Estover Community College Campus

Innovate UK project number	450026
Project lead and authors	AECOM, University of Exeter and University of Bath for Kier Construction
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Building sector	**Location**	**Form of contract**	**Opened**
Schools	Plymouth	Design and build	2012
Floor area (GIA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
16,900 m^2	2 (predominantly)	A (19) / N/A	Very good

Purpose of evaluation

The study objectives were to document the design intent for the new campus, understand if the 60% energy-related carbon dioxide emissions reduction target had been achieved, compare the overall energy use with existing benchmarks for similar buildings, survey the campus staff about their opinions on all aspects of the new buildings, deliver energy awareness training to building users through structured sessions and materials, identify opportunities for how energy use could be reduced, evaluate the indoor environment during occupation, and evaluate how future climate change may influence the indoor environment.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
No	Yes	Partial

Electricity calculated at 58.4 kWh/m² per annum, Thermal (fossil fuel) approximately 145 kWh/m² per annum. The study found problems with the installation, commissioning and documentation of the energy metering. This limited the ability to monitor and target reductions for energy consumption. Around 71% of total annual electricity consumption is submetered for the whole campus. Many heat meters and flow meters produced unreliable readings. The campus, including the existing Sound House, used about a third more than expected from a energy assessment and over twice a typical secondary school benchmark. This was thought partly due to atypical end uses such as sports pitch floodlighting and out-of-hours use of the campus.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	63 of 142	44%

The school campus performed well for all summary comfort variables. Respondents expressed high satisfaction with air in summer. This may be related to the natural ventilation strategy that allowed for large windows to be opened, as well as the reduction of solar gains through solar control glazing. Some respondents stated that the automatic lighting control was frustrating. Daylight glare was an issue in some rooms due to large areas of glazing. Some respondents stated that either there were not enough meeting rooms or larger ones were needed. Some respondents mentioned that there was not enough storage.

About this document:

This report, together with any associated files and appendices, has been submitted by the lead organisation named on the cover page under contract from the Technology Strategy Board as part of the Building Performance Evaluation (BPE) competition. Any views or opinions expressed by the organisation or any individual within this report are the views and opinions of that organisation or individual and do not necessarily reflect the views or opinions of the Technology Strategy Board.

This report template has been used by BPE teams to draw together the findings of the entire BPE process and to record findings and conclusions, as specified in the Building Performance Evaluation - Guidance for Project Execution (for domestic buildings) and the Building Performance Evaluation - Technical Guidance (for non-domestic buildings). It was designed to assist in prompting the project team to cover certain minimum specific aspects of the reporting process. Where further details were recorded in other reports it was expected these would be referred to in this document and included as appendices.

The reader should note that to in order to avoid issues relating to privacy and commercial sensitivity, some appendix documents are excluded from this public report.

1 Introduction and overview

1.1 Introduction

This report details the findings of the Building Performance Evaluation (BPE) of Estover Community College's new school campus (see Figure 1.1). This was led by Kier Construction, the Main Contractor, working with the leadership and facilities management teams at the campus and with AECOM, the University of Exeter, the University of Bath, and the Centre for Sustainable Energy. The project has been funded by the Technology Strategy Board (TSB) under their BPE programme. The two year study began in May 2012 and was completed in April 2014.

The BPE study has found that overall the new the school campus is very successful in delivering its primary function of providing facilities and an environment conducive to good teaching and learning. Occupant satisfaction is extremely high in comparison to a reference non-domestic benchmark set and staff greatly appreciate the design of the new campus with its high levels of natural light and large open spaces. The staff also like the high level of manual control they have over teaching spaces with openable windows, secure night ventilation, local controls on radiators, and simple light switches. Furthermore, there is also some evidence to suggest that pupil behaviour may have improved as a consequence of the design of the new school campus.

However, the BPE also discovered that although the school campus delivers its intended purpose to a particularly high standard, it may do so at an energy penalty, with electricity consumption above modelled energy assessment expectations and industry benchmarks. However, close inspection of these benchmarks has raised the possibility that they may not be wholly applicable due to a lack of clear industry guidance over which facilities the benchmark schools data set contains (i.e. kitchen, server room, sports pitch floodlighting, etc) and what hours of use they represent. That aside, the BPE was able to identify several areas of wasted energy use and has made recommendations to reduce these with short estimated payback periods.

Only a basic building management system (BMS) was specified as part of the new campus design. This was not intended to fulfil the operational requirements of a full building energy management system (BEMS). So, the BMS provides only limited functionality for monitoring and targeting reductions in energy consumption. During the BPE, it was however learnt that there were number of operational difficulties with the BMS affecting control of building systems and energy consumption in certain spaces.

Additionally, problems with the installation, commissioning and documentation of the energy metering were found. This has limited the school’s ability to both monitor and target reductions for energy consumption. Without this BPE study, it is highly unlikely that this issue would have been identified and acted upon.

Specifically, the study objectives were to:

- document the design intent for the new campus,
- understand if the 60% energy-related carbon dioxide emissions reduction target has been achieved,

- compare the overall energy use with existing benchmarks for similar buildings,
- survey the campus staff about their opinions on all aspects of the new buildings,
- deliver energy awareness training to building users through structured sessions and materials,
- identify opportunities for how energy use could be reduced,
- evaluate the indoor environment during occupation, and
- evaluate how future climate change may influence the indoor environment.

The following Sections describe the processes and analyses undertaken to successfully complete the above objectives.

1.2 Project background

The school campus is located in Plymouth, UK. The new development has a total gross building area of approximately 16,900 m^2. During a typical 7 hour teaching day for about 190 days per year, the school campus is the centre of education for around 1,600 pupils, from ages 4 to 18. On a standard working day, there will be around 200 teachers and other support staff on site for about 200 days per year.

The construction project for the new campus involved the replacement of local primary and secondary school buildings, bringing both together onto a single site along with 'Speech and Language' and 'Severe Learning Difficulty' units. An innovative aspect of the Main Contractor’s proposal was that the new school campus would be constructed around the dilapidated existing secondary school in three distinct phases. This phased approach allowed many parts of the original school to still be used during the construction process and ensured retention of the playing fields. The new buildings are predominately two storeys and are grouped into self-contained learning clusters, which are interlinked over the changing levels of the site to form a series of four plateaus. Construction of the three separate phases was continuous, beginning in spring 2009 and completing in summer 2012.

The BPE was originally intended to examine only buildings from Phase 1 of the construction (consisting of blocks Austen, Tenzing, Cann Bridge, Cade North, Cade South, and northern half of Faraday) - see Figure 1.2. During the course of the project, it became clear that the configuration of the energy metering made the process of accurately apportioning energy use to the different phases almost impossible. The scope was therefore later extended to cover Phase 2 (southern half of Faraday and the Sports Hall) and Phase 3 (Graham Browne building and the Primary School), as well as the existing Sound House building, the only remaining part of the original school.

1.3 Key findings for the project

The BPE team considers the following to be the overall key findings for the project:

- *Design*
  - An occupant survey revealed that staff generally hold favourable opinions about their environment, with the school campus performing extremely well in the vast majority of assessed criteria.
  - The (predominant) natural ventilation strategy provides staff with a high level of control over the

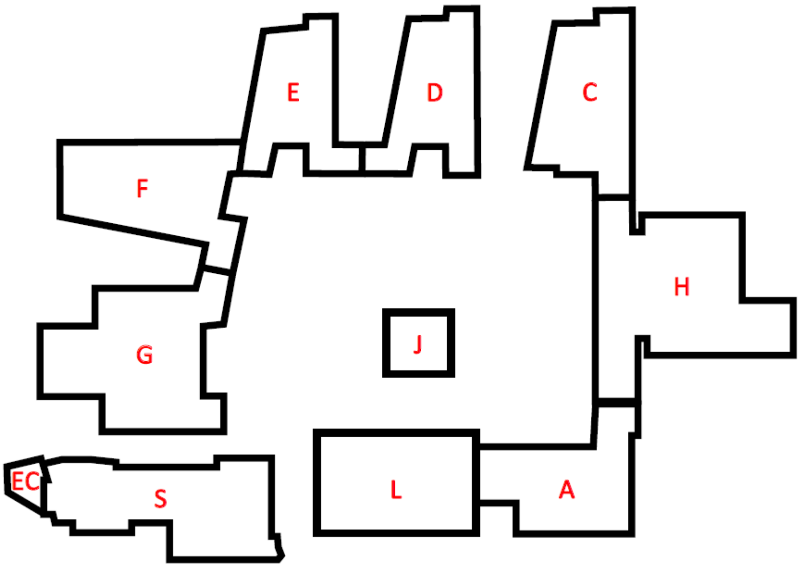
internal environment of teaching areas leading to high occupant satisfaction.
- The BMS does not include the necessary energy management and analysis tools to carry out long term energy monitoring and diagnostics.

- *Installation, commissioning, training, operation and maintenance*
  - The actual operating hours for the campus buildings extend significantly beyond those required for core teaching during term time.
  - Significant problems became apparent with the installation, commissioning, maintenance and reliability of the building management system (BMS), with periods in which the Facilities Management team were unable to use it to control building systems.
  - There have been considerable problems with the installation, commissioning, documentation, labelling and reliability of energy metering.
  - Around 71% of total annual electricity consumption is submetered for the whole campus. (From measurements made during the BPE, it is believed that the existing Sound House building accounts for a further 11% of total annual electricity consumption, indicating a total of 82%. For reference, the Building Regulations Part L target for new buildings is that 90% of energy consumption should be submetered.)
  - The gas boilers are not separately submetered, even though they represent 94% of gas consumption.
  - Many of the heat meters and flow meters produce unreliable readings.
  - The level of training for the Facilities Management team could have been improved, particularly with respect to the BMS system.
  - Extensive maintenance and supplier issues with the biomass boiler meant that it was only in operation for a few months and has now been ‘mothballed’ by the school.

- *Energy management*
  - The hot water system is operating out of term time leading to wasted heat, through losses in the district heat main.
  - Standby loads for small power appliances account for around 65,000 kWh of electricity consumption per year which is approximately 7% of total electricity use and represents a cost of about £7,500.
  - In terms of electricity consumption, the school campus, including the existing Sound House building, uses around a third more than expected from a modelled energy assessment and over twice a typical secondary school benchmark. This is thought to be due in part to atypical end uses such as outdoor sports pitch floodlighting, and out of hours use of the campus.
  - Analysis of the heat consumption data shows that the school campus is using slightly less heat than a typical secondary school benchmark, although this is somewhat higher than best practice.

Figure 1.1: Views from inside the school campus.

1.4 Site plan



Operation reference	Block	Faculty
E	Austen	Maths, English
D	Tenzing	Humanities, Languages
C	Cann Bridge	Special needs
H	Primary	-
A	CADE South	Dining, Food tech
L	CADE North	Library, Art, Admin
S	Sound House	Music, Drama
G	Sports	Sports, Dance
F	Faraday	Science, D&T, ICT
J	Graham Browne	Multi use hall
EC	Energy centre	-
Note: the diagram above uses the operational building references		

Figure 1.2: The school campus site layout and block references used during construction and operation.

2 Details of the building, its design, and its delivery

2.1 Buildings overview

The school campus consists of 10 buildings with an Energy Centre housing biomass and gas boilers, which provide heating through a local heat network. These buildings are all two stories apart from the Graham Browne building, which is a one storey multi-functional hall in the centre of the campus, and the Cann Bridge 'Severe Learning Difficulty unit' at the south east, which is also single storey. Although considered discrete buildings, many are interlinked through internal circulation areas which form double height atrium spaces.

The majority of these blocks provide classroom teaching facilities for various subject areas (see Figure 1.2), offices for administration staff, and IT facilities. A Dining Hall, kitchen facilities (which are additionally used to produce food for several smaller neighbouring schools) and a main IT server room are located in Cade South.

The only remaining part of the original school is the Sound House which provides drama and music facilities. Although the original intention was to refurbish this building, budget restrictions meant this was not possible. The Sound House has several studio areas (large performance areas) with Bleacher seating and stage lighting. Practice rooms provide classroom facilities. There are two plant rooms containing existing AHUs for the studio areas and its own heating plant serving approximately half of its area, the remainder being supplied through the new local heat network.

The Graham Browne building was completed as part of Phase 3. It is a multi-use hall (1,270 m^3) in the centre of the campus. It contains a double height presentation space with Bleacher seating, WCs, and a small plant / store room.

The Primary school was part of Phase 3 of the construction and provides facilities for approximately 200 pupils. It has slightly different operating hours to the rest of the site with classes starting at 09:00 and finishing at 14:30. It mostly consists of classroom teaching areas, but also has a gym (1,284 m^3), which is occasionally used for exams for the secondary school and after school clubs.

Additionally, there is a Youth Centre, a Nursery, and the Tamar Centre on site, which have not been considered as part of this BPE study. These buildings have separate submeters for gas and separate mains electricity supplies.

2.2 Design intent

The new school campus benefitted from funding from the DCSF's low-carbon schools initiative to achieve a 60% reduction in energy-related carbon dioxide emissions below 2002 Building Regulations guidance, which was demonstrated at design stage through the use of DCSF’s Carbon Calculator. To achieve the 60% reduction, a biomass boiler was specified as the primary heat source as part of the overall strategy to reduce carbon dioxide emissions. Gas boilers were also included to supplement the biomass boiler for meeting peak heat demands as well as to act as duty boilers during maintenance of the biomass boiler. Also contributing to this low carbon objective, the specified materials and construction approach were intended to produce well-insulated buildings with low thermal transmittance ('U-values') and air permeability. Relating to energy use and the indoor environment, the campus was constructed in accordance with the following guidance:

- Energy use and carbon dioxide emissions:
  - Building Regulations Approved Document L2A 2006 (ODPM, 2005)
  - DCSF Carbon Calculator (DCSF, 2008)
- Ventilation and summer thermal comfort - Building Bulletin 101 (DfES, 2006a)
- Acoustics - Building Bulletin 93, (DfES, 2006b)

The BPE team were unable to find any direct reference to the guidance used for winter thermal comfort design or daylight design. It is assumed that both these aspects were designed in accordance with Building Bulletin 87 (DfES, 2003).

The new two storey buildings have predominantly been constructed using in-situ concrete slabs and columns. The external envelope for the lower levels is insulated timber frame with external brick leaf. The upper levels generally have an insulated render system outer leaf with a timber frame inner leaf. Table 2.1 summarises the design U-values for the various construction elements, while Table 2.2 summarises the design U-values for the glazing.

Table 2.1. Summary of design thermal properties for construction elements.

Construction element	**Area weighted average thermal transmittance U-value W/m²K**
External Wall	0.25
Internal Wall	1.28
Roof	0.18
Internal Ceiling	1.72
Ground Floor	0.22
Doors	2.20

Table 2.2. Summary of design thermal and other properties for glazing.

Glazing type	**Typical thermal transmittance U-value**	**Typical g-value BS EN 410**	**Framing ratio**
	W/m²K	**-**	**%**
Low emissivity Suncool High Performance	1.4 (Including frame)	0.41	10
Standard Double Glazing	1.8 (Including frame)	0.72	10

The buildings were designed to use natural ventilation as much as possible to help reduce energy demand. The natural ventilation is manually controlled through openable external windows (some of which have secure grilles allowing them to be act as night vents) and internal fanlights above internal doors into atrium areas. Mechanical ventilation is only used when required for specific areas such as the Library, Kitchen, Dining Hall, and Server room. High thermal mass in the classrooms (achieved with the aid of exposed concrete soffits), cooled with secure natural cross ventilation at night-time, which is intended to reduce the risk of overheating from the combined effects of high external air temperature, solar-, equipment- and occupant-related heat gains. This design strategy is intended to avoid the need for mechanical cooling.

The embodied energy impact of the heavy-weight construction has been mitigated by limiting it to floor / roof slabs within teaching rooms only. By contrast, the open plan areas, circulation and large spaces have lightweight roofs. The internal partitions are also lightweight to provide floor plan flexibility for future change of use, an important consideration in the education sector.

Electric lighting for classrooms has been provided through low energy fittings controlled through manual switches with movement sensors to automatically turn off lights when no presence is detected for 20 minutes. Additionally, the lighting level for these areas is automatically regulated according to natural daylight levels. The design of the lighting system aims to maximise natural daylight in the teaching and circulation areas, with glazing accounting for approximately 40% of the area of elevations. While the large amounts of glazing are provided to maximise daylight within the building, this could result in overheating from excessive solar gain. To reduce this, solar control glazing is used to the east, south, and west faCades which lessens the solar (shortwave infrared) radiation entering the building. However, during winter solar gain can be beneficial and may help to reduce the demand for heating, which is assisted by a low-emissivity coating within the glazing system.

Following the guidance in Approved Document L2A (2006) stating that 'at least 90% of the estimated annual energy consumption of each fuel' should be submetered, extensive energy submetering is installed across the campus, from which data are captured by a building management system (BMS). The submetering is intended to allow disaggregation of energy end uses and covers heat, gas, and electricity distribution.

The Energy Centre houses the gas boilers, the biomass boiler and thermal store, and associated pump sets including those for the three low pressure hot water (LPHW) flow and return circuits to other blocks. In addition there are a number of smaller 'satellite' mechanical plant rooms around the site, which contain local heating and hot water distribution equipment supplied from these three Energy Centre LPHW circuits, including pumps, hot water storage calorifiers, and some air handling units (AHUs).

2.3 Design process

Following a design competition in 2007, the project was procured under a design and build contract and funded by the Department for Children, Schools and Families (DCSF), with top-up funding from Plymouth City Council, the Main Client. The Main Client and their consultant's involvement, once the initial brief was set, was mainly to oversee delivery in terms of ensuring all regulatory elements of the brief were met and to ensure the budget was maintained rather than to be an active part of the detailed design process.

Significantly, the end users of the school were activity involved in developing the initial design. The Architects and Main Contractor were heavily involved in a process of refining and pinning down the brief during the early stages of design to ensure that the required facilities could be delivered for the budget. This process included realisation that the initial brief prepared by the Main Client's architects did not match exactly with the school's needs. This may be due, at least in part, to the original brief being principally based on generic Building Bulletin 87 requirements.

The Main Contractor ensured an active process during the early design that regularly checked the end user wishes against buildability and allowances in the budget to arrive at a solution that could satisfy the operational requirements of the school and be delivered within the contract sum. End users were involved through an independently facilitated Design Quality Indicator (DQI) assessment, during which their priorities were understood through a series of structured questions. This process focused on the use of spaces and the grounds and also the relationship the buildings have with the local community. It also helped to identify areas where there was a difference between the priorities of the end users and the assumptions of the designers.

During the development of the design there was pressure on the budget which at times was significant. Of course, this is not unusual and responsible management of costs is essential on all projects. However, interviews with key members of the design team indicated that this focus on cost may have reduced the effectiveness of the design process. In particular, this included only limited involvement of the original Building Services Designers during installation, commissioning and handover.

As part of the process of developing the final Contractors Proposals, there were many meetings with the school including end of stage meetings to sign off the design along with independent DQI reviews. Although many end users were involved in the design process, it seems that the subsequent Facilities Manager had very little involvement, which if available would have been desirable and may have helped to prevent some of the maintenance issues that subsequently emerged at the completed campus.

The expectations of the Main Client and school appear to have been effectively managed and successfully fulfilled. In this respect, the school campus' Finance Director has suggested that the finished project is very close to the original vision that was developed during early concept sessions, which is an encouraging finding and reflects the overall success of the design process.

2.4 Construction process

The construction process was conceived so that the operation of the existing school could be maintained throughout. This meant that phased construction around the existing buildings was required, with the project being completed in a total of three distinct phases between spring 2009 and summer 2012 (see Figure 2.1). Another key benefit of this approach was that it was possible to retain the existing playing fields. The phased build also allowed the construction team to react to issues raised by the school in completed buildings while still on site and engaged in works in other areas. However, this did present some issues in terms of defects periods for systems which spanned construction phases (such as the BMS).

The site of the campus slopes from west to east, which resulted in the various blocks being constructed on a series of four 'plateaus'. On the plateaus there are a total of nine new blocks, plus the existing Sound House building (the only building retained from the original school) which make up the secondary school, with the primary school located to the south of the site. The total gross internal area (GIA) of the buildings included in the BPE study is approximately 16,000 m^2.

Generally, commissioning of the various building services was carried out by the M&E Subcontractor with specialist equipment (such as the biomass boiler) being commissioned by the installer. The Buildings Services Designers' role included witnessing the commissioning of the installed service systems.

Table 2.3. Design and construction team for the school campus.

Duties	Notes
Main Contractor	Selected through a design competition
Architects	Took the project from concept through to completion of all phases
Building Services Designers	Early phases completed in designer's Plymouth office, but this closed part way through the project meaning a change in team and the work was relocated to the Exeter office. Responsible for performance design initially, but separately appointed to the M&E Subcontractor to carry out detailed design at a later stage
Building Services Subcontractor	Responsible for the detailed design and installation of the building services

Figure 2.1. Arial photograph showing the construction phasing plan.

2.5 Operating hours

The operating hours for the school campus are somewhat irregular. Monday to Friday lessons begin at 08:30 and finish at 15:00. However, pupils can begin to arrive on site from 07:30 as breakfast is available and served between 7:30 and 8:30. Various after school clubs mean that a proportion of pupils can still be on site until 16:30 or later. Teachers typically begin arriving from 07:30 and regularly work in their classrooms for a few hours after pupils have left. Facilities Management (FM) Team members arrive on site from 06:30. In the evenings, they carry out a site wide walk around to lock up all buildings from 20:00 and leave at 20:30. Cleaning staff arrive onsite from 04:30 and leave at 20:00. The Sports Centre provides facilities to the wider community and is operational until around 22:00 on weekdays and is open on weekends and school holidays in addition. Teaching is split into separate periods (Table 2.4) with pupils moving to different classrooms throughout the day as their timetables require.

The school campus has around 190 teaching days a year spread across 6 terms. Additionally there are 10 inset days where teachers will be present put no pupils. There are 60 days of holiday a year (including bank holidays). The FM team will commonly be present on site during holidays and teachers will often (and without prior warning to the FM team) turn up on site to work in their classrooms, with the expectation that certain building services (heating, hot water, etc) will be provided.

Table 2.4. Timetable for a typical school day.

Time	Period
<08:30	Breakfast
08:30 - 09:00	Tutorial
09:00 - 10:00	Period 1
10:00 - 11:00	Period 2
11:00 - 11:20	Break
11:20 - 12:20	Period 3
12:20 - 13:20	Period 4
13:20 - 14:00	Lunch
14:00 - 15:00	Period 5

2.6 Log Book review

As part of the BPE process, the school campus' Log Book for Phases 1 and 2 has been reviewed. Building Regulations Approved Document L2A (2006) recommends good practice for such log books is to follow the template provided by CIBSE Technical Memorandum 31 (2006, TM31). This defines a log book as a summary document written for the building's FM team covering a wide range of information. For the purposes of this review, the existing Log Book has been compared against the TM31 guidance. The full review can be found in Appendix 10.2.

In general, the Log Book reviewed for this project contains some useful information for the Facilities Manager, but is limited in providing the general users (i.e. other FM staff) with general guidance on using the systems at their disposal. There is much information that has been extracted directly from other technical documents, but it did not seem to have been edited for a more general audience. Some inaccurate information was also found.

2.7 Soft Landings review

Phase 1 of the school campus development has been included in the 'Soft Landings for Schools Case Studies' (UBT, 2010). There were, however, no contractual requirements for Soft Landings to be followed for any of the phases. The Architect and Main Contractor introduced aspects of Soft Landings during the pre-handover and aftercare stages, including this BPE study, to proactively enhance the delivery process. To understand to what extent the principles of the Soft Landings (SL) Framework were included in the project and the potential impact of the approach taken, a series of interviews has been undertaken with key members of the design team, delivery team and client representatives. The findings of the interviews have been reviewed and compared to the principles and various activities of the SL Framework to highlight gaps. The full review can be found in Appendix 10.1. As part of the early design process, it was found for instance that following an exercise of capturing end-user needs through independently facilitated engagement, the performance brief was developed. Encouragingly, there is some evidence to suggest that the final outcome achieved for the campus is very close to this original vision. However, specific issues that would perhaps have been more fully addressed by a thorough SL approach include:

- Metering and monitoring - The BPE team spent a significant amount of time trying to understand the metering system as installed, capturing and verifying data from it and making sense of the submetering hierarchy. While this concerted effort was possible within this study, this situation is not conducive to the school being able use the system to actively and effectively manage their energy consumption without outside assistance.
- Training - the level of training for the Facilities Management team could have been improved, particularly with respect to the BMS system. Additionally, finding new and more effective ways to inform users about how to interact effectively with the building and its systems would be useful for future projects, as current approaches tend to deal adequately with users present at handover, but fail to accommodate new users after completion.
- A lack of maintenance contracts at the point of handover has caused some issues with specific systems on the project, most notably with the biomass boiler plant and the BMS. It may be useful to consider how building operators can be supported more effectively in this area.
- Ensuring the requirements for specialist functions are defined early during design would be beneficial in terms of ensuring there is time available for optimisation, rather than having to settle for what can be delivered in the time available. For example, the BPE team understands that in this case the ICT solution was agreed at a very late stage, which hindered finalising the design.

2.8 Building access

The school campus is located in Estover, a suburb to the north east of Plymouth. The site is within walking distance of a significant number of residential properties giving good access to the site for pupils who live locally, as well as for the wider community who use the site. There are bus stops for routes to Plymouth city centre available immediately outside the site.

There is limited car parking provided on site for both staff and visitors to the school and library. However there are also a much greater amount of spaces for visitors to the Sports Centre. The total number of spaces is around 100. The Energy Centre is situated on the northern side of the site near the main entrance to allow easy access and turning space for lorries for maintenance and biomass fuel deliveries.

