Innovate UK

Building Performance Evaluation Programme

Findings from Non-Domestic Projects

Innovate UK
Technology Strategy Board

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Contents

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Executive Summary

Learning from these flagship monitoring projects can help meet our binding commitment to cut four-fifths of UK carbon emissions.

There is no way to meet the Government's 80% carbon reduction target by 2050 without a revolution in the way we construct and operate buildings. The past 10 years have allowed lots of experimentation into different ways of cutting energy use in buildings, but independent evaluation of how much energy is actually used when buildings are handed over is very rare. As a result, there is still no consensus about the best strategies to achieve true low carbon performance

This interim study set out to look at the findings from 50 leading edge buildings that were monitored under Innovate UK's £8million Building Performance Evaluation programme. It looked across the projects where data was available, focusing on the fabric and systems that are being used in different projects, and how satisfied occupants are with their buildings.

This is not intended as a comprehensive review of the non-domestic portfolio. Further in-depth analysis of the entire programme is underway, with lessons learnt being tailored to the needs of different audiences, over the coming months.

From schools to supermarkets, offices to clinics, we have tried to assess which strategies work well and what pitfalls to avoid. We have endeavoured to measure the gap between designers' objectives and what actually happens when occupants move in, and why this 'performance gap' is so common.

The work found that projects encountered significant problems with integrating new technologies, and especially configuring and optimising building management systems (BMSs). Some teams also had maintenance, controls and metering problems with their biomass boilers, photovoltaic arrays and solar water heaters, and one air source heat pump had operational issues in cold weather. There were also problems with automatic window controls to support natural ventilation. Part of this is inevitable during the early adoption phase of new technologies, because installers lack experience of fitting unfamiliar systems in different contexts.

The message to designers and clients is clear: be wary of using innovative systems unless you know that the installers have used them successfully before in similar contexts. And remember that it is the individual installers who matter – make sure that the individual (not just the company) has first-hand experience themselves, or has a mentor to walk them through it.

The average airtightness test result was 6.1 $m^3/m^2.h$ – significantly better than the minimum requirement for air permeability the in the Building Regulations. However, surprisingly, there is hardly any correlation between airtightness and carbon performance.

There does appear to be some link between BREEAM ratings and actual energy use, with the two 'Outstanding'-rated buildings using less than 100 kWh per square metre per year for gas and electricity together. However, on average, 'Excellent' buildings actually used more energy than 'Very Good' ones, so there are complex messages here.

Two community centres stand out as exemplary in terms of carbon emissions: Mildmay and Angmering, and both have carbon emissions below 26 $kgCO_2$ per square metre per year. This is lower than any other building in the group, and getting on for a third of the average carbon emissions across the whole set of buildings (75 $kgCO_2/m^2/y$). A third community centre, in Coleford, also has excellent carbon performance: 37 $kgCO_2/m^2$/year.

Natural ventilation is often a feature of low-carbon buildings, whereas poor control of space and water heating – and lighting – often contribute to high emissions. Biomass boilers appear to polarise: they are often temperamental, but if they can be made to work they bring much lower emissions.

There were quite a few cases of multiple systems being installed and fighting each other – cooling against heating, or different heating systems jockeying for control.

Controls are something of a minefield, and there is a tendency to make controls for heating, lighting and renewable energy systems over-complicated. This risks putting occupants off using their controls, which makes it much harder for them to cut CO_2 emissions by avoiding unnecessary energy use.

Building management systems were also found lacking. Like user manuals, they often seemed to be installed as a tick-box exercise to comply with Building Regulations (or BREEAM for manuals), with insufficient thought put into how occupants need to use them. Further, where BMSs were installed without being integrated with other system controls this led to conflicts and confusion. This was doubly frustrating for performance evaluation, because BMSs are typically intended as a way to monitor energy use, as well as the simplest way to intervene in controls.

Background

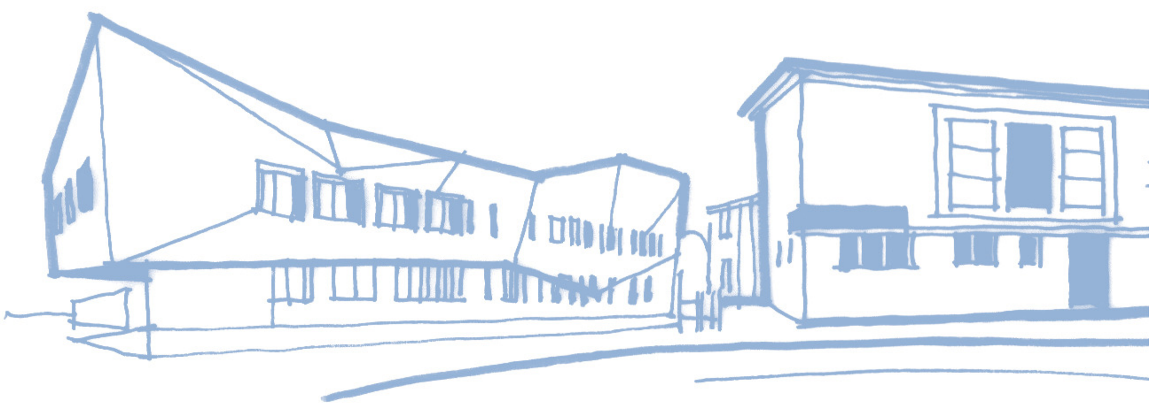
The UK Government has set challenging targets for reducing CO_2 emissions and improving sustainability: cutting greenhouse gas emissions a daunting 80% by 2050. Given that around 45% of emissions come from buildings, there is no way to meet the target without addressing buildings.

The Building Performance Evaluation Programme aimed to understand how to reduce the impact of the built environment. All too often the aspirations set out in the design of a building are not met in practice, leading to higher energy use and emissions than expected. The reasons for this are varied, from issues with building energy modelling at the design stage, to changes to the specification prior to construction, rushed or incomplete commissioning, and/or unanticipated user behaviour after handover.

This report aims to analyse and evaluate the key trends that appear in documentation and reporting that the non-domestic projects submitted to Innovate UK, in order to pull out high-level conclusions and findings common to all projects, highlight instances of best practice, and share lessons learned. This is not an exhaustive analysis of all aspects of the non-domestic projects in the programme.

This report presents many problems, but also some solutions, based on findings from the BPE Programme. We think the difficulties encountered underline the importance of evaluation as the first step in improving building performance.

We focused in particular on design strategies and technologies that worked well, and those found to be less successful in reducing energy use and carbon emissions. Our main objective was to make unambiguous recommendations to project teams and clients about which approaches to use for future low carbon buildings.



The Study Buildings

A total of 50 non-domestic buildings were included in the BPE Programme[1]. On paper they are an exemplary group, including five BREEAM Outstanding, 20 BREEAM Excellent, and two EPC A+ ratings, and they comprise a wide range of non-domestic uses, including:

- Schools and Higher Education
- Offices
- Community Centres
- Supermarkets
- Hotels and Restaurants
- Visitor Centres
- Healthcare
- Libraries

For this study, we analysed energy use and other aspects of performance for all 50 buildings. The precise data available varied a little from project-to-project, and some sections of this report have figures for fewer buildings because some buildings did not record every detail. However, in all cases we had access to actual energy use data, and design documents used as part of the planning application for the buildings.

The Building Performance Evaluation (BPE) Programme aimed to compare the performance of multiple domestic and non-domestic buildings by collecting specific data for each project using common templates (available in the "Resources" section of https://connect.innovateuk.org/web/building-performance-evaluation - registration required). However, this goal is very difficult to achieve in practice. We found that project reports were inconsistent in terms of scope and detail, apart from the initial application form to the BPE programme. The Evaluators (appointed by Innovate UK to support participants in the programme) also noted how difficult it is to obtain information, which underlines how difficult evaluation work can be – even for projects with funding specifically for this purpose.

Further information on all of the buildings in the BPE study is in the Appendix. For each project this gives, where available, the floor area, the Building Emission Rate (BER), the design air tightness, the tested air tightness, the annual electricity use per square metre, annual heating fuel per square metre, and the environmental rating (BREEAM).

[1] Further information on the BPE Programme portfolio is available via the Knowledge Transfer Network https://connect.innovateuk.org/web/building-performance-evaluation

201 Bishopsgate is a high spec office in the City of London, with a floorspace of more than 37,000m^2 over 14 storeys, designed for low energy performance, despite the inclusion of a highly glazed façade. Each occupant has access to their own locals controls for lighting and HVAC, allowing for a great level of personal climate control. Linked to this, there was a focus on sub-metering of landlord and occupant areas, and tenant engagement.

Sector: OFFICE

The **Bath Campus** study includes 'R5 - Woodland Court', a new 355 bed student residence, and '4 West', a 5,200m^2 mixed university building (both refurbished and new). Fabric energy efficiency and air tightness was considered, particularly for 4 West, which received planning permission prior to the 2006 update to the Building Regulations. Both projects have roof mounted solar thermal arrays, and achieved BREEAM 'Excellent' ratings. (Note figures in this report are for Woodland Court.)

Sector: HIGHER EDUCATION

The **Bermondsey Square** development in London is made up of two blocks, the first being a 79-bedroom hotel and the second including offices, retail space and apartments. Heating is provided through a district heating network from a local plant room, served by gas boilers, with an evaporative cooling system specified for the offices. The building is primarily naturally ventilated. In this multi-tenancy building, 'Green Leases' and engagement were explored to address the impact of the users on overall environmental performance.

Sector: OFFICE & HOTEL

The **Blue Bell Health Centre** in Liverpool is a 2500m^2 scheme designed with high levels of insulation, air tightness and triple glazed windows, and mechanical ventilation with heat recovery, following Passive House principles. It also includes solar hot water panels, and a heat pump to provide space heating and supplement the water heating.

Sector: HEALTHCARE

Bessemer Grange Primary School is a 1950s school with a new extension built in 2010, housing a Children's Centre and an Early Years Centre. The new building had high environmental ambitions and scored in the top 5% for user satisfaction with comfort and performance. It was built using a 'glulam' timber frame, with 120mm of insulation in the walls and a sedum roof. It achieves low gas consumption, but electricity use is high and there are problems with the solar water heating.

Sector: SCHOOL

Greenfields Community Housing HQ has office accommodation for around 100 staff, and community facilities for its tenants. It has three ground-source heat pumps, and mechanical displacement ventilation in winter, using a thermal labyrinth. It got a BREEAM 'Very Good' rating, although the interface for its BMS was omitted from construction for cost reasons. There were also problems with heat-pump controls. The server room alone uses as much energy as heating and cooling for the whole building.

Sector: OFFICE

Estover Community College, Plymouth, is a 16,900m^2 school for 1600 pupils aged 4-18. It was built in stages, so old school buildings could be used for teaching during construction. The BMS was not correctly commissioned. It was problematic for controlling the buildings, and it proved unsuitable for energy monitoring and diagnostics. A biomass boiler was installed, but problems with fuel and maintenance mean it is no longer used.

Sector: SCHOOL

Castle Hill Primary School in Kingston upon Thames has a classroom extension of 820m^2, a new dining hall of 300m^2, and a PV array. Air tightness for the dining hall was disappointing, at 11.85m^3/m^2/h. The new buildings did well on overheating, but sometimes had high CO_2 concentrations, suggesting ventilation issues. Electricity use was lower-than-expected for both buildings, but gas use in the dining hall was 4.5 times higher than the design estimate.

Sector: SCHOOL

Rogiet Primary School in south east Wales is a single-storey building for 210 pupils, with community and playgroup facilities. Its six classrooms use natural ventilation with automatically-controlled windows. It has a wind turbine (meeting 6% of electricity demand) and solar water heating, but gas use is 3.7 times expected use – partly due to high losses from the hot water system, especially during holidays.

Sector: SCHOOL

Cressex Community School in High Wycombe is a 11,600m2 three-storey secondary school with a biomass boiler. It consists of four blocks, arranged around an atrium. It has good insulation and airtightness, with few thermal bridges. The biomass boiler has had problems with the fuel store, with fuel getting wet. Occupants also report concerns about temperature and humidity.

Sector: SCHOOL

Angmering Community Centre in West Sussex is a single-storey, timber frame building of 563m^2. It has a multi-purpose hall, two meeting rooms and a central display/refreshments area. It has ground-source heat pumps and a 10.2 kW PV array on the roof, which meets 19% of the electricity demand. The heat pumps achieved a coefficient of performance of 3.68 – a little lower than expected.

Sector: COMMUNITY

Eli Lilly Research Office is a two-storey building with a steel frame structure and lightweight curtain walling with overhangs to limit solar gains. It was designed for 130 people, but in fact current staffing is much lower. It has natural ventilation using Passivent, with mechanical ventilation and cooling for use in summer.

Sector: OFFICE

Jarman School of Arts comprises drama and film studios, computing and editing suites, a large art gallery, teaching rooms, academic and administrative offices. The steel-frame structure has exposed concrete ceilings, and zinc cladding externally. The building was well received, but there are problems with noise, and thermal conditions. Energy use also rose each year for the first three years, and there are problems controlling the under-floor heating.

Sector: EDUCATION

The Sustainable Construction Academy in Kent is a 2,900m2 intended to teach about construction. It has workshops and teaching spaces, with a café and offices, arranged around an atrium, but it is currently under-used. It has a 26.7 kW solar electric array on the roof. The installed biomass boiler has now been decommissioned because of complexity and cost.

Sector: EDUCATION

Staunton on Wye Primary School in Herefordshire is a three-classroom school for 90 pupils, with a pre-school for 26. It has a timber frame construction, with local stone on the north facade and timber cladding on the south. It has a green roof and natural ventilation. Very high insulation values include triple-glazed windows. Good ventilation during winter needs the teacher to intervene.

Sector: SCHOOL

Premier Inn and Beefeater Restaurant in mid-Sussex is a 60-bed hotel with a 220-seat restaurant. It has a ground-source heat pump and heat-recovery ventilation, and originally it aimed to reduce usual energy consumption by 70%. It uses a 140mm timber frame with triple glazing. There are LED lights with auto controls. Post construction, there were problems with air tightness and thermal bridges.

Sector: HOTEL/RESTAURANT

Graham Head Office in Hillsborough, N Ireland, is 3,200m2 and provides office accommodation for 250 employees. It has a 240 kW biomass boiler that needs to be cleaned out every two weeks, with an oil backup boiler. The design got an ‘Excellent’ BREEAM rating. It has good daylighting and natural ventilation using BMS-controlled louvres as well as windows. One third of electricity use is for the server room and outdoor lighting.

Sector: OFFICE

Ore Valley Business Centre in Scotland provides office space for start-up companies. It was designed to accommodate 45 people on each of three floors, but it is currently under-occupied. It uses the Termodeck ventilation system, which appears to have worked well, although local electric heaters are used to supplement the central heating system. The BPE identified high energy use for lighting.

Sector: OFFICE

University of the West of Scotland Ayr Campus is a 17,800m^2 building for up to 4,000 students. It has biofuel boilers, but these proved problematic – particularly because of difficulties achieving the correct biofuel mix – so backup gas boilers are used instead. The campus has mechanical cooling including fan coils, and mechanical ventilation.

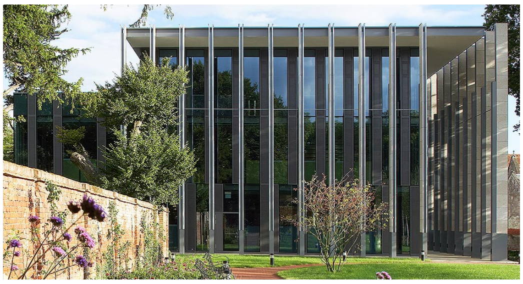
Sector: EDUCATION

The National Composites Centre near Bristol aims to bring together design and manufacturing processes for industrial composite materials. It is 8,500m2, and has mechanical ventilation but not cooling, and occupants have reported summer overheating. It has a 138 kW photovoltaic array, which is generating more power than anticipated. However, overall the building’s electricity demand is much higher than expected.

Sector: INDUSTRIAL

The Pines Calyx, Dover, is an earth-shelter building, and all walls are made from rammed chalk. It was intended to be the most sustainable events venue in Europe, and has a hybrid heat pump-solar heating system that includes 3.8 kW of PV. The project team viewed it as an ‘experimental’ building because virtually every aspect, from the structure to services and energy systems, was innovative. They anticipate 30% savings from 2014 to 2015.

Sector: CONFERENCE CENTRE



Bourne Hill Offices in Salisbury provide office space for Wiltshire Council. They consist of a refurbished listed building, 1,500m^2, and a modern extension, 2,360m^2. The new extension has a concrete frame with glass curtain walling, and a green roof. Both buildings have conventional services, with no renewables, but there is rainwater harvesting. The extension has stack effect ventilation, and uses night-cooling.

Sector: OFFICE

South Place Hotel in London has 80 bedrooms and two restaurants. It has mechanical ventilation and cooling, with fan coils providing heating and cooling in bedrooms. It has a combined heat and power system, which seems to have saved about 5% of carbon emissions. The hotel has high electricity use, partly because it is pitched as a high-end luxury hotel.

