Innovate UK

Building Performance Evaluation Programme: Findings from non-domestic projects

Getting the best from buildings

January 2016



Innovate UK

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Executive summary

Acting on lessons from flagship monitoring projects will help the UK meet its commitment to cut four-fifths of carbon emissions.

Aiming for true low-carbon performance

Meeting the Government's 80% carbon reduction target by 2050 will be an unattainable goal, unless there is a revolution in how the country constructs and operate buildings. The past 10 years have allowed the industry to experiment cutting energy use in buildings in many different ways. It is rare to find independent evaluation of how much energy buildings actually use when developers hand them over. As such, there is still no consensus about the best approaches for achieving true low-carbon performance.

Looking at 50 buildings

This study looked at findings from 50 leadingedge buildings, chosen from the wider BPE portfolio. Innovate UK had monitored these buildings under its £8 million Building Performance Evaluation Programme (BPE) competition. The study examined projects where data was available, focusing on the buildings' fabric and systems, and how satisfied occupants are with the properties.

Measuring the performance gap

From schools to supermarkets, offices to health centres, the study aimed to identify which strategies work well and what pitfalls to avoid. It also aimed to measure the gap between designers' objectives and what happens when occupants move in, and why this 'performance gap' is so common.

Considering new technologies

The study found that projects faced big problems integrating new technologies, especially configuring and optimising building management systems (BMSs). Some teams also had maintenance, controls and metering difficulties with their biomass boilers, photovoltaic arrays and solar water heaters. Additionally, one air-source heat pump (ASHP) had problems operating in cold weather. There were also problems with automatic window controls to support natural ventilation. This is partly inevitable when people start using new technologies, because installers lack experience fitting systems in different buildings.

Designers and developers should take care when using innovative systems, unless they know the installers have used them in similar ways before. It is vital that the individual installer – not just the company – has hands-on experience of the technology, or a mentor who can guide them.

Positive airtightness results

The average airtightness test result was $6.1 \text{ m}^3/\text{m}^2\text{h}$, which is significantly better than the Building Regulations' minimum requirement for air permeability. Surprisingly, there is hardly any link between airtightness and carbon performance.

The link between ratings and energy use

There appears to be some link between **BREEAM (Building Research Establishment** Environmental Assessment Methodology) ratings and actual energy use. Two 'Outstanding'- rated buildings used less than 100 kWh per square metre per year for gas and electricity together. On average, 'Excellent' buildings used more energy than 'Very Good' properties, so the results are complex.

Identifying exemplary buildings

Two community centres - Mayville and Angmering – are exemplary for low carbon emissions. Both have carbon emissions below 26 kgCO₂ per square metre per year. This is lower than any other building in the group, and around a third of the average carbon emissions in every building (75 kgCO₂/ m^2 /y). A community centre in Coleford also has an excellent carbon performance of 37 kgCO₂./m²/year.

Focusing on system challenges

Natural ventilation often features in low-carbon buildings. Poor control of space, water heating and lighting typically leads to high emissions. Biomass boilers are often temperamental, but deliver much lower emissions when they work. There were also numerous cases of multiple systems fighting each other, for example, cooling working against heating and different heating systems jockeying for control.

Unnecessarily complicated controls

Controls are a problem. Heating, lighting and renewable energy system controls are often too complicated for people to use confidently. Occupants can lack confidence using their controls, which means more energy use and CO₂ to visit the Knowledge Transfer Network (KTN) emissions.

Problems with building management systems

BMSs were also lacking. Installers often seemed to set up systems and provide manuals to merely comply with regulations, without thinking enough about how occupants will use them. What is more, installing BMSs without integrating them with other system controls caused conflicts and confusion. This also made evaluating buildings difficult, because BMSs typically monitor energy use and help intervene in controls.

Unlocking better buildings

Innovate UK has joined forces with the Digital Catapult Centre to launch the Building Data Exchange which will:

- give designers, developers and policymakers access to the data and lessons required to make buildings more efficient
- provide the sector with more opportunities to innovate by using the right data
- help increase digital skills throughout the construction sector

To access the results from projects in the BPE, Click here to visit Digital Catapult Building Data Exchange. For more information about Innovate UK's work in the built environment. **Click here** building performance evaluation.

Background

The UK Government has set challenging targets to cut greenhouse gas emissions 80% by 2050. As around 35% of emissions come from buildings¹, achieving this will only be possible if the country revolutionises energy performance. This report recommends to designers and developers the approaches they should use.

The gap between aspirations and reality

Too often, buildings do not match the original aspirations of designers. This leads to higher-than-expected energy use and emissions. There are many reasons for this, including building energy modelling difficulties during design; specification changes before and during construction; rushed or incomplete commissioning; and unanticipated occupant behaviour.

Analysing trends

This study analyses the main trends from documents and reports that non-domestic projects submitted to Innovate UK. These documents and reports enabled the study to identify high-level conclusions and findings common to all projects; highlight best practice; and share lessons learned. However, this is not an exhaustive analysis of all aspects of the programme's non-domestic projects.

Why evaluation is vital

The study focused on design strategies and technologies that successfully reduced energy use and carbon emissions, and those that did not. The report reveals many problems – and some solutions – based on the programme's findings. The difficulties found show why evaluation is a vital first step towards improving building performance.

The study buildings

The BPE non-domestic study portfolio included 48 projects with 56 buildings. The results for these buildings were exemplary, including five BREEAM Outstanding, 20 BREEAM Excellent, and two EPC A+ ratings.

Building uses

The buildings comprise a wide range of non-domestic uses, including:

- schools and higher education
- offices
- community centres
- supermarkets
- hotels and restaurants
- visitor centres
- healthcare
- libraries

Access to data

The study analysed energy use and other performance aspects for 50 buildings from the portfolio. The precise data varied a little between projects. Some sections of this report also have figures for fewer buildings, because some buildings did not record every detail. In every building, the study had access to actual energy use data, and design documents that were part of planning applications.

Obtaining consistent information

The BPE aimed to compare the performance of multiple domestic and non-domestic buildings. It did this by collecting data for each project using common templates. However, achieving this goal was difficult. The study found that the project reports' scope and detail were inconsistent, apart from the initial application forms to the programme. The evaluators (appointed by Innovate UK to support programme participants) also found obtaining information difficult. This underlines how challenging evaluation work can be, even for projects with funding for this purpose.

Further information

You can find further information on the buildings in the appendix. For each project, you will see, where available, the:

- floor area
- Building Emission Rate (BER)
- design airtightness
- tested airtightness
- annual electricity use per square metre
- annual heating fuel per square metre
- environmental rating (BREEAM)



201 Bishopsgate is a high-specification office in the City of London, with a floor space of more than 37,000m² over 14 storeys. It is designed for low-energy performance, despite featuring a highly glazed façade. Each occupant has access to their own controls for lighting and HVAC (heating, ventilation, and air conditioning) – delivering a great level of personal climate control. Linked to this, the project focused on sub-metering landlord and occupant areas, and engaging with tenants. **Sector:** OFFICE



Angmering Community Centre in West Sussex is a single-storey timber-frame building of 563m². 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 co-efficient of performance of 3.68 – a little lower than expected.

Sector: PUBLIC SERVICE



Asda Langley Mill supermarket is a 6,293m² building in Nottinghamshire with a sales area of 3,675m². 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. This was offset by higher-than-usual heating energy. It also achieved very good occupant satisfaction. Sector: RETAIL



The Bath Campus study includes 'R5 - Woodland Court' - a new 355 - bed student residence - and '4 West', which is a 5,200m² mixed university building (refurbished and new). The project considered fabric energy efficiency and airtightness, particularly for 4 West, which received planning permission before the 2006 update to the building regulations. Both project have roof-mounted solar thermal arrays, and achieved BREEAM 'Excellent' ratings. (Please note, the figures in this report relate to Woodland Court.) **Sector:** EDUCATION





The Bermondsey Square development in London comprises of two separate buildings. The first is a 79-bedroom hotel, and the second includes offices, retail space and apartments. Heating is provided through a district heating network from a local plant room. This heating network is served by gas boilers, with an evaporative cooling system specified for the offices. The building is mainly naturally ventilated. This multi-tenancy building explored 'green leases' and engagement to address how users affect overall environmental performance. **Sector:** OFFICE AND HOTEL



Bessemer Grange Primary School is a 1950s school with an extension built in 2010. The school houses 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. However, electricity use is high and there are problems with the solar water heating. **Sector:** EDUCATION



The Blue Bell Health Centre in Liverpool is a 2,500m² scheme. It follows Passive House principles and features high levels of insulation, airtightness and triple-glazed windows, and mechanical ventilation with heat recovery (MVHR). It also includes solar hot water panels, and a heat pump to provide space heating and supplement the water heating. **Sector:** HEALTHCARE



Bourne Hill Offices in Salisbury provide office space for Wiltshire Council. They comprise a refurbished listed building (1,500m²) and a modern extension (2,360m²). 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



BRE Scotland Innovation Park Visitor Centre is a single-storey building that showcases the future of Scottish housing. It is highly insulated, with good airtightness, an air-source heat pump (ASHP), solar electric panels, solar water heating, heat-recovery ventilation, and efficient lighting. There were problems with ventilation and heating, which meant replacing the heating system. Energy use was also higher than expected. Sector: CULTURE



Brighton Aldridge Community Academy is a two-storey 10,588m² concrete-framed school, built on the site of previous high school, for 1,150 pupils. The construction is generally very traditional, focusing on natural ventilation and good daylighting. It has a biomass boiler (now unused) and a solar hot water array. It also has excellent airtightness. This is part of the POE Feedback into School Design project, with Thamesview School. **Sector:** EDUCATION



Brine Leas Sixth Form is a three-storey, 2,969m² new-build school, and contains various innovative technologies designed to improve performance. This includes a heat-recovery system, solar hot water, and cooling from an ASHP. Occupants control high-level window openings through the BMS, and manually at low levels. Sector: EDUCATION



