from recognised leaders in the area of building performance evaluation. This report and its associated Data Protocols Matrix provides a response to the requirements of the Green Construction Board’s (GCB) brief for mapping standard protocols for data collection and knowledge acquisition methods that are used to understand building performance. This report pulls from a number of sources:

- Literature review of protocol sources, journal articles, conference papers, and reports
- Survey of academic and government departments, know to own, be developing, or be using data and knowledge acquisition tools
- A workshop of known experts and practitioners to identify the key tools and protocols in use or in development for buildings and infrastructure projects
- On line surveys of individuals active in building performance evaluation and assessing life-cycle carbon and life-cycle costing
- Experience of previous research projects such as PROBE (Post-occupancy Review of Buildings and their Engineering), the Carbon Trust Low Carbon Buildings Performance (LCBP) and low Carbon Buildings Accelerator (LCBA) programmes
- Initial tools funded under the TSB Design and Decision tools programme
- Experience from current TSB Building Performance Evaluation (BPE) and Invest in Innovative Refurbishment (IIR) research programmes.

The study has indicated that currently there are a limited number of protocols available, and that in the main these are associated with the consistent reporting of greenhouse gas emissions. The study has considered and proposed definitions within the area of building performance evaluation for protocol; method and tool. Consideration has been given to the nature and types of data currently collected and sought to identify any gaps within current practices. Whilst the energy performance of buildings, their installed systems and occupant behaviour have been studied since the mid-1970s, little effort has been put in to ensuring a consistent approach to the evaluation processes. Measurements can be made, systems tested and processes studied but without agreed protocols and methods the value of the understanding that can be developed is lost to the wider industry.

The most recent work, funded via the Technology Strategy Board’s (TSB) Innovative Buildings platform has encouraged participants to undertake a number of measurements using consistent approaches to gather data on the buildings performance and report the findings consistently. These have included measurements on the performance of the building fabric (heat flux, thermal imaging and in domestic projects a co-heating test); collecting data on energy consumption at a building and a system level with analysis using CIBSE TM 22 method; semi-structured interviews and questionnaires to help determine occupants satisfaction with the building and its environment, and a standardised reporting method using templates.
The Evaluators appointed by TSB have noted that nearly all teams have faced a number of challenges in following the prescribed methods including: failure of logging equipment and metering; limited processes for cleaning and checking data prior to analyses; varying levels of understanding in interpreting the measured data, and a limited understanding within the project team of the measurement techniques. It is acknowledged that one of the aims of the TSB programme is to build a greater knowledge base and help ‘flow’ the skills from the limited number of Evaluators into the wider industry. However, the difficulties experienced over collecting data and the confidence in the data, simply high-light the immaturity in the market.

The industry workshop was successful at bringing together practitioners from various branches of building and infrastructure performance analysis. The workshop sessions were used to identify frequently used methods and tools for collecting and analysing data in the following areas:

- Operational energy and carbon dioxide analysis
- Infrastructure works
- Human factors
- Construction process tools
- Physical measurements

Participants were asked to consider the use of these methods alongside the commercial realities of using data tools and templates and communicating the results to clients.

Although it was intended to identify the most frequently used tools in the key topic areas, delegates regularly identified more, although the details of procedures became more sketchy and anecdotal beyond the top two or three methods or tools. Although delegates were often aware of a particular tool, experience tended to be confined to the top one or two tools, procedures or (particularly in the case of carbon assessments) a published protocol. Regulatory requirements, such as airtightness testing and energy performance certification, were frequently acknowledged as processes by which data about a specific aspect of a building's performance were gathered.

The main tools used for building performance data collection and knowledge acquisition tended to be those championed and developed within government-funded research such as the Energy Efficiency Best Practice programme, PROBE, Carbon Trust and Technology Strategy Board programmes. In general, the tools with greatest visibility and practical application tended to be those with government patronage or backing, tools that are commercially available, and tools and procedures for which benchmarks are available.

The workshop delegates identified that training and technical support is vital for the continued development and use of a method or tool. Where this is lacking tools and methods quickly fall out of use. With the current limited market for building performance evaluation all tools and methods tend to be known to a small group of consultants, and in some instances for example the Leesman Index, practitioners become registered to demonstrate their skill level and expertise.
On-line surveys of academia and central government departments were not wholly successful at identifying tools and procedures beyond those already known and used by those working in the field of building performance evaluation.

Further work is needed to help establish appropriate methods for collection of energy and environmental data, particularly in the domestic sector, where the current approaches result in significant quantities of data without clear rules for data cleaning and analysis. An approach to this could be the development of a route-map for rolling-out core BPE methods for the non-domestic, domestic and infrastructure sectors, with meaningful short and medium-term targets consistent with the Government’s recommendations for delivering BPE as a component of Government Soft Landings.

Our initial concept for this project was the creation of an underlying schema and basic content of a Wiki whereby protocols, methods and tools could be searchable with links to relevant near-neighbour methodologies. This approach we believe still has value but further work on the management and curation of the Wiki is needed.

In reviewing our findings from this study we believe that there are a number of opportunities for the Green Construction Board to positively influence the wider adoption of the use of building performance evaluation and the allied use of data collection techniques and knowledge acquisition.

For building performance evaluation methods and tools to become main place in the construction industry specific modules and credits in architecture and building engineering courses need to be developed to introduce the industries young engineers and architects to the subject. The Green Construction Board is well placed to initiate discussions with the institutions via the Construction Industry Council to set a programme of work to achieve this outcome.

There is a growing community of building performance evaluators from both academia and commercial practice that have come together as a consequence of the government funding for the TSB innovative buildings programme and work around the Zero Carbon Hub. The practice of evaluating the performance of our buildings to develop a deeper understanding of how to achieve better performance is still at a ‘cottage industry’ stage, and will continue to need a level of support over the coming years if it is to develop into a mainstream activity. Ways of supporting this developing network that are shared between industry and government need to be explored, and the Green Construction Board could act as a host body to enable the development of ideas and routes to implementation.
TABLES

Table 1    Scope of performance issues covered by the data protocols scope of work (modified version of Table 1 from Low Carbon Routemap for the UK Built Environment) .................................................. 10
Table 2    Key terms and units of measurement ................................................................................................. 16
Table 3    Summary of Data Protocols and Knowledge Acquisition Matrix ......................................................... 18
Table 4    The primary tools for measuring building performance for the key topic areas in Building Performance Evaluation. Further details are provided in the appropriate section ..................... 30
Table 5    How operational energy, human factors and physical measurement activities map onto project plans, such as RIBA Plan of Work 2013 and Soft Landings stages .............................................. 74

APPENDICES

APPENDIX A: Building Operational energy tools .................................................................................................. 54
APPENDIX B: Carbon and infrastructure ........................................................................................................... 57
APPENDIX C: Physical measurement of building performance ................................................................. 59
APPENDIX D: Human factors in buildings ....................................................................................................... 62
APPENDIX E: Commercial realities for BPE .................................................................................................. 64
APPENDIX F: Industry workshop report ........................................................................................................ 66
1 INTRODUCTION

BSRIA has undertaken a desk study on behalf of the Green Construction Board (GCB) to identify the currently available standard protocols for data collection and knowledge acquisition. The study has reviewed available literature and sought input from recognised leaders in the area of building performance evaluation. This report and its associated Data Protocols Matrix provides a response to the requirements of the Green Construction Board’s (GCB) brief for mapping standard protocols for data collection and knowledge acquisition methods that are used to understand building performance.

All the approaches identified in this research have been entered into an interactive spreadsheet: Data Protocols and Knowledge Acquisition Matrix.xls, which should be read in conjunction with this report.

In most cases there was very little published evidence, testing or experience with building performance tools. An understanding of the use of each tool, their strengths and weaknesses and their future potential, was derived from anecdotal feedback. There is no single body or organisation that is either analysing the tools or responsible for their development. Similarly, there appears to be no organisation outside of academia consistently (other than TSB) applying the tools and learning from experience. Within academia a number of Universities, most notably, Leeds Met.; have been developing methods for measuring the performance of the building fabric in the domestic sector. The method uses a range of techniques to investigate the causes of the observed differences between the design estimation and the measured values. This work resulted in the publication of Leeds Met’s protocol for undertaking a co-heating test on a dwelling.

Building performance evaluation is a new and entirely separate knowledge domain which has no obvious professional home. Its practitioners come from a variety of backgrounds and professions, so no single professional body is responsible for the development of protocols, tools and methodologies. The process by which such things are developed is largely unstructured, occurs within a policy vacuum, and has tended to be championed by a small band of enthusiastic individuals, many of whom are now working as BPE evaluators contracted to contemporary TSB research programmes.

1.1 BACKGROUND

Energy consumed in constructing, maintaining and using the built environment – buildings and infrastructure – is a significant contributor to greenhouse gas (GHG) emissions. It is estimated that energy use (regulated and unregulated) in domestic and non-domestic buildings alone accounts for 36 per cent of the UK’s GHG emissions. Transport represents 24 per cent while industrial emissions are about 22 per cent. A considerable portion of these emissions are to support the supply chain and construction activities for the built environment.

The Green Construction Board’s Low Carbon Routemap for the UK Built Environment, shows energy consumption in non-domestic buildings for 2010 in Figure 1. Heating is the most dominant energy consumption at 58 per cent, but lighting is also significant at 25 per cent. In part, this project was
commissioned in response to a lack of understanding of the real energy and carbon emission performance of built assets as shown in Figures 1 and 2, and the consequences on the people that use the buildings.

<table>
<thead>
<tr>
<th>Category</th>
<th>Cooling and ventilation</th>
<th>Hot water</th>
<th>Heating</th>
<th>Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail</td>
<td>3.4</td>
<td>1.8</td>
<td>12.5</td>
<td>13.8</td>
</tr>
<tr>
<td>Education</td>
<td>3.1</td>
<td>3.8</td>
<td>16.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Warehouses</td>
<td>1.1</td>
<td>1.1</td>
<td>12.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Hotel and Catering</td>
<td>3.2</td>
<td>4.2</td>
<td>8.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Government</td>
<td>3.5</td>
<td>5.5</td>
<td>12.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Health</td>
<td>1.3</td>
<td>3.0</td>
<td>11.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Commercial Offices</td>
<td>3.9</td>
<td>1.3</td>
<td>9.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Other</td>
<td>4.8</td>
<td>3.3</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Sport and Leisure</td>
<td>8.5</td>
<td>3.5</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Communication and Transport</td>
<td>1.3</td>
<td>2.4</td>
<td>1.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Figure 1 Non-Domestic Regulated Energy Use (TWh) in 2010. (Source Low Carbon Routemap for the UK Built Environment)

Figure 2: Capital carbon represents about 18 per cent of the total emissions in the built environment. Materials account for over 50 per cent of capital carbon emissions. Source: Low Carbon Routemap for the UK Built Environment
Table 1 Scope of performance issues covered by the data protocols scope of work
(modified version of Table 1 from Low Carbon Routemap for the UK Built Environment)

<table>
<thead>
<tr>
<th>High level</th>
<th>Mid level</th>
<th>Capital carbon</th>
<th>Operational energy carbon emissions</th>
<th>In</th>
<th>In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic buildings</td>
<td>Housing</td>
<td>Construction of new housing</td>
<td>Heating</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Refurbishment of housing</td>
<td>Housing refurbishment (not maintenance)</td>
<td>Cooling</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Non-domestic buildings</td>
<td>Public buildings</td>
<td></td>
<td>Heating</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td></td>
<td>Cooling</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td></td>
<td>Hot water</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Retail and distribution</td>
<td></td>
<td>Ventilation</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Refurbishment of non-domestic buildings</td>
<td></td>
<td>Lighting</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unregulated electricity</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Energy and associated carbon dioxide emissions</td>
<td>Construction works</td>
<td>Electricity</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Telecommunications</td>
<td>Communications networks</td>
<td>Use of telecommunications</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Construction works</td>
<td>Water supplies and sewerage</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Transport</td>
<td>Construction and use of transport networks</td>
<td>Vehicle emissions</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Waste</td>
<td>Construction of waste treatment</td>
<td>Emissions from waste treatment</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Refurbishment of infrastructure</td>
<td>Infrastructure refurbishment (not maintenance)</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Post-occupancy research of completed non-domestic buildings, from the PROBE project through to the Building Performance Evaluation (BPE) research funded through the Technology Strategy Board, has consistently found a significant gap between energy use and carbon dioxide emissions estimated in the early stages of design, and the actual energy and carbon emission outcomes. In many cases the disparity is a factor of three higher, and in the worst cases upwards of a factor of five. In addition, it is often found that between 30-50% of the energy used in non-domestic buildings can be at night or outside of normal occupied hours. The reasons can be many and varied, but in general the consumption is due to wasteful running of heating, ventilation, refrigeration and lighting systems.

In the domestic sector studies\(^1\) undertaken at Elm Tree Mews in 2010 for the Joseph Rowntree Foundation highlighted similar problems to the non-domestic sector. More recent studies undertaken by the Zero Carbon Hub have highlighted the gap between the estimated performance of the home at the design stage and the actual performance when built and occupied\(^2\). Their most recent report *Closing the Gap between Design and As-Built Performance, Evidence Review Report*\(^3\) has highlighted the common issues of a lack of communication of the design intent; a lack of ownership of the energy performance requirements and the deeper lack of skills and knowledge in the industry over the energy performance issues.

\(^1\) Low Carbon Housing, Lessons from Elm Tree Mews, Bell et al, November 2010
\(^2\) Carbon Compliance for Tomorrow’s New Homes, Zero Carbon Hub, July 2010
\(^3\) Closing the Gap between Design and As-Built Performance, Evidence Review Report, Zero Carbon Hub, March 2014
Building Performance Evaluation (BPE) is a relatively new term. It was coined during the preparation phase for what became the TSB’s Building Performance Evaluation research programme in order to distinguish the act of studying buildings at any time in their lives (from inception to occupation) compared with the more specific process of post-occupancy evaluation (POE). In Richard Reid’s briefing paper for the Industry Workshop (see Appendix E) he observed that client’s often do not understand the terminology of BPE and are confused over the services being offered under the different banner headings.

BPE can be carried out at any time, using whatever scientific, statistical, anecdotal or procedural method is regarded as appropriate to use in the specific context. The building blocks of BPE for non-domestic projects, as adopted by the TSB research programme, are shown in Figure 3. Essentially, the bedrock of BPE is a cradle-to-operation set of responsibilities, where the client and project team are aiming for specific performance outcomes, and a facility exists for the project team to undertake before and after investigations in order to set objectives, then subsequently to fine-tune a building up to three years after handover. In this context POE is but a small part in the overall BPE process.

For domestic projects a greater emphasis has been placed on the performance of the building fabric, in part a response to the ‘fabric first’ approach that many home designers have taken to meeting the requirements of the Code for Sustainable Homes. An initial review of the domestic BPE projects4 funded via the TSB has highlighted that the domestic sector supply chain has struggled with the integration and engineering requirements of more complex building services installation. Frequent issues have arisen with particular technologies such as MVHR, but the issue here is the lack of skill in carrying out the commissioning measurements in accordance with the documented method using calibrated measurement equipment.

The investigations have also focused on the handover procedures to occupants and the level of understanding that is gained on how to best operate the installed systems. Similar challenges to the non-domestic sector have been experienced with a variability to the interpretation of the TSB suggested approaches and the level of forensic investigation that has been possible.

The on-going work by the Zero Carbon Hub on the Design vs As-built Testing and measurement work group has further highlighted the challenges of developing an agreed set of measurements to carry out, the methods to use and how to best share the knowledge. The final report for the project is expected in June 2014.

---

4 Low Carbon Homes, April 2013, to be published by the Technology Strategy Board
Figure 3 The fundamental building blocks of BPE, as adopted in 2010 by the Technology Strategy Board’s Building Performance Evaluation research programme for non-domestic building evaluations. The BPE programme has led to a set of reporting templates.

The qualities needed for BPE (and POE for that matter) are shown in the foundations of Figure 3. The data collection processes are the techniques that can be adopted to understand how a building is working (knowledge acquisition) are shown in the core requirements. “Other appropriate methods” acknowledges a wide range of things that can be done, from assessment of as-built drawings to structured interviews with contractors and project stakeholders. Diplomacy, tact, discretion (and also persistence) are key virtues in both BPE and POE. None of these attributes are easily taught.

Analysis and reporting of the data are just as important as the use of the methods and tools used to collect the data. Hence the focus on consistency, transparency, comparability in reporting (vital in use of terms and units of measurement) and accessibility to the results for all those who need to learn from the outputs. Non-technical audiences need to be accommodated.

Building performance evaluation does not fit within the normal industry classifications: it spans the professions (architecture, services engineering and facilities management) and it is multidisciplinary, often to a confusing extent. While it draws on laboratory research it is predominantly about empirical field work, visiting and studying real buildings in use and talking to real people.

It is vital that professionals involved in the design, construction and operation of buildings gain the skills to both measure building performance issues and act on the results. To this end the Green Construction Board sought to identify the standard protocols for data collection and knowledge acquisition used to generate feedback on building performance. By standardising the protocols, measurement methods and metrics (both quantitative and qualitative), the GCB hopes to improve comparability of performance across the built environment. In turn, it is hoped that this would encourage an increase in the voluntary collection of data and assist with the development of suitable performance metrics.
1.2 GCB420: PROJECT AIMS AND OBJECTIVES

Project objectives
To review what data collection and analysis protocols are available, and what needs to be done to develop them to produce effective tools for the generation of high quality knowledge and understanding.

Additional aims
To help inform the debate about setting clear targets for building performance, key metrics and setting outcomes. GCB intends to encourage the industry towards the greater use of voluntary data collection and assessment of building performance.

Project Scope
BSRIA has undertaken a review of available literature to identify common protocols for data collection and knowledge acquisition that covers both quantitative and qualitative approaches for:

- Operational energy (carbon dioxide emissions)
- Performance of fabric and services
- User satisfaction
- Specific organisational factors (e.g., related to building typology, such as issues related to user surveys in domestic dwellings and other potentially invasive forms of data gathering)
- Embodied energy and carbon dioxide performance

BSRIA has also sought to:
- Identify areas of best practice and the conditions required for it to become routine
- Identify the potential gaps and barriers (both methodological and technical)
- Address dissemination issues
- Identify commercial sensitivities
- Point out ethical sensitivities, such as data anonymity and survey confidentiality
- Identify the need and desire for a knowledge hub/network (a community of practice) to inform education and training for better built environment outcomes.

1.3 DEFINITION OF TERMS

For the purposes of assessment by the Green Construction Board, the approaches listed in this report have been classified as being a protocol, a method or tool. The categorisation is an attempt to apply order to approaches that have been developed at different times for different purposes over a long period. The methods and tools described herein do not always therefore fit easily or logically into the categories. By virtue of their longevity and/or industry and institutional championing, some tools have become the accepted methods, and therefore a de facto industry standard.

Protocol
A documented set of primary requirements for data collection to be used in the evaluation of the performance of a built asset. A protocol may have either regulatory provenance, or some other level
of authority recognised and accepted by the construction market and its clients. At present, there are few protocols for Building Performance Evaluation.