2.9 Discussion

By targetting a 60% energy-related CO_2 emissions reduction, the design intent for the new campus was to significantly surpass the minimum standards set out in Building Regulations. The design appears to be generally sound and most of the key principles relevant to such a low carbon building were incorporated. These principles include a well insulated and airtight building fabric, energy efficient building services with appropriate controls, some use of low carbon fuels and the application of passive design to reduce the use of or to eliminate the need for energy using systems.

The phased construction was very successful, enabling the school to continue to operate throughout the project. It also brought the additional benefit of the team being on site during the initial occupation of the blocks completed in earlier phases of the build, as they were then able to react to any problems raised by the school. However, there were some issues such as dealing with shortcomings to site wide systems that were not identified during the construction period, for example the BMS, pipework insulation in plant rooms and also control of the kitchen AHU.

The actual operating hours for the campus buildings extend significantly beyond those required for core teaching during term time. At design stage, heavy reliance is typically placed on the use of the standardised occupancy profiles included with the National Calculation Methodology applicable to Part L of the Building Regulations. But, the latter may significantly underestimate the true duration of occupied periods.

There is significant room for improvement in terms of the Log Book for Phases 1 and 2. The BPE team believes this may have suffered from a lack of time and resources at the end of the project and because it was completed by the M&E Subcontractors, rather than the Building Services Designers.

Although the school campus was not specifically procured as a Soft Landings project the Main Contractor has still undertaken many activities that can be characterised as part of the Soft Landings Framework (particularly during the pre-handover period and aftercare stages).

While it has not been formally assessed in the scope of the BPE, access to the site by public transport and for pedestrians, cyclists, cars, buses and lorries appears to be appropriate. Pedestrian movement within the site also seems to have been suitably considered, benefitting both staff and students.

3 Review of building services and energy systems.

3.1 Building services

3.1.1 Electric lighting

Electric lighting throughout classrooms and general areas is provided by suspended linear fluorescent ('T5') luminaries providing direct and indirect lighting. Figure 3.1 shows an example of the typical lighting installed in classrooms. Typical installed room lighting loads range from 0.6 kW_e to 1 kW_e depending on room size. Luminaries within all classrooms have control gear so that lighting levels can be automatically regulated according to natural daylight levels. In general lighting is intended to be switched on manually with passive infra-red (PIR) movement detectors switching the lighting off when a room becomes unoccupied again (see Section 7.10). These typically have a 20 minute delay, although in practice the precise time varies, depending on commissioning.

The Sports Hall has a relatively high installed load (10 kW_e) to allow sufficient lighting levels for indoor cricket and is manually controlled. The manual light switch is not in the Sports Hall and is instead located in the reception area which does not provide a view of the Hall itself (see Section 6.5.4).

Figure 3.1. General electric lighting installed in classrooms (left) and Sports Hall (right).

3.1.2 Heating

The school campus is heated through a combination of a Heizomat RHK-AK 500 Biomass Boiler (500 $kW_{biomass}$) and 2 no. Ferrolli GN4/12 fully modulating, condensing gas fired boilers (516 kW_{gas} and 452 kW_{gas}) - See Figure 3.2. The biomass boiler provides heat to a primary low temperature hot water (LTHW) circuit. The biomass boiler is intended to act as the lead heating source with the gas fired plant, which is also connected to the primary LTHW circuit, acting to provide additional heat as required. The primary boiler plant provides low temperature hot water to meet the space heating demand of the buildings and provides hot water to the air handling unit heater batteries and hot water calorifiers via a 10,000 litre thermal store located in the Energy Centre between the biomass boiler and the primary flow and return header. The thermal store is intended to reduce inefficient cycling of the boiler plant. The LTHW boilers are located in the Energy Centre at the northern end of the Sound House.

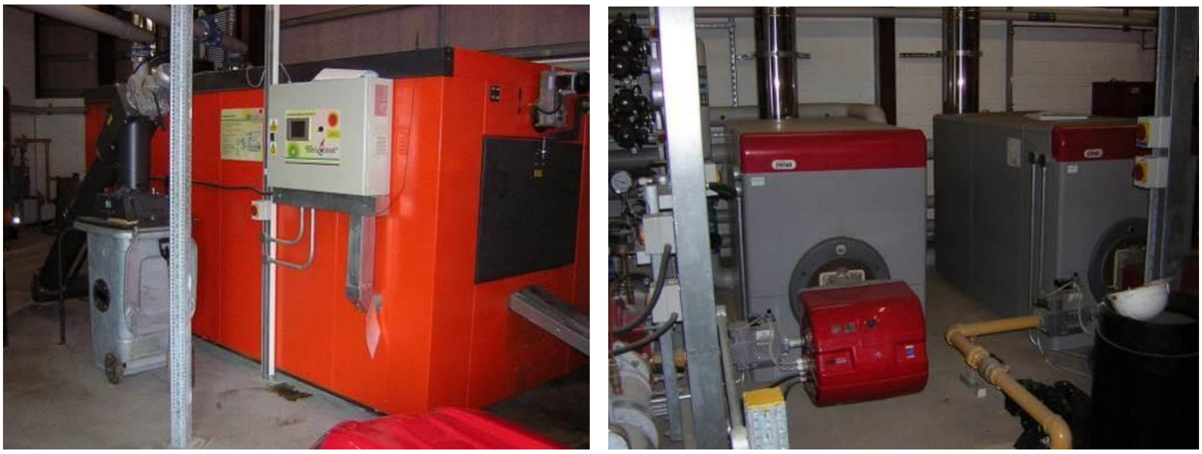


Figure 3.2. Heizomat RHK-AK 500 Biomass Boiler (left) Ferrolli Gas Boilers (right).

Each LTHW circuit (primary and secondary) is provided with a duty and standby circulating pump set. These pump sets are inverter driven, with the pumps speeds set to maintain a certain pressure at a predetermined point in the circuit. There are pump sets in the Energy Centre and in all associated plant rooms. Table 10.1 in Appendix 10.3, adapted from CIBSE Technical Memorandum 22 [CIBSE, 2006], shows pump sets, ratings, and run hours for the Energy Centre. It is worth noting that the CT pump sets around the school appear to be operating continuously, which is potentially leading to unnecessary energy consumption. This is discussed further in Section 8.

In general, space heating is provided throughout the campus by steel panel radiators, except in Cann Bridge's central circulation area and in the Graham Browne multi-use hall, where it is provided through underfloor heating. The installed controls in the Graham Browne building are much simpler than those found elsewhere on the site and are completely manual.

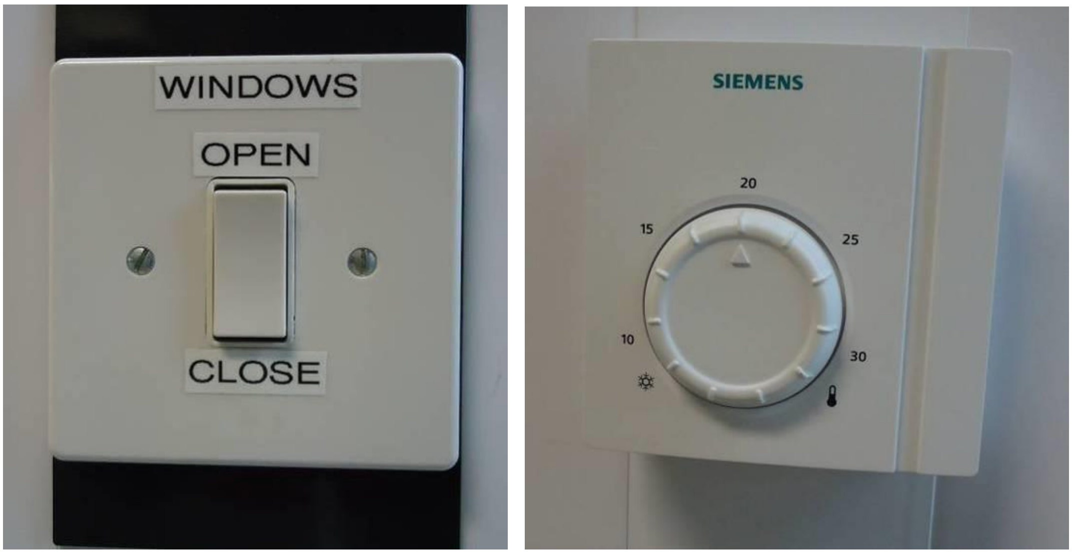


Figure 3.3. Building service controls in the Graham Browne building: rocker switch for opening / closing high level windows (left) and analogue thermostat for controlling under floor heating (right).

The hall in the Sports Centre is heated through high level radiant panels (Figure 3.4). Space heating temperature control for individual spaces is provided through heating schedules and temperature setpoints defined through the BMS. Local control is provided through thermostatic radiator valves (TRVs) on radiators.

Figure 3.4. High level radiant panels in the main hall in the Sports Centre.

Half of the Sound House is heated through the new plant in the Energy Centre and the other half is heated through 5 No. gas boilers (70 kW_{gas} each) located in an attached plant room.

Domestic hot water (DHW) is provided to all blocks via storage calorifiers in each of the block plant rooms. The calorifiers in turn receive heat from the local heat network LTHW circuit from the Energy Centre. A secondary return system is provided on the domestic hot water system with connections within 300 mm of each outlet to maintain system temperatures at acceptable levels and minimise bacterial proliferation during periods of low usage.

Each plant room contains a storage calorifier sized for the requirements of the block it serves. DHW is used for hot taps in all toilets and 22 no. showers in the Sports Hall. The DHW system operating temperatures are maintained through the LTHW circuit at all times through the year, even during school holiday periods.

Figure 3.5. Storage calorifier in the Faraday / Austen plant room (left) and Sports Centre plant room (right).

3.1.3 Cooling

The majority of the school campus is naturally ventilated, with no active cooling provided. However, there are a limited number of areas where the high heat gains necessitate active cooling, which is provided through split units. These areas are:

- **Dance Studio (24m^2) (Sports Centre).** Cooling set point 22°C, no local control, controlled through BMS.
- **Fitness Suite (20 m^2) (Sports Centre).** Cooling set point 22°C, no local control, controlled through BMS.
- **Main Server room (25m^2) and IT office (22m^2) (CADE South).** Cooling set point 19°C with local control.
- **Server hub rooms (16m^2) (in each block).** Cooling set point 18°C with local control.

No local control is provided for cooling in the Dance Studio and Fitness Suite. Instead the BMS will initialise cooling if the internal temperature rises above 22°C. The main server room, IT office, and server hub rooms all have local control (Figure 3.6) with particularly low set points selected.

Figure 3.6. Cooling manual control system for main IT and hub server rooms.

3.1.4 Ventilation

All classrooms are naturally ventilated through a combination of manually openable windows and ventilation louvres on the external faCade and a fanlight above the internal door leading to the atrium. In general, one of the opening casements is opaque with a secure grill attached externally allowing it to remain open overnight. This allows rooms to take advantage of night time cooling in warmer months (Figure 3.7). Successful operation of the night ventilation strategy requires the occupants to open the opaque casements at appropriate times, i.e. they should not be left open over night when the external temperature is low. However, there are no temperature displays to indicate to the occupants when this should be done, instead relying on their own judgements.

Classrooms have carbon dioxide (CO_2) sensors fitted, which have 'traffic light' displays to indicate to the occupants when it would be appropriate to open windows, at least in terms of internal CO_2 levels as a general indicator of indoor air quality (Figure 3.8). These displays take the form of three 3 mm LEDs, which are difficult to interpret from a distance. They were also observed to be obstructed by furniture and clutter in a number of classrooms (Figure 3.9).

Figure 3.7. Night ventilation window (left) and fanlight above door (right).

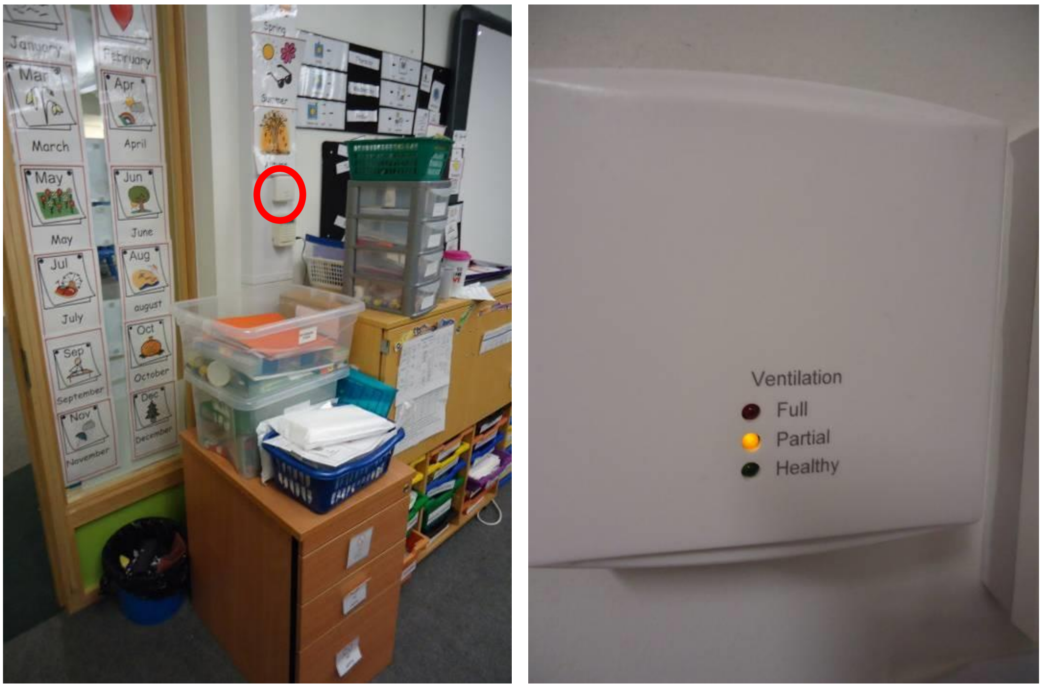


Figure 3.8. CO_2 sensor on wall in room C130 Cann Bridge block highlighted in red and close up. Note that its design does not make it stand out on a crowded wall.

Figure 3.9. CO_2 sensor on wall in room L210 Cade North block highlighted in red, obscured by general clutter.

Mechanical ventilation is installed in areas where the use of the space or processes require it – such as in rooms with no external wall, science laboratories and coupled with active cooling in areas with potentially high heat gains. Classrooms in Faraday block (science) and Cann Bridge block (Severe Learning Difficulty unit) have additional supplementary mechanical ventilation systems. These are controlled through manual controls (Figure 3.10). Heat recovery to reclaim heat from the exhaust air stream and minimise energy requirements is only included in the air handling units (AHUs) in the Kitchen and Dining room. Local extract ventilation is provided to various areas including individual toilets and kitchenettes.

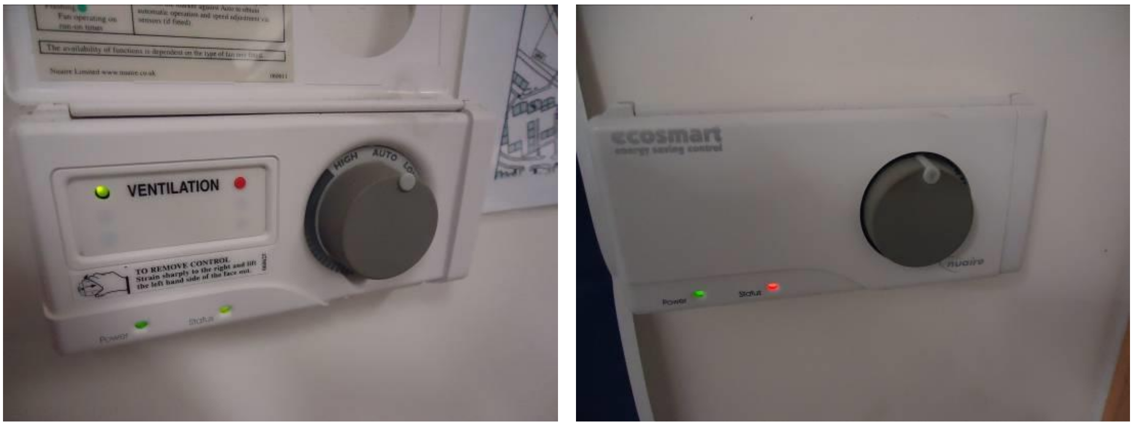


Figure 3.10. Supplementary mechanical ventilation control used in the Faraday science laboratories with the shutter open and closed respectively (left). Note that when this is closed the user cannot see the labels that indicate the operational mode (right).

3.2 Building management system and metering

3.2.1 Building management system

A Schneider building management system (BMS) is installed that controls and monitors the building services across the campus. Software for the BMS is installed on a laptop in the FM team's office. As well as performing building service control and monitoring functions typical to most BMS's, the building services specification (BMS: Mechanical Services Automatic controls and BMS Specification) also states that the BMS *'...will allow interrogation by users (the school campus and end-user) for use as an education aid.'* Building

services are controlled by the BMS with time schedules being pre-programmed to control conditions in all areas. For a full report on the BMS, see Appendix 10.5.Metering
The building services specification documents (Part A: Electrical Services Specification) require the following types of meters to be provided at the school campus:

- Low-resolution pulse units shall be fitted to all utilities, gas, water, and electricity, with its consumption being replicated to the monitoring and targeting system.
- Electricity submeters for lighting, general small power, and IT equipment in each block.
- Heat submeters for all blocks with pulsed output

As the school campus has been built on the site of an existing school building in three distinct construction phases, the arrangement of utility meters and submeters is relatively complex. For example, there are 3 electric utility meters and 3 gas utility meters. The metering is discussed further in Section 7.2.

The energy submetering strategy was communicated from the design team to the construction team by means of an electrical schematic drawing. However, the operations and maintenance (O&M) information supplied to the BPE team did not contain any as-built schematic drawings and attempts to locate this schematic have proved to be unsuccessful, despite requests to the M&E Subcontractor.

3.3 Appliances and equipment

3.3.1 Classrooms

Typically classrooms have the following small power loads: one computer for the teacher, a projector, an interactive whiteboard, and a sound system. Classrooms in the Tenzing and Austen blocks each also contain a netbook charging station (Figure 3.11), housing netbooks that can be distributed to pupils in the classroom as required. There are between 15 and 20 netbooks in each charging station, roughly equating to one for every two pupils.

Figure 3.11. Netbook charging station in room D207 Tenzing block.

Several classrooms around the campus provide specialist facilities for particular activities or requirements. There are two design and technology classrooms in Faraday which contain a large variety of small power equipment for various applications. Art classrooms in Cade North contain a variety of 'unregulated' loads (i.e. those not covered by Building Regulations), including a 26 kW_e kiln for firing pottery. Discussion with the teacher indicated that the kiln was only used at particular times of the year for firing pupil's pottery. However, when it is used it tends to operate for a number of hours overnight.

3.3.2 Staff room

A Staff room is located in Tenzing block Level 1. Here there is a 2.2kW_e water boiler, 2 fridges, 3 microwaves and a toaster. Teachers tend to occupy this room during breaks.

Figure 3.12: Kitchen appliances in Staff Room, Tenzing block.

3.3.3 IT hubs

Austen, Tenzing, and Faraday blocks all contain IT hubs in their central atrium areas. These have around 12 thin client PCs and one photocopier.

Figure 3.13: IT hub in Tenzing block.

3.3.4 Kitchen and Dining Hall

The school campus has catering facilities on site serving hot and cold food, with approximately 250 - 350 meal covers per day. The Kitchen is located in CADE South adjacent to the Dining Room. On a typical term time weekday, breakfast is served from 07:30 until 08:30, the main lunch service runs from 13:20 till 14:00. After this the kitchen is shut and catering staff leave from about 15:00. This was observed to be the case during several site visits. The majority of kitchen appliances are electrical (approximately 123 kW_e total installed load), although there is an oven and a large 12 ring gas hob (30 kW_{gas}), 2 gas fryers (each 15 kW_{gas}), and 2 gas brat pans (10 kW_{gas} and 7kW_{gas}), representing a significant installed gas load also (approximately 92 kW_{gas} total). The kitchen has a dedicated AHU with 4 kW_e supply fan, and 5.5 kWe extract fan.

The Dining Hall is a double height space with a heated volume of 2748 m^3. It is used for breakfast and lunch periods. The Dining Hall has an installed electric lighting load of 5.4 kW_e and has a 2.6 kW_e AHU.

Figure 3.14: Kitchen (left) and Dining Hall (right) in Cade South.

3.3.5 Sports Centre and outdoor sports pitches

The Sports Centre was completed in Phase 2. It contains a double height Sports Hall with a heated volume of 4514 m^3, a fitness suite, a dance studio, and classroom facilities. After school hours and on weekends the Sports Block provides facilities for after school sports clubs. It is noted there is no swimming pool on the campus.

There are also two outdoor sports pitches served with floodlighting. A multi-use games area (MUGA) provides a playing surface for a variety of sports including 5-a-side football and netball. It is mainly used for school sports lessons. The 3G pitch is mainly used for football and is regularly in use after school hours. The floodlighting for both is enabled via a timeswitch from 15:00 until 22:15, but is not necessarily switched on as a photocell ensures the luminaires are off during daylight hours. In practice, lighting typically comes on for the 3G pitch from 18:00 until 22:15 in winter. Installed lighting loads for both pitches are 18 kW_e each.

Figure 3.15. Sports Hall.

Figure 3.16. MUGA pitch (left) and 3G pitch (right).

3.4 Discussion and key findings

This section has briefly reviewed the building services at the school campus, which are comprised of:

- Electric lighting - For general teaching areas, the design follows good practice with efficient lamps and a control strategy that responds to available daylight and actual occupancy. The Sports Hall has a high installed load with manual control; although this is straightforward to operate, there would be an increased possibility of unnecessary use with a high energy penalty.
- Heating - Heat is generated by a lead biomass boiler augmented by two efficient gas-fired condensing boilers. In combination, this would provide a reasonably low carbon source of heat. Conventional controls are provided with time controls and room thermostats.
- Cooling - Through the campus wide passive design strategy to limit overheating during summer, there are only a few areas in the campus that need to be serviced with active cooling, i.e. those with very high equipment heat gains or intended for high levels of physical activity.

- Ventilation - The natural ventilation approach used for general teaching spaces is suitable for its intended purpose and, under manual control, is understandable by the occupants. Indoor air quality control is aided with visual indicators. Night-time secure ventilation for summertime temperature control can be achieved by opening the vents, but relies on occupants anticipating the external temperature during the next day. Conversely, vents left open during cooler periods may lead to unnecessary heating energy demand.

Note there is no vertical transportation present on the campus. This section has also reviewed:

- Building management system and metering - The BMS is intended to operate, monitor and manage the mechanical and electrical services across the campus. Utility meters are provided for gas, water, and electricity use, from which data are recorded by the BMS. Electricity submeters are provided for electric lighting, general small power, and IT equipment in each block, with heat submeters for all blocks and on the supply side from heat generators. However, there is no requirement set for the length of time for which data should be retained by the BMS, or for analysis software to allow meaningful long term analysis of energy data. Further, the BMS software is installed on a laptop computer which is located in the Facilities Manager's office. This software is not consistently in operation on the laptop, so alarms are not necessarily seen in a timely manner.

- Appliances and equipment - Various ICT systems are commonplace in most teaching spaces throughout the campus. In addition, science, design and technology spaces contain a diverse range of specialist equipment. A full hot and cold catering kitchen serving breakfast and lunch is provided. The Sports Centre and outdoor floodlit sports pitches are used for teaching and for community activities. Similarly, the Graham Browne multi-use hall is used both for teaching and out-of-hours for external community activities.

Key findings of this review of the building services and energy systems are that:

- In general, the low carbon design strategy with natural ventilation, little installed active cooling, good daylight provision and low energy electric lighting, with space heating and hot water provided primarily through biomass assisted by gas boilers would help to achieve a low energy and low carbon campus.

- Automatic controls are provided for some, but not for all services and systems, which therefore implies that appropriate manual control by occupants (staff, students and visitors) is important for maintaining good indoor environmental conditions and for energy use.

- Many spaces are used intensively, not only for teaching, but also for extended out-of-hours activities. This has significant implications for energy use.

An analysis is presented in Section 6 to indicate whether the building services are actually operating as intended.

4 Occupant survey, interviews and other feedback

4.1 Introduction

For a building project to be considered successful it must meet the needs of the occupants. A crucial aspect of the BPE process therefore is to engage with the building users to document their experiences of the completed building. To achieve this, an occupant satisfaction survey was conducted following the Building Use Studies (BUS) methodology, as described in TSB guidance notes (TSB, 2011). This section presents a summary of the BUS findings with the full reports included in Appendix 10.11.

The purpose of the BUS methodology is to collect and analyse the experiences of the occupants which can highlight potential problems with the building's performance. The BUS methodology poses a range of questions on a variety of topics including thermal comfort, noise, lighting, and personal control.

At regularly intervals throughout project, semi-structured interviews were carried out with key stakeholders. These included approximately monthly telephone discussions with the school campus's Facilities Manager, discussions that have informed much of Section 5. During the early stages of the project, discussions were also held with the school's Finance Director. Informal interviews were also carried out with key members of staff.

The BPE team made visits to the campus at approximately monthly intervals for the full project duration. While the main purpose was to manually record metered energy data, informal feedback received from occupants on these visits has been recorded throughout the project. Noteworthy comments received in this way have been included within Section 4.3.

A separate walk through building survey was carried out on 17th December 2013, and the findings structured according to TSB's existing template. The detailed findings from this survey are presented in Appendix 10.12 and have been incorporated within Sections 5, 6, and 7.