Sector: HOTEL

Cheshire Oaks on the Wirral is Marks & Spencer’s second-largest store, at 19,400m^2. It uses CO_2 as a refrigerant to cool food, with heat recovery from the refrigeration. It also has a biomass boiler for use in winter (a gas boiler functions in summer), displacement ventilation linked to earth-duct cooling, pre-fabricated lime-hemp wall panels, rainwater harvesting, and a 300m^2 ‘living wall’ beside the car park. Energy use compares well with benchmarks.

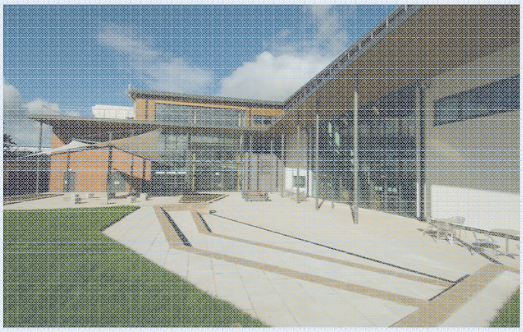
Sector: RETAIL

The **BRE Scotland Innovation Park Visitor Centre**, is a single-storey building to showcase the future of Scottish housing. It is highly insulated, with good airtightness, an air-source heat pump, solar electric panels, solar water heating, heat-recovery ventilation, and efficient lighting. However, there were problems with ventilation and heating which meant the heating had to be replaced. Energy use was also higher-than-expected.

Sector: VISITOR CENTRE

Brighton Aldridge Community Academy is a two-storey 10,588m^2 concrete framed school, built on the site of previous high school, for a total of 1150 pupils. The construction is generally very traditional, with a focus on natural ventilation and good daylighting, with a biomass boiler (now unused) and a solar hot water array. It has excellent air tightness.
Part of the *POE Feedback into School Design* project, with Thamesview School.

Sector: SCHOOL



Brine Leas Sixth Form is a three-storey, 2,969m^2 new build school, and contains a number of innovative technologies designed to improve performance. This includes a heat recovery system, solar hot water, and cooling from an Air Source Hear Pump. Window openings are controlled through the BMS at high levels, and manually at low levels.

Sector: SCHOOL

Crawley Library is a new four-storey building, arranged around a central atrium, with cantilevered floors that provide some shading to lower levels. It was designed to have good thermal mass, efficient ventilation with night cooling, and renewable energy generation from a biomass boiler and solar water heating.

Sector: LIBRARY

The **Creative Exchange** in St Neots is a four-storey building providing 705 m^2 of shared workspaces. It includes high thermal mass construction, an earth duct to cool incoming air, natural ventilation, good daylighting, solar hot water, and a green roof. Air tightness and the building management system were problematic, and initial flooding of the earth duct meant a pump was installed after handover.

Sector: OFFICE

Dartington C of E Primary School in Devon consists of four clusters of single-storey buildings. The total floor area is 1,990m^2. It has underfloor heating from air-source heat pumps, and solar electric and solar thermal panels. It also has rainwater harvesting. Value engineering late in the programme resulted in sacrifices in mechanical and electrical engineering. Energy use rose from the first to the second year of occupation – partly due to a colder winter.

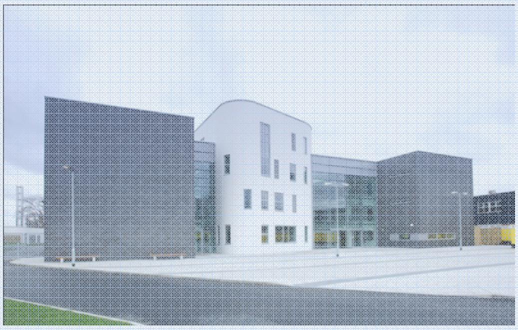
Sector: SCHOOL

Houghton Le Spring Primary Care Centre includes a number of low energy design features. It has optimised passive design and orientation to control solar gains, and high thermal mass from exposed concrete. It also has low-energy natural ventilation including a 'thermal wall', and a number of renewable energy systems (GSHP, PV, SHW and Wind). Partly as a result, it was rated BREEAM Outstanding at design stage.

Sector: HEALTH

iCon Daventry is a new 4000m^2 building providing space for new high tech companies, together with a conference centre and a public meeting place, intended to be a demonstration for good sustainable design. The building is a highly insulated timber frame construction, with features such as Phase Change Materials, extract air source heat recovery and summer passive stack ventilation.

Sector: OFFICE



Loxford School in Ilford was designed with close collaboration between the architects and M&E engineers to be naturally cross ventilated with simple controls. It included manual and automatic opening windows, and sensor feedback to users, a Ground Source Heat Pump, and solar shading. The evaluator highlighted that handover was somewhat compromised by the lack of a Soft Landings approach, leading to operational problems with motorised vents and the BMS.

Sector: SCHOOL

The Main Place, Coleford Community Centre is a two storey, 982m^2, naturally ventilated building providing community facilities. The construction is primarily traditional load bearing masonry, though includes some steel framed open plan elements. The envelope was designed to maximise energy efficiency through air tightness and good U-values.

Sector: COMMUNITY CENTRE

Mildmay (formerly Mayville) Community Centre, located in Islington, is a 19th century brick building, completely refurbished up to the Passive House standard, with very high levels of external insulation and air tightness. The building also incorporates an 18kWp PV array, solar thermal hot water and a GSHP to supplement heating requirements.

Sector: COMMUNITY CENTRE

Pennywell Academy, located in Sunderland, merges three existing schools into one new academy as a cluster of interlinked buildings with a total area of 10,200m^2. While it was designed as a largely passive building, once the contract was let the ventilation system was changed to mixed mode. In terms of renewable energy generation, the school includes a biomass boiler.

Sector: SCHOOL

Petchey Academy is a new 1200 place academy, completed in 2007. It comprises a four-storey concrete frame, split into two wings around a central, ETFE covered space. The school contains a number of energy intensive uses, including a training kitchen.
This is part of a study of three academies, also including Pennywell and Stockport Academies

Sector: SCHOOL

Pool Innovation Centre is a timber clad, three-storey multi-tenant office building, located in Redruth. It is predominantly naturally ventilated, with low level openable windows and high level automatic windows with manual override. Pool has a lightweight steel frame construction.
This is part of a study of three academies, also including Petchey and Stockport Academies

Sector: OFFICE

Thamesview School, in Gravesend, is a two-storey 8,250m^2 school with a large central atrium, built as part of a PFI contract. It features biomass and two gas boilers. It has complex controls, and there were problems in commissioning. The biomass boiler is no longer in use because problems with delivery.

This is part of the *POE Feedback into School Design* project, with Brighton Aldridge Community Academy.

Sector: SCHOOL

Thomas Paine Study Centre at the University of East Anglia is a three-storey academic building with a large plant room on the roof. It has a large lecture theatre, seminar rooms and offices: accommodation for 1200 staff and students. It is similar to the celebrated Elizabeth Fry Building, which achieved exemplary energy consumption. It uses Termodeck hollow-core floor slabs for ventilation and to maintain even temperatures. An occupant satisfaction survey found it in the top 10% of buildings.

Sector: HIGHER EDUCATION

Tremough Innovation Centre, similar to Pool Innovation Centre above**,** is also a timber clad three storey multi-tenant office building with predominantly natural ventilation, located in Penryn. Tremough has an in-situ concrete frame construction, and also features earth tubes to pre-condition incoming air to the conference centre.

Sector: OFFICE

Stockport Academy is a four-storey expansion and regeneration of an existing school, with space for 900 pupils. It includes mechanical ventilation with heat recovery, ground source heat pumps, and low energy lighting, designed to optimise daylighting provision. This is part of a study of three academies, also including Pennywell and Petchey Academies

Sector: SCHOOL

Woodland Trust Headquarters in Grantham is a timber frame building that follows the National Trust Central Office – another low energy office by the same design team. Despite modest construction costs (£1800/m^2), it achieved class-leading airtightness. It uses novel 'concrete radiators' on the ceiling to reduce summer overheating. It also has 'thin client' IT services, with low energy terminals on each desk rather than PCs.

Sector: OFFICE

Oakham C of E Primary School in Rutland is a 2,600m2 school for 210 pupils. It has a separate nursery, a community room and a hydrotherapy pool. It has well-insulated prefabricated timber walls. It has solar thermal panels intended to heat the pool. It used an adapted version of the 'Soft Landings' framework. Value engineering resulted in energy sacrifices, including removing the pool insulation. Classrooms have lobbies intended as thermal buffers.

Sector: SCHOOL

St Peter the Apostle secondary school, in Glasgow, was A PFI school built for 1500 pupils but currently has 1600. The floor area is 16,185m^2, spread across four three-storey blocks. It has reversible heat pumps that are able to provide heating and cooling, and gas boilers for heating. It has a mixture of under-floor heating, radiators and radiant panels to deliver heat. There are some issues with controls and the BMS, and over-reliance on electric light increases energy use.

Sector: SCHOOL

Asda Langley Mill supermarket is a 6,293m^2 building in Nottinghamshire with a sales area of 3,675m^2. It was intended as a test site for natural ventilation, and has a small amount of mechanical extract ventilation. Unlike other supermarkets, it has no mechanical cooling. The store reported 8% savings of the usual energy for ventilation and cooling, but this was offset by higher-than-usual heating energy. It also achieved very good occupant satisfaction

Sector: RETAIL

Vale and North Cotswolds Hospitals are two hospitals in Gloucestershire. They are similar sizes and have similar facilities and almost identical fabric and building services. They both have combined heat and power (used infrequently), solar water heating (unusual in hospitals), reversible heat pumps, and some solar shading. Both appear to be using more energy than they should, and report issues with thermal comfort – although both are liked by occupants. Both hospitals were economical to build.

Sector: HOSPITALS

College Lake Visitor Centre in Tring, Hertfordshire, is a 362m^2 building with a single-storey section including a grass roof and a timer two-storey section. It has under-floor heating from two 12 kW air-source heat pumps, and a 3.4 kW solar electric array, providing 8% of the electric demand. Energy performance is good and (very unusually) close to the design estimates. The heat pump coefficient of performance was calculated at 1.9. The BPE helped to resolve issues with wasteful water and space heating

Sector: VISITOR CENTRE

What causes over consumption?

One of the key goals of the BPE Programme was to explore why the environmental performance of buildings often falls short of expectations. We tried to identify instances where good design practices, procurement processes, or operational management, helped a project to reduce the performance gap.

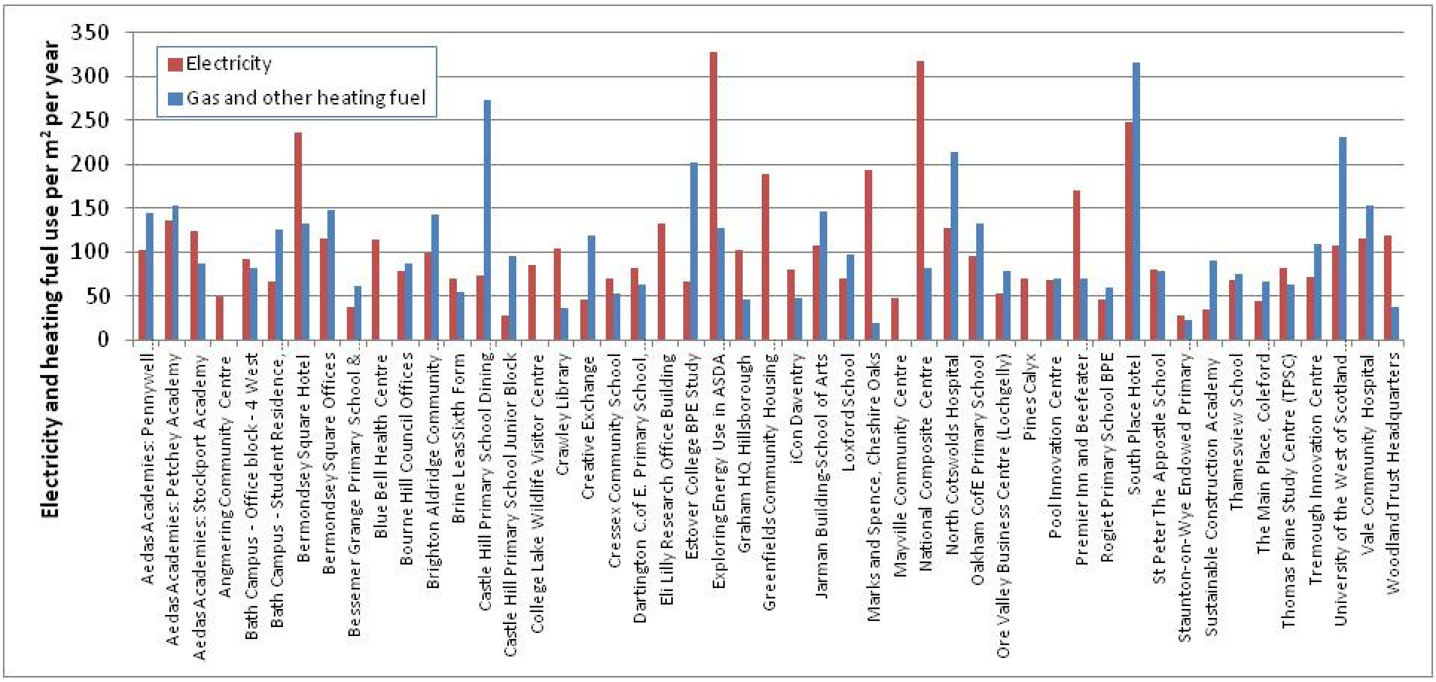
Evaluating the Performance Gap

The BPE approach helps to measure the performance gap in reality, and this in turn depends on monitoring energy use in buildings accurately. Project teams did this using CIBSE's TM22 methodology and worksheets – a systematic approach to conducting an energy survey, recording findings, and estimating possible savings from making changes.

We start with actual electricity and heating fuel use, where fuel use includes gas, oil, biomass and biofuel. We have normalised the data by floor area, so the energy figures here show electricity or fuel use in terms of kWh per square metre per year, see graph below. The range of energy use per m^2 is very wide: from 28 to 367 kWh/m^2 for electricity, and from 0 to 316 kWh/m^2 for fuel (seven of these buildings are all-electric, with electricity used for heating). The average (mean) electricity use is 103 kWh/m^2, while the mean for fuel is 92 kWh/m^2. Both electricity and gas use are important, so we can only assess a building as performing well if it achieves low electricity *and* fuel use – at the same time as keeping occupants comfortable.

Carbon emissions and costs are almost always higher for electricity than for gas (the most common heating fuel) – typically about three times higher. Carbon emissions from biomass and biofuel are much lower, but even for these fuels it is important to use no more than necessary – because there are limited supplies of bio-energy, and savings would free them up for use elsewhere.

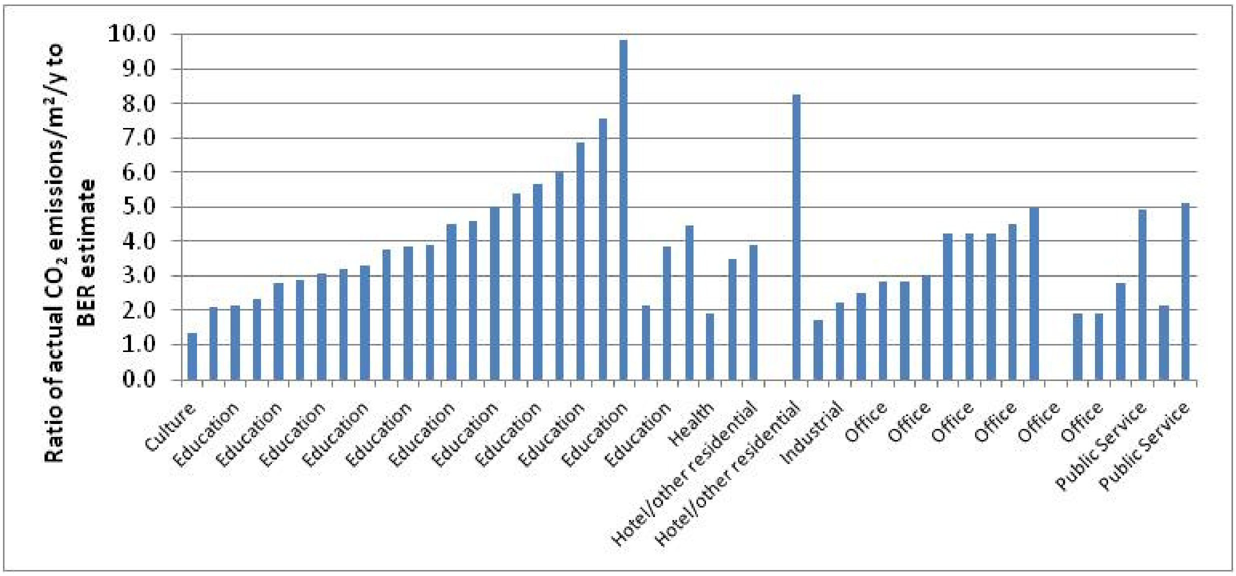
The stand-out success stories from an energy perspective are the Staunton-on-Wye Primary School, with electricity and fuel use both below 30 kWh/m^2; the Mildmay Community Centre, with electricity use of 47 kWh/m^2 and no fuel use; and the Angermering Community Centre, with electricity use of 49 kWh/m^2 and again no fuel use. We examine why these projects perform so well in 'Why do some buildings perform better?', below.