**Method**
A documented building assessment procedure for meeting the requirements of a protocol, which is accepted by the construction community as a de facto standard. A methodology may lay down all or some of the following: the data collection method, analysis techniques, units of measurement, calculation method, carbon dioxide conversion factors, and possibly reporting conventions.

**Tool**
A procedure, either open-source or a commercial product, that enables a specific building assessment to be conducted in line with the accepted approach (in terms of data collection, analysis technique, units of measurement, calculation method and reporting conventions).

**Data**
In the context of building performance evaluation data can be collected around a range of characteristics that can be measured (as described in Jez Wingfield’s briefing paper – Physical Measurements of Building Performance (domestic and non-domestic buildings), see Appendix C) and human factors, as described in Adrian Leaman’s paper (Appendix B). In summary, data may be:

- Dimensions – e.g. size, shape, orientation, tolerances, floor areas, cavity widths, duct diameter, depth of loft insulation etc.
- Material properties – e.g. type of material, insulation thermal conductivity, emissivity, moisture content, bulk density etc.
- Building element properties – e.g. U-value, window air permeability, hot-box tests etc.
- Whole building properties – e.g. building heat loss, building air leakage, air temperature/humidity, indoor air quality, differential pressures etc.
- Services – e.g. heat flows, energy consumption, boiler efficiency, flow temperatures, flue gas, duct leakage, ventilation specific fan power, operation of controls, control set points, thermostat hysteresis etc.
- Process issues – e.g. build sequencing, drawing conflicts, specification/drawing errors, lack of availability of materials, ad-hoc design, training, provision of documentation, commissioning etc.
- Durability and time dependent factors – e.g. airtightness degradation over time, dust friction increase due to build-up of dust, mechanical ventilation with heat recovery (mvhr) filter changes, settlement of insulation, boiler servicing etc.
- Human need, attitudes, behaviour and the prevailing circumstances.
1.4 GLOSSARY OF TERMS AND UNITS

The following table (Table 2) lists the key terms and units used throughout this report and in the data protocols matrix. It does not include scientific definitions and conventions used in scientific testing, such as air and water tests and heat flows, other than those used for regulatory compliance.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Unit</th>
<th>Convention</th>
<th>Additional information</th>
<th>Also see</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air change rate</td>
<td>ac/h</td>
<td>The volume of air in a space changed per hour</td>
<td>Mechanical ventilation systems can recycle internal air</td>
<td></td>
</tr>
<tr>
<td>Air permeability</td>
<td>m³/(h.m²)@50 Pa</td>
<td>Measure of airtightness of the building fabric. Testing usually conducted at 50 Pascals</td>
<td>Values for building types expressed as air permeability. Minimum requirements established for new construction via Building Regulations, Part L</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>m²</td>
<td>For non-domestic buildings, gross internal area (GIA) measured to the internal face of the perimeter walls. Can also be Treated Floor Area (TFA) to account for unheated areas.</td>
<td>SBEM and SAP documents define relevant floor areas for energy performance assessment required by Part L.</td>
<td></td>
</tr>
<tr>
<td>Boiler efficiency</td>
<td>%</td>
<td>Energy delivered by the water as it leaves the heat raising system to supply the emitters, divided by the gross calorific value of the energy in the heat raising fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon (embodied)</td>
<td>kgCO₂/kg</td>
<td>The sum of all fuel-related carbon emissions and process-related carbon emissions</td>
<td></td>
<td>See all ‘cradle-to’ factors</td>
</tr>
<tr>
<td>Carbon dioxide (operational)</td>
<td>kgCO₂/m²</td>
<td>Usually expressed per annum</td>
<td>Depends on definition of m². Some methods define internal areas differently</td>
<td>Area</td>
</tr>
<tr>
<td>Carbon dioxide (equivalent)</td>
<td>CO₂e</td>
<td>To cater for different fuels</td>
<td>With regard to the specific environmental effects of each greenhouse gas</td>
<td>Global warming potential</td>
</tr>
<tr>
<td>Carbon emissions factor</td>
<td>kgCO₂/kWh</td>
<td>Usually expressed per annum</td>
<td>Different factors used by DCLG and Defra reflecting actual mix of fuels to generate electricity and expected mix of fuels going forward.</td>
<td></td>
</tr>
<tr>
<td>Cradle-to-gate</td>
<td></td>
<td>All input and output flows (as applicable from system boundaries) between the confines of the cradle up to the factory gate of the final processing operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cradle-to-gate plus end of life</td>
<td></td>
<td>Cradle-to-gate plus the end of life processes, excluding the use phase</td>
<td>Cradle-to-gate</td>
<td></td>
</tr>
<tr>
<td>Cradle-to-grave</td>
<td></td>
<td>Cradle-to-gate plus operation, plus end-of-life processes</td>
<td>Cradle-to-gate plus end of life</td>
<td></td>
</tr>
<tr>
<td>Electrical load</td>
<td>W/m²</td>
<td>Regulated and unregulated electrical loads (lights, pumps, fans and controls)</td>
<td>Depends on definition of m². Some methods define internal areas differently</td>
<td>Area</td>
</tr>
<tr>
<td>Energy</td>
<td>kWh/m²</td>
<td>Usually expressed per annum</td>
<td>Depends on definition of m². Some methods define internal areas differently</td>
<td>Area</td>
</tr>
<tr>
<td>Topic</td>
<td>Unit</td>
<td>Convention</td>
<td>Additional information</td>
<td>Also see</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Energy</td>
<td>p/kWh</td>
<td>For energy costs</td>
<td>Depends on tariff and items included</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>kWh per pupil</td>
<td>No convention established. Used by some researchers to benchmark schools</td>
<td>Either of the two variables can change. (False conclusions can stem from no fixed point of reference).</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>kWh per bedroom</td>
<td>Used for hotels and residential developments such as student accommodation</td>
<td>Benchmarking complicated by electrical loads that differ between buildings</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>kWh per cell</td>
<td>Sometimes used as a metric for prisons and detention centres</td>
<td>Benchmarking less prone to variable electrical loads</td>
<td></td>
</tr>
<tr>
<td>Energy (embodied)</td>
<td>MJ/kg</td>
<td>Total primary energy consumed from direct and indirect processes associated with a product or service, and within the boundaries of cradle-to-gate</td>
<td>Most tools only focus on the impact of bulk structural materials at product stage, leading to underestimations for construction projects.</td>
<td>Cradle-to-gate</td>
</tr>
<tr>
<td>Fan power</td>
<td>W/(litres/s)</td>
<td>Specific fan power: total circuit watts of the fans that supply and exhaust air, including losses through switchgear and controls/ divided by the design air flow rate</td>
<td>Check for supply and extract fan power</td>
<td></td>
</tr>
<tr>
<td>Global warming potential</td>
<td>GWP</td>
<td>Emissions of greenhouse gases. Each gas is normalised to relative to the impacts of one unit of carbon dioxide</td>
<td>As defined by the Greenhouse Gas Protocol and PAS 2050:2011</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Greenhouse gas</td>
<td>GHG</td>
<td>Gases that absorb and emit thermal infrared radiation in the atmosphere</td>
<td></td>
<td>GWP</td>
</tr>
<tr>
<td>Life-cycle assessment</td>
<td>LCA</td>
<td>Assessment of the energy and materials used and pollutants or wastes released into the environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life-cycle costs</td>
<td>£/m² GIA</td>
<td>Usually gross internal area (GIA)</td>
<td>Depends on definition of m². Costs generally do not include VAT</td>
<td>Area</td>
</tr>
<tr>
<td>Lighting</td>
<td>Lamp lumens per circuit-watt</td>
<td>With luminaire: luminaire lumens for circuit watt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear thermal transmittance - Psi value</td>
<td>W/mK</td>
<td>The excess thermal transmittance of a thermal bridge per metre length</td>
<td>Limits for specific details are set within the SAP and SBEM documentation.</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity (lambda)</td>
<td>W/mK</td>
<td>Property of a material indicating ability to conduct heat</td>
<td>Manufacturers declare values of thermal conductivity relating to 90% of production within a 90% confidence level.</td>
<td>U-value</td>
</tr>
<tr>
<td>Thermal index</td>
<td>Dimensionless</td>
<td>Also known as a surface temperature factor. Used to define thermal bridges and predict condensation risk</td>
<td>A ratio, of temperature drop across a building element to total inside/outside difference</td>
<td></td>
</tr>
<tr>
<td>Thermal resistance</td>
<td>m²K/W</td>
<td>The property of a component that indicates its ability to resist the flow of heat</td>
<td>Added to give total thermal resistance of a building element</td>
<td>U-value</td>
</tr>
<tr>
<td>Thermal transmittance (U-value)</td>
<td>W/m²/K</td>
<td>Thermal transmittance of a building element</td>
<td>The inverse of total thermal resistance including boundary layers and cavities</td>
<td>Thermal conductivity</td>
</tr>
<tr>
<td>Water</td>
<td>Litres per person</td>
<td>Consumption usually expressed per day</td>
<td>Complicated by rainwater recovery for non-potable uses</td>
<td></td>
</tr>
</tbody>
</table>
2 RESEARCH PROCESS

BSRIA liaised with industry specialists in building performance to identify the common data protocols, methods and tools used to understand building performance. It pulled upon many sources of information: historical, such as the PROBE research project of the mid-1990s, and contemporary, such as the Building Performance Evaluation (BPE) research programme funded and run by the Technology Strategy Board (TSB).

Other sources of guidance were identified during the desk research, such as academic literature and published research outputs, and investigation of current research initiatives that aim to create tools for professionals to use, such as the TSB-funded Design and Decision tools programme. Digital sources were searched to identify protocols, methods and tools that met the GCB criteria. Views were solicited from individuals known to or recommended to BSRIA for their knowledge and expertise in various forms of building performance analysis. These people formed the core of a workshop, held to identify and review the methods and tools used currently in building performance evaluation.

2.1 LITERATURE REVIEW

BSRIA’s library service was used to search the web, conference abstracts, and published material to identify protocols, methods and tools, and log them in a database. This was cross-referenced with the knowledge of BSRIA staff and known research projects. The data protocols matrix that accompanies this report represents the desk review of data collection and analysis protocols used in building performance analysis.

2.2 ON-LINE QUESTIONNAIRES

The desk review was supported by on-line questionnaires sent to schools of architecture and engineering, BSRIA contracts, and government departments to identify protocols, methods and tools in use or in development.

Due to the project timing it was necessary to conduct the on-line questionnaires during the academic summer break, and responses were understandably few. Despite repeated efforts by BIS staff, only one response to the government survey was received (from the Ministry of Justice).

2.3 WORKSHOP

An industry workshop was held with leading BPE practitioners and academics working in the field. Delegates were polled on their knowledge of the tools and asked to identify the strengths and weaknesses of the various approaches used in BPE. Each tool or method was categorised, mapped against all stages of a project delivery cycle, and ranked against a range of qualities and attributes. An attempt has been made to judge each tool for its usefulness, reliability, robustness, availability of technical support, training requirements, along with other criteria.
3 RESULTS

3.1 LITERATURE REVIEW

There are a growing number of assessment tools and methods being used to evaluate the environmental performance of the built environment, in terms of embodied carbon, operational energy and carbon, and the performance of specific systems in buildings. The scope is both wide and deep, within which there are few mandated or regulated methods, and a great many commercial and non-commercial (academic) methods and tools available for the study of a variety of performance factors. New tools are regularly proposed, mainly via the academic arena with some being funded via the Technology Strategy Board’s innovation programmes.

Rather than attempt to identify and describe every single method or tool in use or in development, BSRIA has produced a matrix that is intended to be a live document with the capability of being hosted on the web with its content crowd moderated in the form of a Wiki. This matrix of tools was created in MS Excel and is to be read in-conjunction with this report.

The matrix is available as: Data Protocols and Knowledge Acquisition Matrix.xls

Currently the matrix is classified by a number of operational and performance measures. A brief summary is given in the table below of the different functions and the numbers of tools, methods and protocols in each area.

Table 3 Summary of Data Protocols and Knowledge Acquisition Matrix

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Method</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational energy</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Operational carbon</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Embodied energy</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Embodied carbon</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Life cycle assessment</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Human factors</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Strategic overview</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Operational review</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Project review</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Physical measurement</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Process</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Functional performance</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Technical performance</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Totals</td>
<td>4</td>
<td>74</td>
</tr>
</tbody>
</table>

From the table it is clear that there are only a limited number of protocols currently available and the majority of these are associated with the assessment and measurement of greenhouse gas emissions. The majority of processes that we identified fall either into the category of ‘method’ or ‘tool’ and in a significant number of cases do not rely on measured data for the assessment of the assets performance, but simply an assessment of the design data or the expected performance based
on a design teams judgement. In some instances the methods make an assessment of the expected performance using benchmarks within the methodology, that are either based on historical information, regulatory requirement or the originators ‘best estimates’ of good practice. In a strict sense it could be argued that these methods should be excluded as they are not based on measured data collection. However, the project is about knowledge acquisition and these methods are now regularly used to evaluate the environmental performance of an asset so have become part of the dialogue between clients and project teams to express the likely performance. They are also in part the mechanism by which the industry acquires knowledge (even if this is not based on real performance) about the different performance aspects of buildings. For example, few in the industry would have discussed the likely energy or water consumption targets for buildings prior to BREEAM becoming widely recognised and the benchmarks within the assessment method raising expectations over performance. The limitation is that BREEAM and other assessment methods are based on a calculation or designer’s assessment of performance, not actual measured data.

It is interesting to note that embodied energy and carbon between them have the greatest number of methods, followed closely by operational energy. This suggests two drivers: one, the regulatory focus on using carbon and the government drive to move to a low carbon economy, and two, a focus by academia on the methods and calculations for accounting for carbon within materials, systems and buildings. The issues around the use of operational energy tools and embodied carbon tools were outlined in the two briefing papers (Appendices A and B) prepared by Robert Cohen (Verco) and David Riley (Anglian Water) respectively. These both highlight the need for transparency and consistency in the methods used to be able over time to develop a deep understanding of the true performance of an asset. It is unclear how many of these methods and tools are based on measured data. It is possible that with the limited data sets available for different building types that the majority use either very limited measured data or theoretical modelling.

The significant number (from the total identified) of physical measurement methods confirms that a level of work has been on-going in the area of testing the actual performance of in-situ components. The briefing paper (Appendix C) prepared by Jez Winfield (UCL Energy Institute) for the industry workshop discussed the challenges associated with making measurements and the complexities of relating field data to design calculations that make numerous assumptions about the properties of components; the standards of workmanship and the conditions of operation.

The quality of information currently in the matrix is variable, as it depended on information available at the time of the research, and input from those with experience of a particular protocol, method or tool. All tools have been briefly described and a number of assessment criteria are suggested. Blank fields are expected to be filled through crowd-moderation of the Wiki version of the matrix.

This project sought to create the underlying schema and basic content for the Wiki whereby data protocols and procedures exist on a searchable map, with nearest-neighbour links to other relevant methodologies. An additional plan of work will be needed to program a Wiki based upon the data gathered (see Figure 4).
3.2 SURVEY RESULTS

BSRIA conducted two on-line surveys to gather information on building performance evaluation tools and techniques in use or in development. One survey targeted schools of architecture, built environment and environmental engineering. A second survey targeted central government departments responsible for capital procurement.

The on-line surveys were run via the on-line survey tool Survey Monkey and issued at the end of June and early July 2013. The timing was not ideal as it coincided with mid-summer holiday season and the academic summer break. Overall the response was poor, although those that did respond were helpful.

A third, smaller survey was aimed at known individuals with knowledge or skills in building performance evaluation and these results have been incorporated.

Government departments

In June 2013 an on-line survey was constructed to identify building performance assessment tools and protocols. It was issued by BIS secretariat to all government departments responsible for procurement. Only one survey form was returned by the end of the project, by the Ministry of Justice Estates Directorate, Programme and Project Management Unit (MoJ).

As a government construction client, the MoJ manages its own property, is responsible for energy efficiency, and develops and uses its own building performance data gathering templates. It gathers data on building performance based on energy consumption, occupant satisfaction, and carbon dioxide emissions. It also claims to fund and sponsor development of building performance tools.

The MoJ uses centralised energy management software. Energy display certificates are used across the Estate, and infrared-foot printing is undertaken. A bespoke BREEAM method for prisons is being developed based on the standard BREEAM approach. The MoJ is also adopting an early roll-out of the Soft Landings principles and framework.

No other survey responses were received. The very poor response to the survey is regarded as a major gap in this research. Therefore GCB is recommended to carry out a new survey of government
departments in a way that will obtain greater commitment to supplying information.
(Recommendation 9)

**Academic survey**
The academic survey was issued to a contact list of 40 people in 31 universities and colleges. The list was assembled by BSRIA from its membership and from its contact list of departments of architecture and engineering known to be active in building performance evaluation.

The number of responses was very low. Five survey forms were returned:

1. Glasgow Caledonian University, School of Engineering and Built Environment,
2. Coventry University, Low Impact Building Centre
3. Plymouth University, Environmental Building (Group Chair for Building Performance Analysis)
4. Sheffield University, School of Architecture
5. Cardiff Metropolitan University, Ecological Built Environment Research & Enterprise.

The poor response was probably due to the surveys being conducted during the academic summer break. Nevertheless the responses from the five bodies that did respond were consistent in their responses, which, in the absence of fuller data, are still regarded as insightful. Any specific tools mentioned by survey respondents have been included in the data protocols matrix.

Figure 5 shows responses to the question: ‘what building performance tools have been developed or used by the department?’ Carbon emissions, embodied carbon, life-cycle costing and waste management were minority subjects, while interestingly four out of five are researching into human factors. Bearing in mind that the responses were not from social science departments, this relatively high score for human factors is surprising.

![Figure 5 Building performance tools developed or used by university departments.](image-url)
Figure 6. Stages of a building development to which university-developed building performance analysis tools apply.

Figure 6 shows that BPE tools developed at universities focus more on the strategic and briefing phases and building operation phases. However, as said earlier, the sample is too small to draw too many conclusions.

Figure 7. Professions targeted by tools and protocols developed by university schools of the built environment

The academic bodies were asked to identify the construction professionals targeted with the tools and protocols. Figure 7 shows the spread.

As might be expected, the tools tend to be developed for the use of the academic department and the students, primarily for doctorate studies. Architects, engineers, contractors and building operators were usually targeted, but no university in the poll considered aiming tools at developers, regulators, or project advisors. Facilities managers were targeted by one university, but maintenance personnel were not. Again, it is a small sample, but the orientation towards architects and engineers is clear.
Note that one question “Do you apply your own benchmark datasets to any of the tools?” elicited only three responses, and is not worthy of being graphed. It is concluded that universities that design BPE-type tools generally do not have large enough example datasets to generate their own benchmarks.

When asked “what tools need to be developed”, the responses were:

- Building Information Modelling (BIM) interfaces with existing tools and protocols
- A resilience framework for whole-life costing, as a primary tool for procurement
- BIM whole-life carbon tool
- Modelling of occupant behaviour.

