The Performance Gap: Causes & Solutions
Green Construction Board
Buildings Working Group
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<th>Revision</th>
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The Performance Gap: Causes and Solutions
04/03/13
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Executive Summary

The difference between the initial calculations carried out in the design of a building compared to the actual energy recorded on utility meters can be several times greater; this is referred to as the ‘Performance Gap’. The performance gap often starts life as an optimistic calculation of building energy use. There are increases to the gap as inaccuracies in energy modelling, variations in construction or value engineering alter design intent, commissioning is inadequate or incomplete and finally the building control and management all introduce huge variations once the building is occupied, see Figure A. The solution to bridging this performance gap lies in closing the ‘feedback loop’. This can be done in two important ways – feedback to briefing and feedback to operation.

There also exists a ‘Perception Gap’ in the sense that the initial calculations to prove Part L compliance or generate an EPC do not refer to all the energy a building uses. It excludes small power, IT server loads and other process loads so cannot be compared directly with actual total energy recorded on a building’s meters.

In the formation of an action plan to close the performance gap the key instruments include:

- **Soft Landings Approach** to design, procurement and operation – RIBA stage L -Aftercare
- **Building performance data** – systematic collection of data in a rigorous and consistent way to inform design, modelling, benchmarking - TSB BPE programme
- **Refined Energy Models** – using building performance feedback reflecting the in use characteristics of buildings
- **Regulatory framework** – focus on operational aspects of buildings CRC, DECs

Evaluation of the size of the gap is not a precise science as this will change from case to case. We can only indicate the order of magnitude of the variations and which are first order and high priority areas to address in the design construction and operation of buildings, see Figure A.

Figure A – The Performance Gap Growth from Design to Operation
1.0 Introduction

A building’s energy performance predicted in design, for Part L compliance checking or for an EPC, in the early phases of the production of a building is significantly different to that actually found in practice once the building is completed and occupied. This difference is referred to as the ‘Performance Gap’.

There is a need to make real improvements in building performance. An understanding of why the gap occurs and how it can be minimised is a precursor to achieving this. The objective of this project is to produce simple and compelling messaging which can be used to communicate effectively to a non-technical audience the matters of:

- Why early design calculations of energy for Part L compliance or EPC production are different to what will be seen in the occupied building

- In the design, construction and operation process where factors are introduced that widen the ‘gap’

- How the performance gap can be closed.

A fundamental part of achieving a building with a good performance is succeeding at these three points in the procurement chain, see Figure 1. Failure at any one of these points will result in poor energy performance. The hardest thing to undo is if there is a fundamental flaw in the design. More easily addressed are the management and operational problems.
The cause of the gap between predicted and actual energy use is down to the following headline issues:

- Predicted energy use that is based solely on energy use regulated by Part L of the Building Regulations;

- Energy modelling that does not simulate the occupied building with all its vagaries of operation, control and patterns of use;

- Construction that does not carry-through design intent;

- Commissioning that is not carried out adequately and which may often require a seasonal approach;

- Operation, management and occupant use that has a significant impact on actual energy consumption.

Figure 2 shows some of the principal factors which impact upon the energy performance of the building.
Design - Predicting Energy Use in the Occupied Building

At the design stage, modelling is often used to test design options but is not strictly simulating the occupied state. This is due to a number of reasons. For example, in a speculative development the occupied conditions may not be fully known; and in building energy simulators neither Part L compliance or EPC calculations replicate an occupied building as they only focus on part of the building energy use which is deemed ‘regulated’ – space heating, hot water, fans, pumps, cooling and lighting.

In design, contributions to the performance gap are introduced because typically energy modelling is approached in a naive manner. The approach does not accurately model the impact that building users have or the potential variations in system controls.

- Spaces are often not accounted for e.g. equipment room, circulation space, ancillary spaces, car parks.

- Inadequate allowance is made for small power and IT consumption which often makes up the majority of the electrical consumption of a building.

- Inadequate allowance is made for unoccupied energy use - this can be significant even in well run buildings.

- Perfect control of systems is assumed in energy models - it rarely happens in practice.

- Changes in the design are not followed through to revise the energy prediction; for example changes to insulation, thermal mass, solar exposure, operational hours and controls.