All of these buildings were designed with an emphasis on low energy performance, but the range of actual energy use for electricity and fuel is staggering: from combined energy use from less than 50 kWh/m^2/year to more than 560 kWh/m^2/year.

The Building Regulations mean that designers or developers must calculate a Building Emissions Rate ('BER') for every new building. This gives the estimated rate of CO_2 emissions per m^2 floor area for emissions from regulated energy use (heating/cooling, ventilation and lighting), calculated according to the Government's standard methodology, using approved calculation tools.

Comparing the BER against actual energy use obtained from the TM22 worksheets, only one building (College Lake Visitor Centre) was found to produce emissions that were similar to those predicted, while the rest produced from 1.8 to ten times the emissions rate used to show compliance with Building Regulations. The average was carbon emissions 3.8 times higher than the BER design estimate (see graph below, and caveats in the next paragraph.)

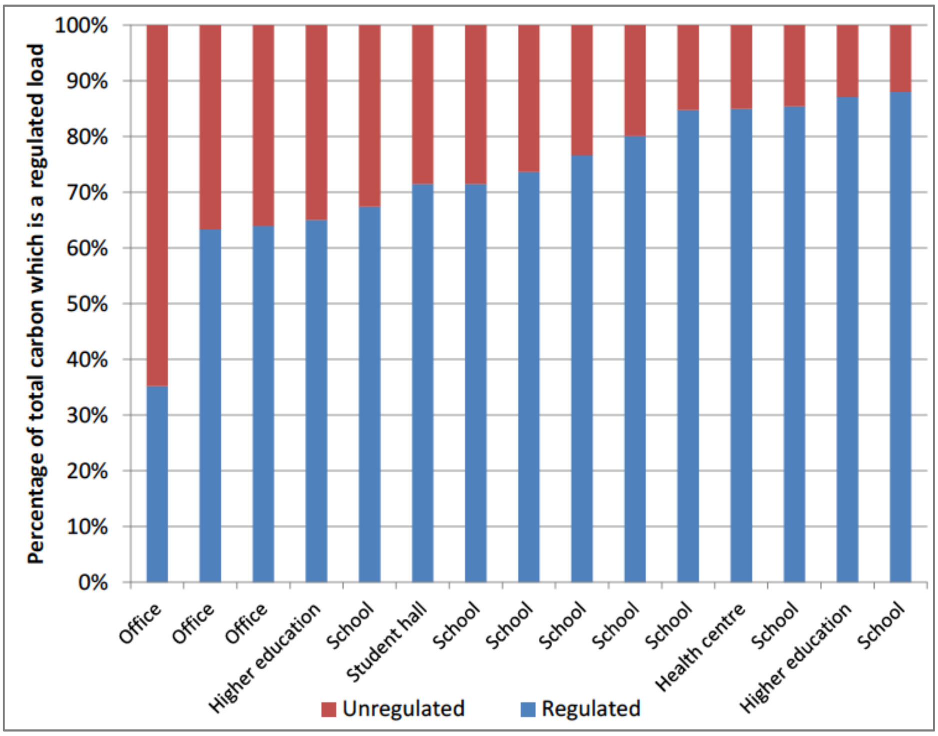


Actual CO_2 emissions are almost always higher than predicted by the BER (Carbon Factors: Electric 0.55kgCO_2/kWh, Gas 0.194kgCO_2/kWh, Oil 0.265kgCO_2/kWh, District heating 0.265kgCO_2/kWh, Biomass 0.025kgCO_2/kWh, from BRUKL)

Of course, the predicted emissions only account for a certain proportion of actual building loads: the ‘regulated’ loads, which fall under Building Regulations compliance. These include heating, cooling, ventilation and lighting, but leave out many other types of energy uses, such as small power and IT, or external lighting (‘unregulated loads’). While these energy uses may only be a small proportion of total operational energy use, they made up more than 25% of energy use for more for half of the sites with data in a study by Robert Cohen in 2013[2], and an actual majority of energy use for one office (65%), see chart below.

In reality the proportion of energy that is unregulated varies between sectors. Retail and industrial buildings, and swimming pools, tend to have high unregulated loads by nature. However, the proportion of unregulated energy use is also rising in some sectors – like schools – because of increasing use of ICT (information and communication technologies).

[2] Cohen (2013) The Performance Gap in Non-Domestic Buildings, presented at Ecobuild 2013. London/Swindon: Verco/Technology Strategy Board. http://greenconstructionboard.org/index.php/resources/performance-gap



Unregulated energy use can be as much as 65% of total actual energy use (Source: Cohen, 2013)

Another area that compliance calculations ignore is energy used out of normal working hours (which are routinely defined too narrowly). For many of the buildings in the Programme, the data indicated that out of hours electricity use often matched, and sometimes surpassed, energy use in hours, due to continuous base electrical loads like servers, and outdoor lighting.

Another way that actual and operational energy uses are assessed in the UK is through certification. These are linked closely to the calculation method in Building Regulations, but they give normalised ratings allowing a simple comparison with similar buildings across the country. Buildings in the UK may have two different types of energy certificate: Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs). EPCs are part of the current Building Regulations procedure, and must also be produced when selling or renting a building. They give a comparison between the designed building and a standard building, modelled using the National Calculation Methodology (NCM). (Not all projects in this study have an EPC however, as some passed through planning before this was a requirement). DECs are a requirement for public buildings above 1000m^2 and optional for other buildings. They give a comparison of the actual energy use based on data from bills over a year, with a standard benchmark for each building category. For both measures, high values are bad, indicating high energy consumption or emissions.

A simple comparison of the EPC and DEC ratings for the 17 buildings that have both is shown in the graph below. This demonstrates that there is very little correlation between the EPCs and DECs, a result noted in previous papers[3]. This reinforces the fact that while the EPCs are a good indicator of the

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[3] E.g. "A Tale of Two Buildings", 2012, Jones Lang LaSalle, www.betterbuildingspartnership.co.uk/download/bbp-jll---a-tale-of-

potential energy performance of a building asset, they cannot take into account changes in the design, or any aspects of operation or occupant behaviour.

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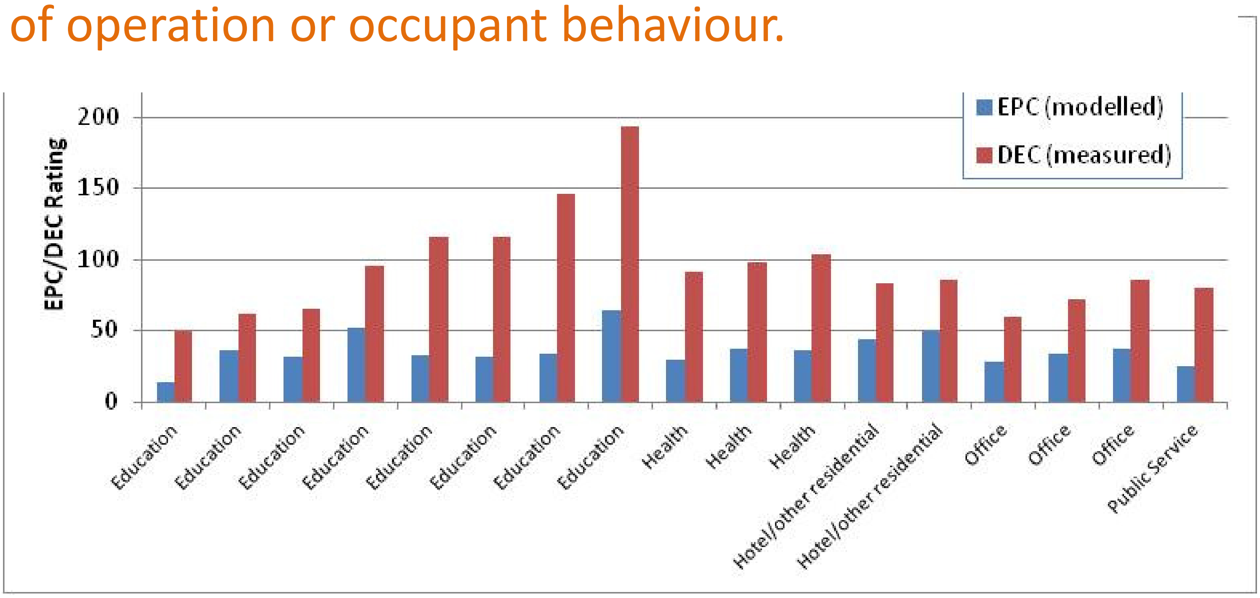
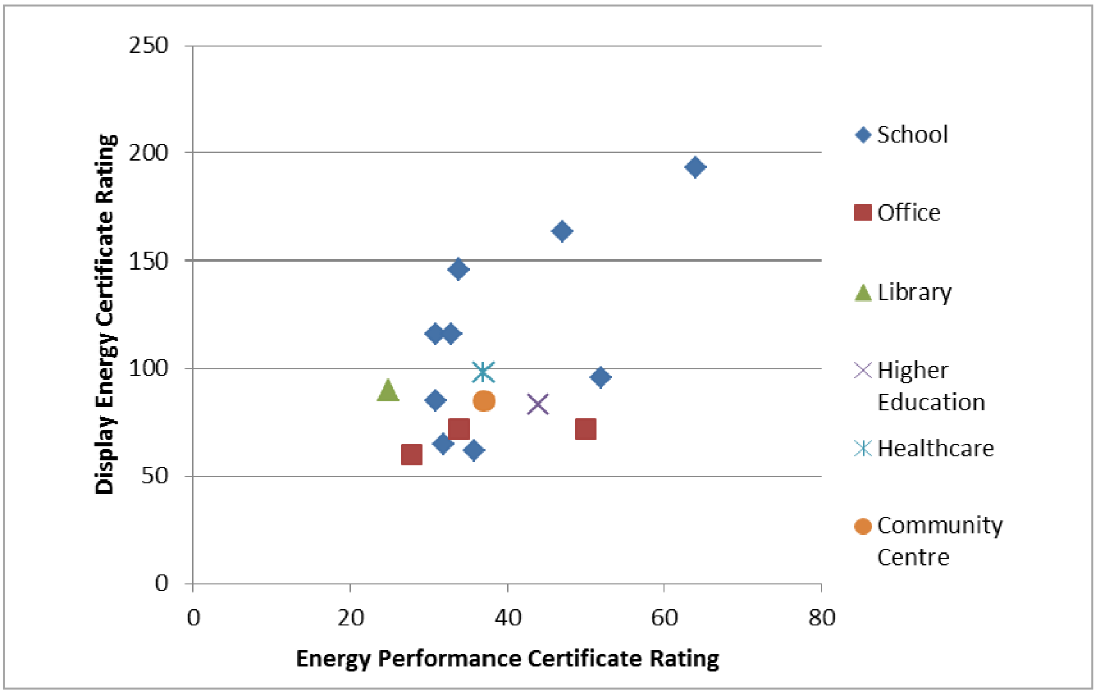


Display Energy Certificate (DEC) ratings, based on measured energy use from bills, are often triple the modelled Energy Performance Certificate (EPC) rating.

two-buildings-2012.pdf



There is no clear trend when EPC and DEC ratings are plotted and grouped by sector.

Overall, there is hardly any correlation between EPC ratings and Display Energy Certificates , and while there is a slightly higher correlation coefficient for schools, this is mostly driven by the outlier with a DEC of 193 (G), which also had a relatively poor EPC of 64 (C).

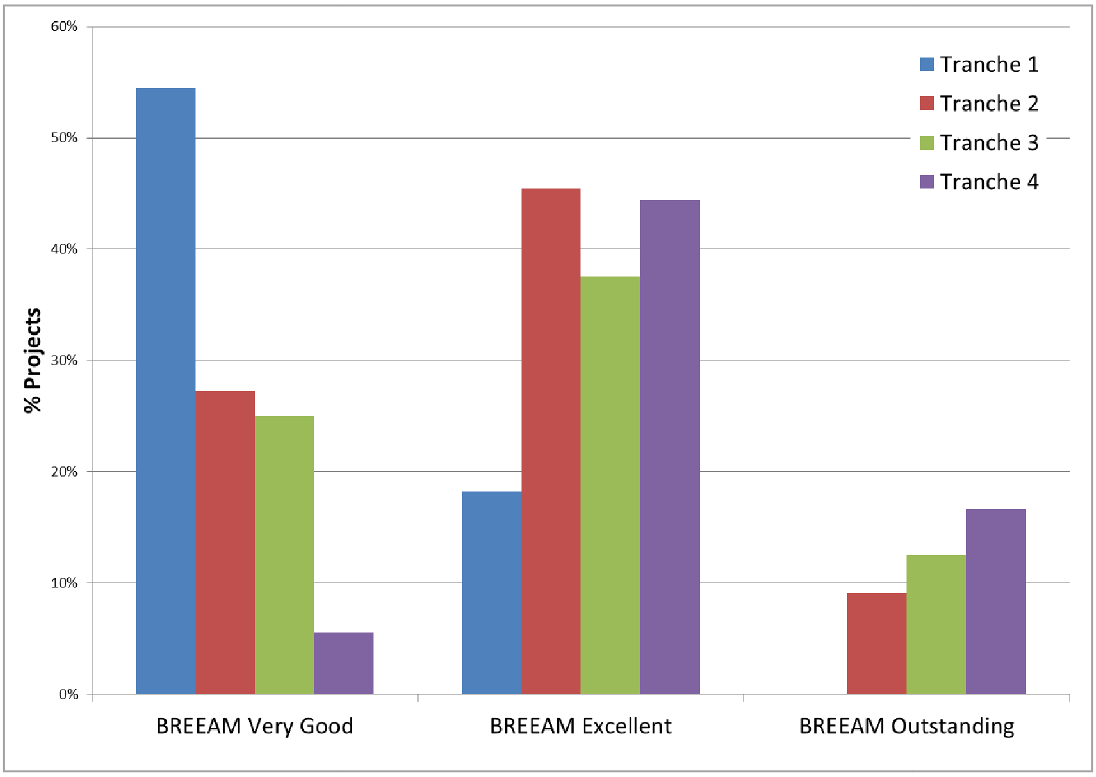
Changing Expectations

The performance gap is not restricted solely to the gap between EPC ratings and actual energy use. Other metrics of sustainable design can also raise expectations. This study points to increasing expectations from clients, with later tranches including more BREEAM 'Outstanding' buildings and fewer 'Very Goods'.

There are many different drivers for this, from a desire for low energy costs, to staying ahead of legislation, to enhancing or reinforcing a green reputation, but nevertheless, an expectation that the building will be perform better than average.

While the buildings in the study are self-selected, it is interesting to note that while the first set of projects to start monitoring (Tranche 1: May 2010), over 50% of the projects were only at BREEEAM 'Very Good', whereas 10 months later (Tranche 4: February 2011), the majority of projects submitted were either BREEAM 'Excellent' or 'Outstanding'. Readers should note that BREEAM 'Outstanding' was only brought in for BREEAM 2008 generally, so for earlier tranches this may not have been an option. On the other hand, the BREEAM standards have become stricter over time, for example, since 2008 a Post Construction Review has been required.

Two other environmental assessment methods were used on projects in the study: Passive House was used in one of the community centres (though the Passive House design principles were referenced in several other projects, without seeking certification), and one of the hospitals achieved a NEAT[4] Excellent rating. Some projects undertook a BREEAM pre-assessment, but decided not to complete the assessment, in one case with the following reasoning: *"…full certification was not pursued since the sustainability credentials of the building were considered to be achieved in its own right"* (Eli Lily Research Office). One project, Bath Campus, noted that chasing BREEAM credits had led to oversizing the Solar Hot Water system, which then caused issues during operation. They also felt that while some BREEAM requirements were met, they were treated as targets, rather than minimum levels (the daylight factor, for example). It seems likely that BREEAM certification generally acts as an incentive to add more low-energy systems, which brings complications and greater risk of unmanageable complexity.



The proportion of projects at BREEAM 'Very Good' fell over time, while those at BREEAM 'Excellent' and 'Outstanding' increased for later BPE project tranches

When the EPC and DEC results are compared with BREEAM scores, there was a very slight average improvement between the BREEAM 'Very Good' and the BREEAM 'Excellent' buildings. However, the EPCs were much better for BREEAM 'Outstanding' buildings, with mean and median EPCs only one third of those for 'Very Good' and 'Excellent' buildings, indicating that to reach the 'Outstanding' score requires extra effort on energy[5]. Unfortunately at this stage, no DECs were available for BREEAM 'Outstanding' buildings, so we cannot assess the performance gap.