4.2 Building Use Studies methodology

4.2.1 Methodology

The BUS methodology was carried out by the BPE team on Monday 10th December, 2012. All school staff members present on that day were given a paper based BUS methodology questionnaire to complete. Students and any visitors to the site on that day were not included in the survey. The standard BUS methodology questionnaire format had been previously amended by adding a question to allow differentiation between the following staff roles:

- Teacher
- Teaching assistant
- Administration
- Catering
- Caretaker / maintenance

- IT support
- Other

The weather on the day of the survey was sunny with light cloud cover. The external temperature was approximately 6°C. The survey team arrived on site at 08:00. The initial intention was to hand out surveys to all teaching staff during a staff meeting which was to be held at 08.30. However, on arrival the survey team were informed that this would not be possible as there would be insufficient time to hand out individual surveys to the 100+ staff, with the meeting only lasting for 5 minute. As an alternative, surveys were placed in each staff member's 'pigeon hole' after first establishing that these would be checked at least once per day. The survey team identified themselves to all teaching staff during the meeting and the Head Teacher reminded all present that they should make time to fill out the survey during the day.

The questionnaires were printed on purple paper to make them stand out from other paperwork, with awareness emails sent to staff a month, a week, and a day before the date of the survey. Drop boxes were provided at reception and in the main staff room along, with a box of sweets with a note saying '*Thank you for completing the survey',* to encourage completion.

On the day of the survey, the team did not bring their Criminal Record Bureau (CRB) documents, as although this had been previously considered, it had not been raised by the Head Teacher as necessary. In practice, this limited the survey team's access to the campus during the day - as they had to be accompanied by a member of staff - and may have had implications for the response rate. However, a walk around was carried out during the morning and lunch break periods to engage any staff members who had not earlier been given a questionnaire, for instance the catering team.

As some members of staff were not present on the day of the survey, they clearly could not complete the questionnaire placed in their pigeon holes, which would bias the response rate. To overcome this, at 17:00 the team removed any remaining surveys from staff pigeon holes and deducted these from the total number of questionnaires handed out.

4.2.2 Response rate

A total of 142 survey forms were handed out, with 63 of them returned completed (16 of these were returned by post less than a week later). Therefore, the overall response rate was **44%**. A breakdown of the responses by staff role is given in Table 4.1.

Survey data analysis produced two reports: 'Data Tables' (see Appendix 10.11.1, which includes the quantitative analysis) and 'Comments' (see Appendix 10.11.2, which lists all the written comments from the survey in alphabetical order).

Table 4.1: Questionnaire responses by staff role.

Staff role	**Responses**	**Percentage of responses**
Teacher	25	40%
Teaching assistant	8	13%
Administration	14	22%
Catering	6	10%
Caretaker/maintenance	2	3%
IT support	3	5%
Other	5	7%
Total	**63**	**100%**

4.3 BUS methodology results

4.3.1 Highlights from the analysis

Figure 4.1 shows the summarised results chart for the main qualitative questions for the school campus. As can be seen, the school campus performs extremely well in all these categories. It is very unusual for a building to achieve such high scores across all the assessed categories and indicates exceptionally high occupant satisfaction. Several of the results are examined in more detail below.

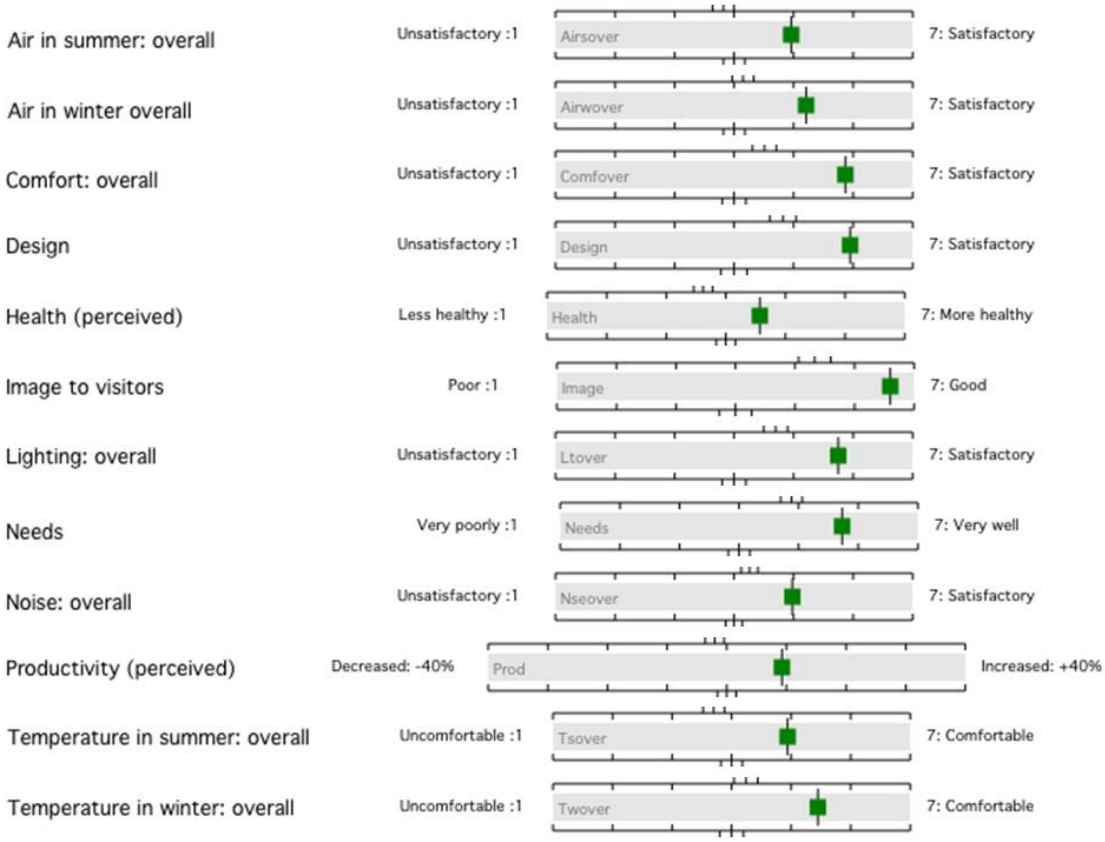


Figure 4.1: Simplified feedback chart for showing the BUS results for the school campus in several key categories.

Image to visitors: Compared to the other buildings in the benchmark data set, 'image to visitors' is in the top 10%. Often, new buildings can score well in this category, but badly in other aspects, e.g. thermal comfort. This is not the case for the school campus which performs extremely well in the majority of categories.

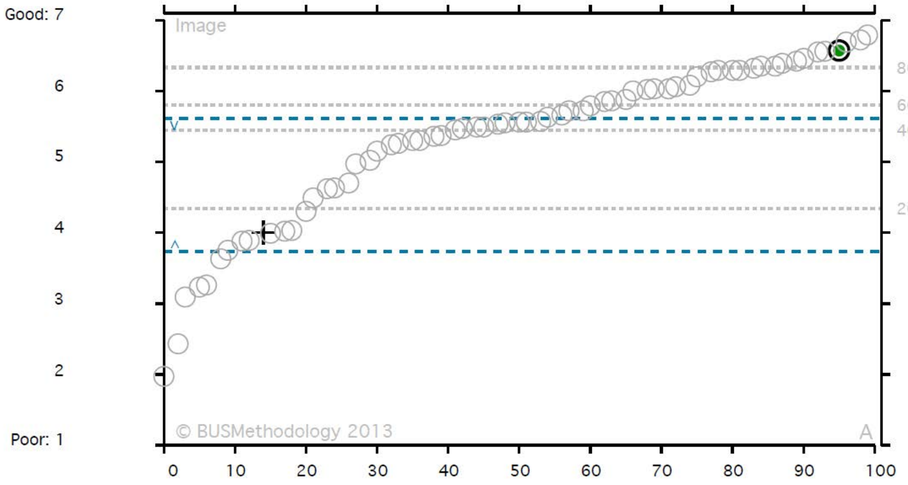


Figure 4.2: 'Image to visitors', the school campus BUS results chart.

Air in Summer Overall: The school campus is the 2nd best performing building in comparison with the benchmark data set for occupant satisfaction with air in summer. This links to the natural ventilation strategy allowing for large windows to be opened, as well as the reduction of solar gains through solar control glazing.

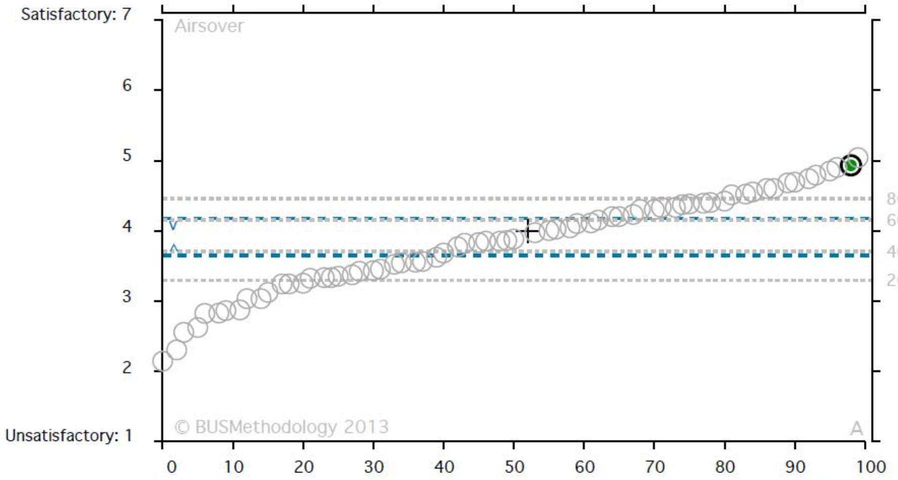


Figure 4.3: 'Air in summer' overall, the school campus BUS results chart.

Control over cooling: The school campus has the highest level of perceived control of cooling of any building in the benchmark data set. (This is interesting as most areas of the building do not use active mechanical cooling and the design allows the occupants to control their internal environments to a high degree through natural ventilation, which was a key part of the design intent.)

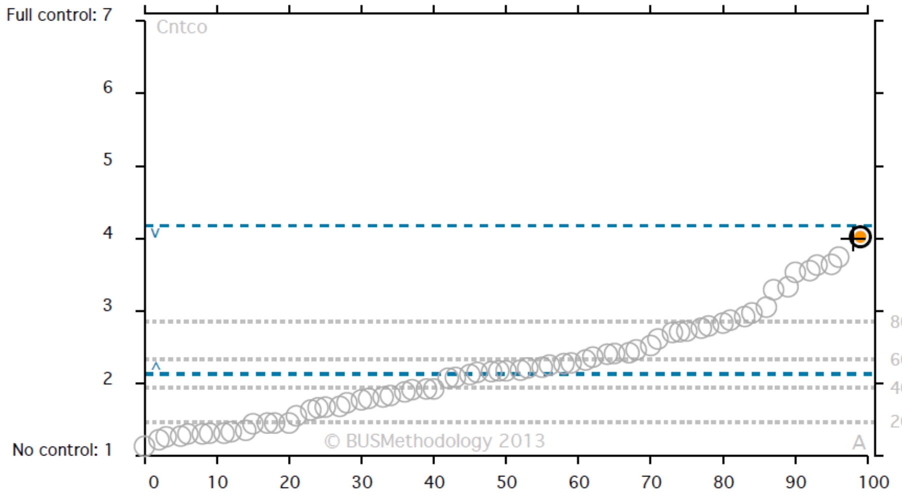


Figure 4.4: 'Control over cooling', the school campus BUS results chart.

Space at desk: The majority of respondents were unhappy with the amount of space provided at their desks. This was particularly true for teachers. These results are backed up by the qualitative comments, for example: *"Not enough room for a proper teacher's desk - little round table. Silly! I have to use a student desk as well"*, *"Not quite enough room to spread out comfortably"*, and *"Only enough room for monitor dvd/video player and keyboard. Nowhere to place notes/worksheets."*

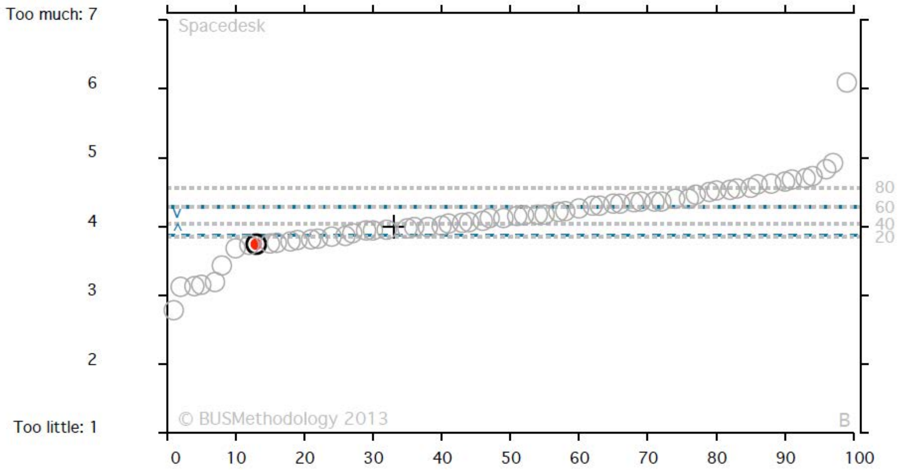


Figure 4.5: 'Space at desk', the school campus BUS results chart.

Storage space overall: Although in the qualitative comments some respondents mentioned that there was not enough storage space, this is not shown in the quantitative responses, where the majority are satisfied with storage. Analysis of the data showed that the staff roles who considered themselves to have the least storage space were Teachers, Teaching assistants, Administration staff, Catering, and Facilities Management.

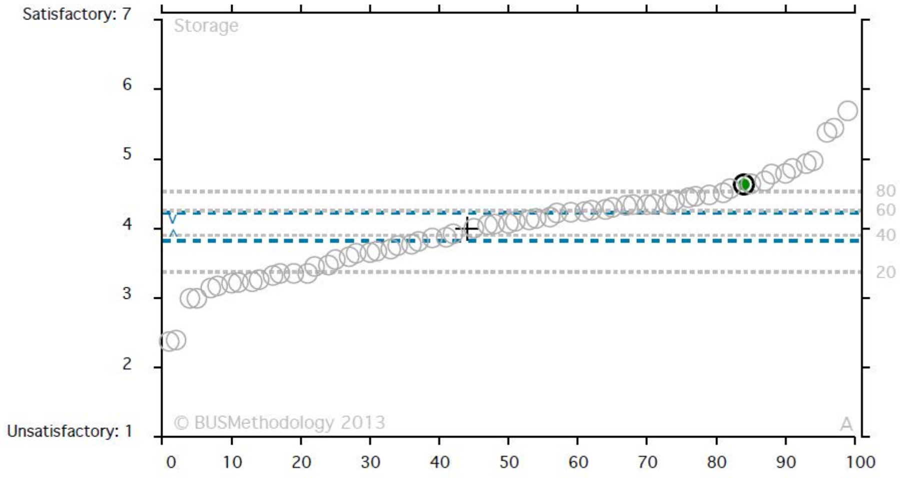


Figure 4.6: 'Storage space overall', the school campus BUS results chart.

4.3.2 Common themes emerging from the survey

The following themes are based on frequent comments from the completed questionnaires. Note that percentages are of the total completed surveys.

(a) Not enough meeting rooms: There were 13 responses to the 'Meeting rooms' question, 10 of these (16%) stated that either there were not enough meeting rooms available or larger ones were needed. There were no positive responses apart from one respondent who thought that a '...*booking system would improve things now'*.

(b) Light: It seems the installed automatic electric lighting is an issue for some occupants with 7 out of 14 responses (11% of overall responses) mentioning it. In general, 5 (8%) out of 14 responses to the 'Lighting' were positive whilst 9 (14%) were negative. Some Respondents stated that the automatic lighting control is frustrating with 5 (8%) out of 14 responses mentioning it; '*Automatic lighting can be a nuisance when you want lights on or off quickly'* and *'Lights going on and off is not ideal. Very tricky to switch on using the quick flick technique.'* Concerning daylight, glare is an issue in some rooms due to large areas of glazing with 6 out of 14 (10%) respondents referring to it. The occupants do have blinds that can be deployed to prevent glare, but some occupants do not think that they are good enough; *'Blinds too light to block out sun'*. The occupants do seem to like the amount of natural light in the building however with 11 (17%) out of 30 responses for 'Things that work well' question relating to the amount of daylight.

(c) Storage and desk space: Out of 23 responses achieved for the 'Storage' question all seemed to suggest that there was *'not enough'* or that they could *'always do with another cupboard*'. Specifically, 7 (11%) of 23 referred to problems with desk or whiteboard storage. Of the 27 'Desk Space' question responses, only 3 were positive. 18 (29%) out of 27 stated that the teaching desks are too small.

(d) Poorly functioning IT: For the 'Things that hinder' question, 7 (11%) out of 37 responses related to IT issues. These include problems such as computers not working and net-books taking a long time to load. The issue of IT is again highlighted in the 'Needs' question where 4 of the 17 responses which consider the IT to be *'inconsistent'* and *'very slow'*. These issues seem to be more about the IT infrastructure and hardware as opposed to the IT staff who were considered by one respondent to be *'amazing'.*

(e) Noise: Noise seems to be mainly an issue during break and lunchtimes with 5 (8%) out of 17 responses referring to it. (This may be expected though when you have a large number of pupils moving between classrooms at the same time.) However, 4 (6%) of the 17 responses flagged up issues with noise being transmitted between classrooms during lessons times, which is a more significant issue with regards to the building design.

(f) Design of the building: There were 25 responses to the 'Design' question, 9 of these were positive, 12 were negative and 3 were both positive and negative. In terms of negative aspects things such as a *'Long walk from car park'*, *'not 100% undercover when moving around'*, and *'Impractical for admin / reception'* were stated. The latter seems to tie in with the administration staff who mentioned the problems of noise and interruptions from students particularly during lunchtime as the admin office is located next to the dining hall. Positive statements include *'Very good'* and *'Great design'*. 21 (33%) out of the 30 responses for the 'Things that work well' questions related to aspects of the architectural design such as the *'break out spaces'* and the *'flow of buildings'.*

(g) Effect on behaviour: There were 18 responses to this questions; 7 (11%) were positive and 11 (17%) were negative. The negative comments were split fairly equally between temperature and noise issues. Interestingly, 3 respondents believed that the behaviour of the students had improved due to the design of the new building.

(h) Health: The question on 'Health' only elicited 8 responses; 4 (6%) of these mentioned positive aspects, 6 (10%) of the responses contained negative comments. These 6 were split equally between the categories of light, noise, and air.

(i) Requests for change: 22 (35%) respondents reported having to contact the Facilities Management team to request a change to the internal conditions. 19 of these issues were related to the temperature; 3 too hot, 6 too cold, 1 control issue, and 8 non-specific. In general though this does not seem to be a major issue as temperature is not widely reported as a problem for the other questions.

(j) Specific issues: Certain specific issues that the occupants have flagged up include:

- Radiator and roof vents in room F121
- Too warm to wear protective coat in D&T lab
- Disabled toilet in PE has persistent drain smell

These issues were fed back to the FM team.

4.3.3 Limitations of the BUS analysis

- Qualitative analysis of the data received by the BPE team was simply arranging the comments received alphabetically. However, the qualitative comments should be considered important as they provide the context to the quantitative results. In appreciation of this, the BPE team independently carried out a thematic analysis to draw out the common themes from the comments.

- It was noted that the ‘Health’ question caused the most confusion amongst the surveyed population. Some respondents queried its relevance and many disregarded it.

- There is no space provided for qualitative answers for the Comfort section. As a result some respondents wrote their qualitative responses all over the questionnaire. This could be a missed opportunity.

- There was confusion amongst some respondents with regards to the scale on particular questions. For instance on the ‘Cleaning’ question the scale goes from unsatisfactory to satisfactory when in reality respondents may perceive cleanliness as being better than satisfactory.

4.4 Informal staff interviews

Informal and semi-structured interviews were carried out with the Finance Director, the Facilities Manager, and members of the FM team. Information elicited in this way has been used to provide context to the data analysis and is incorporated in the relevant sections. Other areas of interest are noted here.

The Graham Browne building was completed in Phase 3 and, during this late stage in the development, manual controls for heating and lighting were specified to reduce costs. The FM believed that the occupants operate this room far more effectively than other areas of the campus due to the simple and intuitive nature of the controls.

The FM team believed the PIR sensors for lighting in the teaching areas are ‘over sensitive’ and often cause internal lights to switch on if someone walks past an external window. They also indicated that teachers would often leave night ventilation windows open over night during the winter term, causing unnecessary heat loss and meaning that the BMS would supply heating to these areas significantly earlier, increasing heating energy consumption.

The overall building design was appreciated by the staff, especially the high levels of space and light. The school's Finance Director has commented to the BPE team that the behaviour of the pupils has improved markedly from the previous school, for example with the open and light areas being perceived to help reduce instances of bullying.

Although the majority of occupants like the design of the new school, there appears to be an issue with the architectural layout at the main entrance. The Facilities Manager has stated that the recessed entrance with a U shape (Figure 4.7) has, on occasion, created a ‘wind vortex’ causing the main entrance doors to slam shut damaging them.

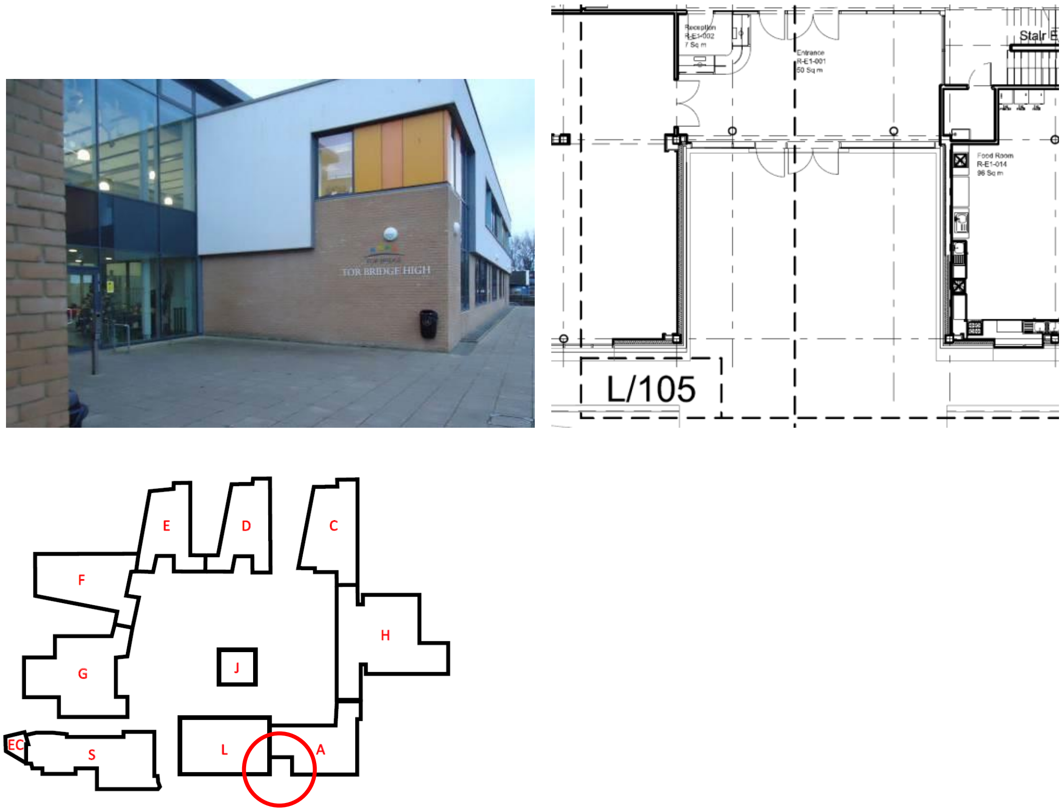


Figure 4.7. North West facing entrance to school. The U-shape can cause wind vortices to occur.

4.5 Discussion and key findings

- The BUS methodology results show that, in comparison to the benchmark building data set, the school campus performs extremely well in the majority of the criteria; in fact it is in the top 10% for 15 of the categories. The response rate was 44% which overall is reasonable considering the difficulties that the survey team had in engaging with the building occupants. The working demands for the teachers meant that there was very little time for them to complete the survey. ***More effective approaches (such as an online version) to implement the BUS methodology in schools could be considered to improve response rates. Thematic analysis of the qualitative response for the BUS methodology can provide important contextual information for building performance and perhaps should be carried out as standard.***

- In terms of thermal comfort the occupants seem to be largely satisfied with how the building and its services are operating. Based on the occupant responses, the summer natural cooling strategy for the classrooms can be considered to be very successful. Aside from certain glare issues, the latter has been balanced with good provision of daylight. ***The manual night ventilation strategy is easy to use and seems to provide high thermal satisfaction for occupants.***

- Problems with noise seem to primarily derive from students during break-times and seem especially pronounced in the administration office which is located next to the dining hall. However, there has been mention of some noise transmission between classrooms during lessons. Issues have also been raised about aspects of fixtures and fittings such as the whiteboard storage, and the small teaching desk space provided. ***Administration offices in schools should ideally not be placed near areas where pupils congregate during break-times e.g. dining hall. This can lead to noise and distraction for administration staff who do not follow the same working pattern as teachers.***

- Some participants stated that the automatic lighting was frustrating due to it occasionally turning on or off inappropriately, but there was only one mention of problems using the controls for classroom lights. It is remarked that the BPE study team had previously been informed that the staff had trouble using them properly. Similarly, there was no mention of the night ventilation – classrooms are equipped with night ventilation windows intended to be used in summer, and some staff have been observed to neglect to close these overnight in winter. ***PIR systems to automatically switch off lighting in classrooms need careful consideration. A system that defaults to absence detection may be more successful.***

- Although storage appeared to be an issue with regards to the qualitative comments, this was not borne out in the quantitative results which saw the school campus perform above average. It should be noted that occupant dissatisfaction with regards to storage space is common to almost all buildings assessed using the BUS methodology, so the campus could be considered to be performing particularly well in this regard.