Castle Hill Primary School in Kingston upon Thames has a classroom extension of $820m^2$, a new dining hall of $300m^2$, and a photovoltaic (PV) array. Airtightness 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. This suggests 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:** EDUCATION





Cheshire Oaks on the Wirral is Marks & Spencer's second-largest store, at 19,400m². 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 300m² 'living wall' beside the car park. Energy use compares well with benchmarks. **Sector:** RETAIL



College Lake Visitor Centre in Tring, Hertfordshire, is a 362m² building with a single-storey section including a grass roof and a timber two-storey section. It has underfloor heating from two 12 kW air-source heat pumps, and a 3.4 kW solar electric array that provides 8% of the electricity 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 resolve issues with wasteful water and space heating. **Sector:** CULTURE



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:** PUBLIC SERVICE



The Creative Exchange in St Neots is a four-storey building providing 705m² 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. Airtightness and the BMS were problematic, and initial flooding of the earth duct meant installing a pump after handover. **Sector:** OFFICE





Cressex Community School in High Wycombe is an 11,600m² three-storey secondary school with a biomass boiler. It comprises 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:** EDUCATION



Dartington C. of E. Primary School in Devon comprises four clusters of single-storey buildings. The total floor area is 1,990m². It has underfloor heating from ASHPs, and solar electric and solar thermal panels. It also has rainwater harvesting. Value-engineering late in the programme meant 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: EDUCATION



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 current staffing is much lower. It has natural ventilation using 'Passivent', with mechanical ventilation and cooling for summer. **Sector:** OFFICE



Estover Community College, Plymouth, is a 16,900m² school for 1600 pupils aged 4 to 18. It was built in stages, so teachers could use old school buildings during construction. The BMS was not correctly commissioned. Because of this, the college faced problems controlling the buildings – and the BMS proved unsuitable for energy monitoring and diagnostics. A biomass boiler was installed, but the college no longer uses it, due to problems with fuel and maintenance. **Sector:** EDUCATION





Graham Head Office in Hillsborough, Northern Ireland, is 3,200m² and provides office accommodation for 250 employees. It has a 240 kW biomass boiler that must be cleaned out every two weeks, plus an oil backup boiler. The design received 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



Greenfields Community Housing HQ provides office accommodation for around 100 staff, and community facilities for its tenants. It has three ground-source heat pumps (GSHPs), and mechanical displacement ventilation in winter, using a thermal labyrinth. It received a BREEAM 'Very Good' rating, although its BMS interface was omitted from construction due to costs. There were also problems with heat-pump controls. The server room alone uses as much energy as needed to heat and cool the whole building. **Sector:** OFFICE



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 various renewable energy systems (GSHPs, PV, solar water heating, and wind). Partly because of this, the building received a BREEAM Outstanding rating at design stage. Sector: HEALTH



iCon Daventry is a new 4,000m² building providing space for new high-tech companies, with a conference centre and public meeting place. The building is intended to demonstrate good sustainable design. It comprises 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



Jarman School of Arts comprises drama and film studios, computing and editing suites, a large art gallery, teaching rooms, and 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 underfloor heating. Sector: EDUCATION



Loxford School in Ilford saw architects and mechanical and electrical engineers collaborating closely on making the building naturally cross ventilated with simple controls. It includes manual and automatic opening windows, and sensor feedback to users, a GSHP, and solar shading. The evaluator highlighted that not using a Soft Landings approach compromised the handover. This led to operational problems with motorised vents and the BMS. Sector: EDUCATION



The Main Place, Coleford Community Centre is a two storey, 982m², naturally ventilated building providing community facilities. The construction is primarily traditional load-bearing masonry, but includes some steel-framed open-plan elements. The envelope was designed to maximise energy efficiency through airtightness and good U-values. Sector: PUBLIC SERVICE



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

Sector: PUBLIC SERVICE





The National Composites Centre near Bristol brings together design and manufacturing processes for industrial composite materials. It is 8,500m², and has mechanical ventilation but not cooling. Occupants have reported summer overheating. It has a 138 kW PV array, which is generating more power than anticipated. However, overall, the building's electricity demand is much higher than expected. **Sector:** INDUSTRIAL



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

Sector: EDUCATION



Ore Valley Business Centre in Scotland provides office space for start-up companies. It was designed to accommodate 45 people on each of its 3 floors, but is currently under-occupied. It uses the Termodeck ventilation system, which appears to have worked well. However, the building uses local electric heaters to supplement the central heating system. The BPE identified high energy use for lighting. **Sector:** OFFICE



Pennywell Academy in Sunderland merges three schools into one new academy as a cluster of interlinked buildings with a total area of 10,200m². It was designed as a largely passive building. Once the contract was let, the ventilation system was changed to mixed mode. Regarding renewable energy generation, the school includes a biomass boiler. This is part of a study of three academies, including Petchey and Stockport Academies. **Sector:** EDUCATION



Petchey Academy is a new 1,200 place academy, completed in 2007. It comprises a four-storey concrete frame, split into two wings around a central, ETFE (ethylene tetrafluoroethylene) covered space. The school features various energy-intensive uses, including a training kitchen. This is part of a study of three academies, including Pennywell and Stockport Academies. Sector: EDUCATION



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. The building 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 almost every aspect, from the structure to services and energy systems, was innovative. The team anticipates 30% savings from 2014 to 2015. **Sector:** CULTURE



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



Premier Inn and Beefeater Restaurant in

mid-Sussex is a 60-bed hotel with a 220-seat restaurant. It has a GSHP and heat-recovery ventilation. The building originally aimed to reduce usual energy consumption by 70%. It uses a 140mm timber frame with triple glazing. There are LED lights with auto controls. After construction, there were problems with airtightness and thermal bridges. **Sector:** HOTEL AND RESTAURANT



Rogiet Primary School in southeast 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 – which meets 6% of electricity demand – and solar water heating. However, gas use is 3.7 times higher than expected. This is partly due to high losses from the hot water system, especially during holidays. **Sector:** EDUCATION



South Place Hotel in London has eighty 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 around 5% of carbon emissions. The hotel has high electricity use. This is partly because it is marketed as a high-end luxury hotel. Sector: HOTEL



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. Its very high insulation features include triple-glazed windows. The teacher needs to intervene to ensure good ventilation in winter. **Sector:** EDUCATION



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, GSHPs, and low-energy lighting to optimise daylighting provision. This is part of a study of three academies, including Pennywell and Petchey Academies. **Sector:** EDUCATION





St Peter the Apostle secondary school in Glasgow, is a PFI school built for 1,500 pupils but currently has 1,600. The floor area is 16,185m², spread across four three-storey blocks. It has reversible heat pumps that can provide heating and cooling, and gas boilers for heating. It has a mixture of underfloor heating, radiators and radiant panels to deliver heat. There are some issues with controls and the BMS. Additionally, the school's over-reliance on electric light increases energy use. **Sector:** EDUCATION



The Sustainable Construction Academy

(SusCon) in Kent is a 2,900m² building intended to teach about construction. It has workshops and teaching spaces, with a café and offices, arranged around an atrium. It is currently under-used. It has a 26.7 kW solar electric array on the roof. Its biomass boiler has now been decommissioned due to complexity and cost. Sector: EDUCATION



Thamesview School in Gravesend, is a two-storey 8,250m2 school with a large central atrium. It was 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 used due to problems with delivery. This is part of the POE Feedback into School Design project, with Brighton Aldridge Community Academy. Sector: EDUCATION



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 – providing accommodation for 1,200 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 maintaining even temperatures. An occupant satisfaction survey found it in the top 10% of buildings. **Sector:** EDUCATION



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

Sector: OFFICE



University of the West of Scotland, Ayr Campus

is a 17,800m² building for up to 4,000 students. It has biofuel boilers, but these proved problematic – particularly because of difficulties achieving the right biofuel mix – so the building uses backup gas boilers instead. The campus has mechanical cooling including fan coils, and mechanical ventilation.

Sector: EDUCATION



Vale and North Cotswolds Hospitals are two similarly sized hospitals in Gloucestershire. They have similar facilities and almost identical fabric and building services. They have combined heat and power (used infrequently), solar water heating (unusual in hospitals), reversible heat pumps, and some solar shading. Both seem to be using more energy than they should, and report issues with thermal comfort. However, occupants like the buildings. Both hospitals were economical to build.

Sector: HEALTHCARE



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 (£1,800/m²), 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

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What causes overconsumption?

A main goal of the BPE was to find out why buildings' environmental performance often falls short of expectations. This is known as the performance gap. The study tried to identify instances where good design practices, procurement processes and operational management helped projects reduce the performance gap.

Evaluating the performance gap

The BPE's approach helps measure the performance gap, which depends on accurately monitoring energy use in buildings. Project teams achieved this using the CIBSE (Chartered Institution of Building Services Engineers) TM22 methodology and worksheets. This is a systematic approach to conducting an energy survey, recording findings, and estimating possible savings from changes.

Actual electricity and heating fuel use

The measurements start with actual electricity and heating fuel use, where fuel use includes gas, oil, biomass and biofuel. The study normalised the data by floor area, so the energy figures show electricity or fuel use in terms of kWh per square metre per year (see fig. 1). The range of energy use per m² is very wide – from 28 to 367 kWh/m² for electricity, and from 0 to 316 kWh/m² for fuel (seven of these buildings are all-electric, with electricity used for heating). The average (mean) electricity use is 103 kWh/m², while the mean for fuel is 92 kWh/m². Electricity and gas use are important. So a building can only be assessed as performing well if it achieves low electricity and fuel use – while keeping occupants comfortable.

Emissions and costs

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. Even for these fuels, it is important to use no more than necessary. With limited supplies of bio-energy, savings would free them up for use elsewhere.