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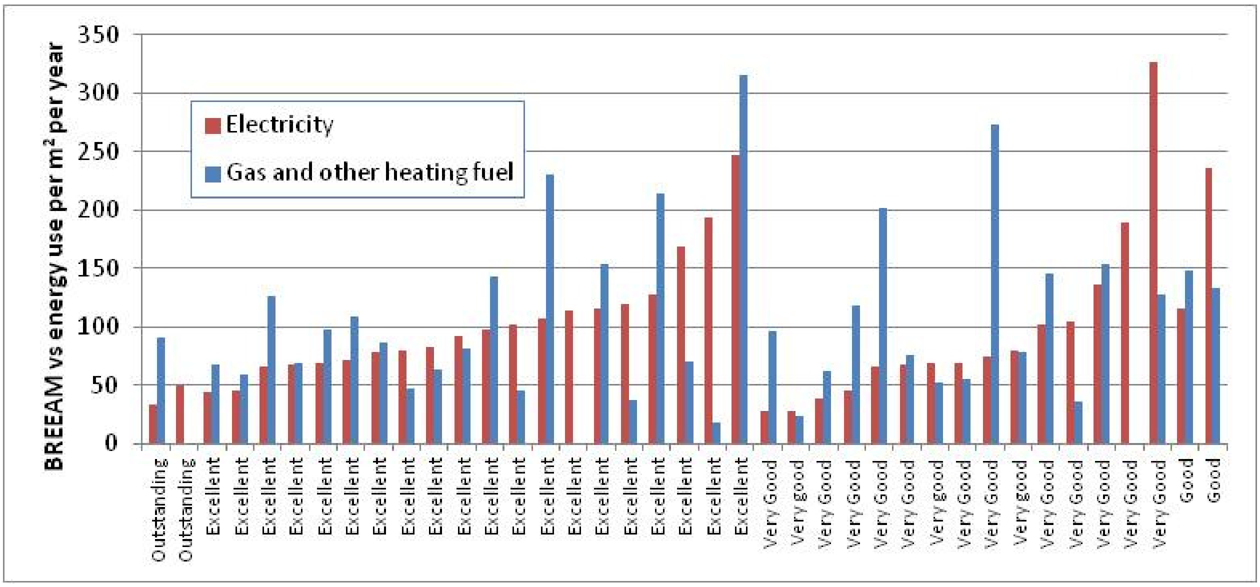
4 NHS Environmental Assessment Tool. This has now been replaced with BREEAM: Healthcare.

5 Previously, BREEAM ratings were explicitly linked to EPC ratings (e.g. an Outstanding building had to have an EPC <25), though this is not the case in the latest version of BREEAM (2011).

Note: Part of the link between BREEAM and EPCs is an artefact of the BREEAM credits, because energy is a mandatory requirement in the BREEAM assessment.



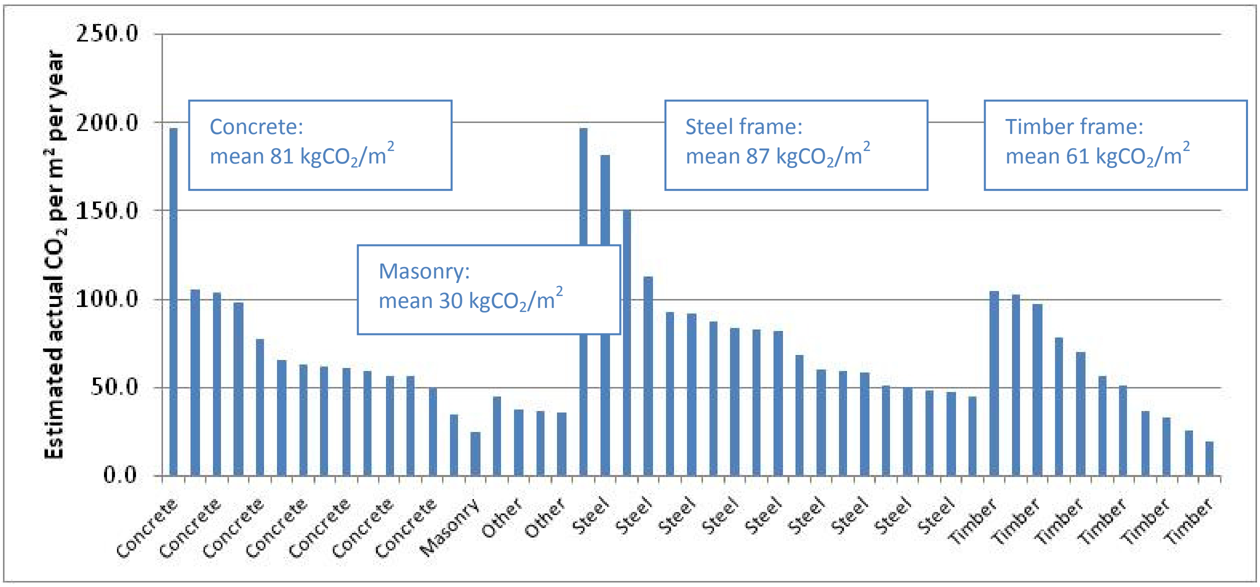
A comparison of BREEAM scores actual electricity and fuel use per m^2 per year. BREEAM 'Outstanding' buildings are indeed more energy efficient than others in the sample (mean electricity and fuel use both below 50 kWh/m^2/year). However, there are only two of them. Arguably more important, 'Excellent'-rated buildings use a little more energy, on average, than 'Very Good' ones (mean electricity and fuel use a little over 100 kWh/m^2/year each for 'Excellent', vs a little below 100 kWh/m^2/year for 'Very Good'. The two 'Good' buildings do seem to perform worse than other BREEAM-rated buildings, with mean electricity use of 176 kWh/m^2/year, and mean fuel use of 140 kWh/m^2/year.

Does the structure, procurement route, or tenure make a difference?

The BPE study also allowed us to collect and compare a series of details for each project about their design, construction and occupation. This included information about their:

- Predominant structure (concrete, steel, timber, or masonry)
- Procurement method (Traditional, or Design and Build)
- Tenure (owner occupier, single tenant, or multi-tenant)

The analysis of structure against carbon emissions was complicated by a marked bias towards steel and concrete frames in this set of buildings. There were surprisingly few 'traditional' masonry buildings of weight-bearing block or construction, and more timber-frame buildings than readers might expect (see chart below). However, on average, steel- and concrete-frame buildings had higher carbon emissions per square metre than timber-frame buildings, and markedly higher than masonry buildings. This is a question that merits further investigation, ideally with a larger sample of masonry buildings.

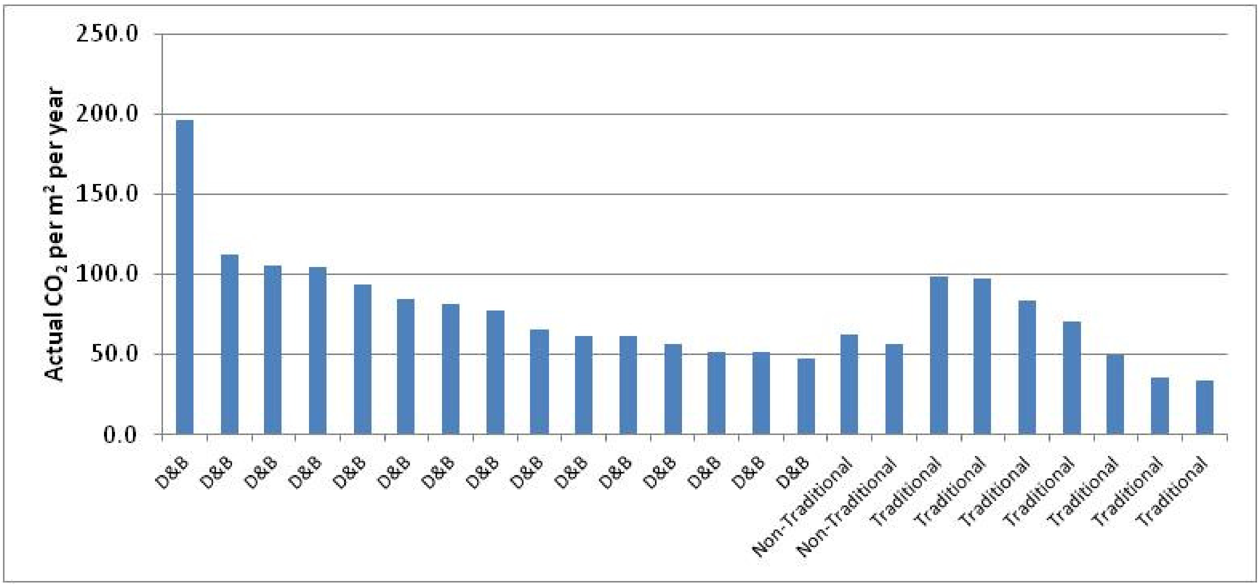


There appears to be a link between structure and annual carbon emissions, with steel and concrete frame buildings emitting more carbon, on average (Carbon Factors: Electric 0.55kgCO_2/kWh, Gas 0.194kgCO_2/kWh, Oil 0.265kgCO_2/kWh, District heating 0.265kgCO_2/kWh, Biomass 0.025kgCO_2/kWh)

There may be intervening variables – for example, high-energy use buildings like hotels, prestigious offices and industrial buildings may be more likely to use steel or concrete frames. Or smaller, easier-to-manage buildings may be more likely to have masonry or timber-frame construction.

Turning to the type of contract, where traditional contracts (with the architect and engineers employed from concept design through to detailed design) are commonly held to give more confidence than 'design and build' (where the main contractor takes responsibility for detailed design). The accepted wisdom is that employing the same design team all the way through means it is more likely that aspirations for good energy performance will be maintained, with less risk of inappropriate substitutions for cost reasons when construction starts.

The buildings in the programme do indeed show some link between the type of contract and carbon emissions (see chart below). Mean emissions for traditional contracts – where the contract type is known – are 66 kgCO_2/m^2/y, against mean emissions of 83 kgCO_2/m^2/y for design and build contracts. The four highest-emission buildings in this group were also design and build. However, a traditional contract alone is no guarantee of low carbon emissions, and the best D&B projects achieved lower emissions than half of the projects with traditional contracts.



Analysis of carbon emissions and procurement route indicated that average emissions are lower among projects with a traditional contract, though the average for design and build contracts is skewed upwards by one particularly poorly performing building. (It is not clear from records what 'non-traditional' means here.)

Why do some buildings perform better?

We have seen that almost all buildings in the BPE Programme have higher carbon emissions in use than expected at the design stage. However, some have only slightly higher emissions whereas others have emissions up to ten times higher than the Building Emission Rate. Here, we focus on a subset of buildings that have exceptionally good performance, and try to see why. Then we turn to a subset with much higher-than-expected emissions, and again look for factors to explain why.

The buildings that achieved low emissions

These buildings had total emissions no more than twice the Design Building Emission Rate (BER), described above. Since the BER only includes regulated energy use – heating and cooling, hot water, lights and ventilation – this is very good performance. (Four projects are excluded from this analysis, because of incomplete data.) We examine each building in turn, trying to identify what explains the exemplary performance.

Project name	Emissions /m^2 (kgCO_2/year)	Ratio of emissions to design estimate (Emissions /BER)	Space and water heating /TM46*	Technologies
Staunton-on-Wye Primary School	13.8	1.3	0.2	Natural ventilation. Under-floor heating and biomass boiler. Solar electric panels.
Angmering Community Centre	23.4	1.9	Unknown	Ground-source heat pump and under-floor heating, Solar electric panels.
Mildmay Community Centre	26.0	1.9	Unknown	Passive House standard retrofit with heat-recovery ventilation and a ground-source heat pump.
Ore valley Business Centre, Lochgelly	44.7	1.7	0.7	Mixed mode, mechanical ventilation using 'Termodeck' hollow floor slabs.
College Lake Visitor Centre, Lochgelly	47.0	1.1	Unknown	Natural ventilation, air-source heat pump, and under-floor heating. Solar electric panels
Bath Campus Woodland Court	60.7	1.9	0.6	Natural ventilation except for kitchen extracts, wet rooms and IT rooms. Gas boilers and combined heat and power. Solar hot water panels.

* This is the heating energy used as a proportion of the TM46 benchmark. Heating energy is gas and other non-electric energy used. For buildings where the heating is at least partly provided by electricity, this value is not known. The latter is from the DEC where available, and where there is no DEC it is calculated.

Staunton on Wye Primary School

This school has 85 primary school places and 22 nursery places. It is the lowest-emission building in the BPE Programme, at only 13.8 kg CO_2/m^2/year. PV panels were added later and further improved the already very good performance (exporting 4.1 kWh/m^2, and saving 2.2 $kgCO_2/m^2$).

Heating is from a biomass boiler with no gas backup. The classrooms are so well insulated that the head teacher has reduced the heating hours to 8.30am – 11am and the building stays warm the rest of the day. Although there is a Trend BMS, controlled by the heat teacher, there are thermostats in each room that can adjust the set point +/- 3C. However, the heat retention relies on closing windows and this has lead to elevated levels of CO_2 in indoor air, which are held to affect pupil concentration. With only trickle vents open levels sometimes rose above 1500 parts per million. Monitors have been installed and when these show high levels teachers open the windows. Also, in the preschool area there have been complaints it is too cold. This is probably because the pre-school children have access to play outside throughout the day, so doors are open and the heat is less well contained in the building.

Lighting in the classrooms has daylight dimming. Presence sensors on corridor lights were removed because of complaints they were over sensitive and on too long.

Angmering Community Centre

Angmering Community Centre is a one-storey building with a sports hall, activity/meeting rooms, a display area and a refreshments area. All heat and hot water is from a ground-source heat pump, with an additional heating element integrated in the heat pumps for very cold weather. There is also a large array of 60 (10.2 kWp) solar electric panels.

This building is designed for very low heat demand. Occupants taking part in physical activities often have to open windows to cool down. There is no central BMS and although there are thermostats in each room users have been asked not to adjust them. The under floor heating responds very slowly and there have been cases where users accidentally turned the heating off altogether.

This building has very little in the way of plug in loads. Lighting accounts for 41% of electricity, heating including hot water is 45%.

Mildmay Community Centre

The community centre has a sports hall, reception area, dining area and kitchen, plus office spaces in continuous use by tenants. This building has been given a Passive House standard retrofit and in the winter of 2013/2014, with occupation levels up to the previous level, it required no space heating at all. The ground-source heat pump is required for hot water however.

This building has no centralised building management system (BMS) - all systems have the standard manufacturer controls only. This was a deliberate design decision, to keep the controls simple, and has proven very successful. The building is also carefully managed, and low energy use is a priority – something that may not be replicable in other contexts.

Passive House design requires very high levels of air tightness. The site manager and construction team were given a short training course to help them understand the demanding requirements. The second test showed they had achieved 0.43 $m^3/h/m^2$ at 50 Pa: 20 times better than building regulations. Ventilation is provided by mechanical ventilation with heat-recovery. The set hours for this can be extended by a timed run-on switch for evening events. In summer, ventilation grilles allow night time cooling and the ventilation system has a summer bypass (important both for energy-saving and to limit summer overheating). It is recommended this is automated as it is easy to forget to change the setting between seasons.

Ore Valley Business Centre, Lochgelly

This is a business incubator unit with office space, meeting rooms and support facilities. The building is steel frame, with a mix of cladding systems including Thermalex for windows, Kalwall for daylight without loss of privacy, and tiled areas. The Thermalex performed better than expected for insulation value, but the other materials slightly worse (see table).

Wall type	Expected U-value	Measured U-value
Kalwall	0.3	0.56
Thermalex	0.276	0.23
Tiled	0.2	0.36
Rendered	0.2	0.20

Although air tightness in most rooms is good there are substantial leaks in the basement and the lift/stair shaft. And although this building already performs well it could have done better still.

Heating in tenanted areas is distributed through a hollow core concrete floorslab system called Termodeck. The Termodeck provides high thermal mass and in summer it takes advantage of night-time cooling. During occupied periods there is no recirculation but there is some heat recovery from exhausted air. Communal areas have conventional radiators and one stairwell has a fanned electric panel heater.

The building management systems and Termodeck have operated well, even though initially the software to allow remote monitoring by Termodeck was not installed. Since then only minor adjustments have been applied. The heat is supplied by conventional gas boilers.

There was no sub-metering beyond floor level in the original design. However, meters installed for this BPE have shown that some tenants have high unregulated power use (plug-in equipment and catering). All tenants have an energy induction course and an energy group meets quarterly.

College Lake Visitor Centre

The centre includes offices, a visitor interpretation space and a café. It has very low energy demand and the solar PV panels provide 8% of the electricity used. Underfloor heating is provided by two ASHPs. Monitoring for the BPE uncovered excessive use of the immersion heater for hot water– this has been fixed by setting the heating permanently in winter mode to make better use of the heat pumps. The occupants have learned over time to manage the underfloor heating, which is slow to respond, and have developed a window opening strategy to maximise ventilation in summer.

Bath Campus Woodland Court

This building provides accommodation for 355 students in five blocks. During the holidays it is used for conference accommodation. The heating, lighting and ventilation is fairly conventional. Windows are openable and radiators have manually operated TRVs. The emissions per m^2 are fairly average. This building is featured here because it performs as expected.