### 3.3 WORKSHOP

An industry workshop was held on 6 August 2013, at which a team of practitioners and individuals associated with building performance evaluation were invited to give their opinions on the most commonly used methods and tools to analyse building performance. Participants have knowledge from both the domestic and non-domestic sectors, and the commercial and academic arenas. It is acknowledged that this group of individuals, whilst knowledgeable within their own fields may not fully represent the views of the wider industry.

The attendees are shown in the Table below. A full description of the workshop and its findings are presented in Appendix F.

<table>
<thead>
<tr>
<th>Attendees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrian Leaman, Building Use Studies</td>
</tr>
<tr>
<td>Anna Poston, Glasgow Caledonian University</td>
</tr>
<tr>
<td>Anna Surgenor, UK-GBC</td>
</tr>
<tr>
<td>Darren Wright, Arup</td>
</tr>
<tr>
<td>David Riley, Anglian Water</td>
</tr>
<tr>
<td>Ian Mawditt, 4Walls</td>
</tr>
<tr>
<td>Ian Orme, BSRIA</td>
</tr>
<tr>
<td>Jez Wingfield, University College London</td>
</tr>
<tr>
<td>Kate Fewson, Closed Loop</td>
</tr>
<tr>
<td>Liz Reason, Greengauge Trust</td>
</tr>
<tr>
<td>Malcolm Hanna, NEF</td>
</tr>
<tr>
<td>Masoudeh Nooraei, Cardiff University</td>
</tr>
<tr>
<td>Michael Lim, AECOM</td>
</tr>
<tr>
<td>Mat Colmer, TSB</td>
</tr>
<tr>
<td>Richard Reid, Arup</td>
</tr>
<tr>
<td>Rob Lambe, Willmott Dixon</td>
</tr>
<tr>
<td>Robert Cohen, Verco</td>
</tr>
<tr>
<td>Roderic Bunn, BSRIA</td>
</tr>
<tr>
<td>Tom Kordel, XCO2, Energy</td>
</tr>
<tr>
<td>Observers:</td>
</tr>
<tr>
<td>Malcolm Hanna, NEF</td>
</tr>
<tr>
<td>Andrew Link, CIC</td>
</tr>
<tr>
<td>Rob Manning, BIS</td>
</tr>
</tbody>
</table>

Note that delegates with specific knowledge in assessing embodied carbon were invited to take part, but were unable to attend on the day. Note also that IES (Integrated Environmental Solutions) was invited to attend, but did not. The workshop was therefore not informed of any commercial developments by one of the main provider of computer simulation tools.
Workshop Approach and Summary Findings
The workshop aimed to identify the most frequently used methods and tools by building performance analysts and sustainability engineers working on infrastructure projects. The participants were asked to identify the strengths and weaknesses in their opinion of each method/tool that they identify across a range of criteria. In addition, delegates discussed the commercial realities, opportunities and constraints associated with using these tools in the real world. The categories selected for analysis were:

- Building operational energy and carbon dioxide emission
- Human factors
- Infrastructure
- Construction process
- Physical measurement

To help inform the discussions Briefing papers were written for each of the sessions, and these appear in Appendices A to E.

Each delegate was provided with a scoring sheet on which they captured their personal views of each method/tool discussed at the workshop. Delegates were split into two groups for each of the five sessions and given a record sheet with the intention of trying to rank the methods and tools identified and discussed. Each tool was also scored by each individual on the group against a range of characteristics and qualities:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Qualities</th>
</tr>
</thead>
<tbody>
<tr>
<td>What it is</td>
<td>Usefulness</td>
</tr>
<tr>
<td>What it does</td>
<td>Accuracy/robustness</td>
</tr>
<tr>
<td>Who owns it</td>
<td>Ease of use</td>
</tr>
<tr>
<td>Public domain/commercial</td>
<td>Credibility</td>
</tr>
<tr>
<td>Development status</td>
<td>Clarity of reporting conventions</td>
</tr>
<tr>
<td>Benchmarks</td>
<td>Future value</td>
</tr>
<tr>
<td>Links to other tools</td>
<td></td>
</tr>
</tbody>
</table>

The groups convened to try and achieve consensus on the ranking of the top five tools (more or fewer depending on the topic), with the personal record sheets enabling delegates to record their personal views. In this way personal experience and knowledge of the tools would be captured and not lost or suppressed when trying to achieve a consensus.

What became apparent from this process was that the majority of participants had detailed knowledge of the methods and tools that they had either helped to develop, or used most frequently and only a limited knowledge of other tools and methods. This in turn demonstrates the early stage development of this area of knowledge capture with experts who have developed an understanding in one or two areas but as yet not applied this on a regular and consistent basis.

The final session of the workshop invited participants to consider the realities of delivering BPE in a fully commercial environment. A briefing paper by Richard Reid (Arup) is included as Appendix E. For building performance protocols to have a future, some significant changes in industry culture are...
needed: being open without blame is hard, and litigation is often unavoidable. Players in the construction process are under strong temptation to spin results to portray them in different ways.

Where results are contrary to expectations, the response can often be to look for excuses for building underperformance, challenge the research methodology, or find reason to criticise the researcher. In government-funded research programmes (where most BPE has been carried out) the public interest is a strong force for objectivity, but in a commercial context, objectivity, impartiality and openness come under pressure in the client-customer relationship.

Current forms of contract do not protect the BPE activities, and will strongly influence how BPE is delivered in future. It begs a fundamental question of whether BPE can be delivered by a party or parties involved in the main building contract, or should be delivered by a party external to the client and building team, similar in status to a BREEAM Approved Professional. The Soft Landings process champions the use of external BPE services, but in practice funding for this service cannot be guaranteed during budget revisions, and protected as a sum after a new building has been handed over to its owner.

The problem is compounded by performance targets being enshrined in a single target value for a particular metric such as energy consumption, consequential carbon dioxide emissions, water use and waste produced by the operation of the building. There are no targets for human factors except for those covered by environmental engineering guidance (temperature bands, humidity level and lighting levels for example). There is also no agreement on what constitutes acceptable variation.

Successive reports published by Government bodies since 2006 have called increasingly for performance metrics for public-sector buildings. The Government report Building for the future: Sustainable construction and refurbishment on the government estate, published in 2007 revealed the gap between existing policy requirements and the targets to which departments are subjected: “If departments are to make progress they will need to focus increasingly on incorporating specific output-oriented specifications in new construction or major refurbishment projects, rather than simply specifying a requirement for BREEAM Excellent.”

A recent report from the Commission of Inquiry into Achieving Best value in the Procurement of Construction Work A better deal for public building also recommended that “post-occupancy evaluation should be mandatory on public sector projects.... with a focus of assessing performance against design expectations.”

The 2013 RIBA Plan of Work has introduced Stage 7 ‘In-use‘, a new stage which includes post-occupancy evaluation and review of project performance. This requires new duties that can be undertaken during the in-use period of the building. The RIBA says that the desired project outcomes may include operational aspects “and a mixture of subjective and objective criteria,” but has not defined what these should be.

It is the view of some of those engaged in BPE that building performance needs to be defined by metrics that address the physical, environmental and human factors. In that scenario, clients need to take responsibility for certain critical factors, such as occupant densities and level of control over
environmental systems. Similarly, if a design presumes the building will have a certain level of facilities support which the client subsequently decides not to provide, the designers cannot be censored for subsequent under-performance.

If a range of targets are set for building performance, within a building performance evaluation framework, responsibility for performance will need to be shared fairly between the client and the project team, not just the responsibility of the professional designers. It follows that the metrics will need to be built into service-level agreements.

The workshop agreed that a commitment to performance transparency has to come before performance guarantees. Performance transparency will lead to feedback with the purpose of fine-tuning to improve on initial performance. Once the feedback loop pick up momentum, the concept of performance guarantees becomes more feasible.

The workshop identified actions to improve building performance transparency mainly, but not exclusively applicable to the non-domestic sector:

1. Energy display certificates to be mandatory for all new non-domestic and refurbished buildings after occupation

2. An absolute energy target (DEC) target for all new building designs

3. A two-stage sign-off for Building Control acceptance of non-domestic buildings (first stage: building completion certificate, second stage energy use reporting).

4. A commitment to fee models that underlie targets (with agreed acceptable variation) as part of a full Soft Landings process whereby the project team stays with the building after handover and influences commissioning, maintenance and management. The commitment needs to start at the pre-design stage and follow through construction, with steps in place to check the both design specification and the building installation as it evolves.

5. Select the appropriate measurement and monitoring regimes/tools to achieve item 4

6. Environmental rating tools to be re-designed to become more part of a linear process from inception to in-use.

7. Create the foundation for building performance evaluation by developing specific modules and credits in architecture and building engineering courses.
4 DISCUSSION OF THE RESEARCH FINDINGS

Given the wide range of methods and tools identified by the desk research and the on-line surveys, the following section focuses on the most frequently used methods and tools identified by the research. Discussion is given about how they may be better supported and developed. We have also given some thought to the current strengths and weaknesses of the methods and tools.

Protocols

The protocols identified by this project are the Greenhouse Gas Protocols which define the structure for carbon reporting, beneath which government departments have created methods, tools and other approaches to aid carbon assessments and reporting. (The basic principles of the Greenhouse Gas Protocol are observed in various BPE methods and tools that convert energy consumption into carbon dioxide emissions and embodied carbon. So while there is no BPE protocol, there is a high degree of consistency throughout.)

There are no established protocols – primary requirements for data collection to be used in the evaluation of the performance of a built asset – used in building performance evaluation (BPE). However, the documentation and reporting templates brought together for the TSB funded BPE programme are a good starting point and could be further developed. BPE is not mandated through the regulatory framework for buildings. National building regulations and local planning requirements do not cover the operational performance of the built asset, as compliance is demonstrated against confirmation that the as-constructed asset is in accordance with the asset design.

While not a protocol for assessing building performance, the Energy Performance of Buildings Directive (EPBD) required all EU countries to introduce energy certification schemes for buildings when new, sold or re-let. The EPBD is a requirement to mandate methods of energy calculation for certification purposes and in England is implemented via Part L of the Building Regulations. The EPBD also established requirements for the inspection of boilers and air-conditioning systems, which in part were also enacted through Building Regulations. This has led to methods of calculation that are now in regular use. In that sense the EPBD is a form of protocol, but not one over which the UK Government has only limited control.

Methods

Although there are no official methods for conducting and reporting building performance, practitioners in BPE have adopted fundamental principles of conducting and reporting energy consumption and carbon dioxide emissions that are broadly consistent with each other. In part based on proven methods of research.

A primary reason for this consistency is that the methodologies in most regular use for reporting energy use have been largely devised (or at least informed by) the same small group of individuals working in the field of building performance. The reporting methods in common use for non-domestic buildings are display energy certification, the CIBSE TM22 Energy Assessment and Reporting Methodology, the Landlords’ Energy Statement and Tenants’ Energy Statement, the
Carbon Buzz reporting platform. These reporting methods require data to be held in specific formats, as input data and for ease of comparison with benchmark datasets, such as CIBSE TM46 Energy Benchmarks. The publishers of these methods (professional institutions, research and industry bodies, and government departments) have therefore produced consistent methodologies, even if that was not necessarily each organisation’s primary objective.

De facto building performance methodologies have emerged through industry-led building performance research projects. An example of this was the PROBE project (Post-occupancy Review of Buildings and their Engineering) that ran from 1995 until 2001. PROBE popularised building performance evaluation by combining three tools of assessment for non-domestic buildings: energy analysis, occupant satisfaction, and forensic walkthroughs. Latterly airtightness testing was added. The results of the evaluation being feedback to the project team and publish for wider industry learning.

Since PROBE, the Carbon Trust, Energy Saving Trust and most recently the TSB have all built on and utilised the same basic approach to evaluating building performance. The TSB adopted the basic PROBE research methods and added several more as the competition programme developed. The TSB funded a revised and updated version of TM22, along with a version for domestic energy assessment, Dom EARM.

In the domestic sector the assessment of energy use has been dominated by the use of calculation methods such as SAP (Standard Assessment Procedure), which is based on BREDEM (Building Research Establishment Domestic Energy Model). The simpler implementations of which do not allow a complete comparison with recorded fuel uses and measured energy consumptions as they are ‘locked’ to a standard occupancy pattern, and in the case of the regulation compliance models a specific region of the country. SAP also has the limitation of not evaluating all the energy consumptions within a dwelling being tied to the regulated energy uses of space and water heating, cooking and lights. Since the advent of Passive House developments into the UK a growing number of consultants have experience of using PHPP, the Passive House energy design tool. Whilst this allows the modeller greater freedom over data entries and the full range of energy consumptions within a dwelling, it is still a modelling tool based on a calculation approach.

Many domestic monitoring projects have been carried out since the Energy Efficiency Demonstration schemes of the mid 1980s, many of which included some element of assessment of the occupants’ satisfaction. This has largely been carried out by the researcher’s developing semi-structured questionnaires to assess particular issues. Unlike the BUS approach there has been no standardisation of the process or statistical analysis of the results.

Working with its nominated team of Building Performance Evaluators the TSB has added guidance on conducting structured interviews, forensic walkthroughs, as-built versus as-designed documentation assessments, occupant satisfaction survey procedures for domestic dwellings, and reporting procedures for all these methods. While the TSB procedures represent the most comprehensive set of methods assembled for BPE, they are currently largely designed for use by researchers rather than by industry. Further work will be needed to make them suitable for wider industry use, but they represent an excellent starting point.
The matrix of data assessment methods also identifies many other methods that have been developed over time. Many of them are not in widespread use.

**Tools**

Table 4 lists the tools and methods identified by the industry workshop and corroborated by feedback from the on-line surveys as most frequently used or known of. The methods and tools identified by the workshop are but a small part of a larger number identified by the literature search. These are provided in the matrix of tools and methods that accompany this report.
Table 4 The primary tools for measuring building performance for the key topic areas in Building Performance Evaluation

<table>
<thead>
<tr>
<th>Topic</th>
<th>Main protocol or methodology</th>
<th>Publicly available methods and tools</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational energy and carbon</strong></td>
<td>Display Energy Certification (DEC)</td>
<td>CIBSE TM22 Energy Assessment Reporting Methodology V3.17 (non-domestic)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ACA DomEARM Version H (domestic)</td>
</tr>
<tr>
<td><strong>Human factors</strong></td>
<td>Building Use Studies Methodology (domestic)</td>
<td>Building Use Studies Methodology (non-domestic)</td>
</tr>
<tr>
<td><strong>Embodied carbon (buildings and infrastructure)</strong></td>
<td>Greenhouse Gas Protocol</td>
<td>Bath University Inventory of Carbon and Energy</td>
</tr>
<tr>
<td></td>
<td>PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services</td>
<td>DEFRA Environmental Reporting Guidelines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>European Product Declaration sheets</td>
</tr>
<tr>
<td><strong>Construction process</strong></td>
<td>TSB BPE process ¹</td>
<td>BSRIA/UBT Soft Landings Framework and associated guidance</td>
</tr>
<tr>
<td></td>
<td>BREEAM²</td>
<td></td>
</tr>
<tr>
<td><strong>Physical measurements</strong></td>
<td>Airtightness testing under Part L of the Building Regulations</td>
<td>Thermography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical monitoring (multitude of procedures)</td>
</tr>
</tbody>
</table>

¹ Not a regulatory requirement, but a condition of receiving funding via the TSB BPE programme. Templates for BPE exist within the programme, but have not been published as a set for wider adoption.
² Not a regulatory requirement, but a mandatory funding requirement for public sector construction such as, schools.

4.1 OPERATIONAL ENERGY AND CARBON

Mandatory energy analysis and calculation of carbon dioxide emissions is carried out via the requirements of Part L of the Building Regulations, with the results reported via the BRUKL (Building Regulations Part L) document to the Building Control authority. The method used to carry out the calculations varies depending if the assessment is for a domestic or non-domestic building. In each case the National Calculation Methodology (NCM) describes the approach, the assumptions and the requirements for the establishing compliance. In the case of non-domestic buildings the NCM is embodied in the Simplified Building Energy Model (SBEM), for which government provides a free to use basic user interface and for which more sophisticated commercial software is available. In the case of the domestic sector the NCM is embodied in SAP.

In both cases the assessment reports results in kilograms of carbon dioxide per square metre per annum (kgCO₂/m² per annum) in order to accommodate savings from on-site renewables and other low and zero-carbon supplies. While not intended as a data collection protocol, the regulatory authority of the BRUKL process drives building designers to analyse energy consumption and report data in a specific format and level of detail. It should be noted that currently, energy modelling on construction projects is at a level necessary to achieve compliance with Part L, and no more.

While analysis of the regulatory process is out of scope of this research project, it is important to understand that the as-built assessment, required for sign-off by local Building Control Officers, infers acceptable performance from various data sheets submitted by the project team. This
includes certificates generated by the fabric airtightness test, submissions on the calculated as-built fabric U-values, plus evidence that energy saving technologies such as high-efficiency boilers and lighting systems have been installed. Statements on whether commissioning and building logbooks have been ‘satisfactorily provided’ are also required.

The BRUKL report, being a requirement to achieve completion, does not, as a consequence, require any in-use energy assessment or the measurement of any physical performance characteristics of the building itself. The energy data required for the BRUKL report relies on values calculated by the building designer(s), rather than measured data.

Any requirement to extend BRUKL reporting into the in-use phase of a building would require a complete overhaul of the regulatory compliance process. Consideration of that option is out-of-scope of this research project. That said, a mechanism to report in-use energy consumption for some non-domestic buildings is provided through Display Energy Certification (DEC). This was an outcome of the requirement of the Energy Performance of Buildings Directive (EPBD), which the UK Government enacted for public sector buildings above a specific total useable floor area. In 2012, despite lobbying by construction bodies and the institutions, Government decided against extending mandatory Display Energy Certification to commercial buildings for reasons of a perceived cost penalty to UK business.

While Display Energy Certification is a useful method to measure and understand energy consumption and carbon dioxide emissions, the process has been designed to be low cost and rapid. A DEC analysis relies on annual fiscal meter readings to give a general indication of how fuel consumption compares against the benchmark for the building type. While the DEC process is a useful first step in understanding performance (and informing high-level remedial actions), it does not analyse energy consumption breakdown by end-use or give any context for the data presented so is of limited value in developing knowledge and understanding around performance.

Energy analysis at a more detailed level requires data collection and assessment by end-use. There are no set ways of gathering data for this purpose. The quality of data depends on the data-gathering mechanisms, notably the level, extent and quality of the sub-metering installations.

The generally-accepted method for obtaining, understanding and reporting energy consumption is to use metered energy data generated by reliable fiscal meters installed by the energy supplier, and supplied on invoices. The accepted convention is to translate twelve months of actual readings (or customer recorded) kilowatts of delivered energy into kilowatt hours per square metre, per annum. This can then be translated, using a carbon factor relevant to the fuel in question, into kilograms of carbon dioxide. These values are then typically compared with external datasets for example, heating degree-days, and electricity and fossil fuel benchmarks.