Success stories

The energy success stories are the:

- Staunton on Wye Primary School, with electricity and fuel use both below 30 kWh/m²
- Mayville Community Centre, with electricity use of 47 kWh/m² and no fuel use
- Angermering Community Centre, with electricity use of 49 kWh/m² and no fuel use

Please see the 'Why do some buildings perform better?' section for more information on this.



Fig. 1: Each building's design emphasises

low-energy performance. The range of actual energy use for electricity and fuel is staggering, from combined energy use less than 50 kWh/m²/year to more than 560 kWh/m²/year.

Success stories

The Building Regulations require designers and developers to calculate a Building Emissions Rate (BER) for every new building. This gives the estimated rate of CO_2 emissions per m² floor area for emissions from regulated energy use (heating/cooling, ventilation and lighting). Designers and developers calculate this according to the Government's standard methodology, using approved calculation tools.

Actual versus predicted emissions

Comparing the BER against actual energy use from the TM22 worksheets, only College Lake Visitor Centre produced emissions similar to those predicted. The rest produced from 1.8 to 10 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 fig. 2 and caveats).





Fig. 2: Actual CO_2 emissions are almost always higher than the BER predicts (Carbon Factors: Electric 0.55kg CO_2 /kWh, Gas 0.194kg CO_2 /kWh, Oil 0.265kg CO_2 /kWh, District heating 0.265kg CO_2 /kWh, Biomass 0.025kg CO_2 /kWh, from BRUKL). NB: Zero-rated buildings against one hotel and one office project are projects with CO_2 data but no BER.

Caveats on energy use from unregulated loads

The predicted emissions only account for a proportion of actual building loads – the 'regulated' loads, which fall under Building Regulations compliance. These include heating, cooling, ventilation and lighting. They omit many other types of energy uses, such as small power and IT, and external lighting ('unregulated loads'). These energy uses may only be a small proportion of total operational energy use. But a study by Robert Cohen in 2013² revealed they account for more than 25% of energy use for over half the sites studied – and most energy use for one office (65%) (see fig. 3). The proportion of unregulated energy varies between sectors. Retail and industrial buildings, and swimming pools, tend to have high unregulated loads. The proportion of unregulated energy use is rising in some sectors like schools, due to increasing use of ICT.

² Cohen (2013) The Performance Gap in Non-Domestic Buildings, presented at Ecobuild 2013.
London/Swindon: Verco/Technology Strategy Board. Link: Click here.





Fig. 3. Unregulated energy use can be as much as 65% of total actual energy use (Source: Cohen, 2013).

Energy use outside working hours

Compliance calculations also ignore energy used out of normal working hours, which are routinely defined too narrowly. For many buildings in the programme, the data showed that out-of-hours electricity use often matched, and sometimes surpassed, energy use in normal hours. This was due to continuous base electrical loads like servers and outdoor lighting.

Assessing through certification

Certificates provide another way to assess actual and operational energy use. They link closely to the calculation method in Building Regulations. They provide normalised ratings that allow people to easily compare buildings nationwide. Buildings in the UK may have two types of energy certificate: Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs). EPCs are part of the current building regulations procedure. They compare the designed building and a standard building, modelled using the National Calculation Methodology (NCM). Not all projects in this study have an EPC, as some passed through planning before this was required.

DECs are for public buildings above 1000m² and optional for other buildings. They compare the actual energy use based on data from bills over a year, with a standard benchmark for each building category. High values on both certificates are bad, as they reveal high energy consumption or emissions.





Fig. 4: Display Energy Certificate (DEC) ratings, based on measured energy use from bills, are often triple the modelled Energy Performance Certificate (EPC) ratings.



Comparing certificate ratings

The graphs in figs. 4 and 5 simply compares EPC and DEC ratings for the 17 buildings with both certificates. This shows very little correlation between the EPCs and DECs, as noted in previous papers³. There is a slightly higher correlation coefficient for schools. This is mostly due to an outlier (an observation that is abnormally distant from other values) with a DEC of 193 (G), which also had a relatively poor EPC of 64 (C).

The BPE study also demonstrates that EPCs are good at indicating the potential energy performance of a building – but they cannot account for changes in its design, operation and occupant behaviour.

³ E.g. 'A Tale of Two Buildings', 2012, Jones Lang LaSalle. Link: **Click Here**.

Fig. 5: There is no clear trend when EPC and DEC plotting and grouping ratings by sector.



Changing expectations

The performance gap refers to more than the difference between EPC ratings and actual energy use. It also applies to other sustainable design metrics, such as BREEAM. The study shows that clients increasingly expect better sustainability from their buildings. This partly explains why later entrants in the BPE competition received more BREEAM 'Outstanding' scores and fewer 'Very Goods'.

Driving better buildings

There are many other reasons for the high scores, including a desire for low energy costs, staying ahead of legislation, and enhancing a green reputation. Clients' higher expectations of buildings are a major factor.

Rising BREEAM ratings

The buildings in the study are self-selected. However, it is interesting to note that over 50% of projects in the first set to be monitored (Tranche 1: May 2010) were only achieving BREEAM 'Very Good'. Ten months later (Tranche 4: February 2011), most submitted projects were either BREEAM 'Excellent' or 'Outstanding'. It should be noted that BREEAM 'Outstanding' only came in for BREEAM 2008 generally, so this may have not been an option for earlier tranches. However, BREEAM standards have become stricter over time. For example, since 2008, the standard has required a Post Construction Review.

Using other assessments

The study used two other environmental assessment methods – Passive House in one of the community centres (although these design principles were referenced in several other projects, without seeking certification) – and NEAT⁴, for which a hospital achieved an 'Excellent' rating.

Problems meeting BREEAM requirements

Some projects undertook a BREEAM pre-assessment but decided not to complete the assessment. One reason was "...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 led to oversizing the solar hot water system, which caused operational problems.

Representatives at Bath Campus also felt that while they met some BREEAM requirements, they treated them as targets, not minimum levels (the daylight factor, for example). It seems likely that BREEAM certification generally encourages designers and developers to add more low-energy systems, which can make them complicated and unmanageable.

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



Fig. 6: The proportion of projects at BREEAM 'Very Good' fell over time, while those at BREEAM 'Excellent' and 'Outstanding' increased for later BPE project tranches.

Comparing EPC, DEC and BREEAM scores

Comparing EPC, DEC and BREEAM scores revealed a very slight average improvement between the BREEAM 'Very Good' and 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. This indicates that reaching the 'Outstanding' score requires extra effort on energy⁵. Unfortunately at this stage, no DECs were available for BREEAM 'Outstanding' buildings, so the study could not assess the performance gap.

It should be noted that 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.

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).





Fig 7: This chart shows BREEAM scores for actual electricity and fuel use per m² per year. BREEAM 'Outstanding' buildings are more energy efficient than others in the sample (mean electricity and fuel use both below 50 kWh/m²/year). However, there are only two of them. Perhaps more importantly, 'Excellent'-rated buildings use a little more energy on average than 'Very Good' ones (mean electricity and fuel use a little over 100 kWh/m²/year each for 'Excellent', versus a little below 100 kWh/m²/year for 'Very Good'.) The two 'Good' buildings seem to perform worse than other BREEAM-rated buildings, with mean electricity use of 176 kWh/m²/year and mean fuel use of 140 kWh/m²/year.

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

Collecting data

The study collected and compared data about each project's 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).





Fig. 8: 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 $0.55 \text{kgCO}_2/\text{kWh}$, Gas $0.194 \text{kgCO}_2/\text{kWh}$, Oil $0.265 \text{kgCO}_2/\text{kWh}$, District heating $0.265 \text{kgCO}_2/\text{kWh}$, Biomass $0.025 \text{kgCO}_2/\text{kWh}$).

A steel and concrete bias

A bias towards steel and concrete frames in the studied buildings made analysing structure against carbon emissions more complicated. There were surprisingly few 'traditional' masonry buildings of weight-bearing block or construction – and more timber-frame buildings than expected (see fig 8). However, on average, steel and concrete-frame buildings had higher carbon emissions per square metre than timberframe buildings – and markedly higher than masonry buildings. This question merits further investigation, ideally with a larger sample of masonry buildings.

Intervening variables

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.

The advantage of traditional contracts

The industry commonly believes that traditional contracts – where architects and engineers work from concept design through to detailed design – provide more confidence than 'design and build' contracts, where the main contractor is responsible for detailed design. It is generally felt that employing the same design team throughout means projects are more likely to achieve their good energy performance goals. This is because there is less risk of contractors saving money by substituting solutions with inappropriate alternatives when construction starts.





Fig. 9: Analysing carbon emissions and the procurement route indicated that average emissions are lower for projects with a traditional contract. However, 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.

Evidence to support traditional contracts

The buildings in the programme show some link between the contract type and carbon emissions (see fig. 9). Mean emissions for traditional contracts – where the contract type is known – are 66 kgCO₂/m²/y, versus mean emissions of 83 kgCO₂/m²/y for design and build contracts. The four highest-emission buildings in this group were design and build. However, a traditional contract alone does not guarantee low carbon emissions. The best design and build projects achieved lower emissions than half of the traditional contract projects.



Why do some buildings perform better?

Almost every building in the BPE has higher carbon emissions in use than was expected during design. However, some have only slightly higher emissions while others are up to ten times higher than the BER. This section focuses on buildings that have exceptionally good performance – and buildings with much higher-than-expected emissions – and tries to see why.