Lighting in communal areas and corridors is activated by motion sensors, including during the day. Many of these initially had faults so that lights were on all the time – these have been replaced. Also initially the corridor lights and stairs were over-bright and over-sensitive, and the switch on-time was the default 20 minutes. The unnecessary light was disturbing the students as well as wasting energy. The light levels have been reduced and the on-time reduced to five minutes.

BPE Projects with higher than expected emissions

These six projects had total emissions at least five times the Design Building Emission Rate. Even accepting that actual emissions include unregulated plug-in appliances, this is a significant performance gap, and it is worth scrutinising the projects to see what we can learn. (These figures are cover the period before the final reports were submitted to Innovate UK, and some of the causes of over-consumption may have been resolved since.)

Project name	Emissions /m^2 ($kgCO_2$/year)	Ratio of emissions to design estimate (Emissions /BER)	Space and water heating /TM46*	Technologies
National Composite Centre	189.9	8.3	0.5	Mixed mode. Night time cooling.
Pennywell Academy	84.2	5.6	0.8	Mixed mode, biomass boiler with gas backup, passive solar shading.
Brighton Aldridge Community Academy	81.6	7.6	1.0	Biomass boiler with gas backup. Underfloor heating in corridors and hall.
Oakham CofE Primary School (with 50m^2 hydrotherapy pool)	78.4	6.0	0.5	Natural ventilation. Gas boilers with underfloor heating on the ground floor, radiators above. Solar hot water panels. For the pool hall, an exhaust air heat pump.
Estover Community College	77.6	6.8	1.3	Mainly natural ventilation. District heating, biomass boiler with gas backup.
Thomas Paine Study Centre (TPSC), Norwich	62.1	9.9	0.2	District heating, via Termodeck. Heat-recovery ventilation.

National Composite Centre

This state of the art industrial facility performs well in terms of heating, though potential savings have been identified by avoiding running heating and lights when the building is unoccupied. Also the main workshop is heated to a higher temperature than necessary. The very high electricity use is mainly due to activities within the building, such as maintaining the Class 8 clean rooms (requiring high-level filtration). Also some of the gas use is also for industrial processes, rather than heating.

The high electricity use has triggered a problem with the metering system. When the meter reading exceeds 1,000,000 units, it drops a digit and reads ten times too low. This makes long-term monitoring very difficult.

Night time cooling has been discontinued for the time being because squirrels were getting in and scavenging for food. The window grilles need mesh to prevent this happening.

The efficiency of the main air handling units (providing ventilation and cooling) could be improved with a variable speed drive, saving 10% of electricity with payback in 0.1 years.

Pennywell Academy

Pennywell is an amalgamation of three schools, totalling 1,120 pupils and 150 staff. It was built during 2008/2009. There are several two- and three-storey steel frame buildings, clustered around a courtyard. Overhanging eaves provide summer shade. The envelope is not a particularly high specification: walls have a U-value (describing insulation efficiency, where lower is better) of 0.35, windows 1.1.

Pennywell Academy was one of three academies studied in the Programme – the other two (Stockport and Petchey) had relatively good performance, with actual building emissions between three and four times the BER. For Pennywell, the total emissions were nearly six times the BER.

Complexity of the BMS and control systems is partly responsible at all three schools – the report suggests that school staff lack the expertise required to use the systems, and have many other tasks that take priority over improving energy efficiency. However, they would not have been helped by the very weak operations and maintenance manuals provided at handover. This was revised and improved during the BPE.

Monitoring has shown that the heating system at Pennywell was operating continuously over the weekend, instead of turning off overnight. Also, the biomass boiler is no longer used – it is not considered value for money, due to high maintenance costs, and there has been a health and safety warning issued about a potential build-up of carbon monoxide in the pellet store. Only one batch of pellets was acquired and used. The gas boilers have been used exclusively since then.

The emissions figures are based on the year to March 2012: since then there have been significant savings from optimising the lighting systems. The infra-red sensors have been made less sensitive so classroom lights are no longer triggered by people passing in the corridors. Also, external lights were on continuously but are now restricted by a schedule. These and behaviour changes have lead to a 20% decrease in internal lighting consumption, a 60% decrease in external lighting and an 18% saving in electricity.

The cooling loads for the school were originally underestimated and the IT energy consumption vastly underestimated. The National Calculation Methodology (SBEM, used to assess energy use for building control as part of the planning application) assumes 50 W/m^2 for IT server rooms, or 500 W/m^2 in data centres. At Pennywell actual use is 1100 W/m^2.

Estover Community College

The college campus comprises 10 buildings, nine of them new, providing facilities for 1,600 pupils from 4 to 18. There is also an energy centre providing heat through a district heating system. The original intention was for a biomass boiler system with gas backup – in practice the biomass boiler has been abandoned, due to a succession of problems with both control systems and mechanical parts.

Part of the high energy use for heating is simply because of extensive out of hours use. However, the hot water systems are operating unnecessarily outside term time, leading to losses from the distribution mains. Total heat consumption from June to August is a third of that in January to February. Summer time hot water could be provided by instant water heaters at the point of consumption, or solar water heaters, and the energy centre turned off.

Most of the school is heated with radiators that have thermostatic radiator valves. The pupils often turn these up to the maximum level, or kick them off – these could be replaced with tamper-proof systems. Also, the sports hall side door is often left open. This is partly because it has been damaged by rough use and does not close easily. It has been estimated that fixing this would cost £900 and save £400 a year.

The hot water pumping systems currently operate continuously even when the boilers are inactive and no heat is supplied. Turning them off would save £1,300 a year. Also, much of the pipework and fitting in plant rooms through the school has inadequate insulation. Fixing this could save £4,400 a year. Together these measures could save 50 tonnes CO_2/year.

The sports hall has 10 kW of manually-controlled lighting. Unfortunately, the switch is in reception, not visible from the hall, so it is often left on when not needed. Further, the car park is currently lit all night.

There is active cooling in some areas, including IT server rooms. These are cooled to 18C, although ASHRAE (the American Society of Heating, Refrigeration and Air-Conditioning Engineers) recommends 27C.[6] The kitchen air-handling unit runs 24 hours a day due to a fault in the control system. Also, computers in many parts of the school have been observed left on all night. These contribute to the rather high (60kW) base load for the school.

All classrooms are naturally ventilated and have at least one casement with a grille, to allow security for night time cooling. However, window opening and closing is purely manual, so building users have to operate these according to their judgement. There are CO_2 sensors with a traffic-light signal to prompt windows to be opened when necessary. However they are often hard to see, either too far away or obscured by furniture and clutter.

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[6] 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance http://ecoinfo.cnrs.fr/IMG/pdf/ashrae_2011_thermal_guidelines_data_center.pdf

Brighton Aldridge

This school is one of two (along with Thamesview School) in the same project designed with similar services and built by the same contractor. Both schools were intended to be heated mainly with biomass chip boilers, but these systems have not been effective. The wood chip supplied does not meet the specification needed and continually jams the feed system. Thus both schools have used gas backup systems instead.

Brighton Aldridge nearly twice as much energy for heating (143 kWh/m^2 at Brighton Aldridge compared to 76 kWh/m2 at Thamesview) partly because of difficulties with the controls. Both schools have underfloor heating that require several hours of pre-heat each day in the main hall and corridors, but in Brighton Aldridge this means the rest of the school is heated too because the systems cannot be separated. The underfloor heating needs 4 hours preheat each day, but this applies to only 25% of the floor area. It is estimated that fixing this could reduce heating consumption by 30%. However, this explains only about 65% of the difference between the two schools' heating consumption. Brighton Aldridge uses a Honeywell Tridium BMS while Thamesview uses a Trend BMS (as does Staunton on Wye Primary School above).

Oakham Church of England Primary School

This primary school for 210 pupils has a separate a nursery and facilities for children with special needs, including a 50m^2 hydrotherapy pool. The pool accounts for 40% of the school's gas and electricity use. It is currently heated to 33C all year, but savings could be made by reducing heating during the holidays, and possibly reducing the water temperature to reduce evaporative loss. This will mean increasing the air temperature slightly to maintain comfort levels. Also, the pool heat loss could have been reduced by about 10% (13,000 kWh/year) by insulation below the pool. This was not done to reduce costs, and because they were working to pre-2010 Building Regulations, which did not require insulation under the pool.

Some of the high emissions relative to BER are due to the heavy operating schedule. The nursery has a breakfast club as well as after school clubs. The server room is currently cooled to 19C, and this could be increased to 25C, saving a few thousand kWh/year. (The servers consume 1.1kW of electricity continuously, or 10,000 kWh/year.) Interactive whiteboards in each classroom contribute to high power use. In addition, there is unexplained high power use in the library and kitchen.

Thomas Paine Study Centre (TPSC)

The Thomas Paine Study Centre is part of the University of East Anglia – an extremely experienced client, with a long history of constructing low-energy buildings. It is a three-storey building with offices, lecture theatre and seminar rooms. It uses Termodeck hollow core concrete slabs to distribute heating and cooling, supplied by a district heating/cooling system. In terms of heating consumption this building has performed very well. However, the high overall emissions are due to high electricity use, and 41% of this is due to plant room equipment. It seems the air handling units are operating at high power more of the time than should be needed. Also, 33% of the electricity use is for lighting, which has not been optimised as much as it could.

Lessons learned

Operational issues

- The projects had widely different experiences of biomass boilers – three were abandoned due to mechanical problems and/or high costs. However, one contributed to one of the most efficient buildings. The implication is that biomass boilers must have careful consideration during design and construction, including where the fuel will come from and how it will be delivered and stored.
- There is a tendency to install overly complex control systems - partly prompted by Building Regulations and BREEAM credits. Poor understanding of these systems, or possibly poor functioning, leads to energy wasted out of hours and/or overheating.
- Pumps and plant room equipment for heating and cooling receive inadequate attention and are often allowed to run when other systems are inactive, which is wasteful.
- Underfloor heating must be managed separately from radiator circuits so that the pre-heat requirements for (slower-response) underfloor can be accommodated without heating the radiators too. Occupants also need appropriate information about response times and how best to control underfloor heating.
- Lighting systems are often not adjusted properly during commissioning. This is especially important for systems with PIR sensors. They need adjustment for both sensitivity and timing. This should be a routine check during completion, and the commissioning should not be signed off unless lighting controls are seen to work appropriately.
- Where ventilation is under manual control it is important the controls are simple, and prompts such as CO_2 sensors are easily visible. Initial training for building users is seldom sufficient – because staff change – and simple, enduring guidance close to controls should be available after handover.

Poor estimates of energy requirements

- Operating hours are routinely underestimated – possibly because of optimism bias, and also not anticipating that some building users will seek to work early in the morning, late into the evening, and/or at weekends. Design estimates of energy use should be realistic about the actual hours of use, and allow for extended hours where this is likely (especially in schools and community facilities)
- IT systems and server rooms consume far more power than standard estimates – possibly clients need better advice on how to select efficient computer equipment. This means clients that prioritise energy use should invest time in understanding the energy implications of IT decisions, and allow for the cost of employing specialist assistance.

Excluded projects

Two projects were omitted from this part of the analysis.

201 Bishopsgate This is a very complex building with 11 commercial tenants. The energy monitoring separates landlord spaces and tenants. However, the report is based on a sample of three months and the TM22 is based on only one month.

BRE Scotland Innovation Park This project was excluded because there was no monitoring data available for the PV array. The project aimed to be carbon neutral but this cannot be verified.

Natural ventilation is often a feature of low-carbon buildings, whereas poor control of space and water heating – and lighting – often contribute to high emissions. Biomass boilers appear to polarise: they are often temperamental, but if they can be made to work they bring much lower emissions.

Air Tightness

All of the projects reporting air tightness test results demonstrated compliance with the current Building Regulations standard, with lower infiltration, though not all achieved their design targets.

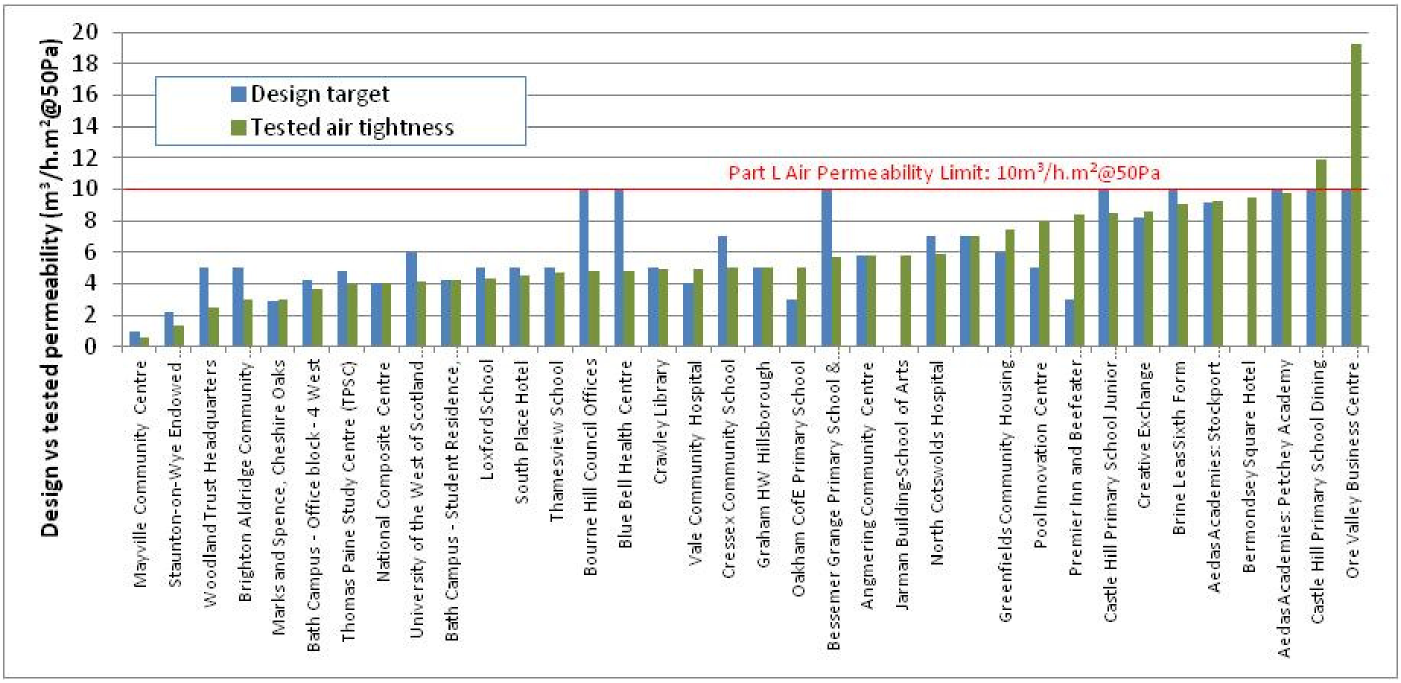
Compliance with Building Regulations

As part of the BRUKL report completed for Part L of the Building Regulations, each project had a design target 'air permeability'. This measures unwanted infiltration of warm or cool air through gaps in construction and/or materials when the building is pressurised to a 50 Pascal differential above the air pressure outside. Out of the non-domestic projects, 36 provided the results of actual air tightness tests, and all-but-one of these also reported a design target for air tightness.

All but two projects met the requirement in the Building Regulations (2010) to achieve air tightness below 10 $m^3/h.m^2$@50Pa. Most had considerably better air tightness than the minimum requirement of the Building Regulations, with an average tested permeability of 6.1 $m^3/h.m^2$@50Pa. Of the 35 with both a design target and test results, 23 were better than and 12 were weaker than the design target, with five buildings within 1% of their target. The highest percentage improvements over design target came where the design air tightness was least ambitious: simply limiting below 10 $m^3/h.m^2$@50Pa. This is not an issue for the performance of the buildings in reality. However, it does indicate that some of the design teams could have reduced the BER (Building Emission Rate) and EPC (Energy Performance Certificate) ratings achieved by their building designs, had they included the improved air tightness level in their calculations.

In total, 16 sites achieved air tightness of less than 5 $m^3/h.m^2$@50Pa, and one site managed to reduce its permeability to less than 1 $m^3/h.m^2$@50Pa: Mildmay Community Centre, which aimed to achieve the Passive House standard. This is doubly impressive for a retrofit project.

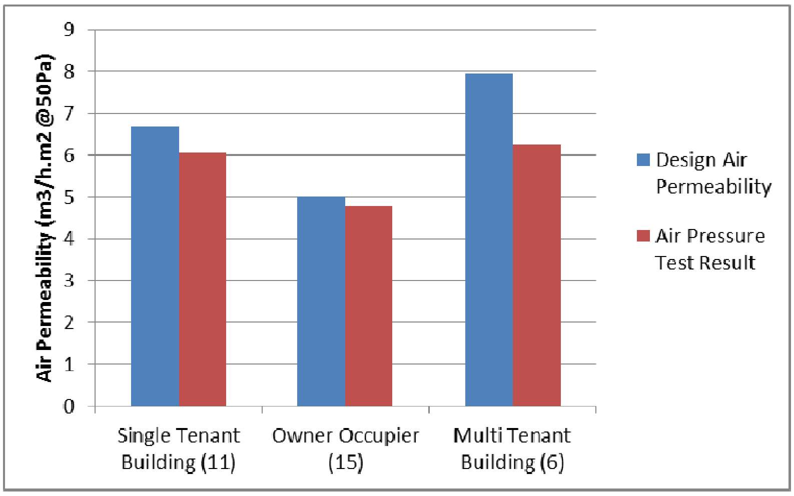
Mildmay Community Centre – Refurbishment of an existing 19th Century building. Envelope: 700mm brickwork, with 300mm EPS (expanded polystyrene) external insulation, triple glazing, new zinc roof with 400mm insulation.