Since 2006 the published guidance on complying with the Building Regulations, Part L given in the Approved Document L2A, has required the installation of sub-meters to measure up to 90% of the estimated energy use. Theoretically, a metering installation that conforms to CIBSE metering guidance can be used to arrive at an accurate annualised energy use breakdown for all sub-circuits thus metered.
Evidence from research projects reveal that sub-metering can be problematic and on occasion fail to deliver useable data.

A brief summary of the issues that cause difficulties is given below to highlight the problems associated with gathering data and trying to carry out analyses based on that data.

- Fiscal meters can vary in quality. Energy suppliers working off old meters can only provide monthly totals, and often mostly estimated readings rather than actual readings which require a visit from the supplier. More recent meters can generate accurate daytime and night time use in kilowatt hours, although they may still be estimated readings by the energy supplier, which cannot be taken as accurate. Suppliers with automatic meter readings can provide daily schedules of consumption, separated by day and night tariff, on a monthly basis. However, this requires the energy supplier to set up the monitoring capability, which does not come as standard.

- The guidance to Part L of the Building Regulations only requires sub-meters to be installed. Most meters installed are of the pulse type, whereby they send signals to a computer head-end but do not store the data locally. Meters are available that can store data locally (such as Modbus meters), but again these need to be specified by the client.

- Sub-meters require calibration and commissioning, and reconciling with main fiscal meters before they can be considered functional. Each meter’s current transformation (CT) ratio (the conversion from the primary current to the secondary current) needs to be appropriate to the load being monitored. Research reveals such calibration and reconciliation is rarely carried out during commissioning. Subsequent inaccuracies in readings may not be spotted leading to difficulties with data analyses.

- Sub-meters do not necessarily communicate reliably and accurately with building management systems. Issues with clock-cycle compatibility can lead to inaccurate readings. The absence of data-logging and/or energy management software means that data will not necessarily be stored by the BMS for future use.

- Sub-meters can be wrongly labelled, wrongly assigned to zones or loads, and installed in a way that combines consumption from more than one load or zone. One or all of these issues combined can make sub-system analysis time-consuming, expensive and inaccurate, and in severe cases technically impossible.

Difficulties with the amount and reliability of energy and environmental data particularly in domestic scale projects have been observed across a number of projects. Improvements in the electronic data-logging equipment with greater storage capacities and the advent of wireless sensors and the use of remote data hosting facilities have all contributed to ever increasing amounts of data being recorded. However, issues with calibration of sensors; correct recording of sensor readings within the hosting database; wireless signal drop-out and clashes can all lead to gaps and/or inaccuracies in the recorded data. Procedures need to be agreed about the processes for cleaning raw data ready
for analysis, as well as the types of analysis that are useful in determining the performance of a building.

4.1.1 Energy assessment tools

Research for this report, and the views of the industry specialists consulted, identified the *de-facto* energy tool for the assessment of non-domestic building energy use as the Excel-based *Energy Assessment and Reporting Methodology*, published by CIBSE as *Technical Memorandum 22 (TM22)*. (Note: Since the research for this report was compiled, CIBSE has published the process for analysing energy use, as *CIBSE TM54 Evaluating Operational Energy Performance of Buildings at the Design Stage*.)

*TM22* originated from BRECSU as a prototype procedure for collecting, assessing and reporting energy use for offices case studies and subsequently published by the CIBSE. The tool was updated and broadened out in 2006 in anticipation that it would become the primary way of assessing energy for Display Energy Certificates. Although this didn’t materialise, the 2006 edition is still sold commercially by the CIBSE. It carries reference energy benchmarks for the range of building types published in CIBSE *TM46*.

The TSB adopted *TM22* in 2010 as the primary method of assessing energy use in non-domestic buildings for its Building Performance Evaluation (BPE) and Invest in Innovative Refurbishment programmes. TSB funded a major update of the *TM22* tool to cater for on-site and off-site renewables, separable and special energy uses, and to enable sub-meter data to be imported for detailed end-use energy assessment. The tool also contains ‘design’, ‘improved’ and ‘in-use’ sheets to enable comparisons to be made over time. *TM22* can also generate an XML file for publication of the results to the Carbon Buzz website.

A separate version of *TM22*, DomEARM, has been developed by Arup for domestic dwellings. The data generated can be output directly to EMBED, the energy database for domestic dwellings developed by TSB. (Note: Since the research for this report was compiled, EMBED has been taken over by Mastodon C for the Open Data Institute). DomEARM is based on similar principles to the non-domestic version, but is considerably less complex in its data input requirements.

Even though it is still published by the CIBSE, the 2006 version of *TM22* is widely regarded as an evolutionary dead-end. The latest version (notionally called the 2013 version) is still in BETA state, and not ready for market use. While most technical bugs have been ironed out by its developer, Verco (acting for the TSB), the program is very complicated and time-consuming to use compared with the simplicity and rapidity of the 1999 version, which can still be used (albeit with inherent limitations).

The 2013 version requires the user to generate operational profiles for the building in question. Many buildings can have multiple users and patterns of operation, which makes data entry laborious. *TM22* 2013 has many critics within the TSB research programme, where people are being paid to use it. It is widely held that considerable re-work will be necessary before the 2013 version can be made
market-ready and can be usable without tying up professionals’ fee-paying time in non fee-earning activities.

Although the 2013 version of TM22 was funded by TSB and developed by Verco, the copyright of the tool is owned by the CIBSE. The Institution therefore needs to put in place a development and publications plan for TM22 that will include a thorough review of the program’s structure, features and functions, and possible re-programming.

Some TM22 experts (the authors included) believe there should be a TM22 ‘lite’ version for simple buildings and for rapid assessment, akin to the functionality of the 1999 version, plus an evolution of the 2013 version for detailed energy analysis. There have been ongoing efforts to persuade CIBSE of the urgency and need of this approach, but at the time of writing there is no firm date for publication.

4.2 HUMAN FACTORS

There are lots of different methods applied in lots of different ways for assessing, measuring or reporting data and knowledge gained from human factors research. The subject area is neither championed by any particular body or organisation, nor moderated professionally, with the exception of university ethics committees who judge what is and is not an acceptable research modus operandi for their graduate researchers.

There are no set methodologies for researching human factors or behavioural issues in buildings, nor for reporting and representing the results. Many are based on sound social and behavioural science methods. By and large the methods in use fall into one of three categories:

- Questionnaires of various kinds, either administered in person or conducted on-line
- Single person interviews, invariably using structured sets of questions
- Group workshops, with or without structured questioning, sometimes with a scorecard approach.

This research identified a number of methods developed commercially or used in academic research. However, it is believed that the low barriers to entry for creating a questionnaire mean that a great many systems have probably been developed, mostly in academia but also possible in government departments, which are not visible to the researcher. The vast majority are likely to be either moribund or only used by a small number of individuals.

Aside from the issue of ensuring the quality of a questionnaire or the quality of an interview technique, the biggest issue facing human factors research in building performance evaluation is capturing the outputs and reporting them faithfully and accurately in such a way that the results can be acted upon, for example by designers or facilities managers. There is also an issue of quality assurance, especially when using the results to build a benchmark or reference database.

The research for this project identified one specific human factors research method regularly used in building performance evaluation: the Building Use Studies (BUS) methodology. The BUS method was
consistently referenced by all those working in the field of occupant satisfaction. Perhaps not surprising as the TSB funded work covers over 100 projects and is a current, on-going programme of work that required the use of the BUS methodology.

The BUS methodology originated in the mid-1990s from a sick-building syndrome survey. This was streamlined into a structured questionnaire which could be rapidly administered and analysed. The resulting survey was tested and developed on the PROBE research project, and subsequently used by the Carbon Trust Low Carbon Building Performance research programme and by the Department of Education for a series of school case studies.

The survey was developed by social scientist Adrian Leaman but is now wholly owned by consulting engineer Arup. It is available through a licensed network of resellers, who are also involved in the method’s ongoing development and technical support.

The survey uses a mix of seven-point scoring scales for comfort indices, such as winter and summer temperature, air quality, noise and lighting, plus questions relating to needs, health and perceived productivity. The questionnaire is best conducted with manual hand-out and retrieval, although an internet-based version is available for particularly difficult contexts or buildings with large populations. A survey tailored for buildings with high transient populations, such as libraries or university teaching facilities, is also available.

The maturity of the BUS method is shown in its rolling database of 50 buildings, against which a survey’s results can be compared. The statistical data is supported by anecdotal information recorded by the respondents in text boxes. (This information is often just as insightful as the statistical score.)

A version for domestic dwellings has been developed for the TSB domestic Building Performance Evaluation programme. This is conducted by interview rather than by hand-out and retrieval, and uses different criteria to achieve statistical accuracy. Within the programme there have been some concerns expressed over the format and nature of the domestic BUS methodology due to the close relationship the domestic questionnaire shows to the commercial one.

As a commercial tool, the BUS method is not open-source, nor is it cheap to buy and administer. The cost of a survey (the licence fee for one survey alone is £1400) is seen as a barrier, largely because the cost-versus-value argument has yet to be made, let alone won.

Clients and designers remain to be convinced of the value that a BUS survey can add to design and facilities management decisions. There is uncertainty over how the results of a survey can be interpreted and responded to (i.e., how precisely a scientifically-justified design would need to be altered based on statistical and anecdotal human feedback). The importance of achieving a high satisfaction score may conflict with a design team’s low energy objectives. For example, low energy design calculations may be predicated on automatic controls, when the occupants might declare themselves more satisfied if they retained full manual control.
The quality of a survey (and the quality of the benchmarks into which survey results are exported) is highly dependent on the quality of the practitioner. Unlike numerical tools where calculations can be audited, it is not possible to quality control the way a survey is carried out.

The BUS methodology is robust and mature enough to be adopted immediately, but will require a larger user base, a lower first cost, and/or a well-publicised and convincing cost/benefit argument. A larger number of resellers would overcome the perception of an Arup monopoly. Outcomes from a pre-design BUS survey would benefit from being expressed in a performance metric, to which the design team should be able to respond with specific design decisions.

To avoid supporting one specific method, GCB could define the standard requirements for similar tools that would achieve the quality of analysis delivered by BUS, for example, including but not confined to:

- Standardisation of the 7-point scoring range
- Standardisation of comfort variables (e.g., summer and winter temperatures)
- Standardisation of terminology used to define comfort variables
- Ethical-testing of survey systems (for both manual and digital/on-line data collection)
- The availability of open benchmark datasets
- Clear communication of results, with transparency of statistical analysis.

Occupant satisfaction cannot currently be expressed in a design metric that can be reliably measured in the post-occupation phase, although this is thought possible with some development and testing. BUS benchmarking is against a single rolling database of 50 buildings. Many more surveys are required to enable Arup to create benchmarks tailored to building typologies.

Experience from the TSB programmes show that while the BUS survey is easy to conduct, it is also easy to conduct in such a way that the statistical results end up skewed or otherwise distorted. Falsification of survey responses – particularly where surveys are conducted by people with a vested interest in positive results – will also be harder to guard against when there a much larger number of people are using it.

4.3 **EMBODIED CARBON**

The *Greenhouse Gas Protocol* provides the base methodology on how to measure greenhouse gas emissions (GHG). The *Protocol* specifies principles and requirements at the organisation level for quantification and reporting of GHG. It is the most widely-used international accounting tool.

*PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* aims to provide a consistent, internationally-applicable method for quantifying product carbon footprints. The *GHG Protocol Product Standard* was released in 2011 and in addition to providing requirements to quantify the GHG inventories of products, also includes requirements for public reporting.

(Both standards are broadly consistent in their quantification methods, but their differing purpose and standard development processes lead to two different documents.)
The GHG Protocol built on the initial PAS 2050 method in development of its Product Standard. In turn, PAS 2050 drew upon lessons learned during the Product Standard’s development process in its 2011 revision. As a result of this cross-collaboration, the key methodological rules underpinning quantification in both standards are consistent. In particular, key topics that have been brought into alignment include consistent approaches to:

- Sector or product rules
- Inclusion of biogenic carbon
- Recycling
- Land use change
- Delayed emissions

The Royal Institute of Chartered Surveyors (RICS) issued its New Rules of Measurement (NRM) in 2011, which RICS recommends to be included in initial embodied carbon studies delivered by quantity surveyors. The selection has been based on analysing a number of projects. It covers not only the carbon critical elements but also quick wins where data is more easily available and where speedy carbon reductions are possible.

The public Standard PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services describes the method by which GHG emissions should be measured, and defines the units of measurement and reporting conventions.

PAS 2050 is supported by a raft of guidance published in Standards and guidelines published by government, such as ISO 14064-1:2006 Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.

CEN/TC 350 Sustainability of Construction Works is based on European Standard EN 15804 providing a framework for Product Category Rules for construction products. This work has informed the requirements for European Product Declaration sheets used by product suppliers.

Tools for assessing embodied carbon are listed in the DAMASS database accompanying this report.

There are no industry-standard or de facto tools for operational carbon dioxide emissions for infrastructure works, nor for building performance evaluation, that materially improves upon carbon dioxide conversions within conventional, freely-available energy analysis tools.

As explained in this reports Workshop Section companies and enterprises tend to develop in-house tools and procedures. The TSB’s recently completed research programme ‘Design and Decision Tools’, has generated a cadre of new tools that are able to calculated embodied carbon, but all these are mostly still in development and/or a testing phase, and are largely unproven. It is not known whether these tools will enjoy on-going technical support and development beyond TSB funding.

The issue with embodied carbon is not the availability of a tool, but the database of materials properties that underlie the calculations within a particular tool. Life-cycle costing requires architects and building engineers to identify accurately the embodied carbon of construction
materials, and to understand the trade-off between high embodied carbon and low operational carbon and vice versa.

There are several embodied energy and embodied carbon material databases on the market, but on the whole they are proprietary subscription-based resources. Ideally, the construction industry – buildings as well as infrastructure works – needs access to a transparent, robust and reliable publicly-accessible database covering a wide range of construction materials. The database needs to be kept up-to-date.

Of the many databases available, the Inventory of Carbon and Energy (ICE) devised by the University of Bath is one of the largest and most rigorously-assembled publicly available databases. The ICE contains a summary of around 1800 records of embodied carbon and energy for 34 classes of materials used in construction. Raw data has been collated from independent sources and open literature, and has been quality assured to provide users with the confidence in the reliability of the values. Raw data is presented in a way that makes it readily usable in calculations.

All the data was freely available on the web at the Bath University website, but at the time of writing (October 2013) the links had become redundant and the ICE could not be accessed.

Alice Moncaster, Deputy Director of IDBE (Interdisciplinary Design for the Built Environment) at the University of Cambridge and a specialist in embodied carbon analysis, provided the following view of embodied carbon tools:

*There are a great number of tools to calculate embodied carbon, and they are proliferating. Because of a lack of data, most tools concentrate on the impact of bulk structural materials at product stage, ignoring the CEN/TC 350 stages A3-5, B2-5, C1-4 and D. This leads to huge underestimations, of at least a factor of 2.*

*In addition, the use of the CEN/TC 350 standards process-based life-cycle assessment method will also lead to an underestimation of around a factor of 2 according to detailed research due to truncated boundaries. Therefore the embodied carbon emissions calculated by most tools are only a quarter of the real value or less.*

*This matters because these are the real carbon emissions from construction - this is our industry's responsibility. If we are not calculating it we will not reduce it. In contrast, a lot of the operational emissions are the responsibility of the occupier/owner not the designer/builder. So, how do we address the huge gaps in data, and how do we then manage them?*

*We need a national database, which would take not just considerable effort to develop, but also policy to ensure that the data is collected. Then it would need to be managed actively to incorporate constant additions and changes.*

*The UK lacks life-cycle assessments for most composite construction products. European Product Declarations are becoming more established in Europe, but they are mostly unheard of here. We are also lacking any data, or a method by which to collect it, for where our construction products come*
from and how they travel to site, what happens on site in terms of energy used and waste produced, and what then happens to the waste (although the WRAP initiative is improving this).

Refurbishment is another huge unknown area, as is demolition and what actually happens to building materials after demolition.

The WRAP report *Procurement requirements for carbon efficiency - Guidance for building projects and estates management* (December 2010) contains extensive guidance and recommendations for embodied carbon analysis. Specifically, the GCB is recommended to consider the guidance and recommendations contained in ‘Appendix 1: Key regulations and standards in relation to embodied and operational carbon’, and ‘Appendix 2: Guidance on embodied carbon’.

### 4.4 CONSTRUCTION PROCESS

There are few protocols, methods or tools for analysing the performance of the construction process with respect to the performance of new and refurbished buildings (although there are schemes for the assessment of construction performance, for example key performance indicators for M&E contractors). The BRE with Faber Maunsell developed in 2003 a protocol for handing an office building over along similar lines to the Soft Landings approach.

An International Performance Measurement and Verification Protocol (IPMVP) exists. The IPMVP defines standard terms and suggests best practice for quantifying the results of energy efficiency investments and increasing investment in energy and water efficiency, demand management and renewable energy projects. A tailored version may be useful for setting a template for organising BPE process tools into a hierarchical framework.

As far as assessing construction process is concerned, there is not enough to distinguish between methods and tools used to assess construction process in respect of a building’s subsequent performance. It is not really possible, nor helpful, to try and distinguish between the two.

Environmental assessment tools, namely BREEAM, LEED and Ska in the UK, have become the established methods for setting and rating the environmental attributes of a new or refurbished building. The checklists and assessment procedures created for those schemes are therefore the accepted templates for recording design decisions, product specifications and procurement and sustainable management decisions.

The *Soft Landings Framework* contains method worksheets for project inception and briefing, design development and review, pre-handover, initial aftercare, and extended aftercare and POE. A methodology for reality-checking design decisions and performance targets as a building project progresses has been defined in BSRIA BG27/2011 *Pitstopping – BSRIA’s reality-checking process for Soft Landings*. This guidance lays down the process but stops short of specific templates for recording project team discussions, decisions, and outcomes, as each construction firm and/or project team will have its own preferred mechanisms for tracking decisions and managing and reporting risks.
The TSB’s Building Performance Evaluation research programme has led to the assembly of a number of useful documents to guide the auditing and analysis of build process outputs. These documents (mostly in the form of reporting templates) include:

- Pre-visit questionnaire
- Building Information Document (BID) to capture building and construction details
- Guidance for conducting structured interviews (applicable to designers and constructors)
- Comparison of as-built drawings and specifications with design intent
- Assessment of commissioning records
- Forensic walkthrough guidance for the building team and building performance evaluators
- Assessment of O&M manuals, user guides and end-user training materials
- Assessment and reporting of Soft Landings handover and aftercare activities
- Forensic walkthrough process for non-domestic buildings
- Guidance on conducting BUS domestic occupant surveys
- Guidance on conducting BUS non-domestic occupant surveys
- TM22 v3.17 (beta version)
- DomEARM (Version H)

These procedures have proved to be reasonably helpful to both the project teams and the TSB’s building performance evaluators. They could form the basis of a published and agreed protocol for understanding the contribution of the build process to a building’s subsequent performance.

Most recently the work by the Zero Carbon Hub on reviewing the house building process adopted an approach similar to the TSB guidance and the approach taken by Leeds Met. in carrying out studies to inform updates to Part L of the Building Regulations. The method is described briefly in their report\(^5\).