Modern dynamic energy models, Figure 3, are sophisticated tools but are only as good as the input data. A lot of time and effort is needed to carry out accurate simulation of an occupied building. This could be aided with good feedback from existing buildings to give a better understanding of the effects of operation and controls.
3.1 The Perception Gap - Regulated and Unregulated Energy Use

One of the common mistakes is to use the energy figures generated in the Part L compliance or EPC calculations and compare this with actual metered energy use. There will be a difference that is not necessarily a ‘gap’ in performance but a ‘gap’ in perception. The difference is the unregulated or ‘process’ loads. In modern offices and other non-domestic buildings these can be a significant proportion of the total energy used.

Regulated vs. Unregulated Loads

Part L of the Building Regulations currently looks to control the conservation of fuel and power of ‘regulated’ loads. These are loads that are most governed by the building and system design:
- Space Heating
- Domestic Hot Water
- Fans and Pumps
- Cooling
- Lighting

In addition there is ‘unregulated’ energy which might be described as ‘process’ loads which includes:
- Small power
- Computer equipment rooms and associated air conditioning
- Catering

Case Study 1

Case Study 1 illustrates the contribution that unregulated loads have to the total energy use. The 6 storey office building underwent a major refurbishment in 2003 and now accommodates seven hundred people over 9,144m² of gross internal area, see Figure 4. The building energy use is monitored through an automatic meter system (AMS) which provides data down to end-use loads.

Figure 4 Case study 1

The building contains open plan office space from the ground floor to the sixth floor, with small areas of enclosed glass offices and meeting rooms. A central atrium runs from the ground floor to the 3rd floor. The basement floor is taken up with storage rooms, the post room and other small self-contained spaces. It is a mixed mode building with natural vent and comfort cooling from a floor supply system for peak summer.
The building also contains the central server rooms for the company, these rooms contains hard disks for the network drives and the corporate telephone network. The annual electricity data is summarised in Table 1. Regulated electricity represents only 31% of the total, see Figure 5. This split of energy use between regulated and unregulated is not uncommon. The electricity used for the ‘business’ is substantial, particularly the server and server cooling energy use. The organisation would not be interpreted as being one with a high utilisation of IT equipment such as the financial sector where the unregulated load is significantly higher.

Table 1  
Summary of electricity consumption for case study 1

<table>
<thead>
<tr>
<th>Electricity Af = 9144m²</th>
<th>Annual Energy kWh/m²</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>26.4</td>
<td></td>
</tr>
<tr>
<td>Fans, Pumps and Cooling</td>
<td>52.8</td>
<td></td>
</tr>
<tr>
<td><strong>Regulated Electricity</strong></td>
<td><strong>79.2</strong></td>
<td><strong>31%</strong></td>
</tr>
<tr>
<td>Small Power</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>IT and Comms</td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td>Lifts + Miscellaneous</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Servers &amp; Server AC</td>
<td>102.9</td>
<td></td>
</tr>
<tr>
<td><strong>Unregulated Electricity</strong></td>
<td><strong>175.2</strong></td>
<td><strong>69%</strong></td>
</tr>
<tr>
<td>Total Electricity</td>
<td>254.4</td>
<td><strong>100%</strong></td>
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</tbody>
</table>

Figure 5  
Summary of electricity consumption for case study 1
Case study 1 cont.

In this example the fans and pumps and cooling showed greatest divergence between modelling and metered of +44%, caused by control factors, indicating where waste could be avoided. On the other hand, space heating and hot water prediction was under estimated by only 8% which is a reasonable level of accuracy when modelling energy systems.

During the design stage for the refurbishment the building energy performance was predicted in Visual DOE 3.0. It was then compared to actual metered use. The results are summarised in Table 2.