		Ratio of			Buildings with low emissions		
Project name	Emissions/m ² (kgCO ₂ /year)	emissions to design estimate (Emissions/BER)	Space and water heating /TM46*	Technologies	These buildings had total emissions no more than twice the design BER, described previousl As the BER only includes regulated energy		
Staunton-on-Wye Primary School	13.8	1.3	0.2	Natural ventilation. Underfloor heating and biomass boiler. Solar electric panels.	use – heating and cooling, hot water, lights and ventilation – this is very good performance. The report excludes four projects from the analysis due to incomplete data. The study examined		
Angmering Community Centre	23.4	1.9	Unknown	GSHP and underfloor heating. Solar electric panels.	each building in turn and aimed to identify the reasons for their exemplary performance.		
Mayville Community Centre	26.0	1.9	Unknown	Passive House standard retrofit with heat-recovery ventilation and a GSHP.	* This is the heating energy used as a proportion of th TM46 benchmark. Heating energy is gas and other non-electric energy used. For buildings where		
Ore valley Business Centre	44.7	1.7	0.7	Mixed mode, mechanical ventilation using 'Termodeck' hollow floor slabs.	value is not known. The latter is from the DEC where available, and where there is no DEC, it is calculated.		
College Lake Visitor Centre	47.0	1.1	Unknown	Natural ventilation, ASHP, 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.			

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, at only 13.8 kg $CO_2/m^2/year$. The school added PV panels later and improved its already very good performance (exporting 4.1 kWh/m², and saving 2.2 kgCO₂/m²).

Exceptional heat and insulation

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 from 8.30am to 11am and the building stays warm the rest of the day. Although the head teacher controls a Trend BMS, there are thermostats in each room that can adjust the set point +/- 3C.

Carbon dioxide concerns

To retain heat, occupants must close windows. This has led to elevated levels of CO_2 in indoor air, which can affect pupil concentration. With only trickle vents open, levels sometimes rose above 1,500 parts per million. The school has installed CO_2 monitors. When they show high levels, teachers open windows.

Complaints about cold

Some have complained that it is too cold in the preschool area. This is probably because the children can play outside throughout the day, so doors are open and heat escapes.

Lighting

Classroom lighting has daylight dimming. The school removed presence sensors on corridor lights due to complaints that they were oversensitive 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 GSHP, 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.

Low heat demand

The building is designed for very low heat demand. Occupants taking part in physical activities often open windows to cool down. There is no central BMS. Although there are thermostats in each room, the project has asked occupants not to adjust them. The underfloor heating responds very slowly – and there have been cases where people accidentally turned the heating off.

Plug-ins, lighting and heating

This building has minimal plug-in loads. Lighting accounts for 41% of electricity, while heating – including hot water – accounts for 45%.

Mayville (Mildmay) Community Centre

The community centre has a sports hall, reception area, dining area and kitchen, plus office spaces that tenants use continuously. This building has a Passive House standard retrofit. In the winter of 2013/2014, with occupation up to the previous level, it required no space heating. However, the building requires its GSHP for hot water.

Keeping controls simple

The building has no central BMS. Its systems only have the standard manufacturer controls. The designers decided to keep the controls simple, which has proven very successful. The building is also carefully managed. Low energy use is a priority, however, this may not be easily replicated in other contexts.

Meeting Passive House demands

The building's Passive House design requires very high airtightness levels. The site manager and construction team took a short training course to understand these demanding requirements. The second test showed they had achieved 0.43 m³/h/m² at 50 Pa: 20 times better than Building Regulations.

Ventilating the building

MHVR ventilates the building. For evening events, a timed run-on switch can extend its set operating hours. In summer, ventilation grilles allow night-time cooling. The ventilation system has a summer bypass. This is important for saving energy and limiting summer overheating. It is recommended that 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 losing privacy and tiled areas. The Thermalex performed better than expected for insulation value, but the other materials performed slightly worse (see table 2).

Project name	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

Table 2: performance of the cladding systems at Ore Valley Business Centre

Good airtightness

Airtightness in most rooms is good. There are big leaks in the basement and the lift/stair shaft. Although the building already performs well, it could have done better.

Concrete floor-slab heating

A hollow-core concrete floor-slab system called 'Termodeck' distributes heat in tenanted areas. The Termodeck provides high thermal mass and, in summer, takes advantage of night-time cooling. During occupied periods, there is no recirculation. There is some heat recovery from exhausted air. Communal areas have conventional radiators and one stairwell has a fanned electric panel heater.

BMSs and Termodeck

BMSs and Termodeck have operated well, even though initially, remote monitoring software was not installed. Since then, the building has only made minor adjustments. Conventional gas boilers supply heat.

High unregulated power use

There was no sub-metering beyond floor level in the original design. Meters installed for the BPE revealed that some tenants have high unregulated power use, such as plug-in and catering equipment. All tenants attend an energy induction course and an energy group meets quarterly.

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College Lake Visitor Centre

The centre includes offices, a visitor interpretation space and a café. It has very low energy demands. Its solar PV panels provide 8% of the electricity used.

Underfloor heating and hot water

Two ASHPs provide the building's underfloor heating. Monitoring for the BPE showed that occupants used the immersion heater excessively for hot water. The centre has solved this by setting the heating permanently to winter mode to better use the heat pumps. Over time, the occupants have learned to manage the underfloor heating, which is slow to respond.

Summer ventilation

The project has developed a window-opening strategy to maximise ventilation in summer.

Bath Campus - Woodland Court

This building provides accommodation for 355 students in five blocks. It is used for conference accommodation during the holidays.

Heating, lighting and ventilation

The heating, lighting and ventilation are fairly conventional. Windows are openable and radiators have manually operated thermostatic radiator valves. The emissions per m2 are fairly average. The report features this building because it performs as expected.

Solving lighting problems

Motion sensors activate lighting in communal areas and corridors, including during the day. Many of these initially had faults, so 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 disturbed students and wasted energy. The light levels have been reduced, and the on-time has reduced to five minutes.

Buildings with higher-than-expected emissions

These six projects had total emissions at least five times the design BER. Even though actual emissions include unregulated plug-in appliances, these are big performance gaps. The figures only cover the period of the Innovate UK programme. It is expected that the projects may have resolved some problems since then.

Project name	Emissions/m² (kgCO ₂ /year)	Ratio of emissions to design estimate (Emissions/BER)	Space and water heating /TM46*	Technologies
National Composites 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 C. of E. Primary School (including 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	62.1	9.9	0.2	District heating, via Termodeck. Heat- recovery ventilation.

Table 3: buildings with higher-than-expected emissions.


National Composites Centre

This state-of-the-art industrial facility performs well for heating. The centre has identified that it could save money by not running heating and lights when the building is unoccupied. The main workshop is also heated to a higher temperature than necessary.

High electricity use

The centre's very high electricity use is mainly due to activities in the building, such as maintaining the Class 8 clean rooms, which require high-level filtration. Also, some of the gas use is for industrial processes, rather than heating. The high electricity use has caused 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

Night-time cooling was discontinued because squirrels were getting in and scavenging for food. The window grilles have retrofitted mesh to stop this.

Improving efficiency

A variable speed drive could make the main air-handling units (providing ventilation and cooling) more efficient, saving 10% of electricity with payback in 0.1 years.



Pennywell Academy

Pennywell Academy is an amalgamation of three schools, with 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 of 0.35, and windows have 1.1.

Excessive emissions

Pennywell Academy was one of three academies that the BPE studied. The other two –Stockport and Petchey – performed relatively well, with actual building emissions between three and four times the BER. For Pennywell, the total emissions were nearly six times the BER.

Complex BMS and controls

The three schools' complex BMS and control systems are partly responsible for these high emissions. The report suggests that school staff lack the expertise needed to use the systems. They also have other tasks that take priority over improving energy efficiency. However, developers provided them with very weak operations and maintenance manuals, which did not help. This was improved during the BPE study.

The heating system

Monitoring has shown that Pennywell's heating system was operating continuously over the weekend, and not turning off overnight. The school also does not now use the biomass boiler, as it is considered poor value for money due to high maintenance costs. A health and safety warning has also been issued about a potential build-up of carbon monoxide in the pellet store.

Only one batch of pellets was acquired and used. The school has used gas boilers exclusively since then.

Improving efficiency

The emissions figures are based on the year to March 2012. Since then, the school has made significant savings from optimising its lighting systems. The infra-red sensors are now less sensitive, so people walking down corridors no longer trigger classroom lights. Also, a schedule now restricts external lights, which were previously on continuously. These and behaviour changes have led to:

- a 20% decrease in internal lighting consumption
- a 60% decrease in external lighting
- an 18% saving in electricity.

Underestimating loads and consumption

The school's cooling loads were originally underestimated and its IT energy consumption was vastly underestimated. The National Calculation Methodology (SBEM previously assessed energy use for building control as part of the planning application) assumes 50 W/m² for IT server rooms, or 500 W/m² in data centres. Pennywell's actual use is 1,100 W/m².

Estover Community College

The college campus comprises 10 buildings, 9 of which are new. The campus provides facilities for 1,600 pupils aged 4 to 18. An energy centre provides heat through a district heating system. The campus originally intended to use a biomass boiler system with gas backup. It has abandoned this, due to successive problems with control systems and mechanical parts.

Explaining high energy use

Extensive out-of-hours use accounts for part of the high energy use for heating. The hot water systems operate 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. Instant water heaters at the point of consumption or solar water heaters could provide hot water in summer time. The school could then turn the energy centre off.

Heating the school

Radiators with thermostatic radiator valves heat most of the school. Pupils often turn these up to the maximum level, or kick them off, so the school could replace them with tamper-proof systems. Also, the sports hall's side door is often left open. This is partly due to damage by rough use, so the door does not close easily. Fixing this would cost an estimated £900 and save £400 a year.

Hot water pumping systems

The hot water pumping systems currently operate continuously, even when the boilers are inactive and not supplying heat. Turning them off would save around £1,300 a year. Also, much of the pipework and fitting in plant rooms throughout the school has inadequate insulation. Fixing this could save £4,400 a year. Together, these measures could save 50 tonnes of CO_2 /year.