\(^5\) Closing the Gap between Design and As-Built Performance, Evidence Review Report, Zero Carbon Hub, March 2014
4.5 PHYSICAL MEASUREMENTS

As described below, there are many methods beyond the mandatory airtightness testing that cover the wide range of physical measurements that can be carried out to analyse their performance in-use of a building and its systems.

In physical testing, a protocol equates to the accepted parametric units of measurement. (The vast majority are metric, and only one or two still in imperial, owing to the habits of the relevant professions, such surveyors persisting in expressing lettable floor area in square feet.) Most units of measurement are laid down in the authoritative technical guidance issued by the professional institutions (for example CIBSE, BSRIA, ECA, and HVCA) and the accreditation bodies such as BINDT for airtightness.

The common units of measurement are given in Table 1. These units are not in dispute, but some units are caveated as they can be defined differently depending on specific contexts. For example, there is no single definition of floor area. Although this is commonly expressed in square metres, the dimension of a non-domestic space can be taken as gross, net, or treated (conditioned) floor area, and in the domestic arena SAP conventions dictate the measurement of the heat loss envelope for both existing and newbuild properties. Some design packages such as the Passivhaus Planning Package (PHPP) discount partitions and vertical circulation from the floor area calculations, resulting in figures which are significantly lower than the gross internal floor area convention defined by SAP and allied datasets (such as published energy benchmarks in CIBSE TM46).

These differences and variations are permissible and not problematic as long as the unit of measurement is made explicit in any reporting of building performance, particularly when making comparisons with published benchmarks (See figure 6 below).

![Fossil fuel equivalent energy consumption and generation](image)

Figure 8: An example of an energy analysis where energy consumption is reported against the most relevant benchmarks.

Of the many physical characteristics that can be measured, the key ones include:

- Physical dimensions
- Sizes, such as floor areas, cavity widths, depth of insulation (the measured accuracy of which will have a significant influence on reported energy consumption)
• Emissivity of materials
• Internal environment (temperatures and relative humidity)
• Indoor air quality  (carbon dioxide monitoring and volatile organic compound measurements)
• Flow efficiencies of air and water systems
• Heat loss from hydronic systems
• Actual acoustic performance
• Individual properties of individual building elements (such as heat transfer)
• Actual U-values of walls, roof and floors
• Elemental heat loss (positioning heat-flux plates on various elements of the building fabric and measuring the amount of flux flowing through each element for a given temperature difference)
• Whole building tests include whole building heat loss, (for domestic dwellings, a co-heating test), and whole building air-leakage testing
• Actual daylight and electric lighting levels and quality
• Air permeability through elements such as windows and other fabric penetrations.

Physical measurements of buildings (as opposed to the validation of computer models) are mostly about checking that the as-built structures and systems are as is intended: whether the dimensions are as the design drawings, the materials are as the specification, and whether the as-built drawings and installation records accurately reflect the actual construction.

The matrix has listed the most common physical measurements and tests used in the performance testing of buildings and their systems. There are many issues around carrying out sometimes complex measurements on site and being confident that the data obtain are reliable. Methods and tests need to be developed that are robust and can help overcome the restrictions that working within a completed and sometimes occupied building.

The performance characteristics of building services can also be tested, such as the operational in-use performance of ventilation or heating systems, and whether they perform in the way the designers expected at the point of handover. As with as-built versus modelled values, comparing performance criteria (such as specific fan-power) with a design value needs to take into account the local context. With fan power, this would typically include pressure drops created by the downstream ductwork installation as well as additional performance penalties, for example created by in-duct acoustic baffles. Specification changes and product substitution also needs to be taken into account, such as the mid-contract removal of a heat-recovery bypass duct as a cost-saving measure, or the replacement of a specified product by and “equal or approved” product, that may nonetheless possess different operating characteristics.

Airtightness testing and sampling can be far more comprehensive than required for compliance with Building Regulations. The problem with regulatory requirements, however, is that the tests are carried out primarily to achieve the standard set for compliance, not to achieve best practice, nor as a tool to investigate issues in depth in order to build knowledge. For example, tests might beneficially be carried out at different stages in the construction process to follow the development of the air barrier, and before certain areas become inaccessible thereby preventing remedial work or improvements to the barrier.
That said, any physical tests to check the as-built structure against a computer model or laboratory mock-ups, can lead to questions. The assessor would need to be thoroughly aware of the parameters, assumptions and acceptable deviations in the model to be able to judge whether the as-built structure has diverged from the design intention. Thermal conductivity of insulation is a good example. A manufacturer’s claimed performance figure has to be within the 90 percentile of 90 per cent of a production run for the material. The material performance as delivered could be anything within the distribution but its declared performance should be the 90/90 performance. The in situ performance is a function of lots of in situ factors that change the performance of the construction as a whole. This may or may not include a change in the material performance itself that results from site conditions, dirt, handling etc.

There are also process issues that are related to building performance as highlighted by both the Zero Carbon Hub and the TSB BPE programme work. Such as sequencing of work, drawing conflicts, specification errors, and confidence limits in modelling that need to be considered when comparing an in situ value with a design or laboratory value.

The timing of physical measurements is a significant issue. Some tests are very time-dependent. Some can be carried out after commissioning, but others only when the building’s systems have been seasonably commissioned and properly set up for the long term.

The TSB domestic BPE programme and recent work published by the NHBC Foundation6 have both highlighted the challenges around carrying out co-heating tests in dwellings. The TSB programme initially required that co-heating tests were carried out as part of the suite of physical measurements required under a near completion or early occupation project. The tests were to be carried out in accordance with the initial protocol developed by Leeds Met based on their experience with investigating the thermal performance of dwellings. However, the variability in the results being reported and the challenges being faced by many of the domestic project teams, the requirements was relaxed for latter projects. A range of difficulties were encountered by the project teams including:

- Limited access to the dwellings required for testing associated with the construction programme and the builders desire to hand-over the dwellings,
- Testing when external conditions were not suitable either due to a mild winter period, or testing in the late spring,
- Testing being carried out by organisations or individuals not sufficiently knowledgeable about building physics and the type of measurement being undertaken,
- The protocol not providing sufficient information for the teams to undertake a full analysis of the recorded data,
- The teams not being clear about the corrections being applied to the data for the impacts of solar gains or wind effects and making comparisons with design heat loss calculations that made assumptions about air permeability rates and/or ventilation rates.

6 Review of co-heating test methodologies, NHBC Foundation, November 2013
In the absence of published, agreed procedures for many physical measurements (such as for indoor air quality), differences in sample sizes, measurement periods and measurement practice are widespread and normal. A large data sample will reduce the significance of any extreme values (such as product variations and errors in measurements), but in the real world of construction, where there are strict time and cost constraints not usually present in an R&D environment, data samples need to be balanced against the labour cost of both taking the measurements and analysing the results.
5 CONCLUSIONS AND NEXT STEPS

The GCB objectives in carrying out this study were to identify the range and type of protocols for data collection and knowledge acquisition in common use. The study has indicated that currently there are a limited number of protocols available, and that in the main these are associated with the consistent reporting of greenhouse gas emissions. The study has proposed a definition for a protocol, a method and a tool, and has demonstrated that applying these definitions there are a much greater number of methods and tools. Many of these have been developed in response to the regulatory requirements to calculate carbon emissions however, in a sense these are not data collection techniques but they are one way in which knowledge is acquired by the industry over the expected performance of an asset. In part this leads to the expectation of performance in line with these assessments and calculations, which is unlikely to be achieved in practice.

Over time an approach to assessing the performance of a non-domestic building has developed that includes an assessment of the energy performance, occupant satisfaction and a building walkthrough by an experienced individual with a view to identifying potential problem areas. In the domestic sector an equal focus has been placed on the performance of the building fabric, particular since the design strategy of a ‘fabric first’ approach has developed. These broad approaches have been documented for the TSB funded Building Performance Evaluation programme. This has generated a number of useful tools and proformas to enable auditing and analysis of the build process activities and subsequent building performance evaluation. These should be brought together, updated and improved where necessary, and published together as a BPE protocol.

From the early projects funded under the TSB Building Performance Evaluation programme and the work recently undertaken for the ZCH a number of observations can be made:

- Difficulties have been experienced by research teams that do not have a sufficient knowledge of building physics and/or the protocol or method is not sufficiently documented to enable a clear understanding of the data to be collected and the analysis to be undertaken.
- The methods for collecting data on fuel use, internal environment etc. can result in significant quantities of data that require extensive work to analyses.
- To successful collect data on the energy consumption within the building the installed metering systems need to be commissioned and calibrated. In addition, the strategy for sub-metering to ensure that useful data is collected needs to follow a method, such as that set out in CIBSE guidance. Using the data analysis method in CIBSE’s TM22 (or similar) then becomes more viable.

Further work is needed to help establish appropriate methods for collection of energy and environmental data, particularly in the domestic sector, where the current approaches result in significant quantities of data without clear rules for data cleaning and analysis. An approach to this could be the development of a route-map for rolling-out core BPE methods for the non-domestic, domestic and infrastructure sectors, with meaningful short and medium-term targets consistent with
the Government’s recommendations for delivering BPE as a component of Government Soft Landings.

Our initial concept for this project was the creation of an underlying schema and basic content of a Wiki whereby protocols, methods and tools could be searchable with links to relevant near-neighbour methodologies. This approach we believe still has value but further work on the management and curation of the Wiki is needed.

The limited response from the Government departments procuring projects was disappointing. A further survey of the active departments may bring forward some further useful methods being adopted.

In reviewing our findings from this study we believe that there are a number of opportunities for the Green Construction Board to positively influence the wider adoption of the use of building performance evaluation and the allied use of data collection techniques and knowledge acquisition.

For building performance evaluation methods and tools to become main place in the construction industry specific modules and credits in architecture and building engineering courses need to be developed to introduce the industries young engineers and architects to the subject. The Green Construction Board is well placed to initiate discussions with the institutions via the Construction Industry Council to set a programme of work to achieve this outcome.

There is a growing community of building performance evaluators from both academia and commercial practice that have come together as a consequence of the government funding for the TSB innovative buildings programme and work around the Zero Carbon Hub. The practice of evaluating the performance of our buildings to develop a deeper understanding of how to achieve better performance is still at a ‘cottage industry’ stage, and will continue to need a level of support over the coming years if it is to develop into a mainstream activity. Ways of supporting this developing network that are shared between industry and government need to be explored, and the Green Construction Board could act as a host body to enable the development of ideas and routes to implementation.
6 REFERENCES

Energy

- CIBSE TM22: https://www.cibseknowledgportal.co.uk/component/dynamicdatabase/?layout=publication&revision_id=103
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR2MainText.html
  http://www.tjlassociates.co.uk/tm22/
- Housing Evaluation and Performance Studies (HEAPS)
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR20MainText.html
  http://www.greenspec.co.uk/building-design/poe-different-feedback-techniques/
- Building Research Establishment Domestic Energy Model (BREDEM)
  http://www.bre.co.uk/page.jsp?id=3176
- Standard Assessment Procedure (SAP)
  https://www.gov.uk/standard-assessment-procedure
  http://standardassessmentprocedure.com/
  http://www.nhbc.co.uk/Productsandservices/ConsultancyandTesting/Energyservices/FAQs/
  http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf
- Home Energy Master Plan (HEMP)
  http://www.parityprojects.com/households/home-energy-masterplan/
- Lancaster DEMAND (Dynamics of Energy, Mobility & Demand)
  http://www.demand.ac.uk/
- Research Centre on Innovation & Energy Demand
  http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K011790/1
- Leadership in Energy and Environmental Design (LEED)
  http://www.usgbc.org/leed
  http://www.lead.net/
  http://www.cagbc.org/Content/NavigationMenu/Programs/LEED/GoingGreenwithLEED/default.htm
- Greenstar
- Energy Consumption Guide 19
  http://www.energybenchmarking.co.uk/Offices/download.asp
- International Performance Measurement & Verification Protocol (IPMVP)
  http://www.nrel.gov/docs/fy02osti/31505.pdf
- CIBSE TM 39 - Building Energy Metering
  https://www.cibseknowledgportal.co.uk/component/dynamicdatabase/?layout=publication&revision_id=1513
  http://www.sav-systems.com/glossary/cibse-tm39
• DomEARM (Domestic Energy Audit and Reporting Method)
  http://bob.instituteforsustainability.org.uk/knowledgebank/public/bpereport/whattodo/Pages/In-Use-Evaluation.aspx
  www.homesandcommunities.co.uk/download-doc/6154/10395
• National Energy Audit Tool (NEAT)
  http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=304/pagename=alpha_list
  http://en.openei.org/wiki/National_Energy_Audit_(NEAT)
• Landlords Energy Statement
  http://www.les-ter.org/page/home
• Tenants Energy Statement
  http://www.les-ter.org/page/home
Carbon – Operational
• Passive Design Assistant (PDA)
  http://publications.arup.com/Publications/P/Passive_Design_Assistant_help_file.aspx
  https://www.concretecentre.com/online_services/design_tools_and_software/passive_design_assistant_tool.aspx
• Carbon4Cast
  http://www.carbon4cast.co.uk/about-us/
  http://pinpoint.ukgbc.org/resource.php?item=7666
• A Whole Life Carbon Management (WLCM) ‘Key’
  http://gtr.rcuk.ac.uk/project/1CS8296B-B375-4A05-8D87-A6C187816A36
• SPeAR (Sustainable Project Appraisal Routine)
  http://www.arup.com/Projects/SPeAR.aspx
  http://www.oasys-software.com/products/environmental/spear.html
• Simplified Building Energy Model (SBEM)
  https://www.bre.co.uk/page.jsp?id=706
  http://www.ncm.bre.co.uk/
  http://www.ukbuildingcompliance.co.uk/building-certification/sbem-calculations.aspx
• Energy Savings Trust: Monitoring energy and carbon performance in new homes
  "Homes and Communities: Monitoring guide for carbon emissions, energy and water use
  http://www.homesandcommunities.co.uk/ourwork/carbon-challenge
• PAS 2050:2011 Specification for the assessment of the life-cycle greenhouse gas emissions of goods and services
• Environmental Reporting Guidelines
• Greenhouse Gas Protocol
  http://www.ghgprotocol.org/
• Footprint Expert (Carbon Trust)
  http://www.ghgprotocol.org/Third-Party-Databases/Footprint-Expert
• Arup Beacon
  http://publications.arup.com/Publications/B/Beacon_a_new_methodology.aspx
- Environment Agency Carbon Calculator
  http://www.environmenttools.co.uk/directory/tool/url/%2Fgroups%2Ficf/name/carbon-calculator-for-construction-activities/id/482

Carbon – Embodied
- iCIM

- Embodied Carbon and Energy in Buildings (ECB)
  http://www-csd.eng.cam.ac.uk/themes0/resource-flows-1

- Construction Carbon Calculator
  http://buildcarbonneutral.org/

- Embodied CO2 Estimator
  http://eco2.phlorum.com/calculator/index

- Operation and Embodied Carbon Calculator
  http://www.fgould.com/carbon-calculator/

- Thornton Tomassati calculator
  http://www.thorntontomasetti.com/about/corporate_sustainability

- CarbonCritical KnowledgeBase

- CarbonCritical Masterplanning tool

- Embodied Impacts - A guide to understanding the embodied impacts of construction products
  http://www.constructionproducts.org.uk/sustainability/products/embodied-impacts/

- Inventory of Carbon and Energy
  http://www.bath.ac.uk/mech-eng/research/sert/
  http://www.environmenttools.co.uk/directory/tool/name/inventory-of-carbon-and-energy-ice-university-of-bath/id/780

- Timber Carbon Footprint

- Ramboll Carbon Calculator
  http://www.ramboll.com/

Life-Cycle Assessment
- IMPACT
  https://connect.innovateuk.org/web/design-decision-tools
- Butterfly
  http://www.blpinsurance.com/added-services/butterfly/
- CLEAR
- The Greenhouse Gas Protocol
  http://www.ghgprotocol.org/about-ghgp
- PAS 2050
  http://www.carbonlowemissions.co.uk/Standards/PAS2050
- Athena Eco calculator for assemblies
- Athena Impact Estimator for buildings
  http://www.wbdg.org/tools/athena_eie.php
- Building for Environmental and Economic Sustainability (BEES)
  http://fire.nist.gov/bfrlpubs/build01/PDF/b01080.pdf
  http://www.greenbuildingsolutions.org/Main-Menu/What-is-Green-Construction/BEES
- Enterprise Carbon Management
  http://www.environmenttools.co.uk/user/register/name/e3ecm-enterprise-carbon-management/id/428
- SimaPro
  http://www.simapro.co.uk/aboutsimapro.html
  http://www.pre-sustainability.com/simapro
- GaBi
  http://www.gabi-software.com/uk-ireland/index/
- Boustead Model
  http://www.boustead-consulting.co.uk/whatdata.htm
- Umberto Carbon Footprint
- REGIS (Corporate ecoperformance)
  http://www.sustainabilityprofessionals.org/marketplace-product/7650
- CES Eco-selector
  http://www.grantadesign.com/products/ces/overview.htm
- DEMScot Model
  http://www.carltd.com/node/181
  http://www.scotland.gov.uk/Topics/Built-Environment/Housing/supply-demand/chma/marketcontextmaterials/DEMSCOTversion2
- LifeCYCLE
  http://www.erus.mottmac.com/services/lcc/
- The ecoinvent database

**Human Factors**
- Building Use Studies survey (non-domestic)
  http://www.busmethodology.org.uk/
- Building Use Studies survey (domestic)
  http://www.busmethodology.org.uk/
- Building Use Studies survey (transient users)
  http://www.busmethodology.org.uk/
• Oxford Brookes University Healthcare POE Method
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR13MainText.html
• Office Productivity Network Survey
  www.officeproductivity.co.uk
• Overall Liking Score
• Occupant IEQ Survey
  http://www.cbe.berkeley.edu/research/survey.htm
• Thermal Comfort Diary
  http://architecture.brookes.ac.uk/research
• PACES: Building Occupant Survey
• Leesman Index
  www.leesmanindex.com

Strategic Overview
• Rapid Prototyping and Analysis Tool for Environmental and Cost Performance Improvement and Emissions Reductions in Low Impact Buildings (RAPIER)
  http://projectrapier.com/rapierserver/rapierserver/index/
  http://gtr.rcuk.ac.uk/project/9D116793-8A70-4740-899B-FB0AAA31F012
• Concept to Completion Design Tools for Sustainable Buildings
  http://gow.epsrc.ac.uk/NGB OV iewGrant.aspx?GrantRef=TS/H002960/1
  https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0CDgQFjAB&url=http%3A%2F%2Fwww2.uwe.ac.uk%2Fservices%2FMarketing%2Fresearch%2Fpdf%2FISHE%2FPlanning23.pdf&ei=3kAzU5GwDlnxhQeulYDIBw&usg=AFQjCNGt6cjXzVqKblivOqXzXXJYC2GbAg&sig2=wOTUSYLxLcpWbBwRiGrQ&bvm=bv.63738703,d.ZG4
• Pearl Rating System
• VALID (Value in Design)
  http://www.valueindesign.com/
  http://www.adeptmanagement.com/amitechnologiesus/valid.html
• Responsible Retrofit Guidance Tool
  http://stbauk.org/