- In general, the occupants have a large amount of control over their environment due to the design of the building. Existing evidence suggests that occupants are more satisfied with buildings over which they have large amounts of control, which seems to be the case in this situation. However, the extent of control means that there is a larger potential for energy waste. The simple manual localised controls seem to work particularly well in the Graham Browne multi-purpose hall (according to discussions with the FM), but it is unclear whether these would be appropriate across the whole site. For example the local control of cooling to the IT offices where 4 people work (not just the server room) has meant that the occupants have selected a setpoint of 19°C, which seems unnecessarily low. ***High level of control over internal environment seems to lead to high occupant satisfaction, but can lead to potential energy waste. The balance between control and energy needs careful consideration.***

- The 'U-shaped' design of the main entrance to the reception seems to generate wind vortices, which have caused damage to the front doors. This U-shape is common to many of the blocks but the wind vortex has only been evident at the main entrance. ***Entrance areas in a U-shape design need careful consideration (i.e. their orientation) as they can lead to wind vortices forming which can cause damage.***

5 Details of aftercare, operation, maintenance and management

5.1 Aftercare

While the school campus was a case study for ‘Soft Landings for Schools’ (Buckley et al., 2010), interviews undertaken as part of the Soft Landings (SL) review (Section 2.7) indicate that there was no contractual requirement for the Main Contractor to provide any aftercare services. However, as the school campus was built in three separate phases and through the wishes of the Main Contractor, there was an extended period of aftercare as the constructers were on site until summer 2012. The professional team only had limited presence on site and the Building Services Designers were not invited to site at all during the construction process, instead transmitting and receiving any information through the M&E Subcontractor, to whom they had been separately appointed at a later stage.

The lack of a formal requirement for Soft Landings, aftercare and a BMS maintenance contract has had implications for metering and commissioning (see Section 7.2) and has meant that the school did not benefit from robust data to facilitate managing the buildings for optimum energy efficiency. Additionally, operation of the biomass boiler system has been problematic (see Section 7.5), which is of concern considering its use is crucial to reducing operational carbon dioxide emissions from the site.

The Main Contractor has continued to develop their proactive offering around Soft Landings and aftercare and offer to provide two years of continuing engagement as part of their service. This will enhance their commercial offering, demonstrating a continuous learning approach and the adoption of SL principles into their approach to project delivery.

5.2 Operation

The operation of the various systems at the school campus is under the control of the site FM team. Day to day operation of fixed building services such as lighting and ventilation is generally controlled by the building occupants, although in some cases (such as the Sports Hall windows, art room rooflights, and cooling for the Dance and Fitness studios) specific items of equipment are controlled by the BMS (or in practice, manual override of the BMS by the FM).

The FM team consists of 5 people including the site FM who are directly employed by the school campus. They are generally on site during term time week days from 06:00 and leave site at 20:30. (The FM was on sick leave between November 2012 and January 2013 and this period highlighted that without him much of the knowledge of how the building services systems at the school campus operate seemed to be absent.) Obviously, this is an issue for this school, but could perhaps be lessened in other cases through extending initial training and supporting technical users more fully during initial occupation as suggested by the SL framework.

Discussions with several members of the FM team revealed that they consider the job of ‘caretaker’ to no longer exist, as the role has become much more complicated. They were previously more used to reacting to problems such as blocked sinks or changing light bulbs than proactively maintaining complex building services systems such as biomass boilers.

The FM has stated that, in general, there is too much automation at the school and as a result many of the automated systems have been disabled. For instance, the automatic windows in the Sports Hall have been disabled and are now constantly shut and the radiant high level panels have been turned off permanently. It is felt that the Sports Hall can be adequately heated by the occupants playing sport inside. To open the windows the FM must manually adjust the set point for the Sports Hall on the BMS to 'fool' the system into opening them.

As a further example, the Graham Browne building, which provides a lecture / performance space, was completed in Phase 3, at which stage funding for controls was limited and consequently the final installed controls were much simpler than those found elsewhere on the site and are completely manual. The FM considered that the occupants operate this room a lot more effectively due to the simple nature of the controls. However, it was noted on a walk through that the manually operated lights were on even though the room was locked and not in use.

This section sets out findings from a series of discussions that took place during the BPE study with the site FM, as well as drawing on the detailed BMS report that can be found in Appendix 10.5. The technical detail of these issues is covered in Section 7.

5.2.1 Heating

The principal issues with the site heating system have occurred in the Energy Centre and are focused on the biomass boiler. From the outset the biomass boiler did not work for any significant continuous period without issues – indeed during the BPE inception meeting on 31st January 2012, it was reported that the boiler had not run without fault for more than 6 weeks since its installation.

The most significant issue arose when a fault in the control system meant that the biomass boiler was not operational for 5 months and gas back-up had to be used in its place. Additionally, the fuel feed jammed and fuel burnt back into the feed mechanism. The automatic dousing system operated as designed to quench the hot fuel, but as a result flooded the floor of the plant room, which whilst preferable to a fire, did cause considerable work for the FM team.

A specific area of concern within the campus is in the Sports Hall which frequently overheated even during winter and spring periods. While this is in part due to ventilation issues, the situation is exacerbated by the radiant heating panels being supplied by the same constant temperature circuit as the air handling units. The result is that when the BMS considers outside temperatures equate to 'winter' operation, the panels are provided with a constant supply of heat irrespective of the conditions in the specific space being served. Also, despite radiant panels being installed, there do not appear to be any 'black bulb' radiant heat sensors installed, which may be contributing to the control issues here.

5.2.2 Ventilation

The ventilation of the building generally relies on users manually operating opening vents in the external faCade. This ventilation system appears to be operating satisfactorily in most areas with positive findings from the Building Use Study in terms of air quality in the summer and control of cooling (see Section 4.2.4).

The BPE team's discussions with the FM clearly indicate particular frustration around the control and effectiveness of ventilation in the Sports Hall. Even during winter and spring months, conditions in the space make its use problematic and the lack of control available to the FM means that this is difficult to resolve with the existing installation. The key issue is the low level of control provided by the BMS for Phase 2 of the development in comparison to other phases, as well as specific issues with the Sports Hall heating as indicated above (see Section 7 for more information).

5.2.3 Lighting

Lighting for teaching areas is controlled through a manual light switch with PIR sensors to automatically switch off lights after a 20 minute period of no presence detection. Lighting for communal / circulation areas is typically controlled through standard manual light switches. Discussions with the FM indicated that there was some initial confusion regarding the principle of operation for the automatic lighting systems in classrooms until individuals became familiar with it.

According to the building Log Book lighting to teaching areas can be controlled in the following manner:

> *"Upon entrance into the classroom, the lights remain off until the momentary switch in pressed in the down position. This then illuminates all of the fittings. If the momentary switched is pressed again for 3 seconds this will turn the fittings off. If the room is left unoccupied for a set period, the lighting will turn off until such time the switch is pressed again."*

The above passage adequately describes how the light switch system should work, but the situation described assumes that the occupant has held the light switch down when leaving the room which turns the lights off and disables the PIR sensor. However, a walk through revealed that this action had not been carried out in any classrooms. Instead, while all lights were turned off the PIR sensor was still enabled meaning that lights automatically turned on upon entrance to the room.

The occupant satisfaction survey (see Section 4.2.6) also indicated that there was certain dissatisfaction with the lighting system with 14% of respondents giving negative feedback (compared to 8% giving positive feedback).

5.3 Maintenance

There have been some breakdowns with equipment such as some oversink DHW boilers and also bent external door openers caused by pupils hanging on doors (causing them to be jammed open while a nearby radiator is on), but the FM felt these were due to normal wear and tear. He also commented that the routine maintenance burden has increased compared to the old school building and grounds (such as weeding, painting, minor repairs, etc).

There seems to have been an issue with maintenance contracts not being put in place at the point of handover. This was a particular issue with the BMS which experienced significant operational problems. Another example is with the Tyco fire sprinkler system which during the first year had no maintenance contract. It is understood a separate maintenance contract was subsequently put in place.

5.4 Discussion and key findings

- The involvement of the Building Services Designers seems to have been limited after they were separately appointed to advise the M&E Subcontractors at a later stage following initial design. In particular, the Designers were not invited to site during construction. More interaction and communication between these parties may have helped to avoid some of the metering and commissioning issues. ***Increase input from Building Services Designers past initial design period.***

- An extended period of aftercare is essential for streamlining building performance. However, by itself this is insufficient as many of the issues with building performance begin to manifest themselves during the design process. The school campus would have benefitted from the all of the principles of Soft Landings being adopted from the outset of the project along with a fully implemented aftercare service. This would have helped to solve many of the commissioning, metering, and BMS issues that have become apparent during the course of the BPE process. ***Ensure that adoption of all Soft Landings principles is specified in the project brief and that these are followed.***

- The Facilities Management team considers that the role of caretaker no longer exists and that they are expected to be able to deal with a wide range of building services problems. This is an issue for design teams who need to consider the level of expertise available for operating completed buildings. The FM team (or representative) should also be included in the design process to ensure that the building is straightforward for users to understand and that the design can be easily operated and maintained by the FM team. ***The capabilities of the FM team need to be considered during the design process, in which a member of the FM team should be included.***

- It is essential to provide training to the FM team to help them progress from a reactive to a proactive approach. Knowledge of complex school systems should be common to several members of the FM team, in case there are absences due to illness, leave or simply availability. ***Provide training on all building services systems to all members of the FM team.***

- There are some instances at the school campus of occupants using control systems in a way not anticipated by the designers, e.g. the night ventilation strategy and PIR lighting for classrooms. The current approach to ensuring that building occupants use systems as the design team has intended is to explain their operation in the building Log Book and / or to provide training to a sample of the occupants. There are limitations to both these approaches. Log books, appearing late in the design and construction process, are sometimes rushed and copied from complicated design documents. They are often incomplete or out of date and unavailable to the occupants. Training a sample of occupants in buildings with high staff turnover can also prove ineffectual. ***Improved methods of communicating design intent of control systems to building occupants are required, for instance simple to follow 'flash cards'.***

- There seems to have been several concerns with the quality of the fit out, particularly in plant rooms. The FM team have reported that pumps were not installed securely enough (only bolted hand tight) and burst pipes. Installation of fixtures and fittings in other areas of the school is sometimes of low quality with hand rails and benches not being securely fixed to the structure, but attached to plaster board. ***Quality of installation of fixtures and fittings needs to be high, especially in areas where pupils will cause high levels of wear and tear.***

- The school campus has experienced operational issues with several specialised systems, including the BMS and fire sprinkler system, due to the lack of maintenance contracts placed by the client. ***Specialised systems should have maintenance contracts in place at the point of handover.***

6 Energy use by source

6.1 Introduction

Table 6.1 provides an overview of how energy is consumed annually at the school campus. It should be noted that problems with the biomass boiler (explored in Section 7.5) mean that its use has been sporadic over the course of the BPE study. Heat generated from the biomass boiler has occurred during specific periods with high spikes, meaning the annual value reported in Table 6.1 could be misleading. The school has not used the biomass boiler since May 2013, as they consider it does not offer good value for money, relying instead on the gas boilers as the primary means of generating heat, and there are currently no plans in place to reinstate it.

Table 6.1. Fiscal supplies to the school campus - January 2013 to December 2013.

Utility	**Consumption (kWh p.a.)**	**Typical cost (£ p.a.)**	**GHG emissions (tCO_2e p.a.)**	**Emissions factors ($kgCO_2e/kWh$)**	**Meters**
Electricity	1,108,000	£108,141	501,647	0.4528	E26+E28+E31
Biomass	1,216,000	£32,589	10,944	0.0090	H01
Gas	2,191,000	£62,600	404,513	0.1846	G01+G06+G10
	TOTALS -->	**£203,330**	**917,104**		

For more information regarding meter numbers, refer to meter hierarchies Section 6.4.

6.2 EPCs, DECs and actual energy consumption

The transposition of the Energy Performance Buildings Directive (EPBD) for England and Wales resulted in two regulatory requirements: Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs). EPCs must be produced for all new buildings. An EPC is based on the calculated energy related carbon dioxide (CO_2) emissions (in $kgCO_2/m^2$ per year) for the building compared to a notional design to produce an Asset Rating. Produced similarly to the compliance calculations required for Building Regulations, EPCs account only for the 'regulated' loads, whilst also relying on standard profiles for occupancy hours and patterns. The resultant certificate displays the rating on a scale from A (very efficient) to G (very inefficient) providing a record of the building's asset rating. Note that an EPC is not an estimate of expected energy consumption or carbon emissions in use and for this reason should not be used for comparison against actual consumption as a measure of actual building performance.

In contrast to EPCs, Display Energy Certificates (DECs) show the operational rating of the building, being based on the actual energy consumption over the preceding year. The operational rating is displayed on a scale from A to G calculated based on comparison against statutory energy benchmarks for the given building type. Currently, the school has not yet had a DEC produced for the new campus.

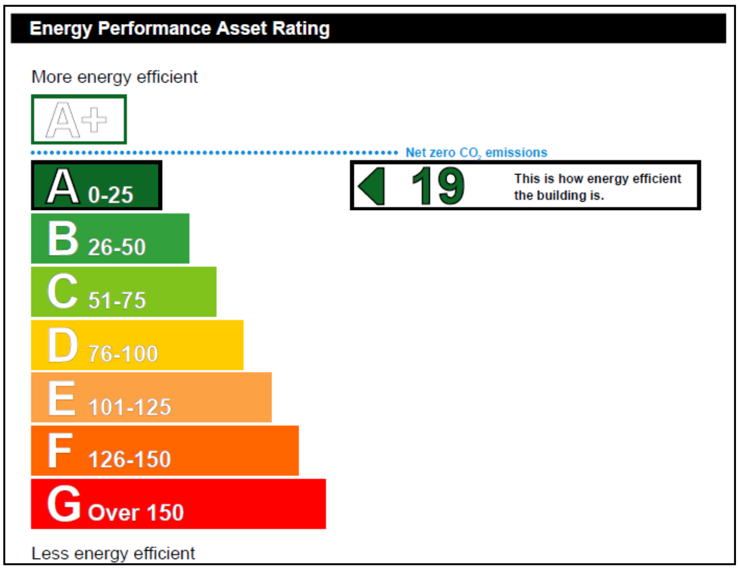


Figure 6.1. EPC rating for Blocks in Phase 1 and 2.

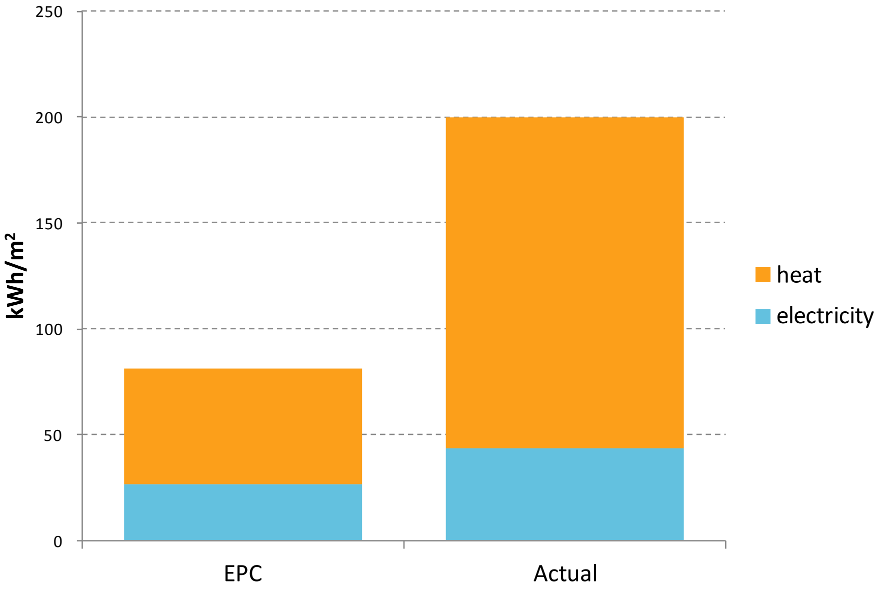


Figure 6.2. Heat and electricity consumption calculated according to the EPC methodology fails to reflect actual consumption (heat pro-rata based on area) for blocks Sports, Faraday, Austen, Tenzing, Cann Bridge. N.B. An EPC is not intended to be an estimate of expected energy consumption.

To highlight the distinction between the EPC and actual consumption, the EPC which covers the Phase 1 and 2 buildings – Sports block, Faraday, Austen, Tenzing, Cann Bridge, CADE North and CADE South was considered by the BPE team. By accessing the original Part L compliance model, a calculated consumption for the fixed building services for heat and electricity was determined. This was then compared to metered electricity consumption for the secondary school (E-26) and heat consumption (calculated through one year's biomass and gas consumption) for the entire site (disaggregating just the secondary school heat is complicated by the configuration of the metering). The results are displayed in Figure 6.2 and show that the consumption calculated according to the EPC methodology is much less than the actual. However, calculations carried out for the EPC only considered 'regulated' loads such as the fixed building services and do not consider additional 'unregulated' loads such as small power and IT which are included in the metered actual electricity consumption. An EPC also relies on standardised profiles for occupancy hours and patterns that differ considerably with the actual profiles.

6.3 DCSF Carbon Calculator

A key part of the design intent for the school campus (see Section 2.2) was to demonstrate a 60% reduction in energy-related carbon dioxide emissions below 2002 Building Regulations guidance at the design stage. This was illustrated by use of DCSF's Carbon Calculator which in turn recommended the use of biomass to meet this target. The target was only intended to apply during the design stage and is not an operational target.

In general the exact calculations that the DCSF Carbon Calculator makes behind the secure spreadsheet is fairly opaque. However, it is the understanding of the BPE team that the 60% reduction target is being applied to the 'regulated' emissions. Although it refers to a small power element, this is to adjust the heating / cooling loads depending on power level of computers.

The BPE team thought it pertinent to revisit this calculation to see whether the school campus had actually achieved this 60% emissions reduction target in use. Figure 6.3 shows the baseline emissions calculations, which include estimations of small power consumption for 2002 Building Regulations and 2006 Building Regulations and the required 60% reduction targets for each. These were the original figures used in the Carbon Calculator. The original calculation was only required to demonstrate the emissions reduction relative to the 2002 baseline. Figure 6.3 also includes the actual total emissions for the school campus which is around 55 $kgCO_2/m^2$ per year. It can be seen that this total is much higher than either of the two targets or indeed the original baselines.

As the school campus is no longer operating the biomass boiler, the BPE team carried out a theoretical calculation to see whether, if the school was operating the biomass to replace 80% of its gas consumption, it would attain the target emissions rate. However, it can be seen that this would only reduce emissions to around 36 $kgCO_2/m^2$ per year, a figure which is still more than twice the target.

It should be emphasised that the original DCSF Carbon Calculator target was intended to apply to only regulated emissions at design stage and was not meant to be an operational target. However, whilst in many ways it is a 'false comparison' (see also Section 6.2), it helps to illustrate the general difference between what is being assumed during design stage and the actual operation of the completed building.

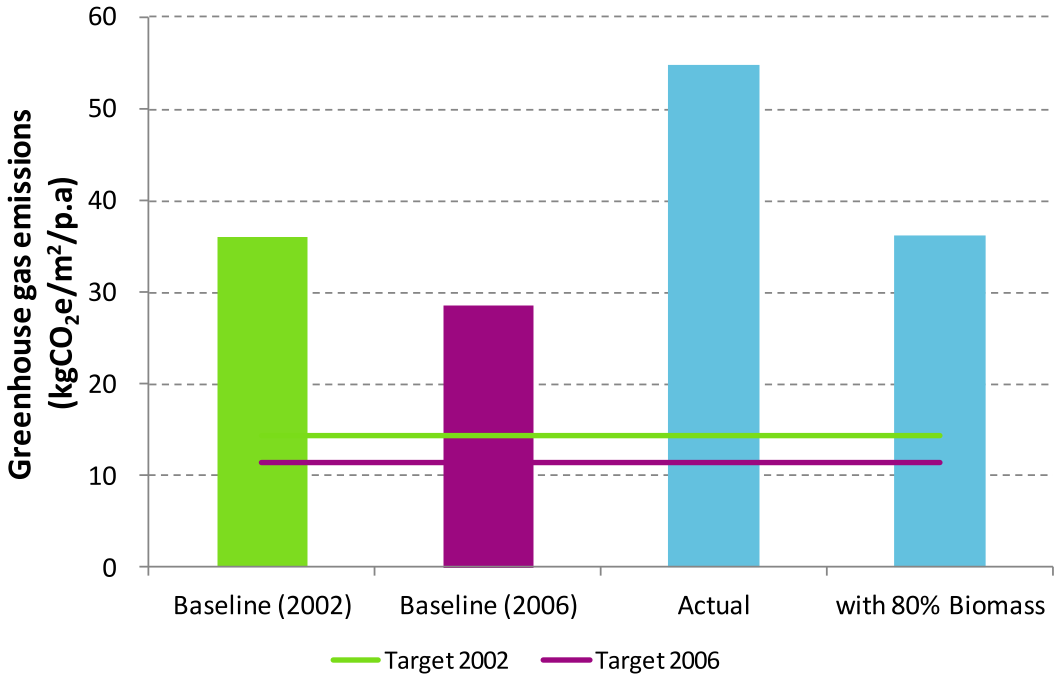


Figure 6.3. Bar chart showing the 60% GHG emissions design target based on 2002 and 2006 Building Regulations against actual emissions, and theoretical emissions if 80% of gas consumption were to be met instead with biomass.

6.4 Energy metering hierarchies

Crucial to understanding how energy is being consumed at the school campus was establishing the metering hierarchies for each energy source. Due to issues with metering and commissioning this process took much longer than first envisaged - see Section 7.2 for further details. The Figures 6.4, 6.5, and 6.6 illustrate the metering hierarchies determined for gas, heat and electricity respectively.

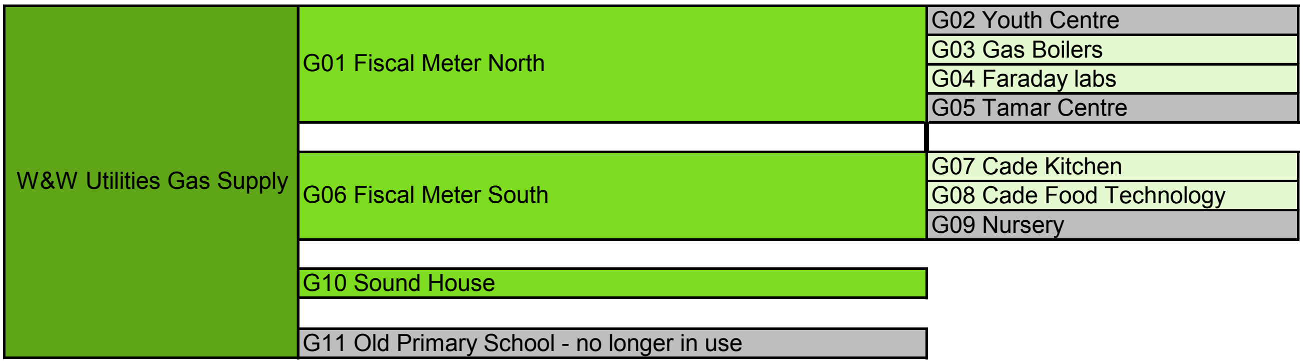


Figure 6.4. Gas meter hierarchy (grey indicates not covered in scope of BPE)

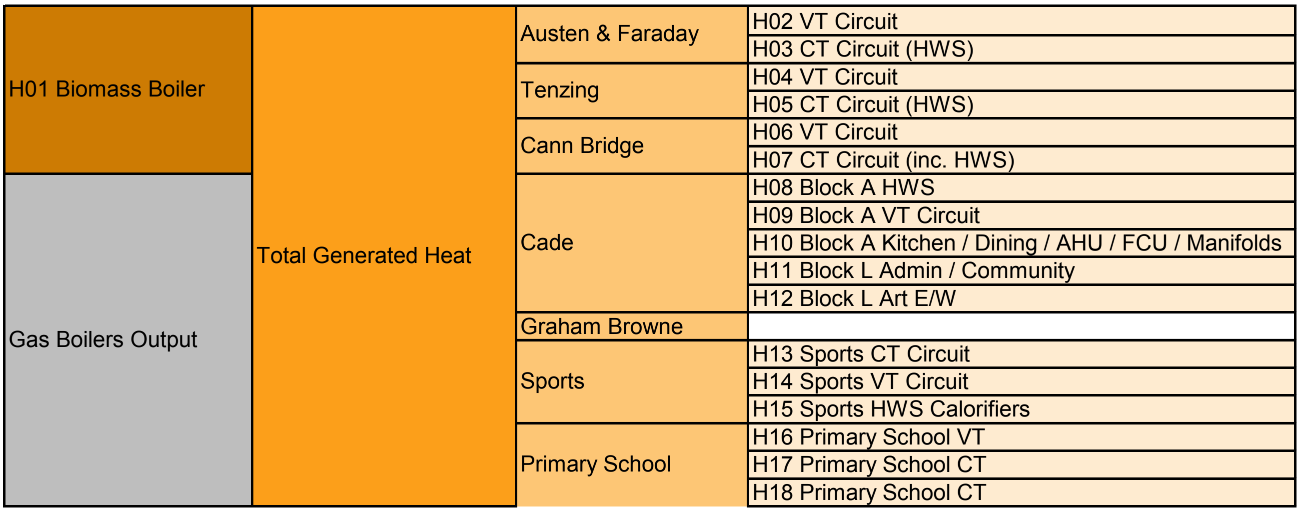


Figure 6.5. Heat meter hierarchy. Note that there was no heat meter on the Gas boilers.