Table 2  Case study 1 energy modelling vs. actual use

<table>
<thead>
<tr>
<th>Post refurbishment</th>
<th>Modelling of refurbished building</th>
<th>At design</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 to 2006 data</td>
<td>Actual</td>
<td>Visual DOE 3</td>
</tr>
</tbody>
</table>

**Electricity**

<table>
<thead>
<tr>
<th></th>
<th>kWh/m²</th>
<th>kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>26.4</td>
<td>Lights and Small Power</td>
</tr>
<tr>
<td>Small power</td>
<td>45.6</td>
<td></td>
</tr>
<tr>
<td>Satellite IT Rooms</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>Comms Equipment</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>Main Equipment Rooms (MER)</td>
<td>54.9</td>
<td></td>
</tr>
<tr>
<td>MER a/c</td>
<td>48.0</td>
<td></td>
</tr>
<tr>
<td>Lighting + SP + IT+ Servers</td>
<td>198.1</td>
<td>117.9</td>
</tr>
</tbody>
</table>

The actual energy a building uses in practice is influenced heavily by the business. In this example we see the main server room and its air conditioning was not included in the original energy model and is a substantial load at 30% of the total electricity use. That aside, the lighting and small power modelling is in fact an over estimate of 25% in comparison to the metered value.

The biggest discrepancy between modelled and metered data occurs on the fans, pumps and cooling where the design under estimated the actual use by 44%. This difference between design and actual is principally caused by the way plant is controlled in practice and therefore being different from assumptions made in the model. There were also variations in the installed system; pressure drops and mass flows of air and water introduced differences in actual energy consumed by fans and pumps.
4.0 Construction & Commissioning

During the construction phase there are changes introduced to the developing building that often are not fully evaluated in terms of the resultant effects on energy performance. This can be more acute if significant design duties are passed on to the contractor as with the Design & Build route of procurement. Commissioning is a critical phase which helps to ensure the building’s function and performance meets owner expectations. This is often squeezed in fast paced programmes resulting in it being inadequate or incomplete.

Construction
The building may not end up as originally intended by the design team as it goes on its path through tender, value engineering and construction:

- Cost cutting exercises may alter the building; watch out for the effects of those things that cannot be seen but which will be felt e.g. insulation, solar protection, building services and controls.

- Contractor designed elements may not end up as originally envisaged.

- Quality of construction maybe different to that envisaged e.g. with degraded insulation or air-tightness.

Commissioning
The quality of commissioning and its co-ordination is critical to how the building will run once occupied both in terms of energy efficiency and the comfort wellbeing and productivity of the people who use it. The ‘watch it’ areas are the interfaces between systems particularly the controls and the interaction between heating cooling central plant and air and water distribution systems.

The responsibility for interfaces often fall down the gaps between work packages and overall responsibility can effectively be taken for the building as a whole with effective commissioning management.

Seasonal Commissioning
Some buildings need longer to fully commission and the idea of ‘seasonal’ commissioning reduces risk and contractor call back and the building is proved in a range of conditions. This is particularly important in the transitional seasons of spring and autumn when plant will be operating on light load and instabilities and inefficiencies could be at their greatest.

Sub-Metering Systems
These are mandatory for new construction and are being integrated into existing buildings. It is common to find the meters installed but not properly commissioned and validated – in some cases the data they are giving is near useless. The validation of the metering system is critical if you are going to manage a building effectively and keep it operating at its optimum.
5.0 Operation

The final link in the chain is the way in which the building is used, managed and maintained and this usually has greatest potential for performance variations. This may not necessarily be the fault of the building operator, but could be symptomatic of flaws in the original building design. The design may have introduced unmanageable complexity in the systems making them difficult to understand. As a consequence the building is difficult to manage and maintain. However, deficiencies in building operation are easy to fix if the building design and construction are sound.

There are number of operational factors that will impact significantly on the building performance:

- The building may not be used as originally envisaged; occupancy hours, densities and activities
- Fit-out may change the building in a way which clashes with the original design intent
- The building may never be finely tuned to match occupancy patterns and operate in different seasons
- Operators and users may find the building and its controls difficult to understand
- Maintenance and energy management may not be up to scratch
- In rented and in particular multi-tenanted buildings the split of responsibilities between landlord, tenants and building managers often inhibits investment and leads to wasteful operation of systems

Case Study 2

The impact of control and operation factors in the occupied building can introduce significant variations in energy use. Case Study 2 is illustrative of the differences in energy use that exist between buildings run in a ‘typical’ fashion compared to the situation where the control and management is optimised. The avoidance of this type of energy waste can realise savings between 20% to 30%.