Sports hall and car park lighting

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

IT and kitchens

There is active cooling in some areas, including IT server rooms. These are cooled to 18°C, although ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) recommends 27°C.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 are left on all night. These contribute to the school's rather high (60kW) base load.

Classroom ventilation

All classrooms are naturally ventilated and have at least one casement with a grille, allowing secure night-time cooling. Window opening and closing is purely manual, so users must judge how to operate them. CO_2 sensors with a traffic-light signal prompt staff to open windows when necessary. However, they are often hard to see, because they are too far away or obscured by furniture and clutter.

⁶ 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance. Link: **Click here**

Brighton Aldridge

Brighton Aldridge and Thamesview School belong to the same project. The same contractor built both schools, which were designed with similar services. The schools were to be heated mainly with biomass chip boilers, however, they have not been effective. The supplied woodchip does not meet the required specification and continually jams the feed system. As such, both schools use gas backup systems instead.

Heating consumption

Brighton Aldridge used nearly twice as much energy for heating (143 kWh/m², compared to 76 kWh/m² at Thamesview). This was partly due to difficulties with the controls. Both schools have underfloor heating that need several hours preheat each day in the main hall and corridors.

However, at Brighton Aldridge, this also heats the rest of the school because the systems cannot be separated. The underfloor heating needs four hours preheat each day, but this applies to only 25% of the floor area. Fixing this could reduce heating consumption by an estimated 30%. This explains only about 65% of the difference between the schools' heating consumption. Brighton Aldridge uses a Honeywell Tridium BMS while Thamesview uses a Trend BMS (as does Staunton-on-Wye Primary School).

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 50m² hydrotherapy pool. The pool accounts for 40% of the school's gas and electricity use. It is currently heated to 33°C all year.

Reducing costs and energy use

The school could cut costs and energy use by reducing heating during the holidays, and possibly lowering the water temperature to reduce evaporative loss. This will mean increasing the air temperature slightly to ensure comfort. Also, insulation below the pool could have reduced pool heat loss by around 10% (13,000 kWh/year). To reduce costs, the school did not install insulation. Additionally, the school did not require pool insulation, as it was built according to pre-2010 building regulations.

Reasons for high emissions and power use

Some of the high emissions relative to BER are due to the school's heavy operating schedule. The nursery has a breakfast club and afterschool clubs. The server room is currently cooled to 19°C, which could increase to 25°C, saving a few thousand kWh/year. (The servers consume 1.1kW of electricity continuously, or 10,000 kWh/year.) Interactive whiteboards in each classroom also contribute to high power use. Additionally, 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. This experienced client has a long history of constructing low-energy buildings. It is a three-storey building with offices, a lecture theatre and seminar rooms.

Heating and cooling

It uses Termodeck hollow core concrete slabs to distribute heating and cooling. A district heating/cooling system supplies the heating. The building has performed well in terms of heating consumption.

High overall emissions

The building's high overall emissions are due to high electricity use – 41% of this is due to plant room equipment. It seems the air-handling units are operating at high power more often than necessary. Also, 33% of electricity use is for lighting, which could be optimised more.

Lessons learned

Operational issues

- The projects had widely different experiences of biomass boilers. For example, three were abandoned due to mechanical problems and/ or high costs. One boiler contributed to one of the most efficient buildings. This implies that designers and developers should consider biomass boilers carefully during design and construction, including where the fuel will come from, and how users will deliver and store it.
- Designers and developers tend to install overly complex control systems, prompted partly by building regulations and BREEAM credits. Users not understanding these systems – and possibly poor system functioning – lead to energy wasted out of hours and/or overheating.
- Pumps and plant room equipment for heating and cooling receive inadequate attention. They are often allowed to run when other systems are inactive, which is wasteful.

- Underfloor heating must be managed separately from radiator circuits. This means users can accommodate preheat requirements for slower-response underfloor without heating radiators. Occupants also need clear information about response times and how best to control underfloor heating.
- Lighting systems are often not adjusted properly during commissioning. This is vital for systems with passive infrared (PIR) sensors, which need adjusting for sensitivity and timing. This should be checked routinely during completion. Commissioning should not be signed off unless lighting controls are seen to work properly.
- Controls for manually controlled ventilation should be simple. Prompts, such as CO₂ sensors, should also be easy to see. Initial training for building users is rarely adequate, because staff change. So, simple and enduring guidance should be situated close to controls after handover.

Poor estimates of energy requirements

- Building users often underestimate operating hours. This is possibly due to optimism bias, and not anticipating that some users want to work early, late, or at weekends. Design estimates of energy use should be realistic about the actual hours of use. They should also 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. Clients possibly need better advice on choosing efficient computer equipment. This means clients should learn how their decisions affect energy use and allow for the cost of employing specialist support.



Excluded projects

The study excluded two projects from this part of the analysis.

201 Bishopsgate

BRE Scotland Innovation Park

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 just one month.

The study excluded this project because there was no monitoring data available for the PV array. The project aimed to be carbon neutral but we cannot verify this.

Natural ventilation often features in low-carbon buildings. Poor control of space, water heating and lighting typically lead to high emissions. Biomass boilers are often temperamental, but deliver much lower emissions when they work.



Airtightness

Every project reporting airtightness test results showed that they comply with the current Building Regulations, with lower infiltration. However, not all achieved their design targets.

Compliance with building regulations

Airtightness tests

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

Improving results

All but two projects met the Building Regulations (2010) requirement to achieve airtightness below 10 m³/h.m²@50Pa. Most had much better airtightness than the minimum requirement, with an average tested permeability of 6.1 m³/h.m²@50Pa. Of the 35 that provided design target and test results, 23 were better – and 12 were weaker – than the design target, and 5 came within 1% of their target. The highest percentage improvements over design target came where the design airtightness was least ambitious: simply limiting below 10 m³/h.m²@50Pa. This is not a building performance issue. However, it shows that some of the design teams could have reduced the BER and EPC ratings by including the improved airtightness level in their calculations.

In total, 16 sites achieved airtightness of less than 5 m³/hr per m²@50Pa. One site – Mayville Community Centre, which aimed to achieve the Passive House standard – managed to reduce its permeability to less than 1 m³/hr per m²@50Pa. This was an impressive result for a retrofit project.





Fig. 9: Broadly, the buildings with the best airtightness (to the left in this graph) are those with the toughest design targets. Many of those with unexceptional targets (in the middle) did much better than their targets. The Ore Valley Business Centre – with poor airtightness – measured at 19.27 m³/h.m²@50Pa, which is equivalent to an air change rate of 6 air changes per hour. It had much better airtightness for individual rooms. However, settlement affected the whole building, and there are serious leaks, especially in the basement.

Tweaking targets

Some projects in the middle of the plot may have tweaked their BRUKL design targets for permeability after they were tested. This would explain the closeness between design and achieved airtightness.





Fig. 11: Design calculated and measured air pressure test compared to building tenancy.

No linking with building type

There are no clear links between airtightness and building type. The results showed some excellent and weak schools, and offices at both ends of the spectrum. In terms of tenancy, owner-occupier buildings had the lowest average design and as-built airtightness. Single-tenant buildings had slightly lower design targets than multi-tenant buildings. However, they did not achieve much higher mean results.

Airtightness and CO₂ emissions

Considering other factors

Comparing actual carbon emissions against airtightness is interesting and surprising. Two of the lowest-emissions buildings (Mayville Community Centre and Staunton-on-Wye Primary School) also have the best airtightness (see fig. 12). Angmering Community Centre is only a little behind Mayville for carbon emissions, yet its airtightness is considerably weaker. This shows that airtightness should not feature too prominently when explaining high carbon emissions, as other factors are also important.





Fig. 12: Plotting CO₂ emissions against measured airtightness shows little obvious link between airtightness and carbon performance. It is interesting that the building with best airtightness - Mayville Community Centre - has the second-best carbon performance.

No clear correlation

Reports on retrofit in the domestic sector⁷ suggest a link between good airtightness and lower CO₂ emissions rates (accepting that airtightness does not guarantee good performance). The graph shows barely any correlation between emissions and measured airtightness results. The black trend line shows only a very shallow gradient. It should be noted that even the domestic study seemed to show no correlation below around 8 m³/hr per m²@50Pa. Additionally, all but two of the projects achieved an airtightness lower than this. Furthermore, though the non-domestic sample includes examples of different building types, they were distributed randomly with no clear patterns.

⁷ Retrofit Revealed, Innovate UK (Technology Strategy Board), 2013, p.14. Link: Click here.

Thermography

Thermography – or thermal imaging – is a useful tool that finds building design problems that are invisible to the naked eye. The projects used thermography to identify problems with air infiltration and leakage, thermal bridging, and underfloor heating.



Fig. 13: 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

Investigating anomalies

In each reviewed case, thermography found more than one anomaly that was worth investigating. This even prompted enquiries that led to solutions for other problems in the building. The technique was very helpful in evaluating underfloor heating systems, and any system that was not immediately visible or easy to assess. It also helped pinpoint areas where the construction details had not been robust, particularly in areas around windows, doors and vents; and at junctions between building elements or irregular (non-90°) corners.