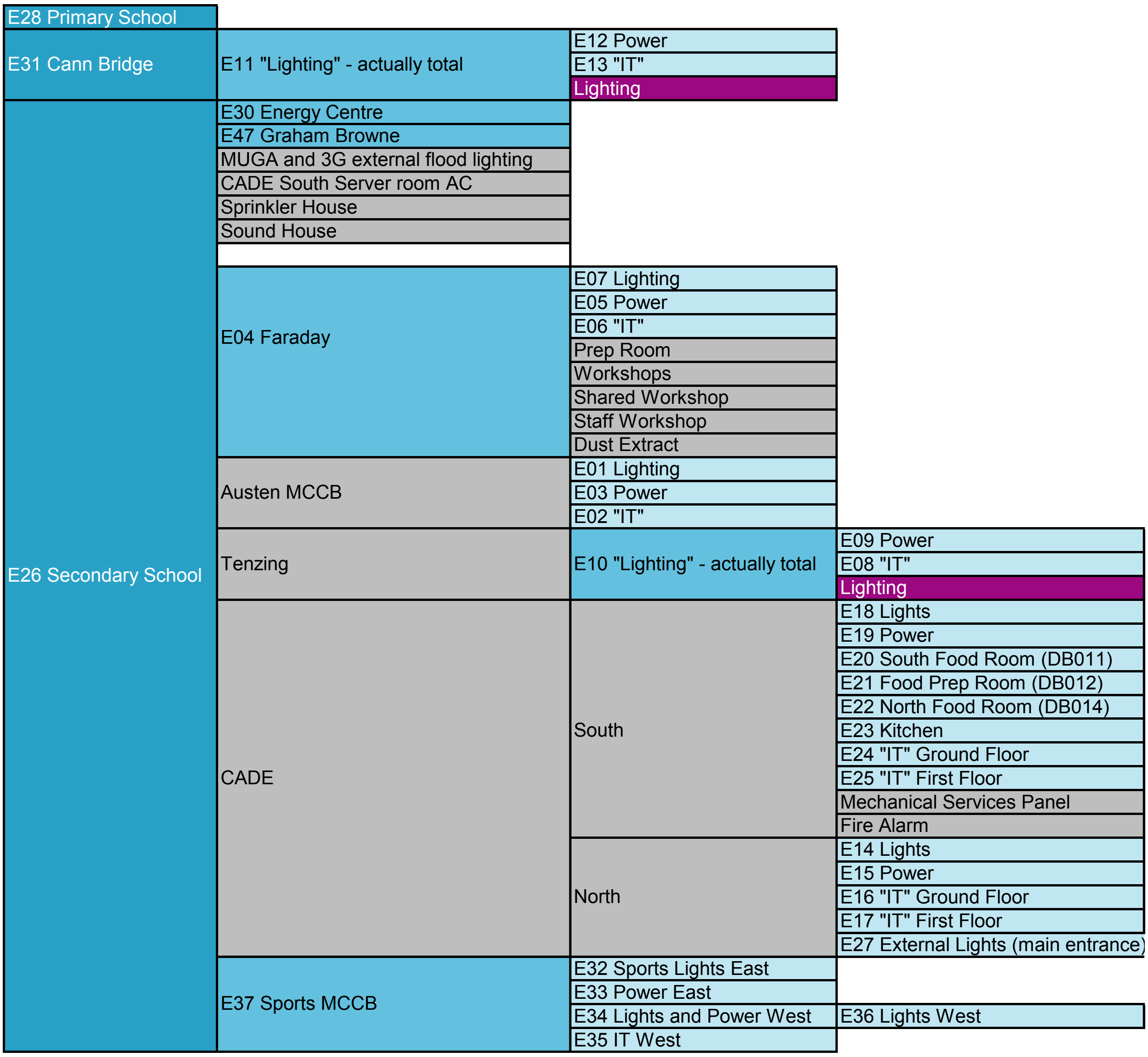


Figure 6.6. Electricity meter hierarchy (grey indicates no submeter)

6.5 Electricity consumption

Annual electricity consumption is around 1,108,000 kWh, based on January 2013 to December 2013. Due to the problems with the electricity submetering (described in section 7.2.1), 29% of electricity consumption in Figure 6.7 is labelled as *'Unknown'*. However, spot checks and temporary clamp metering indicated that much of this is likely to be made up of electricity consumption for the external pitch floodlighting, Cade South server room, the sprinkler house, and the Sound House.

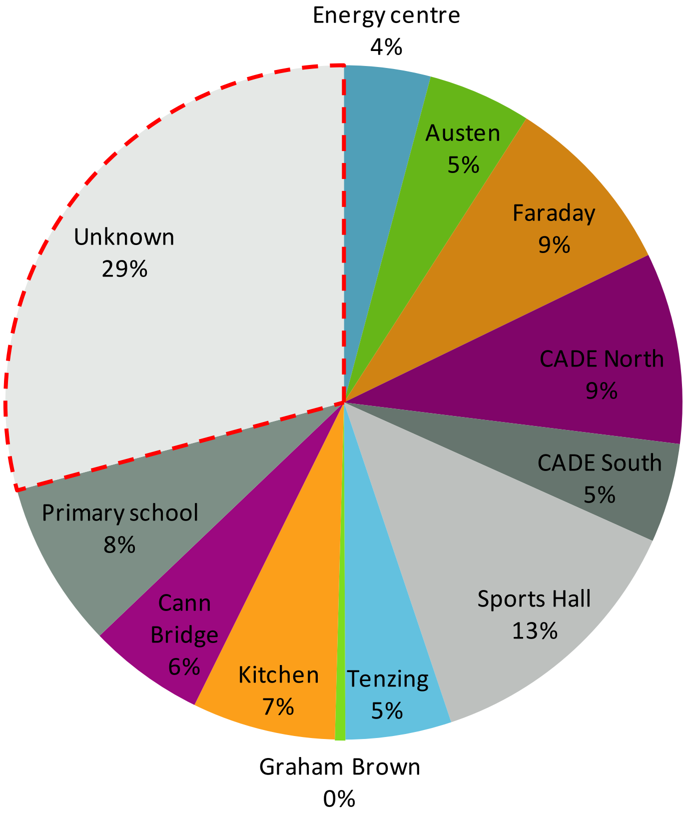


Figure 6.7. Split of electricity consumption amongst the various areas of the school campus based on installed submeters.

The instantaneous reading on each submeter, or set of submeters, was verified using current clamps and found to be accurate. These represent the outgoing distribution circuits from the main switchgear for the secondary school supplies. Inspection of the switchgear revealed several circuits that had no installed metering, hence the large discrepancy noted above. These included sports pitch lighting, the IT server suite, the sprinkler house, the Sound House and certain circuits in CADE South (mechanical services and the fire alarm). Current clamps and data loggers were added to these circuits for a period of a month, and this reduced the discrepancy between the incoming meter and outgoing supplies to only 2%. Over this period, the breakdown of electricity consumption is shown in Figure 6.8.

The BPE team were able to obtain half hourly fiscal electricity data from the energy supplier (British Gas until March 2013 and NPower until the end of the study) for the meter E-26. Meter E-26 records consumption for the majority of the campus, including the Energy Centre, Graham Browne, Austen, Tenzing, Faraday, Cade North, Cade South, the Sound House, and the Sports Centre. Figure 6.9 shows the monthly consumption for E-26 and it clearly shows an upward trend. Interestingly, the total consumption for August (when the school campus is effectively closed) has been increasing each year up to 2012, but decreased in 2013.

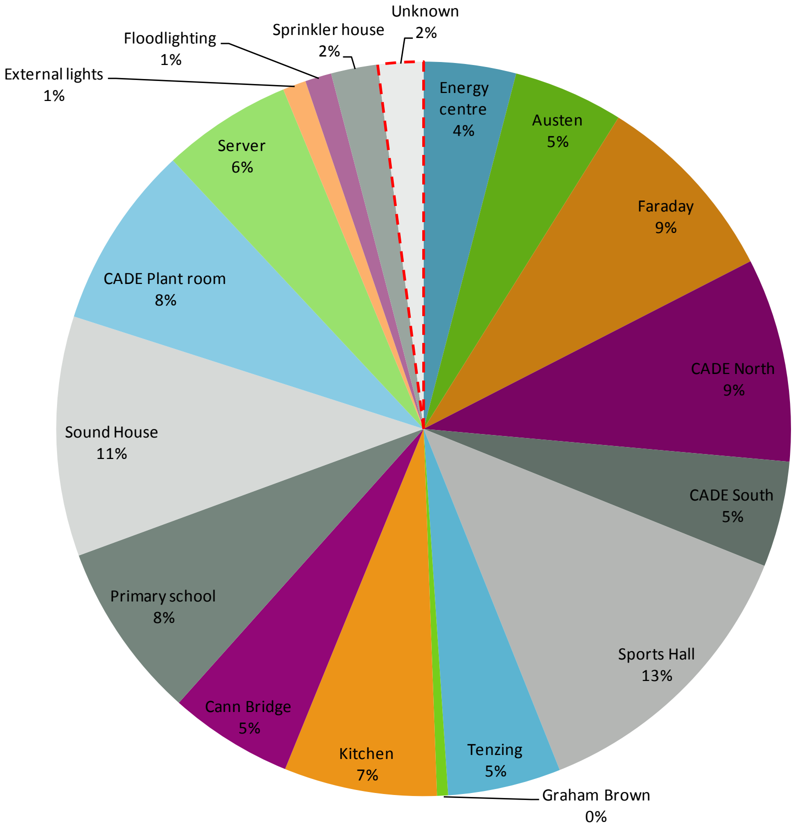


Figure 6.8. Split of electricity consumption amongst the various areas of the school campus based on installed submeters with the additional data from the current clamps used during the period 26/4/13 to 29/5/13.

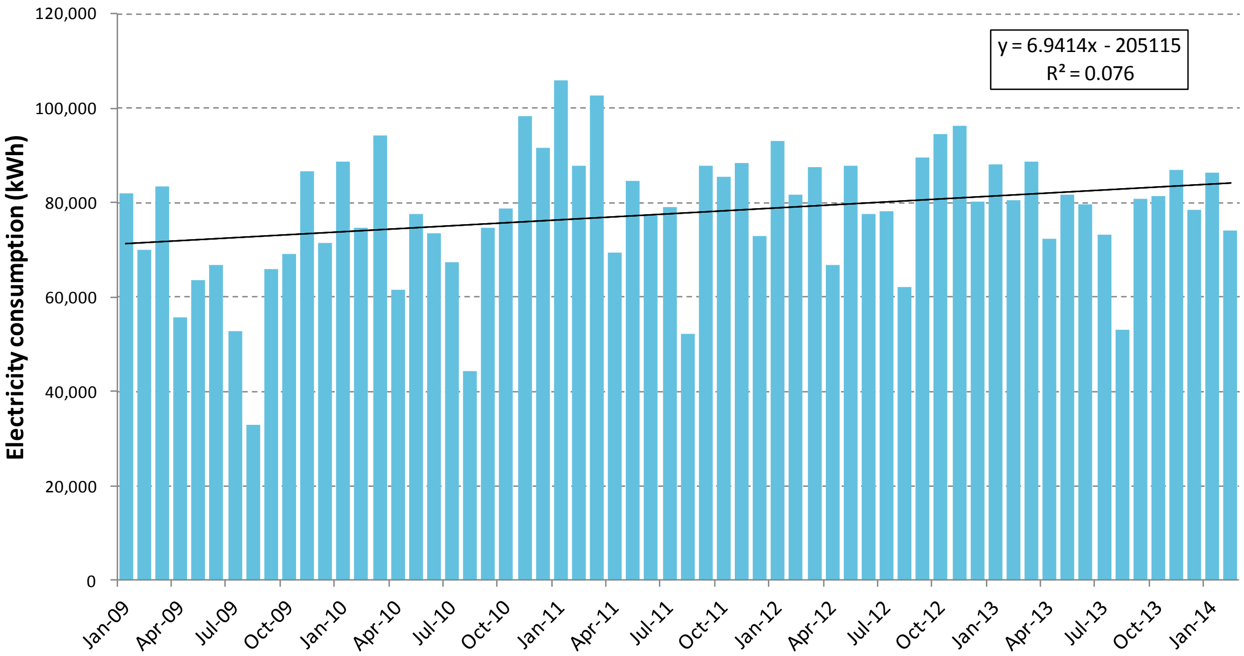


Figure 6.9. Monthly electricity consumption for E-26 meter.

Analysis of the monthly electricity submeter consumption against the total incoming to the site (Meters E26 – Secondary School, E28 – Primary School, and E31- Cann Bridge) clearly shows the consistent un-metered electricity consumption (Figure 6.10) and illustrates the difficulties that the BPE team had in attempting to reconcile the metering and understand when and where electricity was being consumed at the school campus. The almost unusable state of the installed metering meant that it was only possible to collect a fraction of the possible energy data in the BPE study.

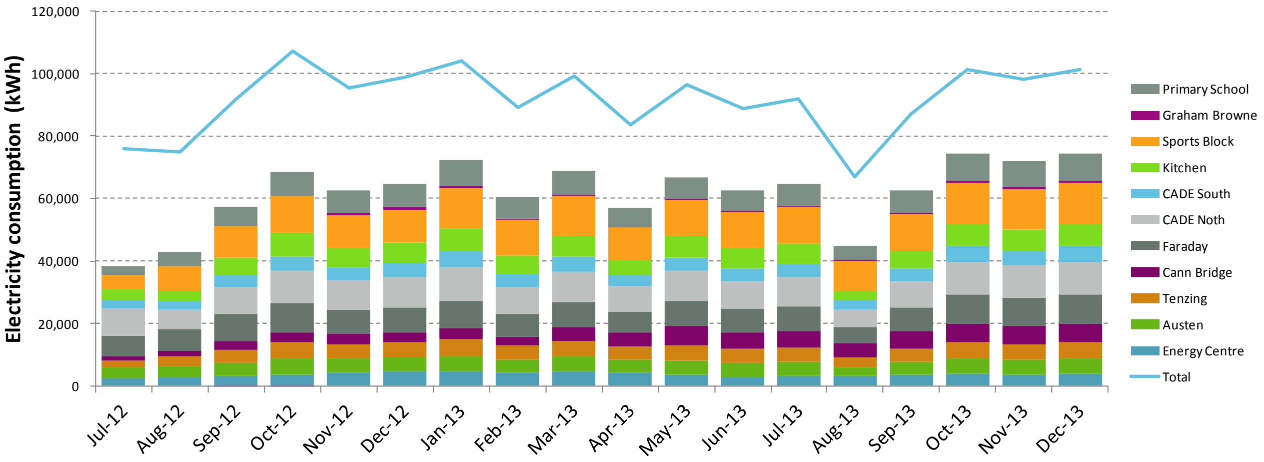


Figure 6.10. Compound bar chart showing monthly submeter electricity consumption against the total electricity incoming to the site (total of meters E26, E28, & E31).

The use of a CIBSE TM22 model (See Section 6.5.2) allowed the BPE team to break down electricity consumption into its various end uses (Figure 6.11). This shows a large proportion of electricity being used for small power (mainly as a result of PCs) and emphasises the significance of appliances being left on standby as discussed previously.

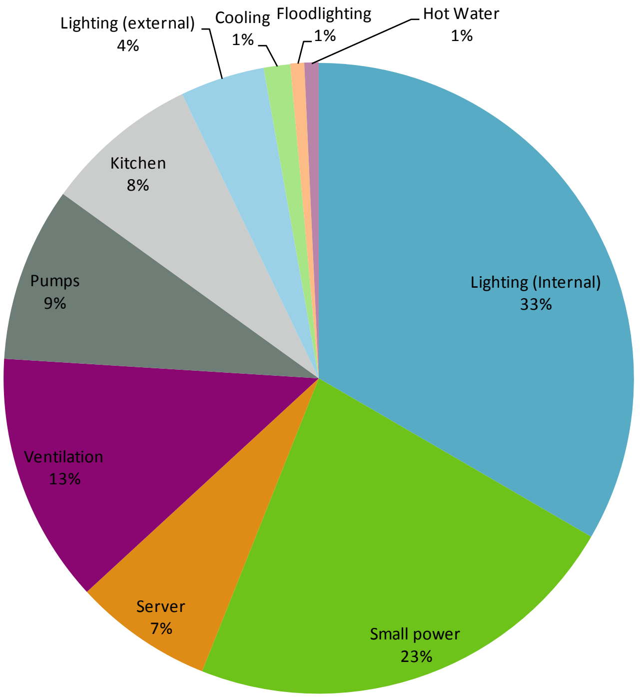


Figure 6.11. Annual end use breakdown for electricity consumption at the school campus, based on assumed data in TM22 model.

Table 6.2. Annual End use electricity consumption figures with data from TM22 model.

End use	Electricity consumption (kWh)	Percentage
Lighting (internal)	329,287	33%
Small power	223,863	23%
Server	70,344	7%
Ventilation	126,454	13%
Pumps	88,181	9%
Kitchen	78,218	8%
Lighting (external)	42,885	4%
Cooling	13,449	1%
Floodlighting	7,036	1%
Hot Water	7,227	1%
Total	**986,944**	**100%**

6.5.1 Half hourly electricity analysis

Half hourly data allow the creation of daily profiles which can be useful for identifying high baseloads and out of hours consumption. Figure 6.12 shows average electricity demand for a typical week during the summer term in 2013. The graph shows an initial spike each day between 05:00 and 06:00 which corresponds to when the cleaners begin work. The highest consumption is between 08:00 and 12:00 when the kitchen is operating. Consumption tends to tail off in the afternoon until about 17:00 when the majority of the teachers have left. There is a small increase in consumption in the evening, again corresponding to cleaning. Consumption reaches it baseline level of around 70 kW by around 21:00. The weekend profile is fairly regular and shows a slight decrease in the early morning – possibly corresponding to external lighting switching off followed by a slight increase around 07:00 when the Sports Centre staff begin to arrive.

Figure 6.13 illustrates the average electricity demand for a typical week during the winter term 2014. The profile shows a similar baseload to the summer profile of around 70 kW. However, the peak load is slightly higher reaching around 250 kW on some days compared to around 220 kW in the summer. Otherwise the profiles for summer and winter tend to be broadly similar. The load in the evening is higher in the winter than the summer and this is likely to correspond to the longer operational time for the 3G pitch floodlights. In Figure 6.13, the Sunday profile increases from around 17:00 to 20:00, which is probably related to the 3G pitch floodlights.

The daily profile for a typical summer week out of term time is shown in Figure 6.14. Again this shows the high average baseload of 70 kW indicating there is no special effort to turn off equipment over the holiday period. There is an increase in consumption from 07:00 until 15:00 which is probably associated with the FM team being on site, but also teachers turning up and working in their separate classrooms. From around 18:00 until 21:00 there is an additional load which varies depending on the day. The time indicates that this is likely to be floodlighting again for the 3G pitch, although during August it would probably not be required from 18:00. It may be that there are possible savings with the floodlighting coming on too early during the summer.

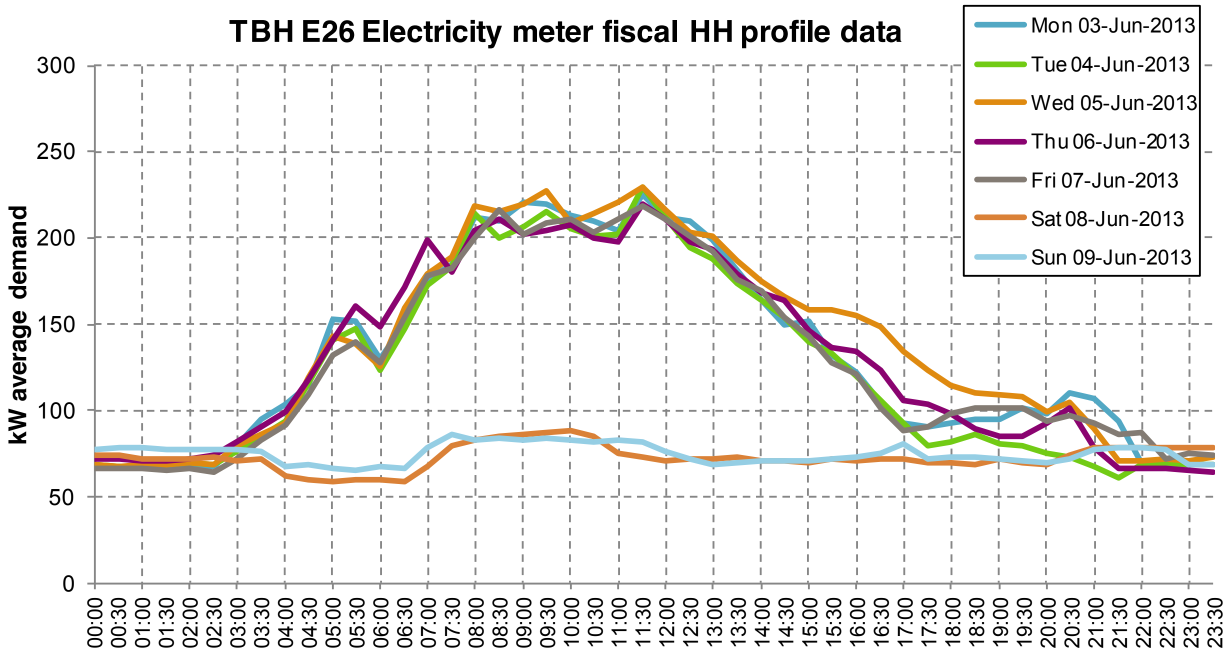


Figure 6.12. Daily profile showing average kWe consumption for each half hour period over a typical summer week during term time in 2013.

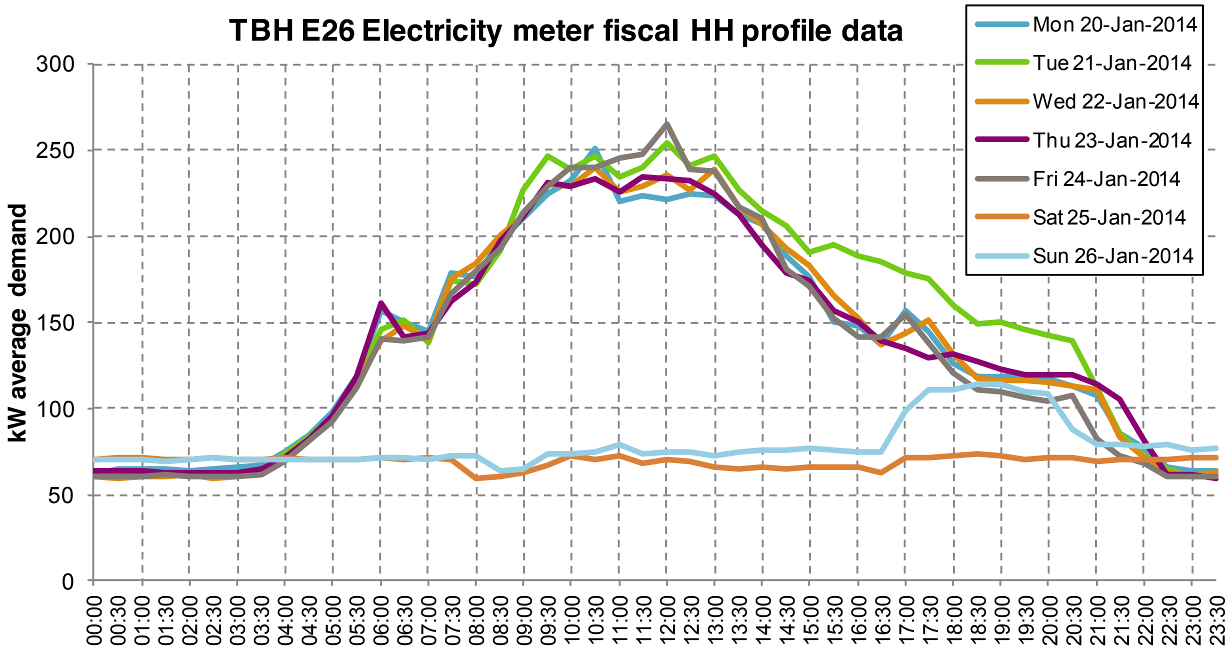


Figure 6.13. Daily profile showing average kWe consumption for each half hour period over a typical winter week during term time in 2014.

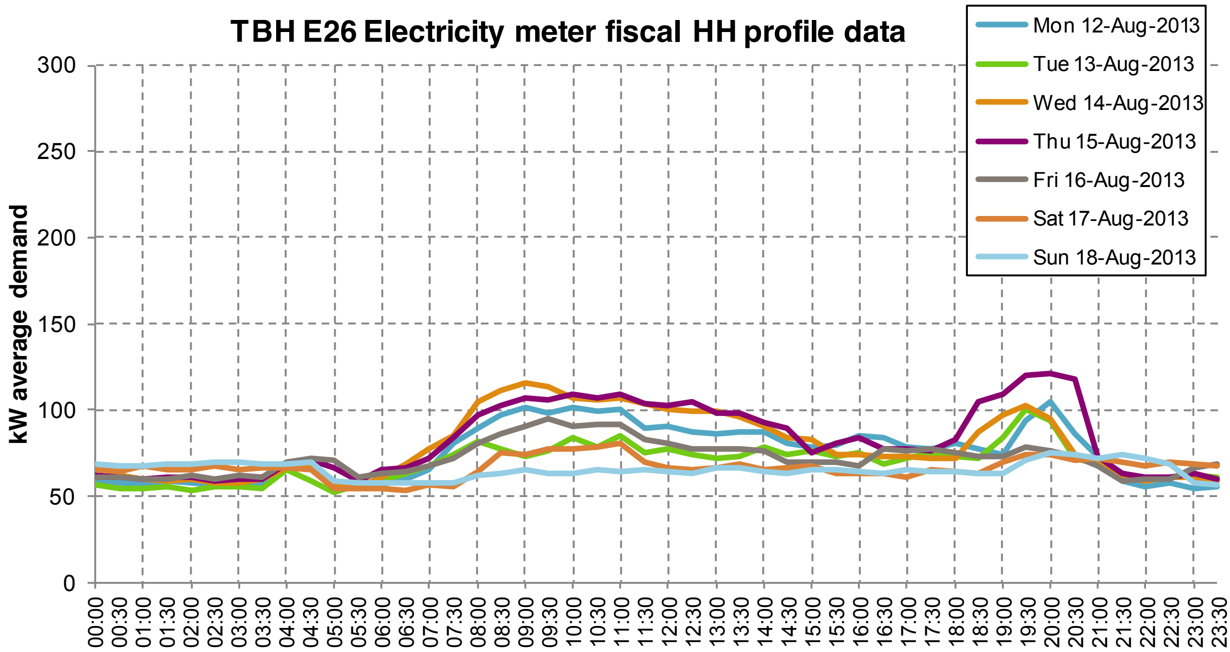


Figure 6.14. Daily profile showing average kWe consumption for each half hour period over a typical summer week out of term time in 2013.