In this example, the building was built in 1929 and was constructed with solid stone faced walls with steel frame and concrete/hollow pot floors and is Grade II listed. The building has a total treated area of 11,873m², over 9 storeys plus basement, see Figure 6.

Figure 6  Case study 2
5.1 Operation

Case study 2 cont.

Although originally conceived as a naturally ventilated building it is now a sealed building that is air conditioned and mechanically ventilated. Plantrooms are located in the basement and on the 9th floor and at roof level. It is served by conventional gas fired boilers and electric chillers and is supplemented by a CHP system.

With a focus on the effective use of the sub-metering system with improved reporting and corrective action together with a review of the BMS control strategies, impressive reductions in energy use were achieved, see Table 3. The savings that were principally due to better management and control amounted to 48% on gas and 13% on electricity which yielded 25% saving in CO₂ emissions in the period 2009 to 2011.

Table 3 Case study 2 annual energy reduction

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity kWh/m²</td>
<td>162</td>
<td>166</td>
<td>141</td>
</tr>
<tr>
<td>Gas kWh/m²</td>
<td>259</td>
<td>222</td>
<td>134</td>
</tr>
<tr>
<td>kg of CO₂/m²</td>
<td>135</td>
<td>131</td>
<td>101</td>
</tr>
</tbody>
</table>

From 2008 the operational rating as defined by its DEC has reduced from a rating of 165 G to 82 D, see Figure 7.

Figure 7 Reduction in DEC rating 2008 to 2011

Worked focused on the validation of the automatic metering system (AMS) and then setting up procedures so that data flowing from the AMS produced useful information upon which decisions could be made. This gave visibility of how the building was actually running and allowed effective corrective action to be put in place.
5.1 Operation

Case study 2 cont.

For example the energy wasted during the unoccupied periods, see Figure 8 where unoccupied electricity demand was consistently around 250kW. This was tackled by reference to end-use loads see Figure 9 where better management was made of non-essential loads such as fans and pumps. This also revealed the inaccuracies in the sub-metering system where the unknown component represented un-reconciled loads which required addressing. Following an AMS validation exercise and a health-check on controls the demand profile showed an unoccupied reduction to less than half of the previous level.

Figure 8  Electricity demand profile before control review

Figure 9  Analysis of end use loads with sub-metering
5.1 Operation

Case study 2 cont.
The operational aspects of the ‘gap’ between design and practice can therefore be very significant with 20-30% variations not being uncommon. It is not usual that these practical issues are included in energy modelling in the design process. But it can be seen that they can have a first order effect on the buildings resultant performance.

Following the review of the building management system and lighting controls, the daytime maximum demand was reduced and non-essential loads were minimised, halving the unoccupied period load.

Figure 10 Resultant power demand profile after interventions on AMS and controls

The building space heating demand line has been plotted on the graph below together with base gas consumption. All gas consumption above and to the right of these lines can be interpreted as waste and has been tackled with improvements in control, the addition of a summer time boiler and modifications to the central boiler plant yielding a 30% saving in gas consumption.

Figure 11 Gas consumption correlation showing waste energy

The control of the gas fired boiler plant and CHP was reviewed and optimised to bring better stability and ensure the CHP always provided the base load for heat. This saw the most dramatic reductions in energy use. Figure 11 shows a correlation of daily gas consumption with mean daily outside air temperature. The spread in data for a given mean daily temperature is indicative of the poor control and wasted gas energy.
6.0 Closing the Performance Gap

Closing the performance gap relies on closing the feedback loop, see Figure 12. In practice this works with the introduction of two feedback loops; one to briefing and early design for new building and the other to those who own and operate buildings. The operational performance of a building is coming to the fore in the consciousness of the design team, contractors and building operators and users through the rise in energy costs and legislation such as the CRC and the limited use for DECs. This awareness should be built upon with a more universal requirement to demonstrate operational performance of the building in use.

The feedback to briefing ensures that lessons learnt from previous building performance evaluation are taken on-board and avoided in the new design.

The design team and contractor must have a focus of how a building will work post practical completion and how changes and variations will impact upon that performance. This ethos is at the heart of the Soft Landings approach to delivering buildings.