Cause	Solution
Bath Campus	In 4 West, thermography found air infiltration around one of the lecture room fire doors, which needed sealing. It also found issues with the HVAC systems – the cooling system risers leaked cold air into office spaces, and radiators needed balancing. The project team recommended further monitoring for areas that reported thermal discomfort, plus monitoring for window opening. In Woodland Court, thermography found issues with windows in part of the halls, which needed sealing. The project team recommended testing the effectiveness of the seals with, for example, gas-decay testing.
Brighton Aldridge Community Academy	Because some spaces reportedly always felt cold, thermal imaging assessed the underfloor heating. It found that, in the hall, the heating was working correctly. Incoming fresh air was set too cold, due to ambiguous labelling of the air-handling unit in the BMS. In the principal's office, thermography found 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, plus cold bridges at the wall/ceiling junction in various rooms. It also showed that heating and cooling were running in unoccupied spaces. This illustrated poor control of the systems.
Creative Exchange	Thermography found air leakage around the roof stair door, and in the ground floor toilet extract. The window frames showed significant cold bridging, which sometimes led to temperatures low enough to cause a condensation risk. It also found that the piping and controls for underfloor heating led to uneven room temperatures.
Graham Head Office	Thermal imaging and in-situ transmittance tests evaluated the as-built thermal performance of various building elements. The U-values for the curtain walling and masonry north wall were close to the design U-values – and the roof U-value was much higher: 0.34 W/m ² K, compared to 0.11 W/m ² K. Thermal imaging also highlighted areas needing further attention, such as high heat loss at the top of some windows; and thermal bridging between the floor slabs and walls, and the junction between the curtain walling, masonry wall and roof.
Thamesview School	The survey showed some good detailing and construction, including expansion joints in the external wall, at the wall/ground floor junction, and in most of the door/window frame wall junctions. The underfloor heating also functioned well. It found air infiltration in some floor-to-ceiling window frames at the floor, and in some 'non-orthogonal' frames (without right-angles). It also found air leakage on some fire exits and external doors to the drama studio, with potential discomfort in these spaces. Additionally, the survey found thermal bridging at non-orthogonal corners and junctions, and in one of the windows in the administration block, due to discontinued insulation.
Thomas Paine Study Centre	Thermography evaluated the fabric heat storage strategy, particularly where items and materials, such as a suspended ceiling and plasterboard, had covered the thermal mass of the building. Infrared photos showed there was often poor thermal contact between finishes and the heavyweight building frame, reducing the benefit of thermal mass. For example, imaging easily found discrete dabs of adhesive, showing the lower temperature of the adjacent building core, while the rest of the plasterboard was warmer. The project also used thermography to investigate stratification in rooms. This assessed the displacement ventilation and Termodeck systems.



Renewable energy systems

Just under two-thirds of the buildings included onsite renewable energy generation to reduce their energy requirements. However, two-thirds of these experienced problems, which reduced their savings.

The renewable energy challenge

Renewable energy systems, which are often increasingly complex, can contribute to the performance gap between as-designed and actual energy use. Projects also found it difficult to commission uncovered problems, and manage the controls for multiple renewables.



Common themes

A variety of problems

The projects experienced several problems with PV and solar hot water panels. These were generally linked to maintenance, control and metering. Various biomass boilers also suffered operational problems, which often meant projects left them unused. Their problems included inadequate installed sensors; flue heights that were too low and needed raising; difficulties getting the right fuel; and fuel stores becoming wet so the fuel was unusable. One of the ASHPs also struggled to work in cold weather. Other projects in the BPE study included solar photovoltaics, GSHPs, and wind turbines, but these appeared to pose fewer problems.

The value of PV

A number of projects reported problems with PV monitoring and recording output. These issues do not detract from PV's valuable generated electricity, which help reduce carbon emissions.

Project name	Renewable energy technologies	Problems/solutions
Bath Campus	Solar hot water	The solar hot water system was regularly dumping heat because it was oversized, and had limited load during the summer. The project team found that the Legionnaires Disease protocol led to flushing and reheating the system at 2am daily – using the gas boilers. The team found that gas use when the system was operating was lower than expected. This indicated that the solar pre-heated water was helping reduce emissions.
Bluebell Health Centre	ASHP, solar hot water	The air-source heat pump outdoor units struggled in winter, freezing over during particularly cold periods. This was solved by modifying system operation, giving users more controls, and stopping the 'optimised start or stop' facility – leaving a 'less intelligent' system. The solar hot water system was not linked to the BMS system, which made it difficult to evaluate the system.
Brine Leas School	Solar hot water	The solar water system was not specified with a sub-meter, as the contractor mistakenly believed that the BMS would provide monitoring. Additionally, the system had not been properly commissioned. It was recommissioned successfully two years after the original installation.
Coleford Community Centre	PV	The PV electrical output was displayed in the foyer of the community centre, showing users the energy produced. There was only one output from the PV system. This meant that the output could not be recorded in the BMS system as well.
Pennywell Academy	Biomass	An initial review of the biomass boiler revealed problems from the start. These included 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. This made it impossible to assess their contribution to hot water consumption.

Table 5: experiences with renewable energy systems



Project name	Renewable energy technologies	Problems/solutions
Pool Innovation Centre	Biomass, Photovoltaic	An initial review showed the biomass boiler provided only 53% of the heating requirement. This increased the building's CO ₂ emissions significantly, by relying more than expected on supplementary natural gas boilers. The installed PV array (2.7kWp) was much smaller than the design aspiration (~16kWp). This explains some of the difference between the EPC and actual energy use.
Stockport Academy	Ground-source heat pump	The evaluation found that the heat pump was only providing half its 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 change the system, once they established this was possible. Various sub-contractors and maintenance teams responsible for different items were not interacting effectively. Tender documents had also not explicitly stated the design intent.
Thamesview School	Biomass	The biomass boiler had various design and operation issues. Fumes were recirculating back into school rooms, requiring an increase in the flue height; the hopper was too small, needing extra woodchip deliveries; and the blower delivery system was too loud for the suburban location. The ignition system failed in operation, requiring replacement. Bricks in the boiler also broke, requiring replacement. In the first year of operating, the biomass boiler was only running for around 30% of the time. Maintenance and repair resolved these issues and the biomass boiler ran at full capacity.
Tremough Innovation Centre	Biomass	The biomass boiler 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.

Table 5: experiences with renewable energy systems



Innovative building systems

Innovative systems can potentially help buildings perform better. They may be unfamiliar to design teams and contractors. They need careful fine tuning and maintenance to meet design-stage expectations and avoid unexpected problems. Additionally, installing and replacing them can be expensive.

Common themes

Preparing for a long maintenance period

These projects highlighted the importance of preparing for a long maintenance period. This applies particularly to automatic natural ventilation systems. These tend to have many actuator motors, and rainwater harvesting, where filters need changing more often than expected.

Fine and manual controls

The projects showed how important it is to have fine, and ideally manual, controls. This is especially true of systems such as natural ventilation where, sometimes, "... finding the balance is a nightmare," as a project team member for Tremough Innovation Centre noted.

Prepare for the unexpected

Those managing innovative building systems need to appreciate the potential for unexpected outcomes. The systems' logic might not quite match reality, for example, if occupancy hours are not as expected. This can lead to systems fighting each other to control the environment, and increasing energy use.

Project	Systems	Problems/solutions
Bath Campus	Heat recovery	A continuously operating ventilation system had small ducts and filters at each extract point. This led 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. Fan noise often prompted users to press this switch. 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 should work. A manual override control was added to purge hot air in summer. 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 and stop the temperature dropping below an acceptable level. To do this, users had to carefully control the heating and cooling set points. An interlock between the systems or adjusting set points systems could stop the systems opposing each other.
Graham Head Office	Rainwater harvesting	The rainwater harvesting was considered successful, supplying 40% of the building's total water demand. It needed more maintenance than expected. Water filters especially had to be changed more often than recommended, as sediment in the water blocked them.
	BMS-controlled natural ventilation	The system's problems arose due to various 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 helped identify which motors were faulty, by activating all the louvres at once.
		Louvres in meeting rooms were often switched off. Occupants reported cold temperatures and distracting motor noise. This led to people increasingly using the air conditioning manually in meetings to stop overheating, and then not switching it off after.

Table 6: experiences with innovative building systems



Project	Systems	Problems/solutions
Loxford School	Plenum flaps and night cooling	Automatic plenum flaps and roof lights were open in winter, and the night cooling was not working. This led to cold temperatures in winter and hot temperatures in summer. The project team realised that only CO_2 levels – not temperature – activated the openings. 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 the flaps stayed shut. The system was adjusted to also make temperature activate it 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. The project team discovered that cheaper actuators, with lower power and imperfect alignment with the flaps, had replaced the specified actuators (made by the same manufacturer as the plenum flaps). The team recommended replacing these with the original specified actuators. They also installed coarse mesh to stop pigeons moving inside the open flaps.
	Heat recovery	The frost coil in the air-handling unit had a temperature set point of 16°C, meaning that most of its heating came from the frost coil before heat recovery. Frost coils are usually active at ambient temperatures below 3°C. So the team recommended that the BMS monitors 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 did not work properly. This reduced energy use, as the building lost less heat. In turn, this cut heating demand in the morning, but increased overheating risk in the day, while reducing internal air quality.
	Natural ventilation controls	The natural ventilation controls at the pool were a simple press-and-hold control with no delay. This contrasted with the stepped and delayed system at a similar site (Tremough).
Thomas Paine Study Centre	Termodeck	In the first year of operating, the project team found that the heating and cooling systems ran against each other. This was similar to some other sites using Termodeck. The team carefully fine-tuned the system. This significantly reduced heating and cooling consumption in the space.
		The BMS's interface was so complex, the project needed a specialist to set it up properly. This works against ongoing adjustments.

Table 6: experiences with innovative building systems



Project	Systems	Problems/solutions
Tremough Innovation Centre	Rainwater harvesting	The project traced issues when the system started operating back to a blocked filter on the incoming rainwater supply. This indicated that the storage tank was contaminated with dust or dirt. The team also identified an issue 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 was incorrect. The team had to refit the meter onto the correct pipe.
	Natural ventilation Controls	The manual override has a seven-second delay. So users often pressed the button multiple times, which meant going over the desired setting. The design did not intend this; the installer stated that the system should have a maximum delay of one second.
	Earth tube	The project needed to change the settings on the air-handling unit controlling ventilation through the earth tube. A time delay of one hour had been programmed into the system heating battery, and an actuator to control the flow was not fitted. Consequently, occupants complained that incoming air was too cold.
Woodland Trust Headquarters	Ventilation strategy	Motorised windows were originally set to open when internal CO ₂ levels reached 1,200ppm. A lack of fine control on the window opening caused draughts in winter, so the project increased the threshold to 2,000ppm. While CO ₂ levels rarely reached this new threshold, stuffy conditions led occupants to open windows manually. This made automatic control more difficult.