Figure 6.15 shows the daily profile for the week over Christmas 2013. The baseload is nearer to 60 kW indicating that the occupants have deliberately turned off equipment for the Christmas period. This suggests a maximum baseload target that the school campus should aim to achieve over the summer out of term also.

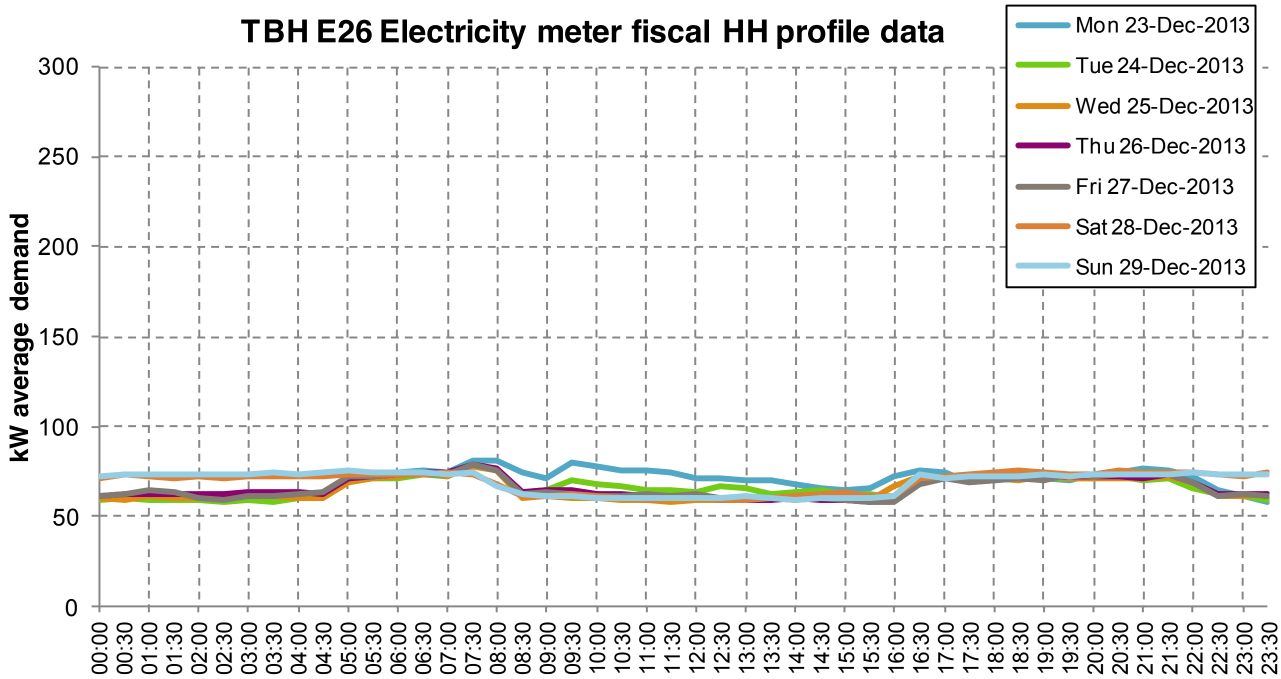


Figure 6.15. Daily profile showing average kWe consumption for each half hour period over Christmas in 2013.

6.5.2 TM22 analysis

The BPE study has followed the CIBSE TM22 Energy Assessment methodology. This methodology provides a framework for estimating the expected energy consumption of individual end-uses through a 'bottom-up' approach considering how the building is used and managed including operating hours and management characteristics. TM22 requires the use of locked Excel pro forma spreadsheets for data entry. A limitation of this approach is that it only allows for 50 submeters to be entered. It also only analyses submeter consumption for electricity meters and does not assess gas, heat, or water meters in detail.

A TM22 model was created for all buildings from all 3 Phases. Figure 6.16 shows an electricity end use breakdown from the TM22 model. The school campus clearly consumes more electricity than the TM22 model indicates. The reasons for this are explored in subsequent Sections. Generally, the most common and significant reason seems to be extended hours of use.

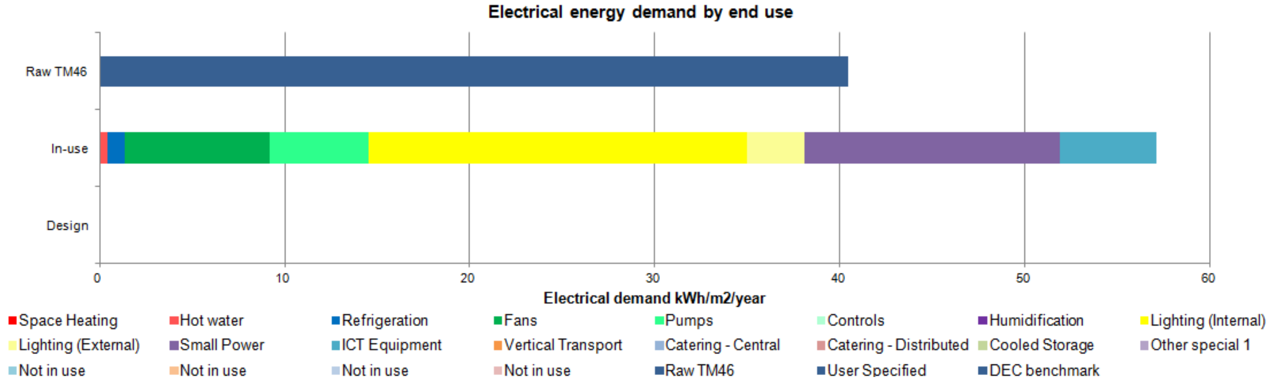


Figure 6.16. Electricity end use breakdown from TM22 model.

6.5.3 Weekly electricity profiles for teaching blocks

The issues with the BMS (documented in Section 7.2 and Appendix 10.5) have meant that it has been possible to only collect a fraction of the potential 15 minute energy data during the BPE study. However, analysing what is available has allowed the BPE team to produce some weekly profiles for electricity consumption for the separate blocks.

In general, the metering strategy has included separate submeters in each block labelled 'IT', 'Power', and 'Lighting'. Examination of electrical installation drawings reveals the distinction between IT and Power, but this is unclear from the meter labelling: IT refers to sockets in general use, so will tend to include small power appliances such as PCs, printers, projectors, etc, whereas Power circuits cover fixed small power appliances, such as hand driers, security and fire alarms, BMS communications equipment, and cleaners' sockets. However, a combination of poor installation and commissioning of submetering has meant that some of the submeters labelled 'Lighting' are actually totals for the block. This is the case for Tenzing and Cann Bridge. Weekly electricity consumption profiles are displayed below for the period Monday 15th July 2013 to Sunday 21st July, which is during term time.

Figure 6.17 shows a weekly profile for Austen block. It indicates that lighting and small power equipment are generally turned off at the end of the day. However, there is a varying baseload for IT (1 kW) and Power (1.5 kW) indicating that small power equipment is being left on standby overnight. The Power profile is constant and does not follow occupancy in the way in which the Lighting and IT profiles do (which may be expected and would represent more efficient management).

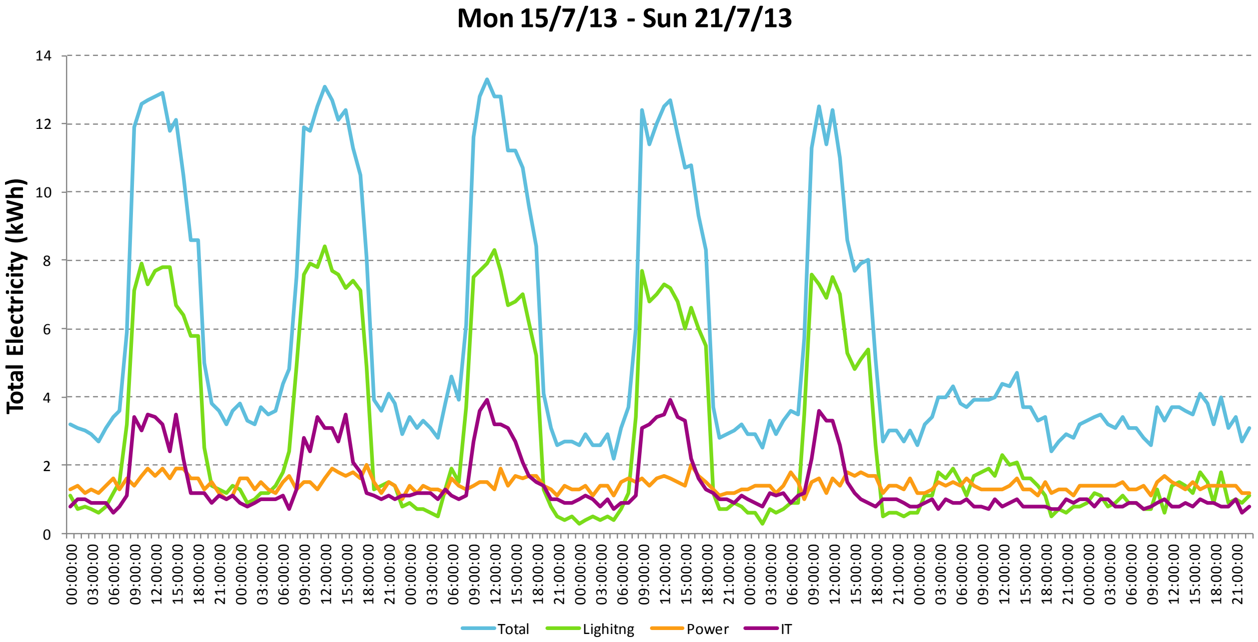


Figure 6.17. Austen electricity consumption profile.

The lighting profile shows a slight dip after 15:00 when lessons finish and some of the classroom lights are switched off. However, a proportion remains on until 20:00 when the FM team complete their final walk around. The baseline for lighting varies close to 1 kW at night time corresponding to the 1 kW of installed external lighting for the block.

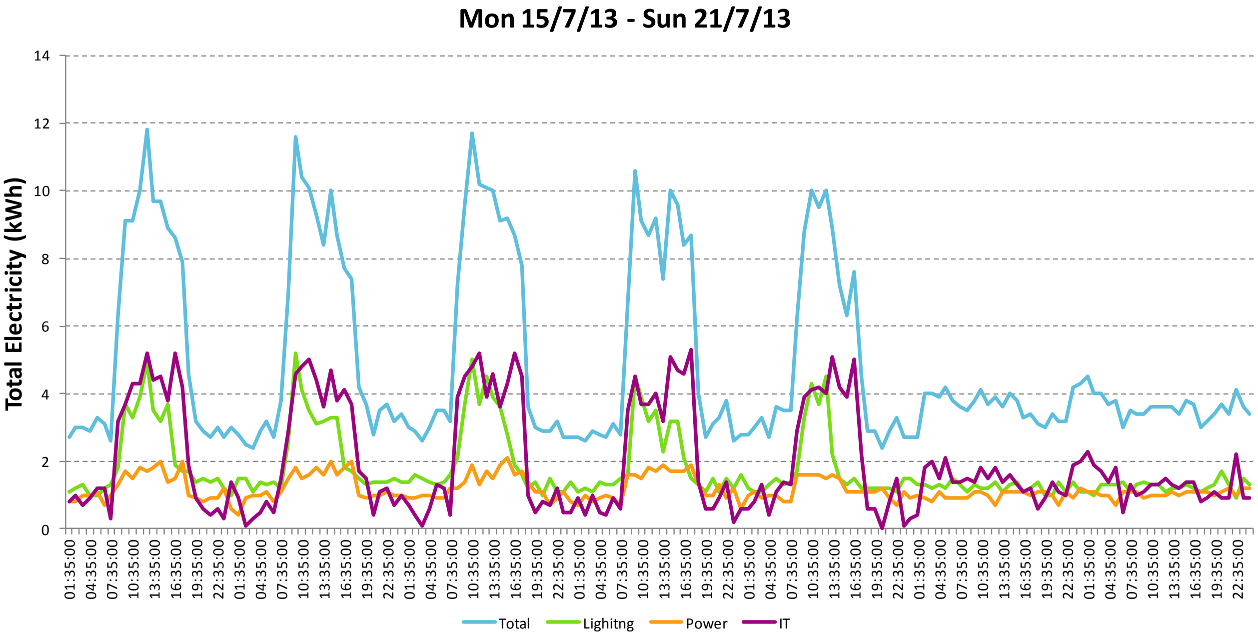


Figure 6.18. Tenzing weekly electricity consumption profile.

Figure 6.18 shows Tenzing block's weekly electricity consumption profile. Although Tenzing's installed lighting load (11.6 kW) is similar to Austen's (13 kW) the consumption is much lower. It is unclear exactly why this is the case but it may be because the submeter labelled 'Lighting' for Tenzing is actually the total for the block meaning the lighting profile has to be deduced through a virtual meter (VM). Consequently, there may be an error with the values stored by the BMS.

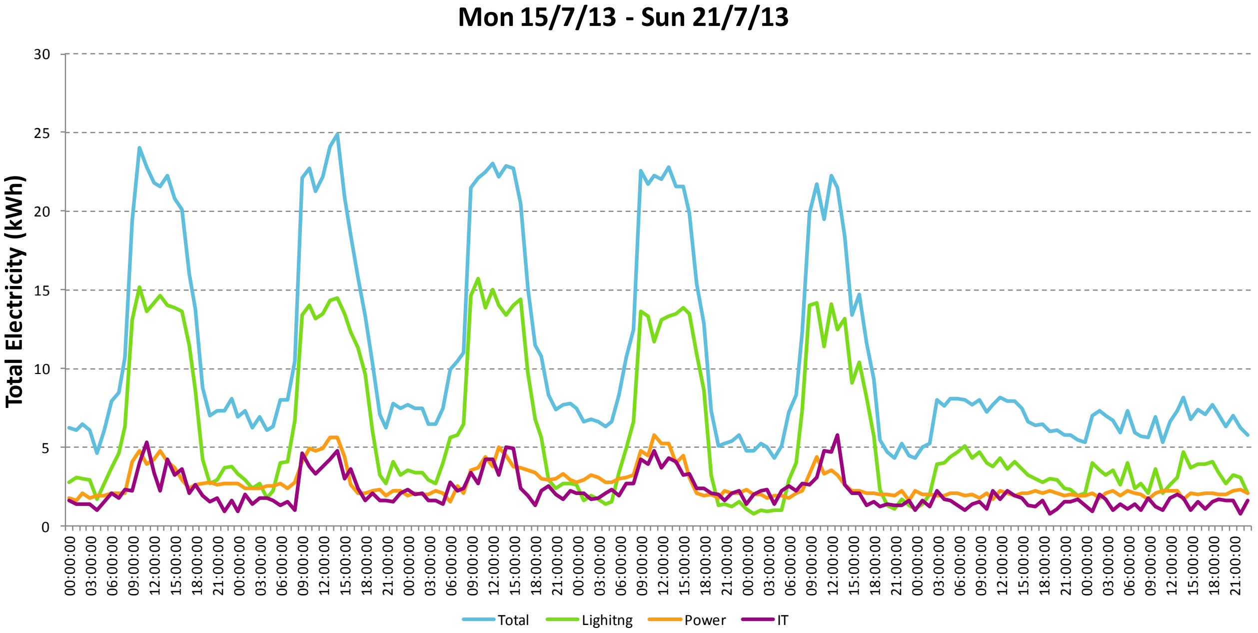


Figure 6.19. Faraday weekly electricity consumption profile.

Figure 6.19 shows Faraday block's weekly electricity consumption profile. Faraday has a higher installed lighting load than the previous blocks (22 kW). The lighting baseload varies significantly between the different days of the week indicating that lights are occasionally being left on overnight.

IT submeter consumption in Faraday peaks at 5 kW during the day, which is similar to Tenzing, but a 2 kW baseload indicates that more equipment is being left on standby. This may be occurring in the Design & Tech workshop that has assorted small power equipment present which are only used for relatively short periods during lessons.

The Power submeter in Faraday actually follows occupancy to a certain degree. Investigation of the sockets covered by this submeter reveal that the circuit in the Staff Room is included, explaining this association.

Figure 6.20 shows CADE North's weekly electricity consumption profile. CADE North contains library facilities, administration offices, and art classrooms. The First Floor IT circuit profile shows that the occupants in these areas are generally very good at switching appliances off at the end of each day. The Ground Floor IT circuit follows occupancy and has a 2 kW baseload, but the equipment contributing to this remained unclear from site visits. Lighting for this block is also occasionally left on overnight.

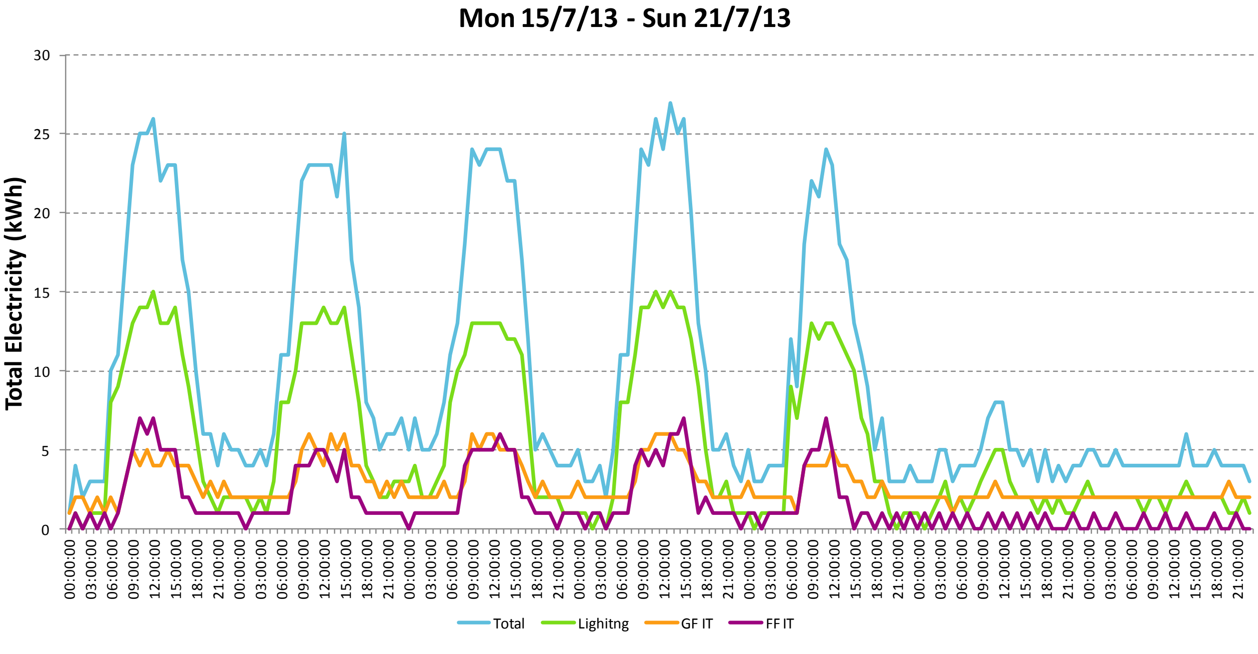


Figure 6.20. CADE North weekly electricity consumption profile.

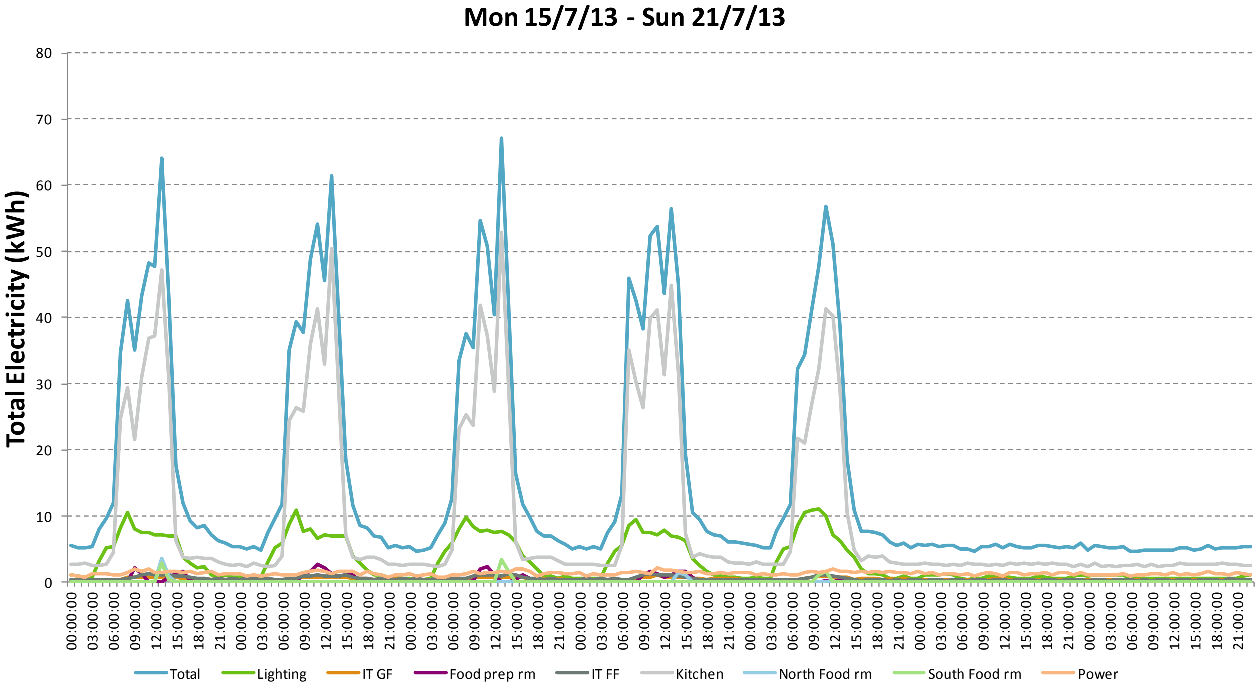


Figure 6.21. CADE South weekly electricity consumption profile.

Figure 6.21 shows CADE South's weekly electricity consumption profile. CADE South's consumption profile is dominated by the Kitchen. As discussed previously there is a certain amount of CADE South consumption (the CADE South Plant room and the IT server room) that is not separately submetered. The installed lighting load is mainly comprised of the 5 kW of lighting in the Dining Hall. Lighting is generally well controlled. Consumption for IT, Power, and the Home Economics rooms is relatively low and well controlled. The Kitchen is examined further in Section 6.8.1.

CADE unmetered electricity

Using the extrapolated annual consumption for unmetered electricity in CADE from clamp meter measurements and comparing this to the surveyed equipment in the CADE plant room produced predicted consumption within 14% of the metered consumption (Figure 6.22).

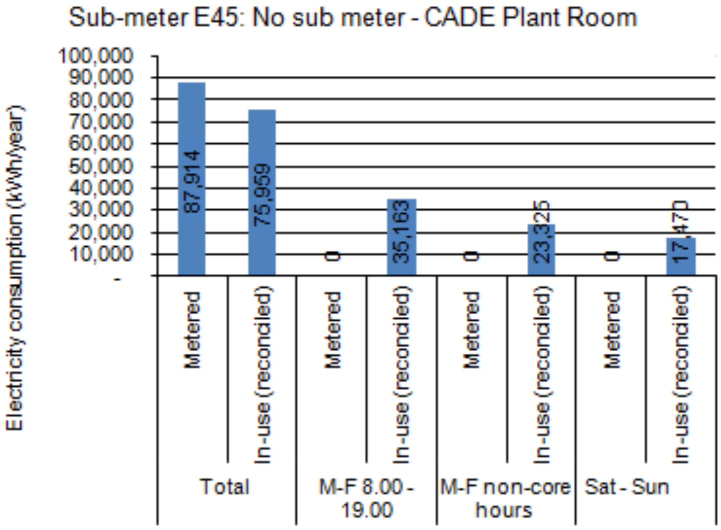


Figure 6.22. TM22 CADE Unmetered comparison.

IT submeters

The TM22 model predictions for the electricity consumption on the IT submeters for the various teaching blocks seem to slightly under estimate the metered consumption. This indicates equipment being left on out of hours and standby loads. During the walk around survey on 17th December 2013 it was discovered that around two thirds of the PCs in the IT hubs for the various blocks were left on. However, these computers are thin client and make a very small contribution to overall electricity consumption.

In general, IT standby loads (primarily in classrooms) may be significantly contributing to overall electricity consumption at the school campus. Approximate calculations (included in Appendix 10.4) estimate the contribution of standby loads to be 7% of total electricity consumption.