Broadly, the buildings with the best air tightness (to the left in this graph) are those with the toughest design targets. However, many of those with unexceptional targets (in the middle) achieved test results much better than their targets. The Ore Valley Business Centre, with poor air tightness measured at 19.27 m^3/h.m^2@50Pa - equivalent to an air change rate of 6 air changes per hour – had much better air tightness for individual rooms, but the whole building was affected by settlement and there are serious leaks, especially in the basement.

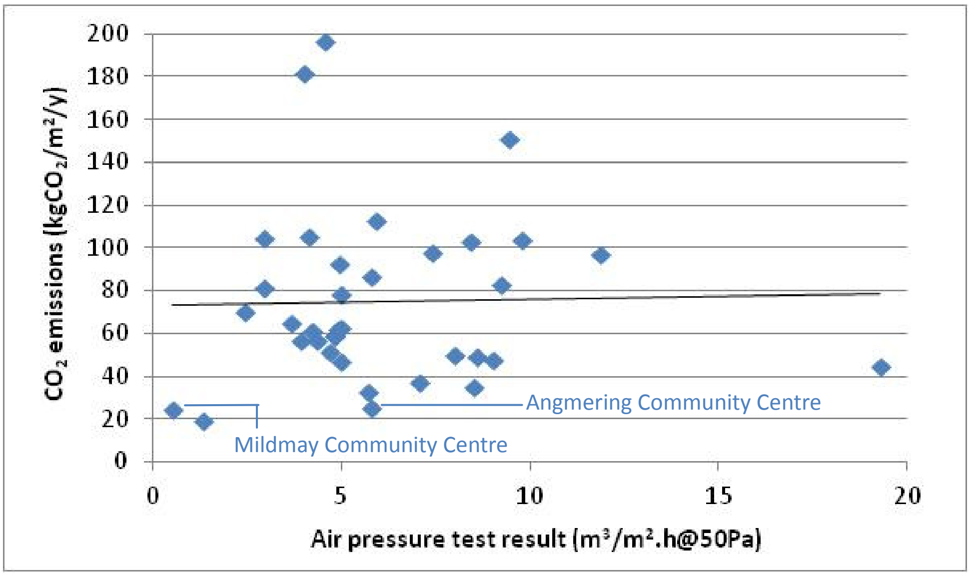
Some of the projects in the middle of the plot may have tweaked their BRUKL design targets for permeability after they were tested – explaining the close match between design and achieved air-tightness.

There are no clear links between air tightness and building type, with some excellent and some weak schools, and some offices at each end of the spectrum. In terms of tenancy, Owner Occupier buildings had the lowest average design air and as built air tightness. Single tenant buildings had slightly lower design targets than multi tenant buildings, but did not achieve much higher mean results when tested.



Air tightness and CO_2 emissions

Comparing actual carbon emissions against air tightness is both interesting and surprising. Two of the lowest-emissions buildings (Mildmay Community Centre Community Centre and Staunton-on-Wye Primary School) are also the two with the best air tightness, see graph. However, Angmering Community Centre is only a little behind Mildmay for carbon emissions, yet air tightness is considerably weaker. This shows that air tightness should not be too prominent in explanations of high carbon emissions – clearly, other factors are also important.

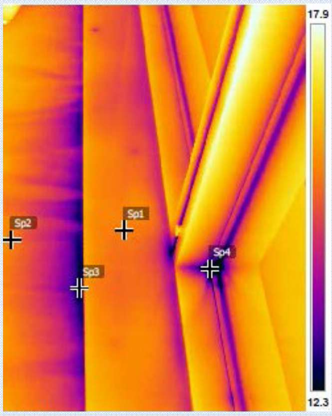


Plotting CO_2 emissions against Measured Air Tightness shows little obvious link between airtightness and carbon performance, but it is worth noting that the building with best airtightness - Mildmay Community Centre - has the second-best carbon performance.

Indeed, in contrast to reports on retrofit in the domestic sector[7], which point to an apparent correlation between good air tightness and lower low CO_2 emissions rates (accepting that air tightness does not guarantee good performance), the graph below shows barely any correlation between emissions and the measured air tightness results. (The trend line, black, shows only a very shallow gradient.) However, readers should note that even in the domestic study there seemed to be no correlation below around 8 $m^3/hr.m^2$ @50Pa, and in this study all but two of the studies achieved an air tightness lower than this. Finally, though the non-domestic sample includes examples of different building types, they were distributed randomly with no clear patterns.

Thermography

Thermography is a useful tool to identify issues in building design otherwise hidden to the naked eye, and in the projects below, it has been used to identify issues with air infiltration and leakage, thermal bridging, and underfloor heating.



Air infiltration (draughts) seen at the junction between the floor and full height window frames, and between the window frame and pane, at Thamesview School.

Common Themes

In each of the cases reviewed, the thermal imaging identified more than one anomaly that was worthy of further investigation, and even managed to spur enquiries leading to solutions for other problems within the building. The technique was particularly helpful in evaluating underfloor heating systems, or any system that is not immediately visible or easy to assess. Also, it was useful in pinpointing any areas where the construction details had not been robust, in particular areas around windows, doors and vents, and at junctions between building elements or irregular (non-90°) corners.

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[7] Retrofit Revealed, Technology Strategy Board, 2013, p.14, https://retrofit.innovateuk.org

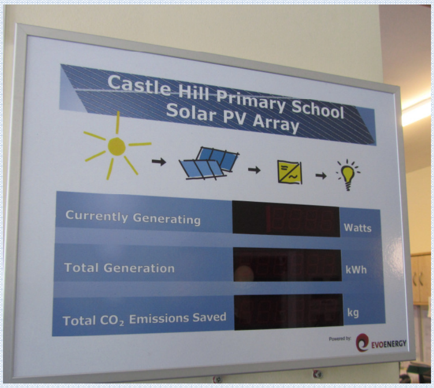
Project Summaries

Project	Issues Identified through Thermal Imaging
Bath Campus	In 4 West, the following actions were implemented following a review of the thermographic survey: air infiltration was found around one of the lecture room fire doors, to be sealed. It also identified issues with the HVAC systems: the cooling system risers leaked cold air into office spaces, while radiators needed balancing. The project team recommended further monitoring for areas with reports of thermal discomfort, and window opening would also be monitored. In Woodland Court, thermal imaging identified issues with windows in part of the halls, requiring sealing, and the project team recommended testing the effectiveness of the seals with e.g. gas decay testing.
Brighton Aldridge Community Academy	Because some spaces reportedly always felt cold, thermal imaging was used to assess the operation of underfloor heating. In the hall, the heating was found to be working correctly, but the evaluation found that incoming fresh air was set too cold, due to ambiguous labelling of the air handling unit in the BMS. In the Principal's office, thermal imaging identified that one of three underfloor heating coils was not working, probably due to a blocked valve.
Crawley Library	Thermal imaging revealed air infiltration around windows in the atrium, ceremony room and conference room, as well as cold bridges at the wall/ceiling junction in a number of rooms. It also showed that heating and cooling were running in unoccupied spaces, pointing to poor control of the systems.
Creative Exchange	Air leakage was detected around the roof stair door, and in the ground floor toilet extract. The window frames showed significant cold bridging, in some instances leading to temperatures low enough to cause a condensation risk. The piping and control arrangement for underfloor heating was found to lead to uneven temperature in rooms.
Graham HQ	Thermal imaging was used in conjunction with in-situ transmittance tests to evaluate the as-built thermal performance of various building elements. The U-values measured for the curtain walling and masonry north wall were close to the design U-values, while the roof U-value was much higher: 0.34 W/m^2K, compared to 0.11 W/m^2K. Thermal imaging also highlighted a number of areas requiring further attention, such as high heat loss at the top of some windows, thermal bridging between the floor slabs and walls, and the junction between the curtain walling, masonry wall and roof.
Thamesview School	The survey indicated some good detailing and construction, including expansion joints in the external wall, at the wall/ground floor junction, and in the majority of door/window frame wall junctions. The underfloor heating was also functioning well. Air infiltration was observed in some floor to ceiling window frames at the floor, and in some 'non-orthogonal' frames (without right-angles), and air leakage was found on some fire exits and external doors to the drama studio, with potential discomfort in these spaces. Thermal bridging was found at non-orthogonal corners and junctions, and in one of the windows in the administration block due to discontinued insulation.
Thomas Paine Study Centre	Thermal imaging was used to evaluate the fabric heat storage strategy, particularly where the thermal mass of the building had been covered over with e.g. suspended ceiling or plasterboard. Infra-red photos showed that there was often poor thermal contact between finishes and the heavyweight building frame, reducing the benefit of thermal mass. For example, discrete dabs of adhesive were easily visible in imaging, showing the lower temperature of the adjacent building core, while the rest of the plasterboard was warmer. Thermography was also used to investigate stratification in rooms, to assess the operation of the displacement ventilation and Termodeck systems.

Renewable Energy Systems

Just under two-thirds of the buildings in the study included some form of on-site renewable energy generation to reduce their energy requirements. However, two-thirds of these had issues, which meant that the savings from renewable were lower than expected.

Renewable energy systems, and the increased complexity that often comes with them, can contribute to the performance gap between as-designed and actual energy use. Commissioning uncovered problems, and managing the controls for multiple renewables also proved difficult.



Castle Hill PV Array and Information Display

Common Themes

Projects included in this study encountered several problems with photovoltaic and solar hot water panels – generally linked to maintenance, control and metering. There were also a number of biomass boilers with operational problems, which often meant they were left unused. Biomass problems included inadequate sensors being installed, to the flue height being too low and having to be raised, to difficulties obtaining the right specification of fuel, to the fuel store becoming wet so the fuel was unusable. One of the air source heat pumps included also had operational issues in cold weather. Other projects in the BPE study included solar photovoltaics (PV), ground-source heat pumps and wind turbines, but these appeared to be less problematic.

For PV, one stumbling block was monitoring and recording output, which was reported as an issue in a number of projects. However, this does not detract from the electricity generated by PV, helping to reduce carbon emissions.

Project Summaries

Project	Renewable Energy Technologies	Problems/Solutions
Bath Campus	Solar Hot Water	The solar hot water system was found to be dumping heat on a regular basis, because it was oversized, and with limited load during the summer. Project team also found that the Legionnaires Disease protocol was causing the system to be flushed and reheated at 2am every day - using the gas boilers. However, they found that gas use when the system was operating was lower than expected, indicating that the solar pre-heated water was helping to reduce emissions.
Bluebell Health Centre	Air Source Heat Pump, Solar Hot Water	The ASHP outdoor units struggled in winter, freezing over during particularly cold periods. This was solved by modifying the operation of the system, giving more controls to the user and stopping the 'optimised start or stop' facility, leaving a 'less intelligent' system. The SHW system was not linked to the BMS system, making evaluation of the system difficult.
Brine Leas School	Solar Hot Water	The solar water system was not specified with a sub-meter, and while the contractor believed that metering would be available through the BMS, this was not the case. In addition, the system had not been properly commissioned; two years after the original installation it was re-commissioned successfully.
Coleford Community Centre	Photovoltaic	The PV electrical output was displayed in the foyer of the community centre to show users the energy produced. However, there was only one output from the PV system, meaning that the output could not be recorded in the BMS system as well.
Creative Exchange	Solar Hot Water	The SHW system failed during the building performance evaluation, having received no maintenance since installation, despite the Operating and Maintenance (O&M) manual recommending checks every six to 12 months. This has not yet been repaired.
Loxford School	Ground Source Heat Pump	Problems with external doors not sealing properly or being left open had led to flow temperatures being increased above the recommended heat pump operation temperature (45°C), and being shut off. This led to higher than expected gas consumption from the back up gas boilers. The design profile for the heat pump was amended to try to improve this. The heat pump did not have heat meters installed, despite annotated space left for this on the LV panel, making it impossible to assess the contribution of the heat pump to meeting the heating load.
Mildmay (Mayville) Community Centre	Photovoltaic	The PV export meter had been connected incorrectly, measuring generation rather than the amount of electricity exported to the grid. This made it impossible to get an accurate figure for the total energy use, as the amount of PV electricity used internally could not be found. This was rectified when the issue was brought to light.
Pennywell Academy	Biomass	An initial review of the biomass boiler showed that there had been problems from the start, including the wood augur becoming stuck, a three port valve bursting, and the main pump developing a leak.
	Solar Hot Water	No sub meters were installed for the solar hot water system, making it impossible to assess their contribution to hot water consumption.
Pool Innovation Centre	Biomass, Photovoltaic	On an initial review, the biomass boiler was found to be providing only 53% of the heating requirement, rather than all of it. This significantly increased the CO_2 emissions of the building, by relying more than anticipated on supplementary natural gas boilers.

		The installed PV array (2.7kWp) was much smaller than the design aspiration (~16kWp), explaining some of the variation between the EPC and actual energy use.
Stockport Academy	Ground Source Heat Pump	During the evaluation it was established that the heat pump was only providing half of the expected contribution. The design intent was to have GSHP-led heating with gas boiler top up, but the opposite was installed. The different maintenance contractors were brought together, and agreed to adjust the system as the design intended, once they established that this was possible. Different sub-contractors and maintenance teams responsible for the different items were not interacting effectively, and that the tender documents had not explicitly stated the design intent.
Thamesview School	Biomass	The biomass boiler had a number of issues, in both design and operation. Fumes were re-circulating back into school rooms, requiring an increase in the flue height; the hopper was too small, requiring additional wood chip deliveries; and the blower delivery system was too loud for the suburban location. In operation, the ignition system failed, requiring replacement, and bricks in the boiler broke, also requiring replacement. In the first year of operation, the biomass boiler was only running for around 30% of the time. However, following maintenance and repair, these issues were resolved and the biomass boiler was running at full capacity.
Tremough Innovation Centre	Biomass	The biomass boiler on this site ran successfully with few issues, but there was a boiler stoppage when fuel ran out. This was because a low fuel-level sensor, specified to connect to the BMS and raise an alert, was not installed.

Innovative Building Systems

This section considers some of the more innovative systems being used in the study buildings. There is often potential for better environmental performance and/or energy savings from trying out new ideas. However, innovative systems may be unfamiliar to design teams and contractors, and often need careful fine tuning or maintenance to meet the design stage expectations, and respond to unexpected problems arising during operation. They can also be expensive to install and replace.

Common Themes

The key theme to emerge from these projects is the importance of preparing for a long period of maintenance. This applies particularly to automatic natural ventilation systems, which tend to have a large number of actuator motors, and rainwater harvesting, where filters need changing more often than many people expect.

For many systems, the projects underscored how important it is to have fine and ideally manual control, particularly for systems such as natural ventilation where in some cases *"finding the balance is a nightmare",* as one of the project team for *Tremough Innovation Centre* noted.

Finally, people managing innovative buildings need to be aware of the potential for unexpected outcomes – due to the logic built in to the systems not quite matching reality, for example if occupancy hours are not as expected. This can lead to systems fighting each other to control the environment, resulting in unnecessary increased energy use.

Project Summaries

Project	System	Problems/Solutions
Bath Campus	Heat Recovery	A continuously operating ventilation system was specified, with small ducts and filters at each extract point, leading to high energy consumption from fans. The corresponding energy benefit was not calculated, so the monitoring team could not assess the net benefit of the system.
Creative Exchange	Earth Tube	The fan controlling the earth tube ventilation was fitted with a local manual override switch, but this was often used because of the fan noise. To combat this, the fan speed was regulated to 20%.
	Natural Ventilation Controls	Users do not understand how mechanically operated vents in the roof up stands are meant to work. A manual override control was added to purge hot air in summer, but the project team found occupants use this whenever they felt the space was overheating, rather than waiting for the system to run automatically.