Operational Review
• Advanced Design + Optimisation (ADOPT)
  http://www.iesd.dmu.ac.uk/~adopt/wiki/doku.php?id=start
• Design Excellence Evaluation Process (DEEP)
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR12MainText.html
  http://www.designingbuildings.co.uk/wiki/Design_quality_for_buildings
• Dynamic Simulation Model (DSM)
  http://www.designbuilder.co.uk/downloadsv1/BREEAMChecklistA10ReportForDesignBuilder.pdf

- **PROBE**
  http://www.cibse.org/content/Ed/PROBE/Introduction%20to%20Probe.pdf
  http://www.cibse.org/knowledge

- **School Building Assessment Manual**
  http://www.usablebuildings.co.uk/fp/OutputFiles/PdfFiles/FR23p1SchoolAssessmentMethods.pdf

**Project Review**

- **AUDE & UW Guides**
  http://www.aude.ac.uk/info-centre/good-practice/AUDE_POE_guide
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR28MainText.html

- **BRE Design Quality Method**
  http://www.bre.co.uk/page.jsp?id=1623
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR15MainText.html

- **CIC DQI**
  http://cic.org.uk/services/the-design-quality-indicator-dqi.php
  http://www.dqi.org.uk/dqi/Common/DQIOnline.pdf

  http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=TS/H003266/1
  http://rec.brookes.ac.uk/research/cpm/

- **Learning from Experience**
  http://www.constructingexcellence.org.uk//resources/toolkits/view.jsp?id=254

- **Low Energy and Sustainable Solutions Online Knowledge System (LESSONS)**
  http://www.iesd.dmu.ac.uk/research/project/lessons.html

- **Medical Architecture Research Unit (Maru) Evaluation Studies**
  http://www1.lsbu.ac.uk/maru/publications.shtml
  http://www1.lsbu.ac.uk/maru/research.shtml

- **Reality-checking (Pitstopping)**
  https://www.bsria.co.uk/information-membership/bookshop/publication/pitstopping-bsrias-reality-checking-process-for-soft-landings/

**Process**

- **Display Energy Certificate (DEC)**

- **Energy Performance Certificates (EPC)**
  https://www.gov.uk/buy-sell-your-home/energy-performance-certificates

- **Handover of Office Building Operations (HOBO)**
  http://www.brebookshop.com/details.jsp?id=140312

- **Optimise**
  http://www.optimise.co.uk/Vision.htm

- **Passive House Planning Package (PHPP)**
  http://www.passivhaus.org.uk/podpage2.jsp?id=25
  http://www.passiv.de/en/04_phpp/04_phpp.htm

- **Soft Landings**
  www.bsria.co.uk
  http://www.designingbuildings.co.uk/wiki/Soft_landings
  http://www.bimtaskgroup.org/government-soft-landings-explained/
Functional Performance

- Energy Management Matrix & Energy Management Assessment
- Healthcare Design Quality Assessment Method
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR23MainText.html

Technical Performance

- BREEAM
  http://www.breeam.org/
  https://www.bre.co.uk/page.jsp?id=829
- Defence Related Environmental Assessment Method (DREAM)
  https://www.dreamassess.com/
- Higher Education Design Quality Forum (HEDQF) Post Occupancy Evaluation Forum Methodology
  http://www.usablebuildings.co.uk/fp/OutputFiles/FR6MainText.html
APPENDIX A: BUILDING OPERATIONAL ENERGY TOOLS

Building operational energy tools
Robert Cohen, Verco

Background
The enterprise of design, construction and operation of energy efficient non-domestic buildings must be focused on the overall energy use and emissions of the buildings in operation. We can then dispel the myths, concentrate on the realities and deliver the emissions cuts expected of them. Transparency of reporting will transform the priority given to energy efficiency. Display Energy Certificates (DECs) were established in 2008 to deliver this transparency. A DEC reports annual operational performance over the past year and the headline result for the previous two years.

In multi-tenanted buildings, DECs can be generated by each tenant occupier if they receive a Landlord’s Energy Statement which identifies their share of the energy attributable to the Landlord’s services. The energy efficiency of the landlord’s services can be reported by a Landlord’s Energy Rating (LER). The LER reflects the energy efficiency of the overall building’s fabric, its HVAC systems and any energy uses in the building’s common areas. The LER together with DECs for each tenant provide a complete picture of the building’s annual energy performance at a headline level.

CIBSE TM22 dissects a building’s annual energy performance to provide a breakdown by end use, benchmarking of the roots of consumption for each end use, and electricity demand profiling.

CIBSE TM54 describes how a building’s operational energy use can be predicted at the design stage.

Annual energy use indicators
Annual energy use (including from any onsite renewable energy sources) is determined by individual fuel or energy source and as a weighted sum (typically of CO₂ or electricity equivalent). The consumption is divided by the measure of extent (usually floor area) to get Energy Use Indicators (EUIs) in kWh/m² for electricity and non-electricity (ie fuel and/or heat), and, as a single metric, a Carbon Performance Indicator (CPI) in kg CO₂/m² or Electricity Equivalent Indicator (EEI) in kWhe/m².

The EUIs provide immediate insight about energy performance: an experienced energy assessor will be able to place them immediately in the spectrum of empirical data for buildings of the same type.

The CPI or EEI provide a single metric by which the building can be ranked for its impact on CO₂ emissions or its energy efficiency. Historically, EUIs have been further adjusted by normalising for variable imposed factors (most often weather and occupancy hours) to produce Normalised Performance Indicators (NPIs). However, normalising the actual energy use can inhibit transparency, so now it is recommended to report unadulterated EUIs, CPIs or EEIs and judge them in relation to benchmarks that are adjusted (tailored) to fit the specific circumstances of each individual building.

Benchmarking
A building is benchmarked by comparing its EUIs, CPI or EEI with benchmarks. Options include:

- Positioning the building’s EUIs, CPI or EEI within a peer group, to give a percentile score, as used in the EnergyStar system in the US.
- Comparing the EUIs, CPI or EEI with criterion values, e.g. the Typical and Good Practice levels commonly used in the Energy Consumption Guides published by the Carbon Trust.
• Calculating Benchmark Ratios between a building’s EUI, CPI or EEI and benchmark values which can be customised to the building. This method is used for DECs, which reports percentage ratings for carbon dioxide (the headline indicator producing the A to G grade), electricity and non-electricity, on a linear scale that runs down to zero. The median rating of 100 lies at the D/E boundary and each grade spans 25 rating points.

**Tailored benchmarks**

The DEC system tailors benchmarks for regional climate (heating degree days), extended hours of use and mixed-use and also allows the exclusion of metered separable energy uses not allowed for in the benchmark.

A more sophisticated form of tailored benchmarking allows thermal and electrical benchmarks to be built up automatically from schedules of energy end uses tailored to the circumstances of a specific building by adjusting for activities. As an example, a tailored benchmark for offices would be based on a schedule of accommodation (e.g. reception areas, cellular and open plan offices, trading floors, call centres, catering provision), occupant hours of use and workstation density, number of floors, and so on. It calculates the annual energy needed for each end use in each category of space, assuming Good Practice or Typical efficiency.

Fully tailored performance benchmarks provide a powerful tool for building operators and energy managers. By working out how much energy a building should be using, they can motivate far more strongly than the less discriminating DEC benchmarks or even the peer group comparison approach. The DEC methodology infrastructure is designed to accommodate further tailoring for each sector, and could evolve towards it without requiring any change to the calculation or software.

**Tree diagram analysis**

The underlying approach for the tailored benchmarks method is called a tree diagram (see below) because it builds up energy consumption from the components - the roots of consumption. It also separates out the asset, control and management elements of energy use.

The full power of the tailored benchmarks approach emerges from CIBSE TM22 where all the components of energy use (i.e. the building’s actual values for each box) can be benchmarked against their typical and good practice values. This signposts the scope for energy saving through management measures, control measures, or improvements in installed plant or equipment. A comparison with design values for each component additionally can reveal the precise sources and causes of any energy performance ‘gap’.
A tree diagram model of a building’s annual energy use.

**Measuring performance over time**

Performance is most commonly reported on an annual basis for entire sites, buildings or premises and for particular end uses. Time-dependence is also important, and will become ever more so as the installed capacity of renewable electricity supplies with fluctuating output grows, especially wind and PV. Buildings that can adapt to gluts and famines in energy supplies may be rewarded. Even where this is not yet a factor, to study energy demand over time can yield big benefits. For example:

- Plots of heating energy use against external temperature show if systems are well-controlled.
- A study of electricity demand profiles over time (typically at quarter or half-hourly intervals) can reveal where things are operating wastefully or unnecessarily, particularly at nights, weekends and public holidays. CIBSE TM22 includes a module to help with this.
- Benchmarking day and night power density loads, in W/m², can also be a useful guide as to how a building is performing in relation to its peers, and can help to reduce unnecessary night use.
APPENDIX B: CARBON AND INFRASTRUCTURE

Carbon and infrastructure
David Riley, Anglian Water

Based on some ONS data carbon in infrastructure accounts for 53 per cent of overall UK annual carbon emissions, if that is broken down about 16% of that is in control of designers and contractors, and 37 per cent under the influence of the end user (government through roads and those who drive on them).

Key to this is what the data is used for. Anglian Water looks for an outcome of smaller carbon footprint in designs. By reducing carbon Anglian Water also reduces costs quite significantly within its capital programme, and reduces the volume of material used to build assets.

Process issues
The process determines scope and boundaries. What activities are included in the measurement: cradle to disposal, or cradle to as-built? Having clear scope and boundaries is important. Methodology is then critical. The Greenhouse Gas Protocol, provides a methodology on how to measure greenhouse gas emissions.

The Greenhouse Gas Protocol has been enshrined in top-level guidance through PAS 2050: 2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

DEFRA has recently updated and combined its guidance into Environmental Reporting Guidelines: Including mandatory greenhouse gas emissions reporting guidance. This also Implements the GHG Protocol. It is useful for operational energy use but not for calculating embodied energy use.

The water industry has its own guidance document issued though UKWIR (UK Water industry research [www.ukwir.org/site/web/content/home]), which provides guidance used by all water companies. This provides a methodology, but not how the measurement should be made, and this comes back to how the data is going to be used. So the application of the guidance takes different forms.

Some organisations have a top-down measurement process, so they look at quantities of the materials used in a programme, and multiply that by an emissions factor to get their total carbon dioxide for an infrastructure project. Others take a bottom-up approach, where they look at individual components built up in an infrastructure project, all m&e, concrete and all other elements.

Data sources
There is a wide range of data sources available, some commercial, some free. The most common source is the University of Bath Inventory of Carbon and Energy. It may have inaccuracies in the data set, but at least it is a common dataset that is being used, and it is being improved all the time. It does give what data is available, where it has been sourced, and what the confidence levels are.

Other sources are European product declaration sheets, generated by factories who report the carbon impact factors of certain materials. However, there are confidence issues with EPDs.
Anglian Water has developed about 1300 carbon models to take into account all processes in the build phase, so that it can model all the elements that (concrete tanks, valves etc that go in the ground).

1. We need to consider process – what is it that is being undertaken
2. What is governance in place to get that lower
3. What are the tools available

The tools available for infrastructure are very small. In Anglian Water has developed its own tool open to all framework contractors, who can load up their design equipment to give us an embodied carbon value. Anglian Water “optioneer” that to reduce carbon further. That’s not a tool open outside of Anglian Water’s business, but had to develop one as it didn’t exist.

**Data**

Awareness across full value chain is important, so that making sure we can encourage suppliers to start reducing carbon emissions within the products and services they offer. They start to reduce through innovation. That feeds through into procurement. So if we ask a supplier to innovate, they will do so if they see 10 -15 years of commercial opportunity, and they will pull innovation through their value chain.

**Benefits:**

- Data helps to reduce carbon and cost
- Don’t need to be 100% accurate in terms of information used
- Use data to unblock the value chain to deliver a low carbon solution.
APPENDIX C: PHYSICAL MEASUREMENT OF BUILDING PERFORMANCE

Physical measurements of building performance (domestic and non-domestic buildings)
Jez Wingfield, UCL Energy Institute

Purpose of measurements – why measure?
Physical measurements can be to check that what is actually constructed versus what has been designed or specified. This could be for example the type of block, specification of joist, dimension of wall, tolerance of cavity, missing component, product substitution or a comparison of a detail with drawings. Typically, the most common existing technique for this is some form of checklist.

Regulatory or planning requirements sometime require physical tests to check compliance. For example, mandatory airtightness testing is required for both domestic and non-domestic buildings in the UK. However, the scope of regulatory tests may not always be sufficiently rigorous for BPE. Measurements can be used to check the performance of contractor/sub-contractors against predefined performance targets.

There may be a need to compare in-situ performance versus that of theoretical models or laboratory test data. You would need to know the basis of the theoretical models/calculations/laboratory conditions and also be aware of how the test parameters are defined and how manufacturer’s data is actually measured. For example, thermal conductivity of insulation is quoted as a 90/90 value but manufacturers do not normally provide the mean or standard deviation of their production.

What types of characteristics can be measured?

- Dimensions – e.g. size, shape, orientation, tolerances, floor areas, cavity widths, duct diameter, depth of loft insulation etc.
- Material properties – e.g. type of material, insulation thermal conductivity, emissivity, moisture content, bulk density etc.
- Building element properties – e.g. U-value, window air permeability, hot-box tests etc.
- Whole building properties – e.g. building heat loss, building air leakage, air temperature/humidity, indoor air quality, differential pressures etc.
- Services – e.g. heat flows, energy consumption, boiler efficiency, flow temperatures, flue gas, duct leakage, ventilation specific fan power, operation of controls, control set points, thermostat hysteresis etc.
- Process issues – e.g. build sequencing, drawing conflicts, specification/drawing errors, lack of availability of materials, ad-hoc design, training, provision of documentation, commissioning etc.
- Durability and time dependent factors – e.g. airtightness degradation over time, duct friction increase due to build-up of dust, mechanical ventilation with heat recovery (mvhr) filter changes, settlement of insulation, boiler servicing etc.
Timing of measurements

Performance of fabric or services at handover/completion under idealised conditions may be different to that after the initial period of occupation or after any defects liability period. In non-domestic buildings with complex services there may be an extended hand-over period with adjustments to plant settings and additional commissioning.

The performance of building fabric may also change over time, for example due to drying, shrinkage, expansion/contraction. A good example of this is airtightness which can change over time due to factors such occupant changes, cracking due to thermal expansion/contraction or failure of seals. Some measurements can be taken during the construction process prior to completion. For example, checks of the effectiveness of the installation of insulation, the performance of an air barrier or duct leakage are best carried out prior to completion of the internal finishes in order to avoid excessive rectification cost if any problems are identified.

It can be advantageous to repeat some types of measurements during the construction process. For example, air permeability measurements are often carried our several times to assess the effect of different stages of construction on air leakage.

Other considerations

Some measurements techniques are complementary and should be considered together in certain situations. For example, it is advantageous to carry out thermal imaging and in-situ heat flux measurements at the same time as a co-heating test.

Some measurements might be invasive or destructive. For example, a borescope can be used to inspect inaccessible voids or cavities, but this may require the drilling of inspection holes.

Consideration should be as to how physical measurements can be linked in with other evaluations (such as Soft Landings, in-use performance, human factors, building control inspections etc.).

There is a need to consider the impact of sampling, variation and measurement error on the effectiveness of measurements. For example, whilst whole house testing is able to provide a high level of information, it is not usually easy to access houses for long periods of time between completion and occupation.

It should be noted that there can be differences between in-situ measurements are similar tests conducted under controlled laboratory conditions. This can be due to factors such as weather or dynamic effects than are difficult to replicate in a laboratory test. Practitioners need to consider how the test conditions might affect the measurement result. For example weather (wind, rain, sun, temperature variation, humidity) and occupancy factors can all influence building performance.

Measurements can give either quantitative or qualitative data, or sometimes a mixture of both. Whilst it is easier to relate qualitative data to performance standards, the use of qualitative techniques should not be ruled out, as long as used appropriately. For example, thermal imaging can be used qualitatively in the context of assessing continuity of insulation. Methods can be used to capture process information (for example, build sequencing).
Buildings will behave differently under dynamic conditions compared to a steady state. Dynamic properties are most likely to relate to real buildings under operational conditions, but steady state properties are still important, especially as they form the majority of inputs to energy models.

The costs of equipment, training and carrying out measurements should be taken into account when assessing and comparing the usefulness of any measurement technique. The relative impact of such costs might be different for a large organisation compared to an SME, or for domestic buildings compared to non-domestic.
APPENDIX D: HUMAN FACTORS IN BUILDINGS

Human Factors in Buildings

Adrian Leaman
Building Use Studies and the Usable Buildings Trust

Human factors are

- A matter of understanding human need, using believable accounts of behavior, attitudes and prevailing circumstances.
- Usually questionnaire surveys will suffice for data gathering but they may not always be appropriate for every situation.
- Non-domestic buildings are surveyed differently to domestic, but many factors are, obviously, common.

Building occupants are happiest when they find

- Comfortable conditions. Thermal comfort is usually the most important determinant of occupant satisfaction: people often say they are too hot in summer, and can be too cold in winter. Noise is also increasingly a downside.
- Rapid response when things go wrong. People are happier when a perceived need is met quickly, or when they are able to intervene to improve things to their satisfaction.
- Design intentions clearly communicated. People may be more willing to forgive perceived faults if they understand how things are supposed to work.
- Opportunities to escape.

People like don’t like

- Unmanageable complexity. This applies to all kinds of building user, including facilities managers, and particularly to usability and manageability. People particularly dislike adverse actions of other people or intrusive technology such as apparently arbitrary automatic lighting systems.
- Space layouts which do not support the primary task or action (e.g. teachers who cannot be heard properly by pupils, office workers who are randomly interrupted, noisy neighbours).
- High occupant densities beyond comfort thresholds set by 1-5.
- Situations where they need to intervene to change things only occasionally.
- Opportunities to act quickly to make adjustments if conditions alter.
- Conditions which are ‘good enough’ rather than ‘just right’.

And they also don’t like

- Being prevented from intervening to change physical settings from an undesirable existing state to a better one.
- Being subjected to arbitrary changes in conditions which they are affected by, but cannot then intervene
- Unfamiliar settings
- Stressful emergencies
- Lack of speedy or effective response from other people who control settings which may affect them
• Being prevented from making trade-offs of their own choosing between lesser evils, for example too much noise or too hot.

**Improvement may come from**

• Better-designed physical device interfaces
• More appropriate locations for devices and switches
• Installers’ actions supervised
• Better user familiarity with operating context and design intent
• Conflict resolution/mediation between different users
• Altered habits and perceptions, perhaps based on convincing and timely cost and consumption information.