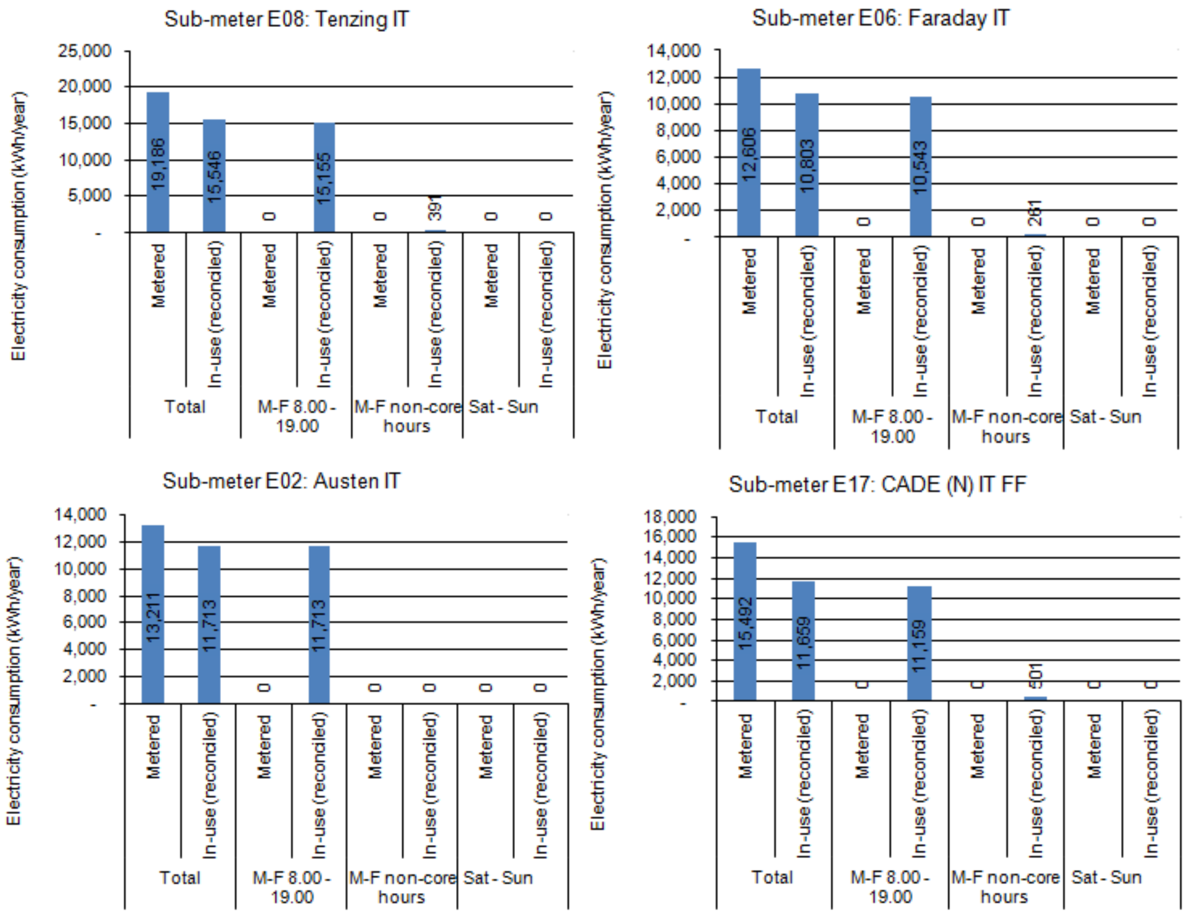


Figure 6.23. TM22 block IT submeter comparison.

Lighting submeters

The TM22 predictions for the Lighting submeters for the teaching blocks are generally quite accurate and are within 5% of the metered consumption. This indicates that lighting is being controlled fairly well and is not being left on for significant periods of time. This should be expected due to the passive infra-red (PIR) controls.

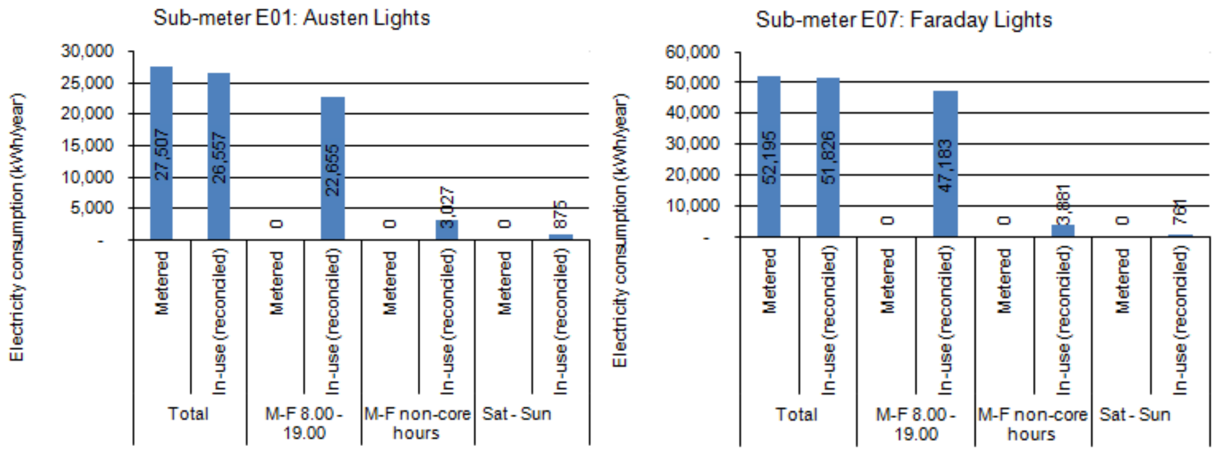


Figure 6.24. TM22 block lighting submeter comparison.

6.5.4 Sports Centre

The TM22 model predicts slightly less electricity consumption than is metered indicating lighting and small power appliances being left on for longer than required.

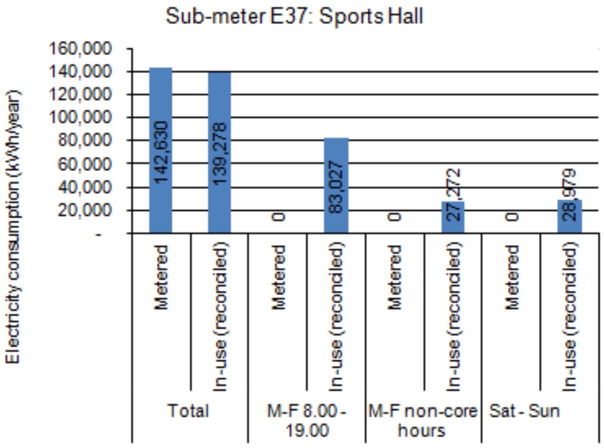


Figure 6.25. TM22 Sports block submeter comparison.

The profile for the Sports Block generated from the BMS appears to be a day out: the 'Monday' profile shown in Figure 6.26 is presumably actually a Sunday. Spot checks on other weeks indicate that this is the case and it was not a bank holiday.

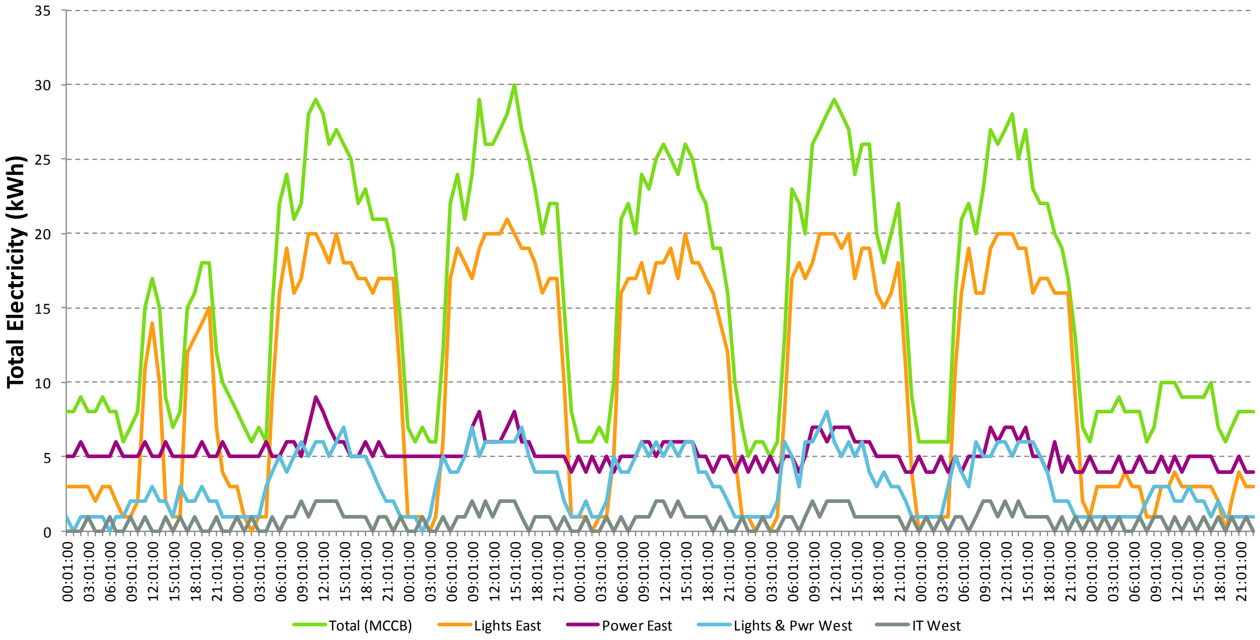


Figure 6.26. Sports Block weekly electricity consumption profile.

The Sports Block has multiple submeters for the various circuits. The installed lighting load is 20 kW with 10 kW of this for the Sports Hall (the Sports Hall requires a high lighting level for playing indoor cricket). Two different lighting levels can be selected using a light switch located in the reception area (Figure 6.27). The placement of this light switch is questionable as the occupant must leave the Sports Hall to change the light level. This may be contributing to the lights being turned on at 06:00 and remaining on all day until around 22:00. The weekly profile is for a period during summer so there is no capacity for daylight dimming. The labelling of the light switch also seems somewhat confusing.

Figure 6.27. Light switch for Sports Hall located in reception area.

The Power East submeter has a consistent profile and seems to govern the Pumps for the heating and DHW circuit, the AHUs for the Dance and Fitness Studios, and the Split Units for cooling in these areas. These all appear to be enabled 24 hours, 7 days a week.

6.5.5 Weekly electricity profiles for individual classrooms

Typically classrooms have the following small power loads: one computer for the teacher, a projector, an interactive whiteboard, and a sound system. During the out of hours walk through survey (see Appendix 10.12) it was discovered that all pieces of equipment in every classrooms were left on standby mode. Classrooms in Tenzing and Austen blocks each also contain a netbook charging station (see Section 3.3.1). It was observed during the out of hours survey that all of the netbook stations were left charging continuously.

Additionally, it was observed that many classrooms had their blinds in the closed position preventing natural light and solar gain. This may be as a consequence of the large windows increasing the possibility of glare, particularly when teachers are using whiteboards. It should be noted, however, that glare was only mentioned as an issue by one respondent to the BUS survey.

To monitor the small power and lighting consumption for individual classrooms, temporary wireless electricity monitors were installed. Four Efergy E1 monitors were installed on the IT power and lighting distribution boards in the relevant plant rooms. Efergy monitors have clip on CTs which transmit wireless signals over a relatively short range (around 50 m) to a monitor. Both the monitor and transmitter are powered by batteries. Efergy monitors assume a voltage of 240V and calculate the consumption in kWh based on the recorded current. Efergy monitors were in place for a 4 week period from 17/12/13 to 22/1/14.

Figure 6.28. Faraday Room F107 Monday 6th January to Sunday 12th January

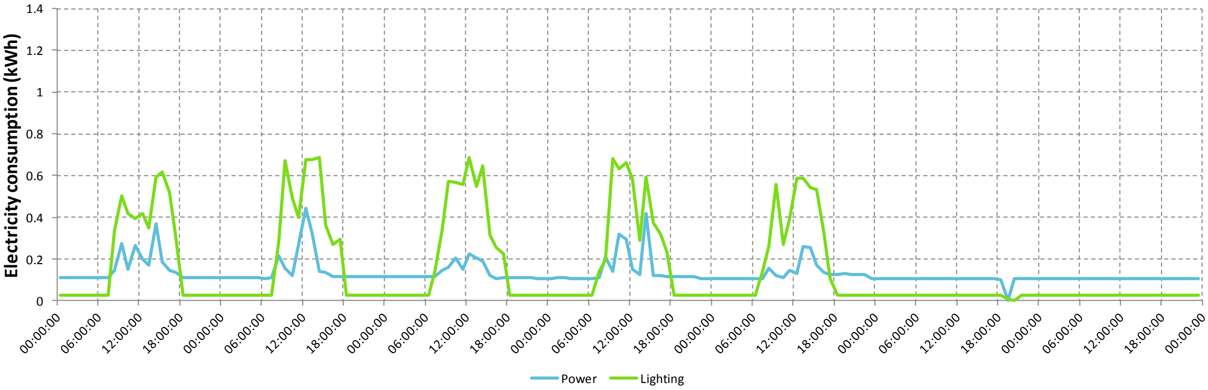


Figure 6.29. Tenzing Room D106 (lighting in D105 also) Monday 6th January to Sunday 12th January

Analysis of weekly profiles for the classrooms reveals that in general there is only a small baseload. For Tenzing there is a 100 W baseload which could be accounted for by the projectors and PCs being left on standby. There is a spike in consumption on Thursday 9th January in the Faraday classroom, potentially this is associated with a piece of Design and Technology equipment, but it has not been possible to verify this. During the out of hours walk through survey it was noted that every classrooms had at least one PC, a whiteboard, a projector, and a sound system all on standby. In the Tenzing classroom it can be seen that often when the lights are turned off there is a corresponding increase in small power consumption. This could conceivably be the lights being switched off so the projector can be more easily seen.

6.6 Gas consumption

An oversight in the metering strategy means the two gas boilers are not separately submetered. Consequently their consumption must be deduced through other submeter readings and assumptions regarding boiler efficiency. Although the biomass boiler is intended to be the primary means of generating heat for space heating and hot water, problems with its operation (see Section 7.5) meant that its use during the course of the BPE study has been sporadic and it has not been used at all since May 2013. Instead, the gas boilers are being used as the primary system to generate heat.

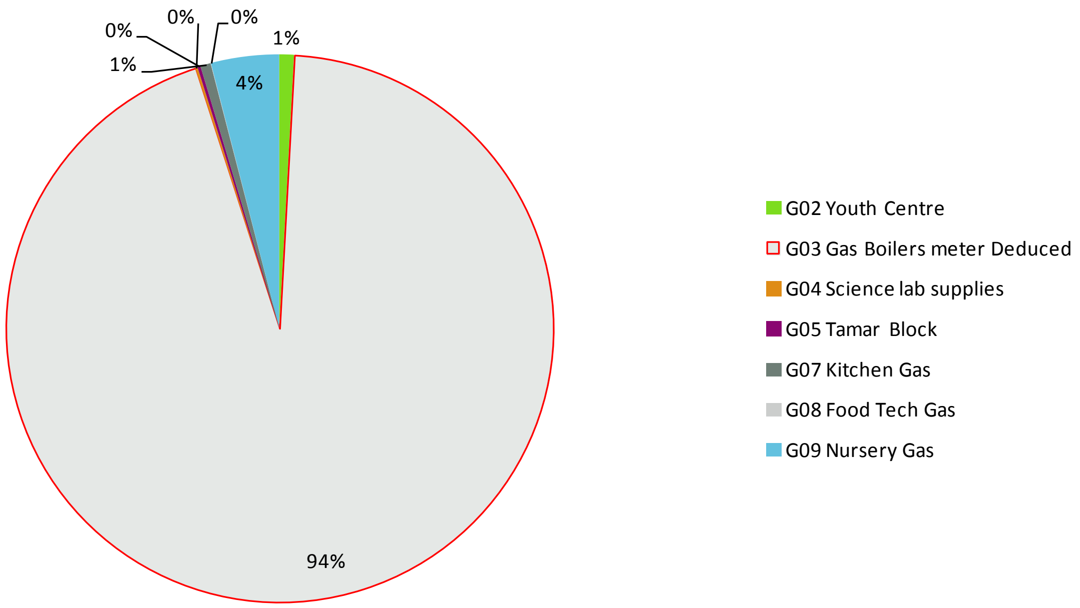


Figure 6.30. Split of gas consumption across the submeters of the school campus.

Figure 6.30 shows how the 2,191 MWh of annual gas consumption are split across the school campus' gas submeters. The gas consumed by the gas boilers had to be deduced from the incoming and other submeter gas readings. It can be seen that this is a problem for effective energy management as the gas boilers use by far the largest proportion of the gas (94%). The Kitchen only represents around 1% of gas consumption, but this is unsurprising as the majority of appliances use electricity.

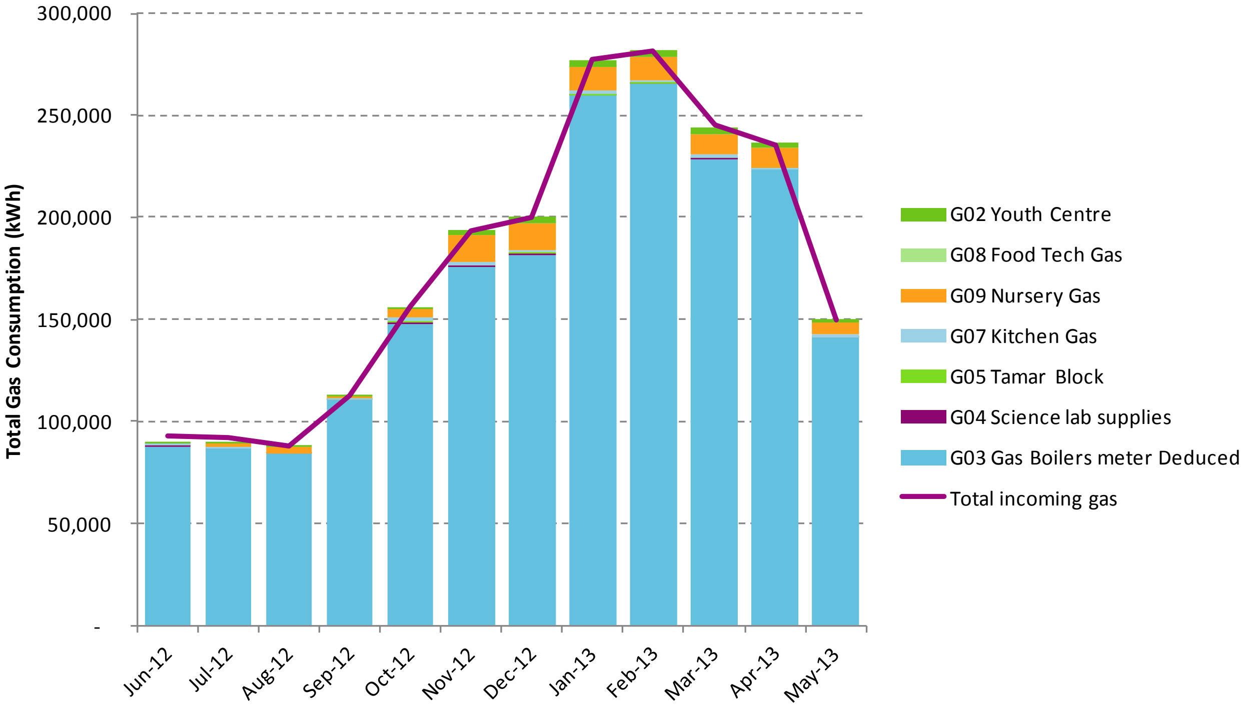


Figure 6.31. Chart showing monthly submetered gas consumption against total incoming gas.

Figure 6.31 shows the total incoming gas (not including the Sound House which has its own gas submeter) against the total of the various gas submeters. As can be seen, these match almost exactly.

6.7 Heat consumption

There are 18 heat meters installed around the site. Unfortunately the vast majority of these are either malfunctioning or are supplying spurious readings. Despite this, energy analysis has indicated that there is approximately 75,000 kWh of non-weather dependent heat demand at the school. This can be seen in Figure 6.32 in which the months of June, July, and August have a similar heat demand when the amount of degree days would suggest that space heating is unlikely to be required. This is especially interesting as the school is not open during most of July and the whole of August. Indications are that the heat demand may be caused by the calorifiers for each block that provide domestic hot water. Discussions with the FM revealed the DHW system is kept running as teachers tend to come in over the summer to work in their classrooms. Anecdotally, 30 – 40 staff members could be present on some occasions during the holiday period. This is arguably resulting in higher than necessary energy consumption as certain building services are operating during periods when buildings are only partially and sporadically occupied.

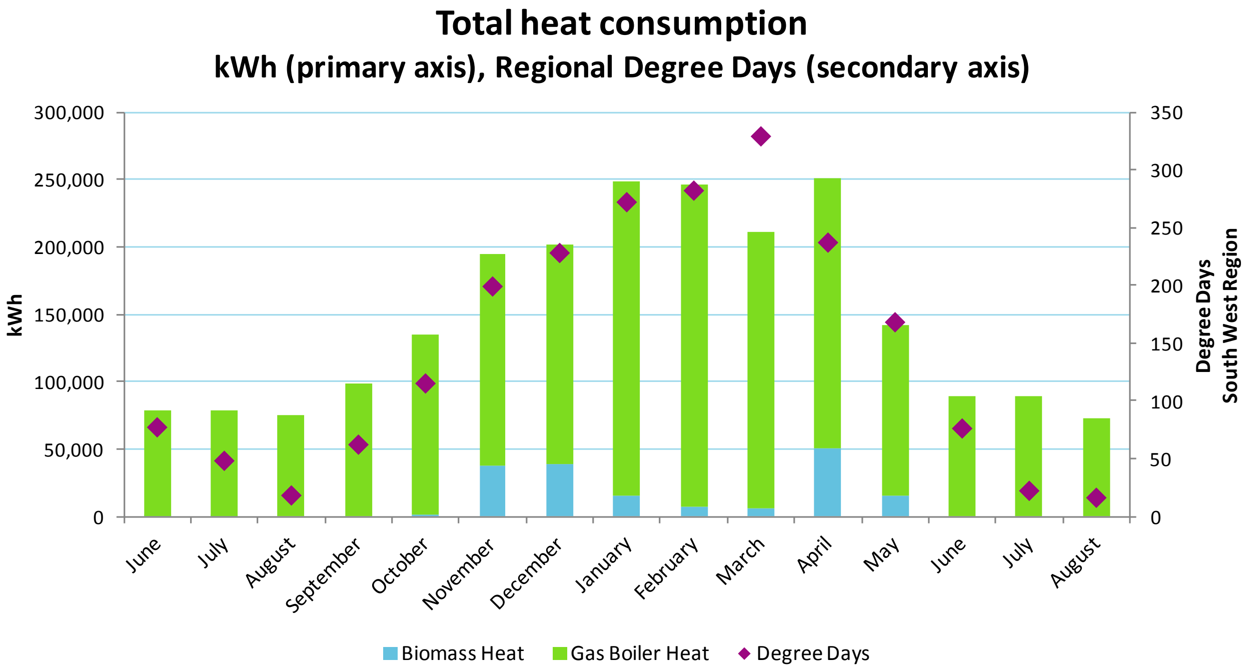


Figure 6.32. School campus heat consumption through biomass and gas against degree days from June 2012 to August 2013.

6.8 Key end uses

A number of key end uses are discussed below.

6.8.1 Kitchen

In general kitchen appliances are switched on from around 6:30 in preparation for breakfast which is served from 7:30. The first daily spike in electricity consumption in the morning corresponds to breakfast service. The second daily spike corresponds to lunch service. The third daily spike corresponds to the 19 kW electric dishwasher being used. During the out of hours walkthrough survey it was found that the majority of appliances in the kitchen are electric and are switched off after lunch service around 14:00. A washing machine was running and a coffee vending machine was also on. The kitchen supply and extract AHU system (fan electrical power ratings 4 kW_e and 5.5 kW_e respectively, Figure 6.34) was running continuously. Apparently this is the result of a fault with the BMS and there is no local control to switch off the extract system. This has been the situation since 6 months into occupation of the new building. Although the manufacturer (Schneider) has investigated the problem with the Kitchen AHU, the situation is unresolved. Extended operation of the kitchen air handling systems is reflected in the low CO_2 concentrations monitored in this room (see Section 7.6). There is a constant baseline load of around 2.5 kW, but this seems to be accounted for by the various fridges and freezers in the kitchen including the walk in fridge, the walk in freezer.

The TM22 model predicts the electricity consumption for the Kitchen is to be slightly higher than the actual metered consumption. This indicates that the majority of appliances (the kitchen extract’s consumption is not included in the kitchen submeter) are being well controlled and are only being used as required.