Houghton Le Spring Primary Care Centre	Night Cooling	Night cooling was proposed for the building, but it is occupied 24 hours per day. This meant that during the night cooling period, the heating system turned on to reheat the space to stop the temperature dropping below an acceptable level, requiring careful control of the heating and cooling set points. Alternatively, an interlock between the systems or seasonal adjustment of set points could stop the systems opposing each other.
Graham HQ	Rainwater Harvesting	The rainwater harvesting was felt to be a success, supplying 40% of the building's total water demand. However, there was more maintenance required than expected. In particular, water filters had to be changed more often than was recommended, being blocked by sediment in the water.
	BMS controlled Natural Ventilation	Initial problems with the natural ventilation system were due to a number of failed actuator motors on louvres needing replacement, and motors for the larger louvres being replaced at handover because they were too small. However, the BMS was useful in identifying which motors were faulty, by activating all of the louvres at once. Louvres in meeting rooms were often switched off, as occupants reported the temperatures getting too cold, as well as the noise of the motors being distracting. This led to greater manual use of air conditioning during meetings to combat overheating, which was then not switched off afterwards.
Loxford School	Plenum Flaps and Night Cooling	Automatic plenum flaps and rooflights were open in winter, and the night cooling was not working, leading to cold temperatures in winter and hot temperatures in summer. The project team realised that the openings were activated only by CO_2 levels, not temperature. In summer, the flaps only opened when CO_2 thresholds were reached, even though temperature rose quicker than CO_2. Also, low CO_2 levels at night meant that the flaps stayed shut. The system was adjusted to also be activated by temperature in summer. The winter opening was limited, and the team recommended using manual window opening to control CO_2 levels.
	Plenum Flap Actuators	Some plenum flaps were stuck open. They discovered that the specified actuators (made by the same manufacturer as the plenum flaps) had been replaced with a cheaper alternative, with lower power and imperfect alignment with the flaps. The team recommended replacing these with the original specified actuators. Coarse mesh was also installed to prevent pigeons from moving inside the open flaps.
	Heat Recovery	The Frost Coil in the Air Handling Unit (AHU) had a temperature setpoint of 16°C, meaning that the majority of AHU heating came from the frost coil prior to heat recovery. Frost coils are usually active at ambient temperatures below 3°C, so the team recommended that the BMS is used to monitor temperatures in the heat recovery system above this level.
Pool Innovation Centre	Night Cooling	The building was specified to use a night purge system to cool the building at night, but this was not working properly. This had the effect of reducing energy use, as less heat was lost overnight. This in turn cut heating demand in the morning, but it increased the risk of overheating during the day, as well as reducing internal air quality.
	Natural Ventilation Controls	In contrast to the stepped and delayed system at a similar site (Tremough - see below), the natural ventilation controls at Pool were a simple press-and-hold control with no delay.

Thomas Paine Study Centre	Termodeck	In the first year of operation the heating and cooling systems were found to run against each other, in a similar fashion to some other sites using Termodeck. Careful fine tuning of the system led to a large reduction in heating and cooling consumption in the space however. The mechanical ventilation controls are arguably more significant in a Termodeck building, and a complex interface through the Building Management System meant it required a specialist to set up the controls properly. This works against ongoing adjustments.
Tremough Innovation Centre	Rainwater Harvesting	Issues at the start of operation of the rainwater harvesting system were traced to a blocked filter on the incoming rainwater supply, indicating contamination of the storage tank with dust or dirt. An issue was identified with the rainwater supply meter. It was incorrectly connected to the mains top up incoming supply, meaning that the first nine months of rainwater data were incorrect. This required the meter to be re-fitted onto the correct pipe.
	Natural Ventilation Controls	The manual override has a seven second delay, which often resulted in users pressing the button multiple times, and overshooting the desired setting. This was not the design intention, and the installer mentioned that the system should have a maximum delay of one second.
	Earth Tube	The settings on the air handling unit controlling ventilation through the earth tube required modification. A time delay of one hour had been programmed into the system heating battery, and an actuator to control the flow was not fitted. As a result, occupants complained that incoming air was too cold.
Woodland Trust HQ	Ventilation Strategy	Motorised windows were originally set to open when internal CO_2 levels reached 1200ppm. However due to the lack of fine control on the window opening, this caused draughts in winter, so the threshold was increased to 2000ppm. While this new threshold was rarely reached, stuffy conditions led occupants to manually open windows, making subsequent automatic control more difficult.

Handover, Commissioning and Maintenance

Once the building is complete, it can be passed to the client team and occupants can start moving in. This is a critical period for any new building's performance, with commissioning often undertaken in the first few months after handover. This is also an important time for spotting and fixing equipment in the defects period, and the new building management team has to learn as quickly as possible how the building ticks.

Common Themes

When construction is finished and the occupants are allowed into the building they need support to settle into their new space. Often there is a building manual or user guide written to assist them in understanding their new environment, and how they should control it. A number of projects reported that user guides commonly contained lots of material that is irrelevant to occupants, were poorly structured, and/or covered more significant aspects with only very basic detail.

Often manuals are drafted mainly to gain BREEAM credits, or for Building Regulations, with the result that they are often done as a tick-box exercise, without really attempting to relay useful information to users. One of the projects even had a user guide written using an out of date version of the specifications and drawings, and included features that were not in the final building.

The period just after commissioning is a particularly vulnerable time, when numerous stakeholders have changing responsibilities, and maintenance contracts can cause conflicts between stakeholders. There were examples of clients requesting that commissioning was wrapped up without being completed, and where the outcomes of commissioning were not properly recorded.

Project Summaries

Project	Issue	Problems/Solutions
Bluebell Health Centre	Building Logbook	The Building Logbook was seen as giving a good introduction to the building and building services, but some sections such as 'Overview of Controls/BMS' were very basic, and did not relate the controls back to the overarching energy strategy. It did not even mention the mechanical ventilation or heat pump controls. Also, the logbook appeared not to be based on the final construction specification and drawings, and included some features that were not installed (e.g. daylight sensing/dimming).
	Building User Guide	A Building User Guide was produced to meet BREEAM requirements, but many sections were either incomplete or sparsely completed. The 'Building Services Information' section gave a vague instruction about optimum operation of thermostats (without specifying the thermostats in question), and did not mention the cooling system, which occupants had questions about. This guide was updated and improved by the FM team.

	Aftercare	With aftercare service, the FM team have sometimes found it difficult to prove that something is a defect. As part of the aftercare, there is a 20-day snagging period, a 12-month defect period, then a 12-year defect period. While the FM team can fix problems themselves, this may void warranties, so they are instructed not to fix anything themselves in the 12 month defect period. However, fixing defects after this period becomes contractually more difficult, which is an issue for large items with long warranties – they cannot fix issues themselves, so they must prove that an issue exists, which can be difficult.
Brine Leas School	AHU Maintenance	The main air handling unit had a dirty air filter during the study, which was not changed as there was no maintenance contract in place. The school had understood that the contractor would deal with maintenance and repairs in the 12 months following completion, but the relevant sections of the O&M manual had been lost. The O&M section detailing the system was recovered, and the school took out an ongoing maintenance contract that covered this.
Creative Exchange	Building User Guide	A Building User Guide was produced, by the BREEAM assessor (also the Environmental/Services Engineers), which was seen as useful. However, it included many sections that were thought irrelevant to occupants, simply to fulfil the BREEAM criteria. This resulted in a bulky document with no clear focus, and this was not handed out to tenants. A second guide was produced and given to tenants, but this missed much of the useful information on the environmental systems and controls in the building.
	Maintenance	The boiling-water taps for tea and coffee stopped working - no maintenance had been carried out and the filters required changing. There was a reluctance by the client to sign a maintenance contract with the supplier due to expense, and for some time the taps did not function. The limited budget for maintenance issues results in issues being addressed very slowly, and evidence points to basic ongoing maintenance not being carried out – the maintenance contractor is often not called out until the issue becomes an emergency. Finally, issues are often raised to the contractor as defects, when they should be part of ongoing maintenance.
	Handover	The building manager and maintenance contractor were not involved in the project until after handover, possibly due to the government funding making it difficult to staff these positions prior to completion. The maintenance contractor was not hired until several months after defect liability, and was simply left with the O&M manual, with little opportunity to engage with the contractor.
Graham HQ	Maintenance (and commissioning)	The M&E engineer is still involved in assisting the FM staff, and retains an interest in the performance of the building (Graham and the M&E company are also working together on other projects).
Petchey Academy	AHU Configuration	The fan inverters were not enabled on AHUs, leading to higher-than-expected fan power consumption.
Pool Innovation Centre	Incomplete Commissioning	One contractor was 'not able' to complete seasonal commissioning for a particular system, where the occupiers was satisfied with the system operation, and presumably not interested in the time, effort and potential cost involved in further commissioning work.
Tremough Innovation Centre	Incomplete Commissioning	The building was handed over to the client before all the commissioning was complete, because construction was behind schedule on the programme and the client needed to begin occupation.

Building Management Systems, Metering Systems and Controls

Any evaluation of building performance would be impossible without the means to measure energy use and environmental performance. Building Management Systems and the meters and sensors that record data are a fundamental part of many buildings, but are often complex, hard to learn, and without attention during commissioning they nearly always go awry.

Common Themes

Building Management Systems (BMSs) are complex by nature, and increase in complexity as buildings get bigger, contain more innovative systems, and attempt to provide comfortable environments for users. Trying to cater for occupants with high expectations of comfort, and little time or patience to learn new systems, can make these systems even worse. Though the systems are complex, it is usually possible for one or more members of the building management team to familiarise themselves with the system, and learn to run the building effectively. In the projects reported here there were several instances where the single person with BMS skills left a building without passing on their precious knowledge.

Heat and electricity meters can take many different forms, and they are often hard for non-specialists to interpret

Trying to cater for occupants with high expectations of comfort, and little time or patience to learn new systems, can make these systems even worse.

A common theme for sub-meters was that while there was a strategy in place, as required by current Building Regulations, it seldom complied fully with the regulations, perhaps due to ambiguities in guidance. Comprehensive and over-complicated sub-metering strategies were often then driven by the need to achieve BREEAM credits, and then not installed as specified, or without due care (e.g. poor calibration, poor placement). A key point noted in the *201 Bishopsgate* project was that the time and cost of setting up complex metering systems should be carefully considered during construction.

After handover, metering responsibility is often with a controls sub-contractor who is not responsible for the M&E systems being monitored, and is unaware of the design decisions that have been made to try to get everything to work together. Finally, there can be a lack of ownership over the data, and often no-one checks the reasonableness of the collected data.

Project Summaries

Project	Strengths	Weaknesses
201 Bishopsgate	Contractors were tasked with identifying energy saving opportunities, using the BMS and metering. Good sub-metering was critical for this task. In one seven-month period in 2011, they found issues leading to a reduction of roughly 20% of the total building electricity consumption. This included refining the local BMS settings e.g. inappropriate time clock or demand settings, switching off the underfloor heating in reception in the summer, and investigating and correcting motion controlled back-of-house lighting - which was consuming energy at weekends.	Each occupant has an individual BMS to control local environmental conditions. The tenants can call for heating, ventilation or cooling at any time, overriding the central BMS, which allows more flexible working hours. These demands were often felt ‘unnecessary’, so this facility was reduced, in discussion with the tenants. Energy use in 2011 had to be estimated for the TM22 analysis, due to sub-meters not recording data correctly before October 2011.
Brine Leas and Loxford Schools		Both schools had issues with zoning and controls. At Loxford School, all of the common lighting was set in a single zone, which led to overuse due to the generally well daylit corridors. A modification was possible. At Brine Leas School, corridor lighting was controlled through presence detection with daylight dimming. The presence of people anywhere in the building meant that the lights were constantly in use. The

		absence of an override for the atrium meant that the lights there could not be turned off separately. At Brine Leas there were also issues with the BMS, where a model with less functionality had been installed as an alternative to the specified system. This lacked key features such as alarm facilities, and made interrogating the system difficult.
Coleford Community Centre	Initially, the BMS was set up to record cumulative totals for meters every 15 minutes, storing up to 1000 data points before starting to overwrite them (after about 10 days). This was modified to half hourly and daily totals, which were set to regularly download to the council's databases to be stored.	Meter reviews identified calibration issues with some electrical meters, where the Current Transfer (CT) ratio was set ten times too high, resulting in only a fraction of energy demand being reported. The meters were recalibrated (apart from one meter, which was password protected and could not be changed). It was later found that the results had been actually already been corrected at the BMS, rather than the meters, though this had not been recorded. This led to a billing issue – tenants were billed for electricity based on the sub-metering, meaning some occupants faced a much higher bill.
Creative Exchange	Local occupant controls seemed to be working well, and tenants were comfortable using them. The tenants generally set the temperature at 19 °C, though some set it higher. The staff were generally happy with the building metering system. Though meter readings were done manually rather than through the BMS, this had the side-benefit that variations in energy use were likely to be noticed quickly.	The current building managers missed the initial BMS demonstration, and the client team representative present at the meeting has now left. Further instruction from the contractor was attempted, but with limited success. Wireless room thermostats were installed, but problems occurred when the batteries ran down. While a battery replacement schedule has been agreed, the batteries were seen as expensive and the batteries were expected to last longer. This caused an overheating problem – the BMS interpreted the failed thermostats as continuously 'on'. The main meter cupboard cannot be opened in wet weather. Thermostats on radiators in the stairwell were heating continuously even when they were set to the minimum of frost protection. This was corrected.
Graham HQ	The BMS was installed without issues (apart from a few sub-meters identified as not recording properly, which were fixed), and the staff are happy that it has been well-calibrated and is reporting the correct figures. The BMS can be used to activate the louvres used for controlling natural ventilation individually or all at once. This is used to occasionally to help identify failed motors when an issue has been reported.	No-one was identified pre-handover to take responsibility for the BMS and meter readings. Staff present at the training session passed on relevant information to the current building manager. The BMS is working well, but many of its capabilities are not being used. For example, features such as night cooling have not been used. This may be due to the complexity of the system. The staff find that the BMS is not suited to collecting and helping to interpret meter data. Data is overwritten after only three weeks. The BMS contractor installed Trend Energy Manager to the BMS to improve energy monitoring. Some of the sub-meters were also identified as not recording

		properly.
iCon Daventry	After a year of operation, the building managers managed to reduce energy use significantly, despite increasing occupancy, by changing the operational regime of the auditorium air handling unit. Previously this was operating continuously for long periods of time, as its poor starting reliability has led to concerns that it would not come online when required.	The monitoring system had issues with faulty meters not recording pulses properly. These were eventually swapped with meters from unused units in the building.
Tremough Innovation Centre	Natural ventilation controls were integrated into the BMS rather than being a separate work package.	The project intended to ensure that all meters and submeters would get hooked up to the BMS, allowing a single point of contact. However the range of contractors involved when the BMS was fitted made the process more difficult. Initially many of the BMS readings were incorrect, due to initial errors in calibration and/or communication between meters and the BMS.
Thamesview School	The BMS system was felt to be working well in general, with careful adjustments and maintenance by specialists following installation improving performance.	The project team felt that general staff do not use the BMS enough, due to a lack of confidence, worrying that they would change a vital setting. Work was done to calibrate the meters against manual readings, and a number of meters were found to give very different results from the BMS. Also some parts of the site were not sub-metered, and required metering to be installed. These issues have since been corrected. The BMS monitoring works on a simple average, causing difficulties in interpreting the data, due to large differences between different parts of the school. Meter logs are difficult to download, with the system making it very difficult to compare more than one week of data.
Thomas Paine Study Centre		The project team noted that the 15 minute recording interval used to record monitoring data was too short to capture some building features, in particular the regenerative heat exchanger, where a flow reversal could happen up to every minute.
Woodland Trust HQ		Unnecessary heating circulation was found outside the heating season, due to the heating pump running during all occupied hours. This issue was corrected at the BMS by the BMS contractor, by allowing the heating pump to operate only when there is demand for heating.

Occupant Satisfaction

The occupants are those most affected by the building design, and those who affect the actual energy use in practice. Yet there is rarely any consultation with them during the design process, and very little feedback from them after handover. An integral part of the BPE study for each of the projects covered here was a Building Use Study, as well as structured interviews with a variety of stakeholders involved in constructing and occupying the building.