Table 6: experiences with innovative building systems



Handover, commissioning and maintenance

Handover is a critical time for any new building's performance, as commissioning often occurs in the first few months afterwards. It is also an important time for spotting and fixing equipment in the defects period. Additionally, the new building management team has to learn how the building works as quickly as possible.

Common themes

Sub-standard guides

Occupants entering finished buildings need help settling into their new space. Building manuals and user guides should help them understand and control their environment. Various projects reported that user guides typically contain lots of irrelevant, poorly structured and overly basic information.

Tick-box exercise

Manuals are often drafted mainly to gain BREEAM credits or to meet Building Regulations. As such, they result from a tick-box exercise, and are not useful to users. One project had even based a user guide on out-of-date specifications and drawings, and included features not in the building.

Incomplete commissioning

The period just after commissioning is a vulnerable time. Many stakeholders have changing responsibilities, and maintenance contracts can cause conflicts between stakeholders. We saw examples of clients asking to wrap up commissioning before it was complete, and improperly recorded commissioning outcomes.

Project name	Renewable energy technologies	Problems/solutions
Bluebell Health Centre	Building logbook	The building logbook provided a good introduction to the building and building services. However, some sections such as 'Overview of Controls/BMS' were very basic, and did not relate the controls to the overall energy strategy. It did not even mention the mechanical ventilation or heat pump controls. Also, it did not appear 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 incomplete or sparse. 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 questioned. The FM (facilities management) team updated and improved the guide.
	Aftercare	With aftercare service, the FM team has sometimes found it difficult to prove that something is defective. As part of the aftercare, there is a 20-day snagging period, a 12-month defect period, then a 12-year defect period. The FM team can fix problems, however, this may void warranties. So the team is instructed not to fix anything in the 12-month defect period. Fixing defects after this period becomes contractually more difficult. This is an issue for large items with long warranties.
Brine Leas School	Air-handling unit maintenance	The main air-handling unit had a dirty air filter during the study. The school did not change this, as there was no maintenance contract. The school understood the contractor would deal with maintenance and repairs in the 12 months following completion. However, the relevant parts of the operation and maintenance manual were lost. The school recovered this, and took out an ongoing maintenance contract.

Table 7: experiences with handover, commissioning and maintenance



Project name	Renewable energy technologies	Problems/solutions
Creative Exchange	Building user guide	The BREEAM assessor (also the environmental/services engineers) produced a building user guide. However, it included many sections that were irrelevant to occupants, simply to fulfil the BREEAM criteria. This resulted in a bulky, unclear document that the project did not pass on to tenants. A second guide was produced and given to tenants. This missed much useful information on the environmental systems and controls in the building.
	Maintenance	The boiling-water taps for tea and coffee stopped working. They had not been maintained and the filters needed changing. The client was reluctant to sign a maintenance contract with the supplier due to expense, and the taps did not work for some time.
		The limited maintenance budget meant issues were addressed very slowly. Evidence points to a lack of even basic ongoing maintenance. The occupants often did not call a maintenance contractor until issues became emergencies. Issues are also 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. This is probably because Government funding made it difficult to staff these positions before completion. The project did not hire a maintenance contractor until several months after defect liability. The project was also only left with the operation and maintenance manual, with little opportunity to engage with the contractor.
Graham Head Office	Maintenance (and commissioning)	The mechanical and electrical (M&E) engineer still assists the FM staff, and retains an interest in the building's performance. Graham and the M&E company are also working together on other projects.
Petchey Academy	Air-handling unit Configuration	The fan inverters were not enabled on air-handling units. This led to higher-than-expected fan power consumption.
Pool Innovation Centre	Incomplete commissioning	One contractor was 'not able' to complete seasonal commissioning for a system. The occupiers were satisfied with the system operation, and presumably not interested in the time, effort and potential cost involved in further commissioning.
Tremough Innovation Centre	Incomplete commissioning	The building was handed over to the client before all commissioning was complete. This was because construction was behind schedule and the client needed to begin occupation.

Table 7: experiences with handover, commissioning and maintenance



Building management systems, metering systems and controls

Measuring energy use and environmental performance is an essential part of evaluating building performance. BMSs and the meters and sensors that record data are often complex and hard to learn. They also nearly always go wrong without proper commissioning.

Common themes

When skills leave the building

BMSs are complex, particularly in bigger buildings which contain more innovative systems that try to keep users comfortable. Catering for occupants that expect high comfort levels – but have little time or patience to learn new systems – can make things worse. One or more members of the building management team can usually learn how to use the system and run the building properly. The study found several instances where one person with BMS skills left a building without passing on their knowledge.



Fig. 15a & 15b: Heat and electricity meters come in many shapes, styles and sizes, making them hard for people to understand and use.

Catering for occupants that expect high comfort levels – but have little time or patience to learn new systems – can make things worse.

Ineffective sub-meter strategies

While there was a strategy for sub-meters, as required by Building Regulations, they seldom complied fully with the regulations. A desire to achieve BREEAM credits was often behind comprehensive and over-complicated submetering strategies. They were not installed as specified, or without due care (for example, poor calibration and placement). The 201 Bishopsgate project demonstrated that projects in the construction stage should consider carefully the time and cost of setting up complex metering systems.

Metering responsibility

After handover, metering responsibility is often with a controls sub-contractor who is not responsible for the monitored M&E systems. The individual also often does not know the design decisions behind making everything work together. Finally, no one owns the data or checks that it is reasonable.



Project	Strengths	Weaknesses
201 Bishopsgate	Contractors identified 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 and corrected issues that reduced the total building electricity consumption by around 20%. This included refining the local BMS settings e.g. changing inappropriate time clock or demand settings; switching off the underfloor heating in reception in the summer; 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. This allows more flexible working hours. The project felt these demands were often 'unnecessary', so reduced the facility after discussions with the tenants. The study had to estimate energy use in 2011 for the TM22 analysis, as sub-meters did not record 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 in generally well day-lit corridors. A modification was possible. At Brine Leas School, presence detection with daylight dimming controlled corridor lighting. The presence of people anywhere in the building meant the lights were constantly on. The atrium did not have an override, so the school could not turn off lights separately. At Brine Leas, there were issues with the BMS. 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 1,000 data points before starting to overwrite them (after about 10 days). The centre changed this to half-hourly and daily totals, and set it to regularly download on the council's databases for storage.	Meter reviews identified calibration issues with some electrical meters. The Current Transfer (CT) ratio was set ten times too high, resulting in just 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 BMS, not the meters, had already corrected results, but this was not recorded. Tenants were charged for electricity based on the sub-metering, meaning some occupants faced much higher bills.



Project	Strengths	Weaknesses
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. Meter readings were done manually rather than through the BMS. However, this helped the project quickly spot variations in energy use.	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. A battery replacement schedule has been agreed. The batteries were seen as expensive and expected to last longer. This caused an overheating problem: the BMS interpreted the failed thermostats as being 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 frost
		protection. The project corrected this.
Graham Head Office	The BMS was installed without issues, apart from a few sub-meters not recording properly, which were fixed. The staff are happy that it has been well-calibrated and is reporting the correct figures. Staff can use the BMS to activate the louvres for controlling natural ventilation individually or all at once. This occasionally helps identify failed motors when an issue has been reported.	Before handover, no one was made responsible for the BMS and meter readings. Staff at the training session passed on relevant information to the current building manager.The BMS is working well, but the project is not using many of its features, such as night cooling. This may be because the system is complex.
		Staff find the BMS is not suited to collecting and helping interpret meter data. The system overwrites data after only three weeks. To improve energy monitoring, the BMS contractor installed 'Trend Energy Manager'. Some of the sub-meters were also found not to be recording properly.
iCon Daventry	After a year of operation, the building managers reduced energy use significantly, despite increasing occupancy. They did this by changing the auditorium air-handling unit's operational regime. This was previously operating continuously for long periods because its poor starting worried users that it would not come online when needed.	The monitoring system had faulty meters that were not recording pulses properly. These were eventually swapped with meters from unused units in the building.



Project	Strengths	Weaknesses
Tremough Innovation Centre	Natural ventilation controls were integrated into the BMS, rather than being a separate work package.	The project aimed to ensure that all meters and sub-meters would link 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. At first, many of the BMS readings were incorrect. This was due to initial calibration errors and/or communication between meters and the BMS.
Thamesview School	The project felt the BMS system was working well generally. After installation, specialists had improved the BMS's performance by adjusting and maintaining the system.	The project team felt that general staff do not use the BMS enough, due to lacking confidence and worrying they would change a vital setting. The team undertook work to calibrate the meters against manual readings. It found that various meters gave very different results to the BMS. Also, some parts of the site were not sub-metered. The project has corrected these issues. The BMS monitoring works on a simple average, making it difficult to interpret the data. This is due to large differences between different parts of the school. Meter logs are difficult to download. The system makes 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. This was particularly important for the regenerative heat exchanger, where a flow reversal could occur up to every minute.
Woodland Trust Headquarters		Unnecessary heating circulation was found outside the heating season. This was due to the heating pump running during all occupied hours. The BMS Contractor corrected this at the BMS, ensuring the heating pump only operated when there is demand for heating.

Table 8: experiences with building management systems, metering systems and controls



Occupant satisfaction

Occupants are at the heart of building design and energy use. However, designers and developers rarely consult with them or ask their opinions after handover. A 'Building Use Study' was a major part of the BPE study, and used to interview various stakeholders involved in in constructing and occupying buildings.