Therefore in the formation of an action plan to close the performance gap the key instruments include:

- Soft Landings Approach to design, procurement and operation - RIBA stage L - Aftercare
- Building performance data - systematic collection of data in a rigorous and consistent way to inform design, modelling, benchmarking - TSB BPE programme
- Refined Energy Models – using building performance feedback reflecting the in use characteristics of buildings
- Regulatory framework – focus on operational aspects of buildings CRC, DECs

On the operational side, visibility of how a building works is vital effectively managing it. Feedback to those who use the building is also important so that they are aware, accountable and motivated to avoid waste.
6.1 Closing the Performance Gap - Design

The feedback to briefing and early design will influence the decisions taken about the building which are very difficult to undo at a later date. Lessons learnt from building evaluation on the effectiveness of energy efficiency measures, usability, ease of commissioning, manageability and probably most important of all, occupant response to the building should help inform future designs.

The source of feedback will grow as designers adopt a soft landings approach and with the aftercare service discover more about buildings in use. This will prove invaluable experience to feed into the designs that then follow. In lieu of this there is a good source of information in the public domain such as the seminal Probe work from 1990s, Usable Buildings Trust and Carbon Trust case studies and latterly the TSB Building Performance Evaluation programme.

Armed with this information the design team have a good chance of delivering a robust design that will avoid the factors that cause the performance gap to creep in and avoid problems that may later emerge when the building is occupied.

The critical factors to address in design are:

- Soft Landings approach - Feedback to briefing and early design is crucial.
- Energy models which reflect practice, which account for user impacts and the nuances in system control, and which model the total building energy use not just regulated loads.

- Consider the total energy of the building that will appear on the meters because this is what the client will compare the outcome to – include process loads such servers and small power loads.
- Consider all spaces in modelling including external light, car parks.
- Consider the unoccupied energy use.
6.2 Closing the Performance Gap - Construction & Commissioning

The design will undergo changes on its path through construction as cost and physical constraints emerge. The changes should always be considered in terms of their effect on how the building will perform when complete. This will mean adopting a soft landings approach in construction. This will be helped if there is a clear statement in the brief as to what operational rating the design team and contractor are working toward. DECs could provide this framework after some refinement of the way in which benchmarks are determined.

The main actions to reduce the gap creep in construction and commissioning are be:

- Soft Landings approach - testing proposed changes as to their effect on eventual building performance.

- Introduce a culture in the design/contractor team to be concerned about how decisions made in construction will work their way through to impacts post practical completion.

- Complete and rigorous commissioning – in some instances seasonal commissioning.
6.3 Closing the Performance Gap - Operation

The operation of a building is where the realities are seen in stark contrast to what may have been claimed in design. However there is a lot that can be achieved in getting the installed systems commissioned and controlled correctly. The experience of optimising existing buildings in this way shows savings of the order of 20% to 30%. Operational energy waste is commonly the largest contributor to the performance gap but can be readily rectified by using a systematic approach to the BMS and controls set ups.

Building operators and users need feedback on performance so that building can be effectively managed. A lot of work in existing buildings is rectifying the ‘drift’ that has occurred in its original commissioning or indeed carrying out commissioning correctly for the first time. Once the building has been brought back on track it is paramount that the feedback effort is maintained and integrated with management procedures. This will create a continuous improvement process.

Feedback is also needed to those who use the building. This should be feedback on the energy use over which they have influence. In some cases this may only be lighting and small power. This instils accountability, motivation to save, and acknowledges where there has been effort.

The critical actions in existing buildings are:

- Energy Management - visibility of how a building is working and feedback information to users and operators, integrate into the management process.

- BMS and control audits to ensure once the building is running at its optimum its stays there.

- Retro-commissioning to get the systems working as intended.

- In rented and in particular multi-tenanted buildings engagement between landlord and tenant needs to be better as the split of responsibilities between landlord, tenants and building managers often inhibits investment and leads to wasteful operation of systems.

- Using the regulatory framework to introduce greater motivation and accountability of building operators and users. The CRC and DECs are good starts but should be extended and tuned to be more effective.
Acknowledgements
We would like to acknowledge the work of the Probe team who were the pathfinders in building performance evaluation work and identification of the performance gap and its remedies. In particularly Bill Bordass and the Bordass 22 (private communication), and the valued insights of Adrian Leaman and Robert Cohen in these matters.

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