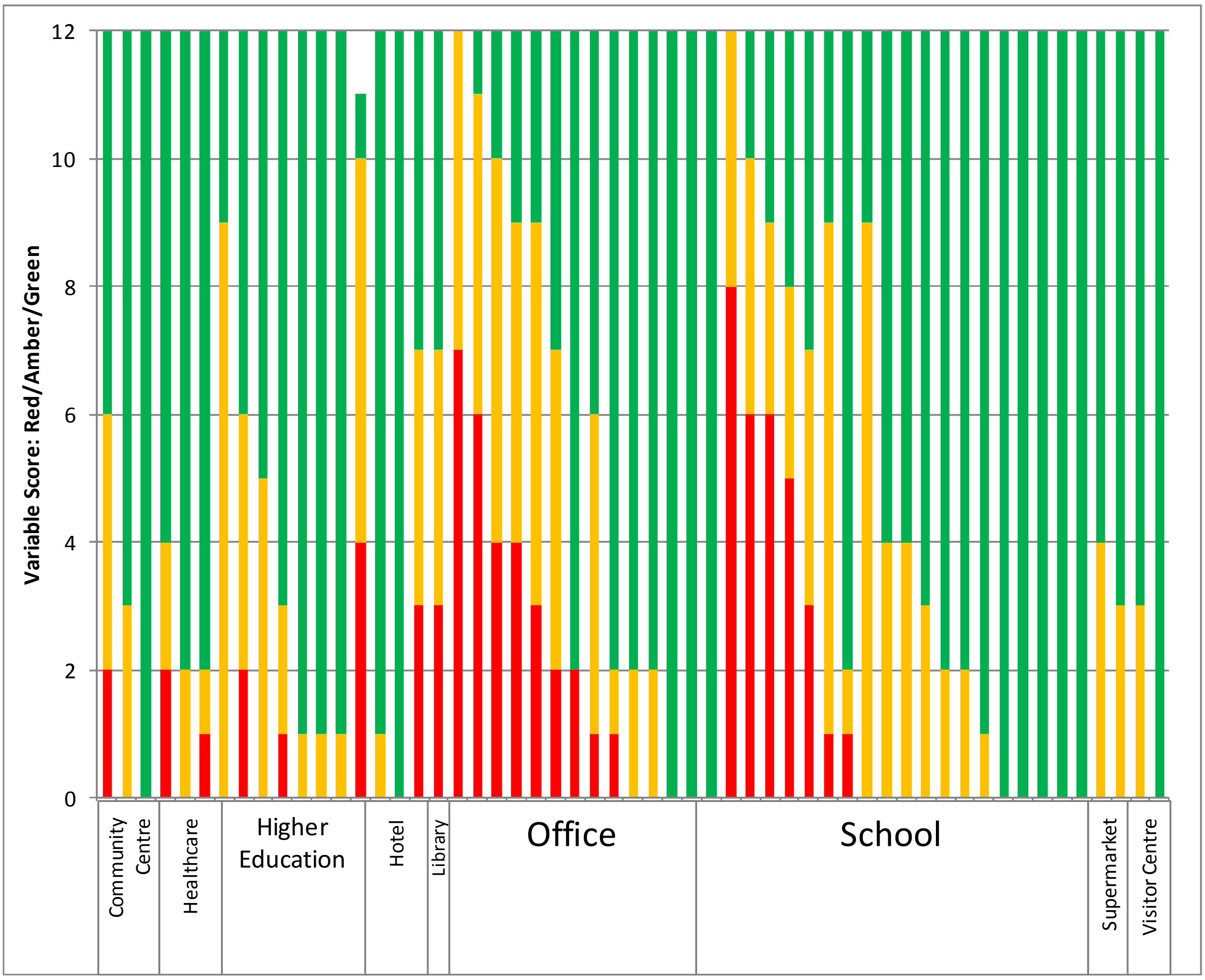
The Building Use Studies (BUS) methodology was used to evaluate post-occupancy satisfaction in each of the study buildings. While not directly an assessment of the performance gap, these surveys indicate whether a building is providing a comfortable and productive internal environment, as it was designed to do. They are also useful for flagging up critical design issues, in particular controls and building management systems.

We analysed 54 BUS studies (note this is a larger sample than other sections of this report, because some of the projects that did BUS surveys did not have a full year of reliable energy data), focusing on the overall summary variables:

- Air in summer
- Air in winter
- Comfort
- Design
- Perceived health
- Lighting
- Needs
- Noise
- Perceived productivity
- Temperature in summer
- Temperature in winter

For each of the variables, a score was given, and compared against the rest of the buildings in the BUS database, using a red/amber/green system[8]. Scores comparing favourably against the stock and benchmark values are marked green, while those that fall below the benchmark are red, and those broadly the same as the benchmark are yellow. Thirty of the buildings studied had no red scores at all, with average or above average scores in all of the variables, while another 11 have only 1 or 2 below-average scores. The worst performing site, Pennywell Academy, had eight red scores, four ambers, and no greens – it was weak in a number of different aspects of satisfaction with comfort, and meeting staff needs.

[8] For more information on the BUS methodology, see: http://www.busmethodology.org.uk/



The majority of projects scored average or above average (Amber or Green) on all of the key BUS summary variables, and only two buildings were below average overall.

The variables that were below average most often were *Temperature in summer* and *Air quality in summer*, with red scores accounting for 31% and 28% of responses, respectively. The other variables rated poorly were *Temperature in winter* (20%), *Perceived health* (19%), *Air quality in winter* (17%), and *Productivity* (17%). The other variables were broadly average or above average across the buildings, with a few exceptions.

On the positive side, more than three-quarters of these buildings scored above average compared to the rest of the BUS database for Image to visitors (83%), Lighting (80%), and Comfort (76%). This suggests that most of these projects are succeeding when it comes to designing buildings that project a positive image, and good daylight and electric lighting, and providing comfortable facilities.

Common Themes

There is consensus in this field that designers should involve occupants as much as possible in design decisions. A number of projects in this Programme tried to involve clients at an early stage in the design process, though this tended to be building managers rather than occupants. This means it is hard to draw out clear conclusions. In some cases, the occupants were keen to find out more about how best to operate their buildings, but were frustrated by a lack of clear directions. In one case, this led to overheating issues where occupants had taken matters into their own hands, and blocked ventilation openings to reduce draughts.

Many buildings had issues with local user controls, intended to give users a sense of control and ownership over their workplaces, and in some instances this led to user controlled thermostats set at 19°C, lower than might be expected. However in some other instances, the freedom given to users caused much higher emissions, where they were given free rein to request heating, cooling and ventilation at any time of day, requiring the systems to always be ready for occupation.

Project Summaries

Project	Issue	Problems/Solutions
201 Bishopsgate	Glare	Glare was an issue for occupants, despite blinds being installed. Light was found to pass through perforations and around the edges of the blinds, resulting in a high contrast, exacerbating glare. The blinds were also metallic, and heated up in sunlight causing discomfort to nearby occupants. Some areas of the building were fitted with secondary blinds to alleviate the glare and solar gain issues.
	Temperature	Some overheating was found when vents near windows were blocked or covered, following complaints of draughts.
Creative Exchange	Temperature	Most thermostats, controlled by local users, were set at 19°C, while fan heaters were only found in the reception area, indicating a generally satisfactory temperature.
Icon Daventry	Controls, Environmental Strategy and Tenant Engagement	Occupants were generally satisfied, but said they wanted clearer information about the controls and environmental strategy (e.g. many tenants had not realised that they could dim the lighting). When asked about the success of the building's design strategy, a high proportion of tenants 'didn't know' about the energy efficiency measures available.
	Noise	Tenants were concerned with noise being heard between units, thought to be transferred through ventilation stacks.
	Temperature	Summer overheating was an issue. Units with openable windows were perceived to be more comfortable. This led to tenants identifying the 'Natural ventilation and Passive Strategies' as the most important factor in the design. Winter conditions were generally good, though the building was sometimes cold first thing.
	Automatic Vent Controls	The automatic response of vents to rain was too slow, and while there was a manual override, the manual opening and closing was also considered too slow.
Pool Innovation Centre	Glare	Occupants reported issues with glare, but due to the ownership and tenure arrangement, they were reluctant to make physical changes, suggesting changes to the office layout instead.
	Temperature	Despite thermostats being set at 22°C, there were complaints of cold temperatures, particularly when moving from summer to winter, leading to occupants often requesting extra fan heaters.
	Wellbeing	The building has two natural ventilation strategies. One side features passive stack ventilation, while the other only has side ventilation from windows and other openings. This led to a 'them and us' mentality between different areas.

Thamesview School	**Temperature**	**Occupants found both summer and winter conditions uncomfortable, due to poor air quality and temperatures.**
	Wellbeing: lack of interaction with building management	The satisfaction survey indicated that the responsiveness of the management team to problems directly affected occupants' thermal comfort. The division between the facilities management team and the school means that occupants are less tolerant and potentially less satisfied, and building a closer link could be beneficial.
	Wellbeing: space planning	There were some complaints about the building space planning – open plan areas were thought to be a disruption to teaching, and there were teaching spaces without windows, or without openable windows, that were felt to be uncomfortable.

Overcoming Challenges

This final section looks across all projects we have included to identify the main challenges that have come up again and again. It also suggests how other project teams can learn from this, by offering potential solutions.

Common challenges

Renewable energy systems

1. *Renewable energy systems are chosen hastily to reach carbon reduction targets.*
2. *Multiple heating systems are used, which become hard to control.*

Energy use

1. *Design estimates overlook unregulated energy*
2. *Design estimates make optimistic assumptions about hours of use.*
3. *Design estimates assume optimal performance of renewable energy generation systems, and subsequent CO_2 reductions.*

Possible solutions

Renewable energy systems

1. *Only specify tried-and-tested renewable energy systems, installed by individuals who have done the job well before.*
2. *Put simplicity ahead of the pressure to tick every box (e.g. in BREEAM), and think about the people who will need to control the systems.*
3. *Ensure that metering and controls are set up correctly to allow proper management.*

Energy use

1. *Remember that regulated energy (heating, lighting, cooling and ventilation) is only part of the building's true carbon footprint, and plug-in appliances can generate the same CO_2 emissions again – or more.*
2. *Accept that out-of-hours energy use is considerable, sometimes as much as the energy used in the working day.*
3. *Consider that CO_2 reductions from renewables may not appear without considerable effort.*

Airtightness

1 *Inadequate forethought in design leads to poor airtightness at junctions, where it can be hard to maintain the air barrier.*

2 *Contractors who are not aware of the air barrier can inadvertently omit parts, or puncture it.*

Innovative Building Systems

1 *Innovative systems seldom work perfectly to start with, and the rush to hand over can squeeze out opportunities to optimise and maintain new systems.*

2 *Unexpected outcomes may occur where built in logic does not match reality, or where occupants do not understand systems, but have access to manual controls.*

Airtightness

1 *Mark the air barrier on all drawings clearly – and brief site staff on the importance of checking the air barrier at all stages of construction.*

2 *Appoint an airtightness champion on site, with authority to intervene if any work risks undermining airtightness.*

3 *Consider writing the airtightness target into the main contractor's contract, with penalties if it is not achieved.*

Innovative Building Systems

1 *Prepare for what can be a long period of commissioning, and document who will be responsible for any fixes.*

2 *Write a clear, concise Building User Guide explaining the operation of the building, and the logic behind new systems that users must interact with.*

Common challenges

Commissioning & handover

1 *The staff actually responsible for operating a building may not be present during handover.*

2 *Building User Guides and Logbooks produced for Building Regulations or BREEAM can miss the information that would be useful to users in understanding how a building works.*

3 *Where clients are in a hurry to move in, commissioning may not be completed properly, leaving loose ends.*

Building Management Systems & Metering

1 *Complex BMS systems need a careful handover, especially where multiple sub-contractors are involved.*

2 *BMS systems are often not set up for data collection, and many record a maximum of just 1000 data points.*

3 *Meters are often not calibrated or installed properly.*

Possible solutions

Commissioning & handover

1 *Ensure that an individual on site is responsible for receiving information before handover, and passing this on if necessary.*

2 *Building User Guides should be written around occupants' needs first, and meet targets (for e.g. BREEAM credits) second.*

3 *Commissioning should not be viewed as an optional extra, but as an integral part of the building process. This should be made clear to all involved, they understand what happens if it goes wrong.*

Building Management Systems & Metering

1 *Appoint an individual responsible for coordinating the different sub-contractors working on the BMS at an early stage.*

2 *Find out the data capacity of the system, and ensure that a procedure is in place to capture it, for example by storing it off-site.*

3 *Meter calibration and data quality should be checked after handover. Many projects here found and corrected problems quickly.*

Appendix: Building Details

Name	Sector	Area (m^2)	BER ($kgCO2/m^2/yr$)	Design Air Tightness	Tested Air Tightness ($m^3/h.m^2$@50pa)	Electricity $kWh/m^2/year$	Gas and other heating fuel $kWh/m^2/year$	BREEAM Environmental Rating
Angmering Community Centre	Public Service	562	12.4	5.77	5.77	49.2	0.0	Outstanding
ASDA Supermarket	Retail and wholesale	6,293	39.9	3		326.9	128.0	Very Good
Bath Campus - 4 West	Office	5,630	32	4.2	3.67	91.9	81.0	Excellent
Bath Campus - Woodland Court	Hotel/other residential	10,418	32	4.2	4.2	66.0	126.0	Excellent
Bermondsey Square Hotel	Hotel/other residential	3,617			9.43	236.0	133.0	Good
Bermondsey Square Offices	Office	3,206				116.1	147.7	Good
Bessemer Grange Primary School	Education	1,370	15.69	10	5.7	38.1	61.9	Very Good
Blue Bell Health Centre	Health	2,649	14	10	4.81	113.8	0.0	Excellent
Bourne Hill Council Offices	Office	4,258	21.1	10	4.81	78.1	86.8	Excellent
Brighton Aldridge Community Academy	Education	10,996	10.8	5	2.93	97.9	143.0	Excellent
Brine Leas Sixth Form	Education	2,843	17	10	9.03	69.4	55.2	Very Good
Castle Hill Primary School Dining Block	Education	302	17.4	10	11.85	73.8	272.9	Very Good
Castle Hill Primary School Junior Block	Education	817	20.7	10	8.49	28.0	95.7	Very Good

Name	Sector	Area (m^2)	BER ($kgCO2/m^2$ /yr)	Design Air Tightness	Tested Air Tightness	Electricity kWh/m^2/ year	Gas and other heating fuel kWh/m^2/year	BREEAM Environmental Rating
				($m^3/h.m^2$@50pa)				
College Lake Wildlife Visitor Centre	Culture	362	43.4	7		85.8	0.0	
Crawley Library	Public Service	4,468	13	5	4.88	104.4	35.3	Very Good
Creative Exchange	Office	705	15.9	8.19	8.6	45.8	118.6	Very Good
Cressex Community School	Education	11,624	14.7	7	4.97	69.2	52.7	Very good
Dartington Primary School	Education	1,981	20.5	4.43		82.3	63.2	Excellent
Eli Lilly Research Office	Office	2,162	28.9	10		132.0	0.0	
Estover College	Education	16,900	9.2	5		65.6	201.6	Very Good
Graham HQ Hillsborough	Office	3,270	13.7	5	4.98	102.1	46.0	Excellent
Greenfields Community Housing HQ	Office	2,180	24.7	6	7.42	189.1	0.0	Very Good
iCon Daventry	Office	3,907	12.4	10		79.2	47.2	Excellent
Jarman School of Arts	Education	2,492	17.3		5.78	107.0	145.7	
Loxford School	Education	14,610	18.5	5	4.36	69.1	97.4	Excellent
Marks and Spence, Cheshire Oaks	Retail and wholesale	19,417	51.1	2.9	2.93	193.9	18.1	Excellent
Mildmay Community Centre	Public Service	800	13.7	0.9	0.51	47.2	0.0	Passive House

Name	Sector	Area (m^2)	BER ($kgCO2/m^2/yr$)	Design Air Tightness ($m^3/h.m^2$@50pa)	Tested Air Tightness ($m^3/h.m^2$@50pa)	Electricity kWh/m^2/ year	Gas and other heating fuel kWh/m^2/year	BREEAM Environmental Rating
National Composite Centre	Industrial	7,758	23	4	4	316.7	81.3	
North Cotswolds Hospital	Health	2,538	28.9	7	5.92	127.9	214.5	Excellent
Oakham Primary School	Education	2,514	13	3	5	95.8	132.7	
Ore Valley Business Centre	Office	1,450	25.7	10	19.27	53.5	78.4	
Pennywell Academy	Education	10,172	14.9	10		101.9	145.0	Very Good
Petchey Academy	Education	10,490	32.5	10	9.78	136.6	153.5	Very Good
Pines Calyx	Culture	307	11.3	0.75		69.0	0.0	
Pool Innovation Centre	Office	3,747	15	5	8	67.5	69.4	Excellent
Premier Inn and Beefeater Restaurant	Hotel/other residential	2,799	30.7	3	8.4	169.2	70.0	Excellent
Rogiet Primary School BPE	Education	1,853	9.8	3.6		45.9	59.5	Excellent
South Place Hotel	Hotel/other residential	6,850	50.7	5	4.54	247.4	315.6	Excellent
St Peter The Apostle School	Education	16,614	25.5	10		79.5	78.6	Very good
Staunton-on-Wye Primary School	Education	809	10.4	2.2	1.34	28.2	23.0	Very good
Stockport Academy	Education	10,419	21.8	9.2	9.24	124.1	87.2	

Name	Sector	Area (m^2)	BER ($kgCO_2/m^2$/yr)	Design Air Tightness ($m^3/h.m^2$@50pa)	Tested Air Tightness	Electricity kWh/m^2/ year	Gas and other heating fuel kWh/m^2/year	BREEAM Environmental Rating
SusCon - Sustainable Construction Academy	Education	2,612	9.4	7	7.08	33.7	90.6	Outstanding
Thamesview School	Education	8,327	24.2	5	4.7	67.3	75.7	Very Good
The Main Place, Coleford Community Centre	Public Service	1,063	13.1	3.58		44.7	67.2	Excellent
Thomas Paine Study Centre	Education	4,301	6.3	4.8	3.94	82.4	63.3	
Tremough Innovation Centre	Office	3,909	11.8	5		71.1	108.2	Excellent
University of the West of Scotland Ayr Campus	Education	17,835	22.5	6	4.12	106.8	230.2	Excellent
Vale Community Hospital	Health	2,522	44	4	4.94	115.3	153.6	Excellent
Woodland Trust Headquarters	Office	2,728	16.2	5	2.44	119.6	37.0	Excellent

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