Highlighting design problems

The study used the Building Use Studies (BUS) methodology to evaluate post-occupancy satisfaction in each of the buildings. This did not directly help assess the performance gap. The surveys indicate whether a building is fulfilling its goal of providing a comfortable and productive environment. The surveys are useful for highlighting design problems, especially those relating to controls and BMSs.

Summary variables

The study analysed 54 BUS studies, focusing on the following overall summary variables. This is a larger sample than other sections in this report, because some of the projects that completed BUS surveys did not have a full year of reliable energy data.

- Air in summer
- Air in winter
- Comfort
- Design
- Perceived health
- Lighting

The scoring system

A score was given to each variable and compared with the other buildings in the BUS database, using a red/amber/green system . Scores comparing favourably against the stock and benchmark values are in green. Those that fall below the benchmark are red, while those broadly the same as the benchmark are yellow.

A closer look at the scores

Thirty of the buildings had no red scores, with average or above average scores in all variables. 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 various aspects of satisfaction with comfort, and meeting staff needs.

- NeedsNoise
- Perceived productivity
- Temperature in summer
- Temperature in winter



⁸ For more information on the BUS methodology click here



Fig. 16: Most projects scored average or above average (amber or green) in all key BUS summary variables. Only two buildings were below average overall.

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Poorly rated variables

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. Temperature in winter (20%), Perceived health (19%), Air quality in winter (17%), and Productivity (17%) also rated poorly.

Positively rated variables

The other variables were broadly average or above average across the buildings, with a few exceptions. More than three quarters of the 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 the projects are succeeding when it comes to:

- designing buildings that project a positive image
- offering good daylight and electric lighting
- providing comfortable facilities

Common themes

Involving occupants in design

There is consensus that designers should involve occupants as much as possible in design decisions. Various projects tried to involve clients early in the design process. However, they tended to be building managers, not occupants. So it is difficult to draw clear conclusions. In some cases, occupants were keen to know more about how best to operate their buildings, but were frustrated by a lack of clear direction. In one case, this led to overheating issues. Occupants had tried to solve an issue themselves, and blocked ventilation openings to reduce draughts.

Local user control issues

Many buildings had issues with local user controls, which aimed to give people ownership over their workplaces. In some cases, occupants set their thermostats at 19°C, which is lower than expected. However, these controls sometimes caused much higher emissions. This is because they made occupants free to request heating, cooling and ventilation at any time of day, so the systems always had to be ready for occupation.

Project	Systems	Problems/solutions
201 Bishopsgate	Glare	Glare was an issue for occupants, despite the building having blinds. Light passed 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 nearby occupants discomfort. Some areas of the building had secondary blinds to alleviate glare and solar gain.
	Temperature	Some overheating was found when vents near windows were blocked or covered. This discovery followed complaints about draughts.
Creative Exchange	Temperature	Most thermostats, controlled by local users, were set at 19°C. 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. They said they wanted clearer information about the controls and environmental strategy. For example, many tenants did not know 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. This noise is 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 '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. While there was a manual override, occupants considered the manual opening and closing was also too slow.



Project	Systems	Problems/solutions
Pool Innovation Centre	Glare	Occupants reported issues with glare. 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. As such, occupants often requested 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 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 management team's responsiveness to problems directly affected occupants' thermal comfort. The division between the FM team and school means occupants are less tolerant and potentially less satisfied. Establishing closer links might help.
	Wellbeing: space planning	There were some complaints about the building space planning. Occupants felt open plan areas disrupted teaching. Additionally, there were teaching spaces without windows or openable windows, that occupants felt were uncomfortable.

Table 9: building occupant satisfaction



Overcoming challenges

This section looks at the main challenges that arose repeatedly across every project. It also suggests potential solutions for project teams.

Renewable energy systems

Common challenges

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

Possible solutions

- 1. Only specify tried-and-tested renewable energy systems, and ensure that they are installed by personnel who have done the job well before.
- 2. Focus on keeping things simple, not ticking every regulatory box (e.g. BREEAM); think more about the people who will be controlling the systems.
- **3.** Make sure personnel set up metering and controls correctly, so occupants can manage them properly.

Energy use

Common challenges

- **1.** Design estimates overlook unregulated energy.
- **2.** Design estimates optimistically assume hours of use.
- **3.** Design estimates assume renewable energy generation systems will perform perfectly.

Possible solutions

- Recognise that regulated energy (heating, lighting, cooling and ventilation) is only part of a building's true carbon footprint. Unregulated energy from plug-in appliances can generate the same CO₂ emissions and more.
- **2.** It is important to note that out-of-hours energy use is considerable and sometimes as much as the energy used in the working day.
- **3.** Consider that CO₂ reductions from renewables may not arise without a lot of hard work.

Airtightness

Common challenges

- **1.** Inadequate forethought in design causes 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.

Possible solutions

- 1. Mark the air barrier on all drawings clearly and brief site staff on why it is important to check the air barrier at every construction stage.
- **2.** Appoint an onsite airtightness champion who is authorised to intervene if any work risks harming airtightness.
- **3.** Consider writing the airtightness target into the main contractor's contract, with penalties if they do not achieve it.



Innovative building systems

Common challenges

- **1.** Innovative systems rarely work perfectly to at the start. Rushing to handover can mean missing opportunities to optimise and maintain new systems.
- **2.** The unexpected can happen if a system's built-in logic does not match reality, or occupants can access manual controls for systems they do not understand.

Possible solutions

- **1.** Prepare for a long period of commissioning, and document who is responsible for fixing problems.
- 2. Write a clear and concise building user guide that easily explains the building's operation, and the logic behind the new systems that occupants will use.

Commissioning and handover Common challenges

- **1.** The staff responsible for operating a building may not be present during handover.
- 2. Building user guides and logbooks produced for Building Regulations or BREEAM often lack information that helps users understand how the building works.
- **3.** When clients are rushing to move in, commissioning may not be completed properly, leaving loose ends.

Possible solutions

- **1.** Ensure that an onsite individual is responsible for receiving information before handover, and passing this on if necessary.
- **2.** Arrange for building user guides that meet occupants' needs first and targets second.
- **3.** See commissioning as an essential part of the building process, not an optional extra. Clarify this to everyone involved, and make sure they understand what happens if it goes wrong.

BMSs and metering

Common challenges

- **1.** Complex BMS systems need handing over carefully, especially when multiple sub-contractors are involved.
- **2.** BMS systems are often not set up for data collection, and many record a maximum of just 1,000 data points.
- **3.** Meters are often not calibrated or installed properly.

Possible solutions

- **1.** At an early stage, make someone responsible for coordinating the different sub-contractors working on the BMS.
- **2.** Find out the system's data capacity, and ensure there is a procedure to capture it, for example, by storing it offsite.
- **3.** Check meter calibration and data quality after handover. Many projects found and corrected problems quickly.



Appendix 1: Building details

Name	Sector	Area (m²)	BER (kgCO ₂ /m²/yr)	Design airtightness	Tested airtightness	Electricity	Gas and other heating fuel	BREEAM environmental
				(m³/h.m²@50pa)		kWh/m ² / year	kWh/m²/year	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	House	2,649	14	10	4.81	113.8	0.0	Excellent
Bourne Hill Council Offices	Health	4,258	21.1	10	4.81	78.1	86.8	Excellent
Brighton Aldridge Community Academy	Office	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
College Lake Wildlife Visitor Centre	House	362	43.4	7	-	85.8	0.0	-
Crawley Library	House	4,468	13	5	4.88	104.4	35.3	Very good
Creative Exchange	House	705	15.9	8.19	8.6	45.8	118.6	Very good
Cressex Community School	House	11,624	14.7	7	4.97	69.2	52.7	Very good


Appendix 1: Building details

Name	Sector	Area (m²)	BER (kgCO ₂ /m²/yr)	Design airtightness	Tested airtightness	Electricity	Gas and other heating fuel	BREEAM
				(m³/h.m²@50pa)		kWh/m ² / year	kWh/m²/year	rating
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 Head Office	Office	3,270	13.7	5	4.98	102.1	46.0	Excellent
Greenfields Community Housing Headquarters	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
Mayville Community Centre	Public Service	800	13.7	0.9	0.51	47.2	0.0	Passive House
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



Appendix 1: Building details

Name	Sector	Area (m²)	BER (kgCO ₂ /m²/yr)	Design airtightness	Tested airtightness	Electricity	Gas and other heating fuel	BREEAM environmental
				(m³/h.m²@50pa)		kWh/m²/ year	kWh/m²/year	rating
Rogiet Primary School	Education	1,981	20.5	4.43	-	82.3	63.2	Excellent
South Place Hotel	Hotel/other residential	2,162	28.9	10	-	132.0	0.0	-
St Peter The Apostle School	Education	16,900	9.2	5	-	65.6	201.6	Very Good
Staunton-on-Wye Primary School	Education	3,270	13.7	5	4.98	102.1	46.0	Excellent
Stockport Academy	Education	2,180	24.7	6	7.42	189.1	0.0	Very good
SusCon - Sustainable Construction Academy	Education	3,907	12.4	10	-	79.2	47.2	Excellent
Thamesview School	Education	2,492	17.3	-	5.78	107.0	145.7	-
The Main Place, Coleford Community Centre	Public Service	14,610	18.5	5	4.36	69.1	97.4	Excellent
Thomas Paine Study Centre	Education	19,417	51.1	2.9	2.93	193.9	18.1	Excellent
Tremough Innovation Centre	Office	800	13.7	0.9	0.51	47.2	0.0	Passive House
University of the West of Scotland Ayr Campus	Education	7,758	23	4	4	316.7	81.3	-
Vale Community Hospital	Health	2,538	28.9	7	5.92	127.9	214.5	Excellent
Woodland Trust Headquarters	Office	2,514	13	3	5	95.8	132.7	-

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