**Overall**

Many usability aspects may appear trivial or low-priority, especially to designers and managers. This can be a tyranny of small decisions for users, many small things adding up to something bigger and undesirable

• Physical interfaces may be inherited with constraints which are expensive to change especially in older buildings. E.g. positions of meters
• Installers’ actions usually suit their convenience at the time not that of the users’, such as location of switches which should be as close as possible to the point of user need
• Users may not understand how things are supposed to work or where things are located or how critical they are. For example allegedly intelligent systems like lighting controls, which may operate in exactly the opposite way the user expects
• Different users will almost always see things differently. For example allergy sufferers often want windows closed in summer
• Habits and behaviours may be acquired and applied randomly whatever the circumstances. For example, windows open or closed in bedrooms at night.

**Best data-gathering techniques**

• Questionnaires are usually best, but must be carefully crafted both for the respondent and the analysis by the researcher
• Concentrate on needs not wants or wish-lists, and...
• How people actually behave, and...
• The factors which are already known to have the greatest effects, for example thermal comfort
• Capture the context as fully as possible
• Give equal weight to quantitative ratings and qualitative observations
• Do not take a blunderbuss approach to physical measurement. Measure only where circumstances demand.
APPENDIX E: COMMERCIAL REALITIES FOR BPE

Commercial Realities for carrying out Building Performance Evaluation
Richard Reid et al Arup

Why carry out BPE?
Buildings exist to meet the needs of the business and people that use them. As designers, contractors, developers, operators and managers we should have some responsibility to demonstrate that buildings meet these needs. To do this we need data and occupants/users feedback to understand what is good or bad; taking these lessons to the ‘next’ building(s).

The introduction of carbon reduction targets and the need to reduce consumption (due to cost and limited resources) means the energy performance of buildings is critical. Closing the performance gap between design and operation is essential to meeting these targets; however as a designer (Arup perspective) we have a responsibility to do this anyway for our clients. It is fair to say our clients expect BPE as part of our service on new build projects.

Energy performance evaluation should not be completed in isolation. It is important to also understand occupant satisfaction. When these two pieces are combined and delivered together we can demonstrate true ‘Building Performance Evaluation’. We will then have the feedback needed to meet the needs of the business and users for which the buildings are created for in the first place.

How do we get our clients to procure BPE?
Clients need to reduce consumption and have efficient buildings can be driven by many factors. These may include rising energy prices, legislation and corporate social responsibility (value of corporate image); also the financial pressures to reduce costs and save money.

These drivers provide an opportunity to engage with clients to create new low energy buildings and address energy performance problems within the existing built environment. There are however some key drivers that make engagement tricky:

- Terminology. Clients often do not understand the difference between services such as BPE, POE, commissioning and Soft Landings.
- BPE on its own may not be enticing enough. Clients often expect a range of solutions in single buildings or across their estate. This might be simple re-commissioning and optimisation, through plant upgrade, full building refurbishment or rationalisation an disposal of assets to meet business demands.
- For new build, clients may expect BPE to be included in the base fee.
- Clients often do not understand the value of BPE. Engineers often do not explain value in the right context (i.e. overall value to business). The projected savings might be small in comparison to the impact on the business income. I.e. some businesses may be more productive in an inefficiently operated building. This is a key consideration.
- Many clients expect alternative fee models (guaranteed/shared saving etc). These fee models present risk to the evaluator and issues around cash flow. They can often not be accommodated for single buildings.
• The market is competitive, with many small energy consultants offering ‘off the shelf’ reports with little substance or value. Others offer BPE for free as a loss leader to other work.
• Availability of data is key. If it is not there then collecting it costs time and money.
• Uncertainty around benchmarking tools and new ones springing up.

The BPE work delivered by Arup is often procured in one of the following ways:

1. BPE as a core part of new build design and delivery (Arup have a new initiative to embed this in all projects).
2. If clients want to reduce energy or improve comfort (these projects are often very competitive to tender and win for some of the above stated points).
3. By troubleshooting an existing building problem (e.g. a chiller issue), reacting to that highlights other issues. The scope may then develop into a BPE study.
4. Case study and feedback to inform future business decisions.

How do we gather and report design lessons without losing context?
During the design and construction process there are many external factors that affect the realisation of a design (procurement route, programme, budget, value engineering, commissioning, etc.). Buildings are often designed for compliance (‘performance gap’). Clients are often not well briefed as to what this means (e.g. EPC/DEC comparison).

The construction industry needs to create a culture of openness without blame where possible (in some cases blame is unavoidable). To deliver buildings that work BPE is an essential part of that process; as it becomes the norm, how can the ‘honesty and objectivity’ required to get good quality feedback be ensured?

• Should the Building Performance Evaluator be part of the same organisation as the designer(s) or another member of the project team?
• Will organisations be prepared to be honest and say how the building they design/construct/maintain is performing? How could the principles of BPE avoid any ‘spin’ on the truth? (Should they be an independent party?)
• Do the contracts we have in place allow this to happen? How do we limit litigation?
• Will professional standards – CIBSE, LEED, BREEAM, Soft Landings provide the answer?
• How do we communicate BPE findings without being hampered by anonymity and confidentiality?
• This is often a client decision which will be influenced by the clients business and how they wish to be perceived.
• Our experience of BPE shows that clients are nervous of information being in the public domain, considering reputation, possible dilution of their brand and share value.
• Organisations don’t want a negative impact to their business, but there can be a good story to be had. Pioneering the way and showing others what they should be doing can provide a competitive advantage to a business.
APPENDIX F: INDUSTRY WORKSHOP REPORT

Operational energy

In the preamble to the session, building performance analyst Robert Cohen from Verco identified the key tools used to study building-related energy use. The main approaches to studying energy use are:

- Display Energy Certificates
- Landlords’ Energy Statement
- CIBSE TM22 for non-domestic buildings, DomEARM for domestic dwellings
- CIBSE TM54 Evaluating Energy Performance at the Design Stage (in development)
- Benchmarks
- Tree diagrams
- Degree-day analysis
- Electricity demand profiles

Benchmarks for energy use continue to be a difficult issue. Although they are fundamental to most of these methods listed above, many benchmarks are either old, or poorly informed.

Before the introduction of Display Energy Certificates (DECs) it was common practice to adjust the actual energy performance against a benchmark. The benefit is that buildings in a portfolio can be grouped and their consumption adjusted for location and conditions. This enables their performance to be compared despite being geographically spread. The downside is that adjusting actual consumption is potentially inaccurate. It is therefore easier and safer to adjust the benchmark. But in order to compare different buildings with each other, a performance ratio or grade is needed, which is how the DEC system works.

The conventional metric for space heating efficiency is to plot metered fuel use against heating degree days. This can be done on a daily or monthly basis depending on the availability of source data. Degree day analysis will reveal how closely matched the heat system is to prevailing weather conditions. If the fuel consumption is a poor match to conditions, it suggests issues with the quality of control of the heating system, and/or the quality of the building fabric.

Electricity demand profiles can be available on a quarter hourly or half-hourly basis. These profiles are increasingly common in non-domestic buildings, either from the energy supplier via automatic meter readings (AMR) of fiscal meters, or from sub-metering installations. An installation that is installed correctly and set up well can deliver quarterly or half-hourly electricity data which be very insightful for understanding what is being used at night and over weekends. Unfortunately, very few sub-metering installations are proving to be useful or accurate.

The operational energy tools identified and ranked separately by each workshop group were as follows.
Note that some of the processes identified above are not tools as such, but mechanisms to either gather data (M&T Energy Bureaus; AMR) or report it (DECs and TM22). The use of this latter group fall more in the knowledge acquisition and understanding category.

There was notable consensus between the groups on the main tools to assess operational energy consumption, and reasonable agreement on their order of priority. Key issues associated with some of the tools are covered below.

Display Energy Certification (DECs)

DECs were regarded as a powerful tool for assessing and reporting energy use and carbon dioxide emissions.

The main comments received from delegates were that while DECs are a great concept, they are highly dependent on the quality of the input data. They are also dependent on published benchmarks covering building typologies, most of which are poorly informed and/or out-of-date. They are also limited in their wider national value by government’s consistent refusal to make energy reporting mandatory for all new and refurbished non-domestic buildings.

CIBSE TM22

CIBSE TM22 Energy Assessment Reporting Methodology for non-domestic buildings was regarded as a very powerful tool, but in its current (unpublished) research version 3.17, is very complicated to use. To be used effectively, TM22 needs training and technical support, but this is currently unavailable.

TM22 is therefore regarded by many as a specialist tool, for use mainly by a few well-trained enthusiasts. The outputs (in kilowatt hours and carbon dioxide emissions) are also open to interpretation, particularly when uploaded to Carbon Buzz, as the data in TM22 can often only reflect the best obtainable version of energy consumption by end-use, rather than a mathematically accurate breakdown. The latter is highly dependent on high quality input data for the various end uses in buildings, such as metered values for fans, pumps, controls and lighting circuits, but this data is either not available or highly questionable due to shortcomings in sub-metering installations (which, as the TSB research is finding, affects the majority of them).
It is also vital to understand the contribution from the occupants’ plug-in power loads. Not only are these not covered by Building Regulations, they are also generally not sub-metered, and where they are, data are not always accurate. Detailed surveys are needed to understand such loads and the degree to which they run in standby mode, and/or are left running at night and at weekends.

The estimations inherent in a TM22 model are easy to misinterpret as being measured values, especially when the data is graphed with no supporting narrative, caveats or explanations. Currently the only public platform for reporting TM22 outputs is Carbon Buzz, which concentrates on identifying the performance gap between designed and as-built rather than accounting for estimations in design models or in a TM22-type analysis. The assumptions and approximations need to be clearly and honestly explained in an accompanying report.

Concern was expressed that a TM22 model, created at project inception and updated through design and construction phases to form the basis of an as-built record, is not something that clients will readily pay for. Consultants also find that it can absorb a lot of fee-paying time to assemble. A concern was also raised that TM22 won’t have a future if it is not widely used.

TM22 is published by the CIBSE. As of summer 2013 it is only available as a beta tool version 3.17 for use by TSB-funded research teams. There is no timetable for a public release. The only published version available from the CIBSE is the 2006 edition.

CIBSE handles all training of the 2006 edition of TM22. No training in the research version of TM22 has been provided outside of the TSB research programme. At the time of writing, no launch date has been set for the new version, and nor has any training been announced.

Overall, workshop delegates rated TM22 highly for its usefulness and for its reporting conventions. Delegates were less sanguine about its robustness of the tool, and some marked it down for not being easy to use. The lack of training was a clear concern.

**DomEARM**

DomEARM (Domestic Energy Assessment and Reporting Methodology) is a tool for understanding domestic energy consumption. It was developed by Arup for the Technology Strategy Board’s Building Performance Evaluation (BPE) programme, and will be published by ACA.

As with TM22, DomEARM currently has a high visibility owing to its use in the Technology Strategy Board’s Building Performance Evaluation research programme. It is owned by ACA and is in pre-release Version H.

Delegates’ experience of DomEARM was limited, but those that knew about it and expressed a view reported that the method was useful, easy to use and credible with the construction industry. Its reporting conventions were consistent with other mechanisms such as Carbon Buzz and DECs, and it was generally regarded to have a future.

However, the accuracy of DomEARM is subject to the same concerns and caveats as TM22, particularly the dependence on the quality of input data, which is itself dependent on the quality of
sub-metering. In highly insulated dwellings with sustainable technologies, accurate consumption data will be required for packaged systems such as solar and PV panels, heat pumps, mechanical ventilation and heat recovery systems (MVHR), and direct-electric reheat-coils in storage cylinders and buffer tanks. Accurate modelling of these systems can be time-consuming and expensive. It can also be invasive to the householder if additional sub-metering or visits by researchers are needed to overcome shortcomings in data.

**Carbon Buzz**

Carbon Buzz is an on-line platform for holding and communicating energy and carbon emissions data from new and refurbished buildings. The Carbon Buzz database and case studies can be browsed for free.

Carbon Buzz is a voluntary system. Participating users and practices can register and start using Carbon Buzz at any time. Once a project template has been created, users can add multiple records to these, each representing an annual energy record for the project. These can be drawn from any project stage from design inception to operation.

Carbon Buzz allows users to analyse and compare data entered for their buildings at each project stage through energy and carbon graphs called energy bars. Users can track, review and compare energy records and contributing factors over time, and generate reports on their data for external use. The operational energy data for a building can be compared against a reference benchmark dataset for the building typology.

The GCB workshop delegates regarded Carbon Buzz as a useful tool for communicating energy and carbon performance, and simple for non-technical users to use. However, as with TM22, concerns were voiced about auditing or moderation of the data uploaded. The responsibility for ensuring data quality currently lies with the person uploading the data.

Concern was also raised about the over-simplification of what is becoming known as the ‘performance gap’. This gap presumes that every difference between design estimations of energy consumption and as-built consumption is a gap, and that every gap is, by definition, a bad thing and indefensible. However, the difference might be a consequence of many (often compounding) issues, such as poorly-informed design targets, a subsequent changes in client requirements, more intensive use or longer hours of use than accounted for in the design, changes to the engineering specification due to budget constraints, or simply a category error in the benchmarking. The building in question may have untypical loads or uses that make it a poor fit against the Carbon Buzz benchmark dataset.

All these issues need to be understood by people uploading data to Carbon Buzz, or viewing case studies on-line. Some workshop delegates highlighted the need for better auditing and training processes to avoid the misinterpretation of published data.

**Human factors**

In the preamble to the Human Factors session, Adrian Leaman from Building Use Studies identified the main techniques for obtaining feedback from people about their needs and expectations, and their experiences in buildings.
The best data-gathering techniques are those where:

- Questionnaires are carefully crafted both for the respondent to fill in, and for the researcher to analyse later
- The method concentrates on needs, not wants or wish-lists
- The research aims to understand how people actually behave
- The research approach captures the context as fully as possible
- The survey method gives equal weight to quantitative ratings and qualitative observations
- The research doesn’t try to measure everything, nor attempt to create a multi-variable dataset that is expensive and difficult to analyse and correlate with other factors, with additional risks of spurious correlations between otherwise unconnected variables.

It is difficult to find enough techniques that meet these criteria. Human factors research is often an academic activity, and most occupancy survey techniques that have transcended academia are, says Leaman: “Rather like shooting stars, they stay around for a few years and then disappear”. According to Leaman, they tend to be abandoned because they don’t generate anything of much use for the assessment of building performance.

Funding to keep them alive is also discontinuous at best. Long-term funding normally requires commercialisation, and commercialisation takes the method out of the public domain and into a commercial service offered by the host organisation, usually to a small community of clients.

The human factors session was run parallel with the infrastructure session, hence only one group discussed the available methodologies. The ranking that follows is more an order in which the methods were discussed rather than a strict ranking. The list was also strongly influenced by the small number of people who use such methods regularly.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Building Use Studies Methodology (domestic)</td>
</tr>
<tr>
<td>2</td>
<td>Building Use Studies Methodology (non-domestic)</td>
</tr>
<tr>
<td>3</td>
<td>Leesman Index</td>
</tr>
<tr>
<td>4</td>
<td>Structured interviews (particularly for domestic dwellings)</td>
</tr>
<tr>
<td>5</td>
<td>Building walkthroughs</td>
</tr>
<tr>
<td>6</td>
<td>Design Quality Indicators (DQI)</td>
</tr>
</tbody>
</table>
**Building Use Studies Methodology**

The method that has gained most traction in the UK is the Building Use Studies (BUS) survey for non-domestic buildings. Workshop delegates rated the BUS positively for being useful, accurate, robust, easy to use and credible, by virtue of being honed both in research projects and latterly in the open market. It can be used as a feedback tool to inform client requirements and the design brief, and also as a tool in post-occupation evaluation (POE). It is not currently used to set performance metrics for occupant satisfaction.

The domestic version of the BUS is more recent, but those workshop delegates that had used it rated it positively for being useful, accurate, robust, easy to use and credible. Its use is enhanced by cross-referencing with other methods, such as structured interviews and walkthroughs of the dwelling.

BUS reporting conventions were also thought to be clear. However, unlike the non-domestic BUS survey, the domestic version of BUS has ethical issues associated with getting agreement with householders to gather, hold and analyse personal information about their lives and their use of their private home.

**Structured interviews**

The Technology Strategy Board has developed a semi-structured questionnaire for use on the Building Performance Evaluation research programme, which offers qualitative information on how a domestic or non-domestic building is performing.

Workshop delegates identified a number of concerns with occupant interviews of all kinds. First, the quality of assessors is paramount. While questionnaires and interviews are straightforward to do, they are difficult to do well, and very easy to get wrong in terms of statistically invalid samples, and introduction of bias. This will affect the validity and credibility of the results.

Second, results from a poorly-conducted survey can infect the benchmark database into which the statistical results are fed unless the survey itself has oversight and the data is audited. This can be expensive, and in any case is fundamentally impractical.

Training of conducting questionnaires and interviews is non-existent in the UK, and the small band of practitioners usually has close relationships with the survey providers. Some delegates were aware of other methods, but they are either poorly understood and/or poorly supported. There are no standards that apply to interviews, neither in the way they are conducted, the way data is recorded, nor in the way results are communicated. To all intents and purposes, interviews, and walkthroughs in domestic and non-domestic buildings are almost totally uncontrolled and un-moderated activities.

**Leesman Index**

The Leesman Index is a commercial tool developed to analyse how well office environments support employees in their work. Leesman is a private company founded early in 2010. The Leesman Index consists of a workplace satisfaction survey used by corporate organisations and their consultants to measure and benchmark the performance of physical working environments.

The Leesman ‘Lmi’ is a benchmark performance satisfaction and effectiveness score. Graded from 0 - 100 it is an indicator of the ability of a workplace to support the activities of the employees it
accommodates. Leesman itself does not offer any consultancy on the findings, but instead supports a group of Leesman Consulting Partners – workplace strategy consultants licensed to use Leesman tools and data.

Although some delegates at the workshop had heard of the Leesman Index, none had used it so there was no experience to draw upon.

**Design quality indicator**
The Design Quality Indicator is a method of evaluating the design and construction of new buildings and the refurbishment of existing buildings. It focusses on three main themes: functionality, build quality and impact.

Being a design assistance tool, DQI is not strictly a data protocol and knowledge acquisition tool for building performance evaluation. Nonetheless, it is in widespread use and has institutional backing and support through being managed by the Construction Industry Council.

The DQI process is a series of structured workshops and on-line tools whereby stakeholders can agree common goals and interrogate designs in order to optimise design for the needs of the building users. Presentations at the workshops brief an assessment group formed from members of the building community. DQI workshops can be continued throughout the design and construction phases.

The workshops are mediated by a dedicated DQI facilitator who is able to assess the results of the online tools and record the opinions of workshop attendees. The online tools take the form of questionnaires.

**Construction Process tools**
In the preamble to the session on construction process tools and protocols, Zack Gill from Willmott Dixon explained that there is no single protocol for data collection and knowledge acquisition during the construction phase. There are a great many methods to assess construction quality, and each has their own methodology, data requirements, skills and training needs, and reporting conventions.

Airtightness testing, thermography surveys, and co-heating tests for co-joined domestic dwellings are specific examples. The processes, units of measurement, skills required and equipment to be used are determined by the protocol author or accrediting organisation (see Table 1).

Mandatory energy audits under the EU Energy Directive will be mandated from December 2015. Assessments will be required on a four-yearly basis, with assessments done by accredited professionals. (The mandatory element will be to conduct the audits, but not to act upon them.)

The overarching method of Soft Landings is designed to augment existing procurement plans such as the RIBA Plan of Work, provide a framework for many tools that would otherwise remain discrete and disconnected from each other.
The lack of a structure for construction process tools showed in the rather random view of the workshop delegates, as shown in the following table. Of the methods identified, only Soft Landings (and its complementary reality-checking process tool, as defined in BSRIA BG 27/2011 Pit-stopping) represents a construction process protocol for managing the performance objectives of a building from project inception through to building operation.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TSB process tools (for BPE and Invest in Innovative refurbishment programmes)</td>
<td>Robust details</td>
</tr>
<tr>
<td>2</td>
<td>Custom BPE tools for an organisation</td>
<td>Soft Landings</td>
</tr>
<tr>
<td>3</td>
<td>Building management committee</td>
<td>TSB BPE protocols</td>
</tr>
<tr>
<td>4</td>
<td>BREEAM rating scheme</td>
<td>Mandatory energy audits</td>
</tr>
<tr>
<td>5</td>
<td>Display Energy Certification</td>
<td>HCA BPE carbon calculator</td>
</tr>
<tr>
<td>6</td>
<td>Soft Landings</td>
<td>PROBE studies</td>
</tr>
</tbody>
</table>

In the absence of a hierarchy of process tools, a possible template might be the International Performance Measurement and Verification Protocol (IPMVP). The IPMVP defines standard terms and suggests best practice for quantifying the results of energy efficiency investments and increasing investment in energy and water efficiency, demand management and renewable energy projects. This possibility is proposed in Recommendation 3.

The IPMVP was developed by a coalition of international organisations (led by the United States Department of Energy) in 1994-1995. The Protocol has become the national measurement and verification standard in the United States and many other countries, and has been translated into ten languages. A major driving force was the need for a common protocol to verify savings claimed by Energy Service Companies (ESCOs) implementing Energy Conservation Measures.
### RIBA 2013 Plan of Work

<table>
<thead>
<tr>
<th>Soft Landings stages</th>
<th>Reality checking in Soft Landings</th>
<th>Operational performance activities related to the construction process</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - Strategic definition</td>
<td>Energy survey of the existing building</td>
<td>Operational energy and carbon</td>
</tr>
<tr>
<td>1 - Preparation and brief</td>
<td>Occasional surveys of existing buildings, workshops</td>
<td>Human factors</td>
</tr>
<tr>
<td>2 - Concept design</td>
<td>Present findings of occupant surveys</td>
<td>Physical measurements</td>
</tr>
<tr>
<td>3 - Developed design</td>
<td>Use end-user expectations to set human factors targets</td>
<td>For different use contexts and different building designs</td>
</tr>
<tr>
<td>4 - Technical design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - Construction</td>
<td>Check client’s requirements against design; reality check.</td>
<td></td>
</tr>
<tr>
<td>6 - Handover and close out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 - In-use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 5: How operational energy, human factors and physical measurement activities map onto project plans, such as the RIBA Plan of Work (2013) and Soft Landings stages.

- **Operational energy and carbon**
  - Physical measurements
  - Human factors
  - Identification of regulatory standards that will apply, and decide whether to go beyond them.

- **Human factors**
  - Energy survey of the existing building, workshops and structured interviews and design quality assessments
  - Ensure theoretical simulation and design models meet the design targets set in the client’s requirements, and that the data are easily accessible for comparison with as-built data.

- **Physical measurements**
  - Present findings of occupant surveys and assessments to occupants and stakeholders.
  - Reality checks 1 and 2: The entire scheme design.
  - Reality check 1: The entire scheme design.
  - Reality check 2: Technical reality check. Focus on critical systems.
  - Reality check 3: Tender award stage reality checking of key items.
  - Reality check 4: Pre-handover reality check of key items.
  - Reality check 5: Post-handover sign off review.
  - Conduct formal energy survey in first post-occupancy evaluation no sooner than 12 months post-completion.
  - Perform occupant satisfaction surveys (permanent users) no sooner than 12 months post PC. Adopt separate survey and/or structured interviews for transient users where appropriate.
  - Assess as-built drawings. Perform in-situ tests within defects warranty period (local U-value tests, thermography survey, local checks for air leakage).

- **documents and weblinks**
  - BSRIA BS27/2011 Pinpointing - BSRIA’s reality-checking process for Soft Landings projects
  - CIBSE Technical Memorandums TM22, 74 and 54 provide energy assessment tools and guidance on benchmarks. Also see www.carbonbuzz.org
  - Design Quality Indicators available from CIC.
  - Building Use Studies (BUS survey) details from www.bu信methodology.org.uk
  - Guidance on physical testing is available from many sources, including RIBA, BSRIA, CIBSE, CIC, and others.

- **Guidance on benchmarks.**
  - Also see TM54
  - CIBSE Technical Memorandums TM22, 74 and 54 provide energy assessment tools and guidance on benchmarks. Also see www.carbonbuzz.org
  - BSRIA BS27/2011 Pinpointing - BSRIA’s reality-checking process for Soft Landings projects
  - Design Quality Indicators available from CIC.
  - Building Use Studies (BUS survey) details from www.bu信methodology.org.uk
  - Guidance on physical testing is available from many sources, including RIBA, BSRIA, CIBSE, CIC, and others.

- **Reports**
  - RIBA 2013 Plan of Work
  - Soft Landings stages.

- **Frameworks**
  - BSRIA BS27/2011 Pinpointing - BSRIA’s reality-checking process for Soft Landings projects
  - CIBSE Technical Memorandums TM22, 74 and 54 provide energy assessment tools and guidance on benchmarks. Also see www.carbonbuzz.org

- **Guidance on benchmarks.**
  - Also see TM54
  - CIBSE Technical Memorandums TM22, 74 and 54 provide energy assessment tools and guidance on benchmarks. Also see www.carbonbuzz.org
  - BSRIA BS27/2011 Pinpointing - BSRIA’s reality-checking process for Soft Landings projects
  - Design Quality Indicators available from CIC.
  - Building Use Studies (BUS survey) details from www.bu信methodology.org.uk
  - Guidance on physical testing is available from many sources, including RIBA, BSRIA, CIBSE, CIC, and others.

- **Protocols for data collection and knowledge acquisition**
  - BSRIA BS27/2011 Pinpointing - BSRIA’s reality-checking process for Soft Landings projects
  - CIBSE Technical Memorandums TM22, 74 and 54 provide energy assessment tools and guidance on benchmarks. Also see www.carbonbuzz.org
  - Design Quality Indicators available from CIC.
  - Building Use Studies (BUS survey) details from www.bu信methodology.org.uk
  - Guidance on physical testing is available from many sources, including RIBA, BSRIA, CIBSE, CIC, and others.
Table 3 shows how operational energy and carbon, human factors, and physical measurements relate to the 2013 RIBA Plan of Work and the Soft Landings stages. The mapping does not indicate who in the project team is responsible for the activities, nor what they will do, nor the specific timing of the activities.

While the table does not imply industry agreement on what activities should be carried out, nor exactly when any particular analysis or measurement should be performed, it provides a starting point for a protocol that places all the potential methods into an umbrella structure. Such a structure should have sufficient flexibility to cater for the specific context of each construction project.

**Soft Landings**

The workshop delegates recognised that Soft Landings is the only published open-source construction process protocol for managing the performance objectives of a building from project inception through to extended aftercare (Stage 7 ‘in-use’ in the 2013 RIBA Plan of Work). It also ties many existing and well-known activities, such as energy targeting and handover routines, together into a coherent and comprehensive structure.

Soft Landings was rated strongly for its usefulness and credibility, but scored lowly for its training and skills support, and speed of implementation by clients and the construction industry. It was, however, regarded as having a strong future.

Soft Landings possibly lacks the accreditation and certification process that may give it more strength and credibility among clients and construction firms who desire a certificate or some other visible credit for adopting the process. Practitioners of Soft Landings may also want to achieve recognition as a ‘Soft Landings Approved Professional’, or similar.

**TSB BPE procedures**

The Technology Strategy Board has assembled a set of procedures for projects funded under the Building Performance Evaluation programme. The procedures and templates include:

- Pre-visit questionnaire
- Building Information Document (BID) to capture building and construction details
- Forensic walkthrough process for non-domestic buildings
- Soft Landings reporting procedure
- Approach to conducting structured interviews
- Guidance on conducting BUS domestic occupant surveys
- Guidance on conducting BUS non-domestic occupant surveys
- TM22 V3.17 (beta version)
- DomEARM (Version H)
- Report writing guidance (primarily for TSB, but a good standard for other purposes and audiences).

The workshop attendees, many of whom are familiar with these tools and processes by virtue of working on BPE projects or being engaged as evaluators on the BPE programme, rated the protocols
and templates highly for their usefulness, while acknowledging that some systems were difficult to use (TM22). Nonetheless the tools have proved effective in practice, and have attained a degree of credibility among BPE practitioners. However, to be done well, it was considered that the TSB methods work best when carried out or followed by experienced practitioners. Many of the tools require training, support and practice.

None of the TSB-backed tools or templates have been published, nor are they publicly available outside of the TSB programme. It is thought beneficial for the TSB templates and tools to be gathered together and made available (free where possible) via a moderated and curated source. This could be the role of a body that represents a technical platform for setting and maintaining standards. This is the report’s primary recommendation (Recommendation 1).

Physical measurements

Working independently, the workshop groups ranked the top physical measurements as shown in the following table.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airtightness testing</td>
<td>Airtightness testing</td>
</tr>
<tr>
<td>2</td>
<td>Smoke tests for infiltration</td>
<td>Building measurements*</td>
</tr>
<tr>
<td>3</td>
<td>Thermography</td>
<td>In-situ U-value tests</td>
</tr>
<tr>
<td>4</td>
<td>Offsite (product) testing</td>
<td>Long-term monitoring*</td>
</tr>
<tr>
<td>5</td>
<td>Sub-metering</td>
<td>Soft Landings*</td>
</tr>
<tr>
<td>6</td>
<td>Ventilation effectiveness/indoor air quality tests</td>
<td>Thermography</td>
</tr>
<tr>
<td>7</td>
<td>Acoustic testing</td>
<td>Co-heating tests (domestic)</td>
</tr>
<tr>
<td>8</td>
<td>Daylight tests</td>
<td></td>
</tr>
</tbody>
</table>

*It is not entirely clear what the group meant by these terms, in this context.

The sheer range of possible physical measurements that could be conducted on a building, during and after construction, was a problem for some of the specialists at the workshop who lacked expertise in physical monitoring.

Airtightness and thermography

Airtightness and thermography were the two major tests identified that apply to most building types, domestic and non-domestic, followed by thermography. Both these physical measurements are covered by standard protocols and reporting conventions which are well established.

Of the two, thermography is subject to far fewer quality controls. Camera settings can be inappropriate, as can the environmental conditions at the time of the survey. Images can also be easily misinterpreted. Delegates therefore ranked the robustness and accuracy of thermography relatively poorly.

Airtightness testing requires more extensive equipment, more intensive training, and is usually conducted by certified testers. The companies that employ the testers are also quality assured by the Air Tightness Testing and Measurement Association (ATTMA). Some delegates expressed reservations about on-site quality control (gaps and openings that should be left open during a test may be wrongly sealed), and the absence of a national database of airtightness results. Mandatory
lodgement of results on a national basis, as with DECs, was recommended, along with a quality assurance process to ensure uploaded data meets a quality threshold (Recommendation 5).

**In-situ U-value tests**

The protocol for in-situ U-value tests is determined by BS ISO 9869:1994 Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance. However, this merely states the conditions for testing and the units of measurement. Each organisation that carries out such tests tends to write its own protocols for its own use. (For example, BSRIA has such a protocol, but it is not publicly available.)

There is no published method for in-situ glazing tests, values for which tend to be derived from laboratory tests as the results of in situ tests have been found to be variable.

**Indoor air quality**

Ventilation effectiveness and indoor air quality tests can involve either simple carbon dioxide sampling with measurements recorded as parts per million, or more complex measurements of a variety of pollutants. In the UK, the ventilation effectiveness is based on room air change rates, while in the US ASHRAE standard 62.1, Ventilation for Acceptable Indoor Air Quality sets the amount of outdoor air per occupant, plus the amount of outdoor air per unit of floor area.

However, there is no standard method of measuring air quality. It depends on the type of space, the purpose to which the space is put, the occupation density, the ventilation openings, and the direction of air movement. There is no agreement even on where to place air quality sensors. Hence there is no agreed protocol for this increasingly important indicator of air quality and human wellbeing.

**Co-heating testing**

A whole-house heat loss test for domestic dwellings is a measure of the whole house heat loss (in W/K) in an unoccupied dwelling. It is the measure of the fabric heat loss plus the background ventilation losses. The test aims to identify discrepancies between expected and measured performance, and consequently any contributory issues from the build process. Leeds Metropolitan University (LMU) has developed a co-heating test protocol, accepted by some practitioners as the de-facto standard in the UK.

Co-heating testing is not widely performed. There can be errors and uncertainties in the testing procedure. Work undertaken by LMU has found that the performance of the building fabric can have a significant influence on overall energy and carbon dioxide emissions. Consequently, very few conclusions can be drawn from in-use monitoring studies unless the performance of the building fabric is fully understood.

The workshop concluded that many of the standard physical tests, such as airtightness tests and thermography, are mature and well-known, but variability in implementation is leading to results of varying quality.
The workshop agreed that the Green Construction Board could champion an over-arching set of physical tests and protocols, and that a process like Soft Landings (and Government Soft Landings) could be the chassis for when and how these tests could be carried out, and how the construction professionals should react to the results (Recommendations 6 & 7).

### Infrastructure protocols

David Riley from Anglian Water briefed the workshop delegates on energy and carbon measurement procedures used on infrastructure projects. Anglian Water is typical of organisations working in the field in that it invests heavily in using carbon data to drive investment decisions within its capital programme, and to evaluate design options to reduce the volumes material used to build assets, obtain smaller carbon footprint, and lower costs.

With infrastructure projects, the process determines the scope and boundaries. It depends whether the scope is defined as cradle to as-built, or cradle to disposal. Having a clear scope and boundaries is important. Methodology is also critical. Here, the *Greenhouse Gas Protocol* provides the base methodology on how to measure greenhouse gas emissions (GHG). It specifies principles and requirements at the organisation level for quantification and reporting of GHG. It is the most widely used international accounting tool.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Workshop order of key infrastructure carbon protocols, data sources and tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Greenhouse Gas Protocol</td>
</tr>
<tr>
<td>2</td>
<td>PAS 2050 2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services</td>
</tr>
<tr>
<td>3</td>
<td>DEFRA Environmental Reporting Guidelines (Includes mandatory greenhouse-gas emissions reporting guidance)</td>
</tr>
<tr>
<td>4</td>
<td>ISO 14064-1:2006 Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals</td>
</tr>
<tr>
<td>5</td>
<td>Inventory of Carbon and Energy (Bath University web resource (currently down) also published as BSRIA guide BG10/2011)</td>
</tr>
<tr>
<td>6</td>
<td>European Product Declaration sheets (EPD)</td>
</tr>
<tr>
<td>7</td>
<td>Environment Agency Carbon Calculator tool</td>
</tr>
<tr>
<td>8</td>
<td>Arup Beacon (a global carbon-reporting tool and supporting methodology that identifies and quantifies carbon hotspots throughout supply chains)</td>
</tr>
</tbody>
</table>

The *GHG protocol* is published by the WSI (and links to *ISO 14064*). It breaks down carbon into a set of three scopes:

1. **Scope 1**: Inputs from outside the construction activity, such natural gas or fuel oil
2. **Scope 2**: Grid electricity or steam generation (mostly electricity)
3. **Scope 3**: Discretionary additional reporting, including embodied carbon, and carbon in the supply chain.

The water industry has its own guidance document issued though UKWIR (UK Water industry Research). This document provides a methodology, but not how the measurements should be made.
The application of the guidance takes different forms depending on each organisation’s interpretation.

Some organisations take a top-down measurement process, looking at quantities of the materials used in a programme, and multiply that by an emissions factor to get total carbon dioxide emissions. Others take a bottom-up approach, where they look at individual components built up in an infrastructure project, covering M&E, concrete and other elements.

Data on the carbon content of materials, processes and products are available from a variety of sources (some free, others commercial), most notably the University of Bath Inventory of Carbon and Energy. The ICE is a common dataset and is being continually improved. It covers the available data, where it has been sourced, and its confidence levels.

The Environment Agency publishes a free Carbon Calculator tool online. The carbon calculator measures the greenhouse gas impacts of construction activities in terms of carbon dioxide equivalency (CO$_2$e). It does this by calculating the embodied CO$_2$e of materials plus the CO$_2$e associated with their transportation. It also considers personnel travel, site energy use and waste management.

Other sources are European product declaration sheets (EPD), generated by factories who have measured the carbon impact factors are of certain materials. Inevitably, the quality of EPD sheets is variable.

Other than carbon content databases, the tools available for infrastructure projects are very few in number and usually commercially available (such as Arup Beacon). As a consequence, Anglian Water developed its own tool and made it available to all its framework contractors, who can apply it to their designs to provide an embodied carbon value.

Work in Europe has led to the EeBGuide for the European Commission, providing guidance on simplified, screening and detailed life-cycle assessments and embodied carbon assessments for construction projects and products. The RICS and the GLA have also recently published methodologies for assessment of embodied carbon for buildings, and WRAP has provided a benchmarking database for embodied carbon for buildings.

The data protocols for infrastructure works are well covered by statutory guidance and government-backed tools. Recommendation 1 in this report, for the creation of an on-line Wiki-nodes-type application, would be a resource for storing information about the protocols, and for their on-going status and development to be crowd-moderated.

**Commercial realities**

Led by Arup’s Darren Wright, the workshop delegates considered the commercial context of building performance evaluation tools and the role of protocols and tools in the real world of building procurement.
Building Performance Evaluation is not proving to be a business proposition on its own. Construction clients want BPE bundled with more consultancy services, and for repeat clients, over more than one building. This might involve plant replacement and optimisation, right up to disposing of an asset. Clients therefore expect building performance evaluation to be done within a project fee.

Clients still don’t understand the value of BPE and its effect on their business. Any cost savings are often very small compared with the value of the client’s business. As a result BPE is difficult to sell as a separate service. BPE can be delivered under different fee models, for example under a shared savings or guaranteed savings contract.

From the delivery perspective, the cost and ease of conducting BPE is strongly dependent on the ready availability of data. If energy data, for example, are not readily available, it can significantly (sometimes prohibitively) increase the study costs. A lack of historical energy data, or lack of access to building management system records, makes BPE work difficult to price. Capturing the building context can be very difficult for complex buildings, and for buildings with complex patterns of use or hours of operation.

BPE works best in a construction culture of openness, without blame where possible. As BPE becomes an essential part of ensuring a building is made to work as intended, it is vital to ensure that honesty and objectivity is maintained in the studies and in the communication and feedback of the results, which can be challenging and inconvenient to some parties (if not commercially toxic).