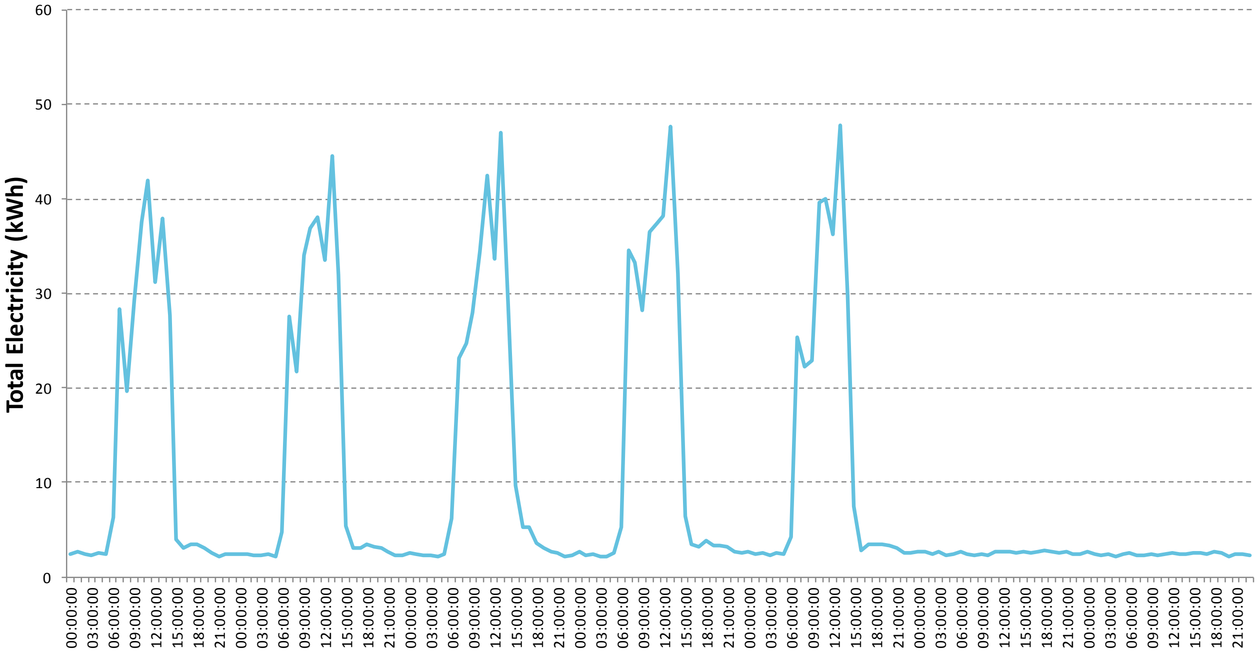


Figure 6.33. Weekly profile for Kitchen Monday 3rd June 2013 to Sunday 9th June 2013.

Figure 6.34. Kitchen extract which was observed to be running continuously.

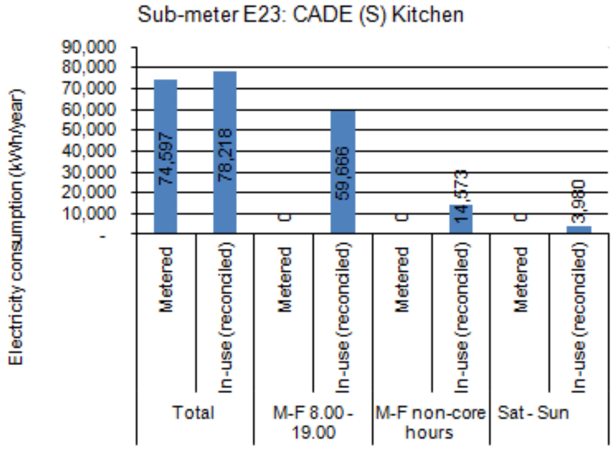


Figure 6.35. TM22 Kitchen submeter comparison.

6.8.2 ICT rooms

There are around 6 dedicated computer rooms scattered around the school. These contain a high density of PCs which are typically thin client. During the walk through survey it was observed that the vast majority of these were switched off. The FM indicated that there is software in place to automatically turn off these computers when they are not needed. However, this software does not seem to extend to other PCs on the site such as those in the IT Hubs.

Figure 6.36. ICT room in Faraday block.

6.8.3 Pitch floodlighting

The floodlighting for the MUGA and 3G pitches is unmetered. Both have installed loads of around 18 kW. Investigation with clamp meters over 31 days produced electricity consumption profile for the distribution board serving the pitch floodlights. Analysis of the data clearly shows a recurring spike of between 14 kW and 16 kW appearing on different days. The time the spike comes on varies between 18:00 and 20:00 and switches off a few hours later with the latest recording at 22:15. It is likely then that this profile covers the consumption for the 3G pitch floodlights which are regularly used during the evening. These lights automatically turn off at 22:15 at the latest according to the FM. The MUGA pitch is more rarely used and does not seem to have been operated during the period monitored with the clamp meters.

Additionally, a separate more regular profile can be seen which comes on every evening (around 18:00) and turns off the following morning (around 06:00). Analysis over the full period shows that as the month progresses the load comes on gradually later and goes off gradually earlier. This is likely to indicate external lighting controlled through photo cells. A site visit counted around 16 car park lights (150 W each) which equates with the recorded data. This is an area of potential saving if the lights are set to turn off for a period during the night. Using the TM22 model and adding these car park lights to the pitch floodlights accurately predicts the clamp meter consumption (which was modified to represent a year, Figure 6.38).

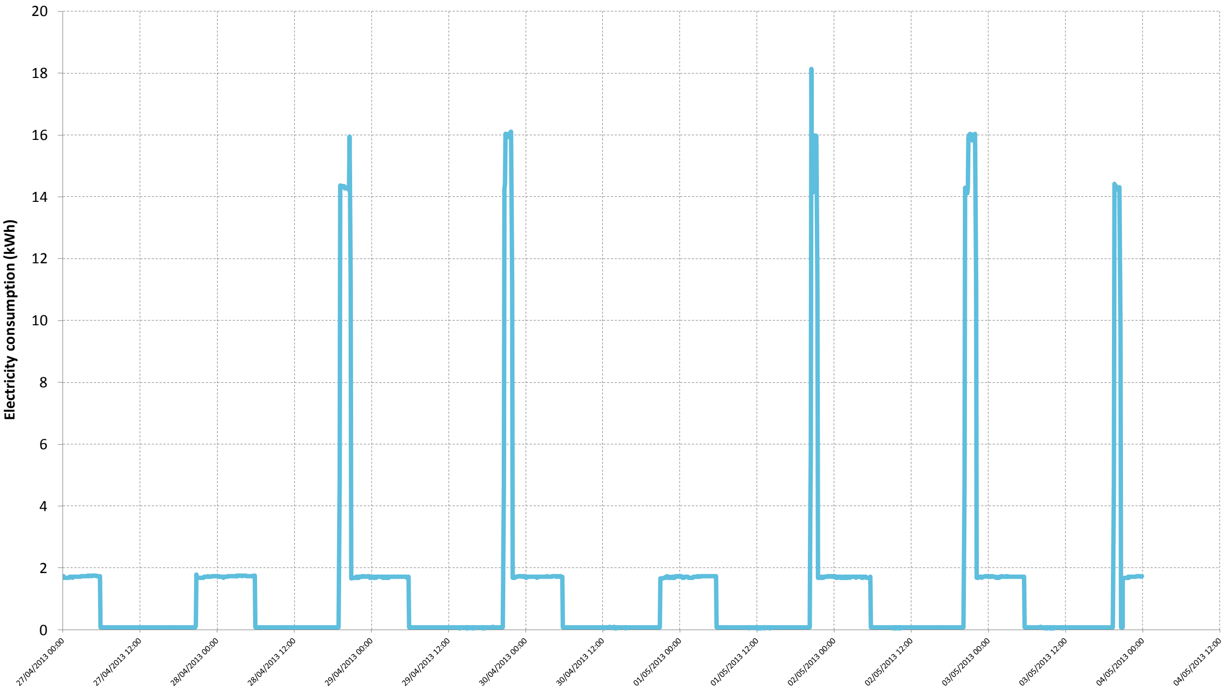


Figure 6.37. Clamp meter profile for MUGA pitch floodlighting from Saturday 27th April 2013 to Friday 3rd May 2013.

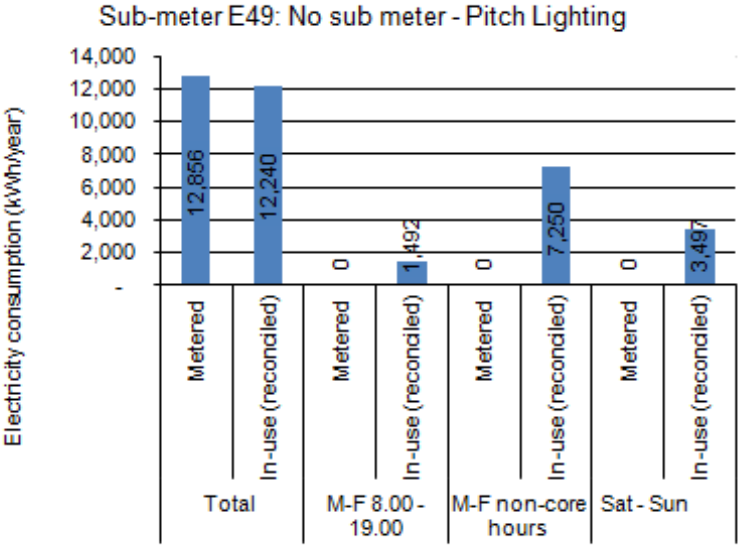


Figure 6.38. TM22 pitch floodlighting submeter comparison.

6.8.4 Baseline loads

Analysis of weekly profiles for the various block revealed baseloads on IT and Power submeters (refer to Section 6.5.3 for a definition of these terms as they relate to this study). Investigation of connected loads on the Power submeters revealed that alarm and fire systems and BMS communications (Figure 6.39) are also monitored through them. These items are present in each block and seem to account for the majority of the baseload for each Power submeter.

Figure 6.39. Alarm and fire systems, and BMS communications systems.

The half hourly analysis reported in Section 6.5.1 indicated that the school campus has a 60 kW baseload. Submeter analysis indicates that Austen, Tenzing, Faraday, Cade North, Cade South, and the Sports blocks contribute around 37 kW of this. The remainder is contributed by the unmetered loads of the Sound House, the server room, Cade Plant room's AHUs (including the kitchen extract fan), trace heating for the sprinkler system, and sports pitch floodlighting. Without usable submetering in these areas it is not possible to determine whether the systems in these areas are running appropriately in line with their required scheduling.

6.9 Benchmarking

The practice of comparing energy consumption of buildings against benchmarks is well established. There is awareness within the industry that much of the available benchmark data are either outdated or difficult to apply with ease, particularly when the building in question has specialised uses. In particular, newer buildings typically have lower heat consumption (due to improved building fabric insulation and more efficient services) and higher electricity consumption (due to appliance proliferation) than indicated in existing benchmark data. In general, benchmarks are useful for determining whether a building is in the 'right ball park' in terms of energy consumption. *Note that to improve the relevance of the benchmarking (and due to the metering layout) the benchmarks shown below for electricity are for the submeter E26 Secondary School and E31 Cann Bridge, with E37 Sports Hall removed. Therefore, the consumption covers blocks Austen, Tenzing, Cann Bridge, Faraday, Cade North, Cade South, and the Sound House. The TM22 model has also been included and in this instance has been modified to only reflect the aforementioned blocks.*

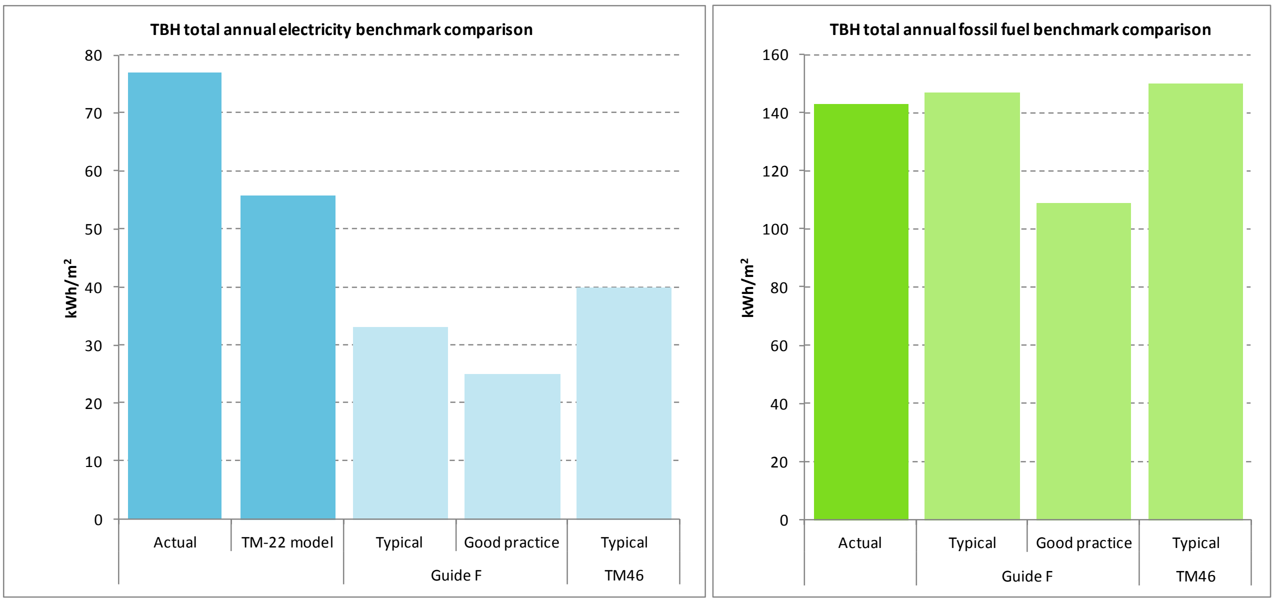


Figure 6.40. Total annual heat and electricity bench mark comparisons for the whole the school campus site.

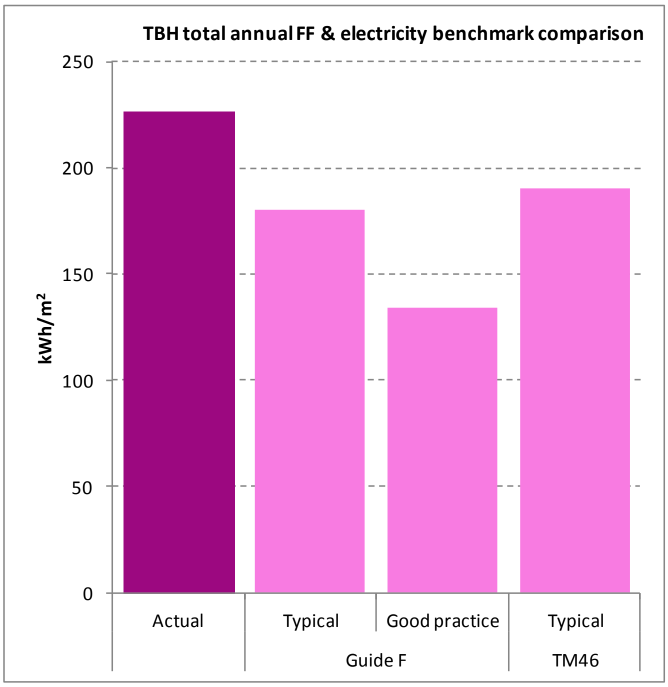


Figure 6.41. Overall annual benchmark comparison for whole the school campus site.

Analysis of the benchmark energy consumption data shows that although the school campus is using slightly less heat than a CIBSE Guide F 'typical' secondary school, it is somewhat higher than best practice. As the school buildings are newly built and have low U-values, its expected performance may be nearer to best practice than to typical. Due to the way in which heat is supplied to the site (from centralised generation in the Energy Centre), there will be losses occurring in the heat network. The performance could possibly be improved if heat was not being constantly circulated during out of term periods.

In terms of electricity consumption, the school campus uses over twice the typical secondary school benchmarks. Clearly this is an area of concern, but it is likely that current industry benchmarks conceived some years ago do not adequately account for the substantial increase in IT during the intervening period. It is also not possible to ascertain the exact basis of the benchmarks. There is a lack of clear industry guidance over which facilities (i.e. kitchen, server room, sports pitch floodlighting, etc) the benchmark schools data sets contains and which hours of use they represent. The unmetered consumption for the Sound House, CADE South plant, Server room, Sprinkler system, and pitch floodlighting all contribute to the relatively large consumption shown in the electricity benchmark comparison.

As an additional form of benchmark, Figure 6.40 includes the electricity consumption calculated according to the TM22 methodology. The assumed hours of use in this TM22 calculation have not been adjusted to match those observed from the actual electricity consumption data. As discussed in Section 6.5.2, the extended hours of use in reality appears to be a significant contributing factor to the total electricity consumption.

Figure 6.42 shows benchmark comparisons by individual blocks, giving an indication of how the various areas of the school are performing. As can be seen the individual teaching blocks compare more favourably than the overall site and are nearer the typical values that would be expected for a site of this nature. However, they still show a discrepancy with the published benchmarks, despite effectively excluding energy consumption from centralised building services and IT equipment.

Several areas at the school campus where relatively high electricity consumption is occurring could be considered atypical for a secondary school. For instance, the kitchen prepares food for other nearby schools, the Sports Centre servers the wider community and is open for long hours, and the Sound House is an older building. By separating these out and adjusting the benchmarks for the school campus' area the electricity benchmark comparison becomes closer, although still indicating high consumption.

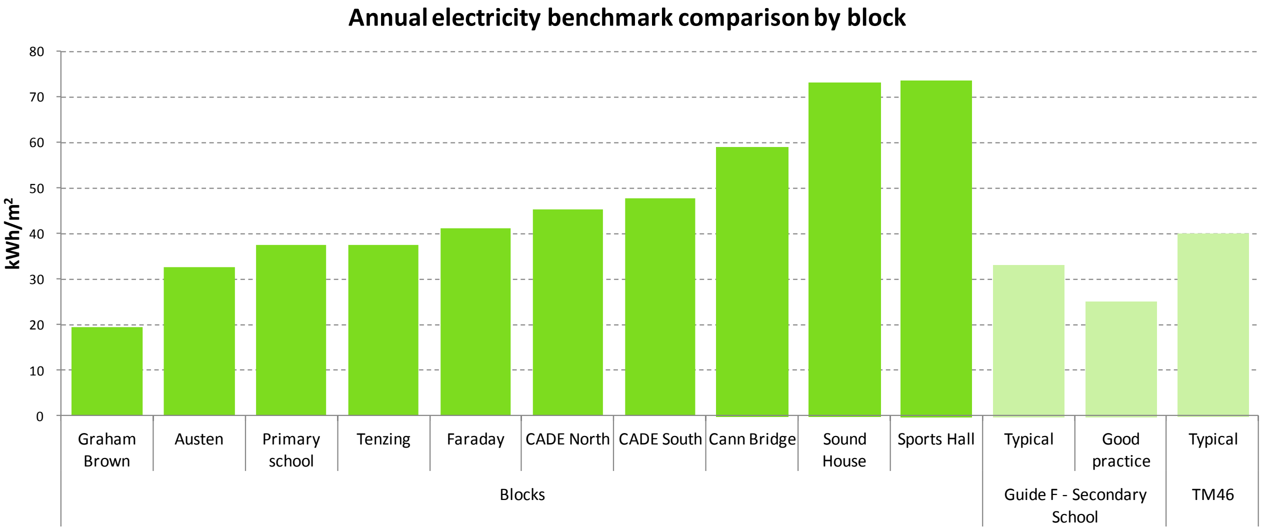


Figure 6.42. Annual electricity benchmark comparison for individual buildings on the school campus site.

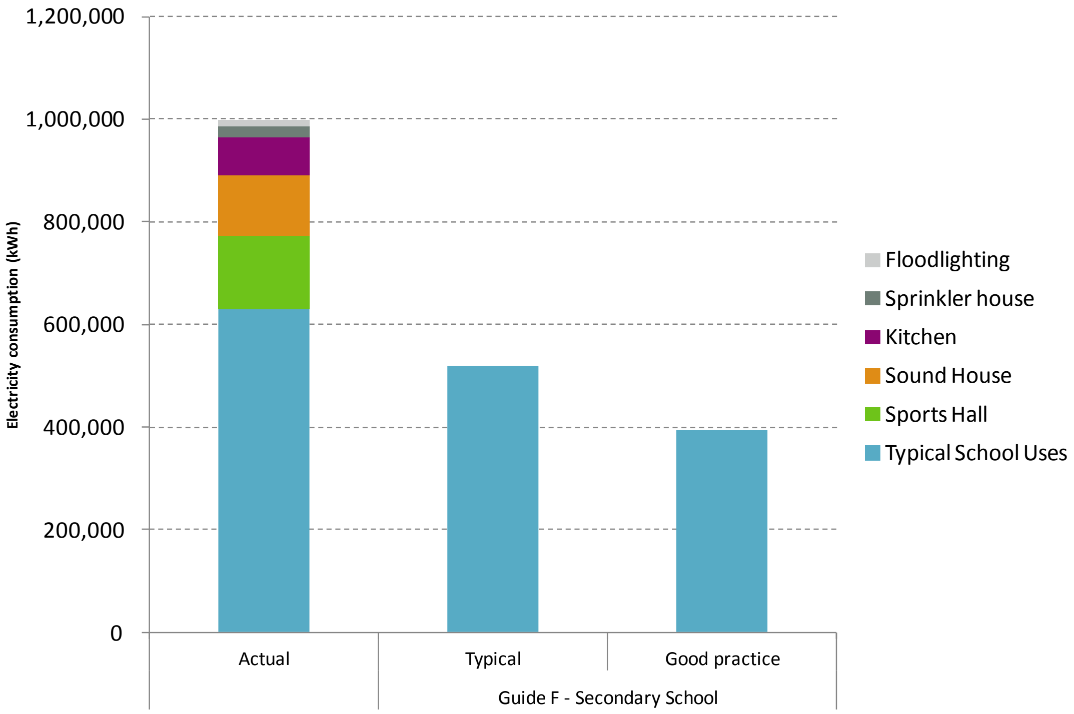


Figure 6.43. Benchmark comparison of the school campus annual electricity consumption with 'atypical' uses separated out.

6.10 Key findings

Key findings of this review of the energy use at the school campus are that:

- Austen, Tenzing, Faraday and Sports blocks achieved a combined EPC rating of 'A'. A 'false comparison' of the energy consumption from the EPC calculation for heat and electricity to actual consumption for heat and electricity for these blocks showed that the actual was around 2.4 times greater. The larger discrepancy stems from heat consumption at around 2.9 times greater than the EPC and electricity consumption which is around 1.6 times greater. ***This highlights that EPCs do not provide an estimate of energy consumption and should not be used in comparison with actual in use consumption, for clear reasons; where there are significant unregulated energy uses, and patterns of use significantly different to those assumed by the EPC calculation methodology.***

- 34% of total annual electricity consumption was unmetered. Current clamps revealed this to be comprised of consumption for the Sound House, the server room, AHUs, trace heating for the sprinkler system, and pitch floodlighting. ***Ensure at least 90% of regulated loads are submetered in accordance with Part L, but also submeter clear areas of potential waste with high loads such as pitch floodlighting and server rooms.***

- Daily profiles for the fiscal electricity meter (E-26) indicate a 60 kW baseload. Sub meter analysis shows that Austen, Tenzing, Faraday, Cade North, Cade South, and the Sports blocks contribute around 37 kW of this. The remainder is contributed by the unmetered loads referred to in Section

6.8.4. ***A lack of usable metering can hamper a site's ability to identify areas of potential energy waste and act upon them.***

- Small power standby loads for PCs, projectors, netbooks, etc are responsible for around 7% of the school campus total annual electricity consumption. ***Standby loads can prove significant, particularly in schools. For specific school campus recommendations, see Section 8.8 and 8.9.***
- Although internal lighting is the most significant end use in terms of electricity consumption (33%) daily consumption profiles indicate that it is being controlled well through the PIR sensors in teaching areas – even though anecdotally the BPE team were told that PIRs were causing lights to come on inappropriately. However, lighting for the Sports hall tends to be on all day and is controlled through manually switching in the reception area. ***Ensure good controls and management for lighting for areas with extended hours of use such as sports halls.***
- The Kitchen electricity consumption profile indicates that appliances are being well controlled and there is only a relatively small baseload largely associated with fridges and freezers. However, the kitchen AHU is running 24 hours a day due to a fault in the control system. ***Specify manual back up controls for extract fans in case of issues with automatic controls. For specific school campus recommendations, see Section 8.5.***
- Gas boilers were not separately submetered even though they represent 94% of the gas consumption. ***Specify submetering for all energy generating plant, even if only intended to provide back up.***
- There can be a significant difference between published benchmarking indicators and TM22 energy assessments for performance in use, highlighting the limitations and discrepancies of using such benchmarks as a means of quantifying an energy 'performance gap' between design expectations and performance in use. ***Consider specifying the approach to be used in producing an In-Use Energy Model including the analysis methodology explained in CIBSE TM54 'Evaluating Operational Energy Use at the Design stage'.***
- There is 75,000 kWh of non-weather dependent heat consumed every month. Heat for the calorfiers is operating over the summer months when there theoretically should be no occupancy. ***Consider specifying direct point of use appliances for domestic hot water at sites which have variable occupancy across the year such as educational establishments. For specific school campus recommendations, see Section 8.3.***
- Car park lighting is on all night. ***For specific school campus recommendations, see Section 8.11.***
- Benchmarking shows that the school campus is performing around the typical level for a school in terms of heat consumption – although with a new school it would be expected that this would be nearer the good practice level. The school campus is performing less well in terms of electricity consumption with regards to existing benchmarks, although this is not an uncommon situation in newer schools.

7 Technical Issues

7.1 Introduction

A number of technical issues underlie the performance of the school and these are explored below. In the main, these issues have emerged through dialogue with the site Facilities Manager (FM), as well as through observations made during site visits. It is important to observe though that aside from the systems mentioned below, the other building services for the new school campus are generally operating as intended and, as highlighted in Section 4, the occupants surveyed are for the most part satisfied with the new buildings.

7.2 Building management system and metering

According to the specification documents the BMS was intended to provide efficient operation, monitoring and management of the mechanical and electrical services installations from a central location in either the main plant room or FM's office. It should allow all mechanical systems to be zoned to permit various functions, hours of use, orientation and extra-curricular activities. Additionally, it should also allow interrogation by users (the school campus and end-users) for use as an education aid. However it is notable that full building energy management system (BEMS) functionality was not specified.

The BMS was examined in depth and the full report is in Appendix 10.5. The study found that there were deficiencies as a result of extensive issues with installation, commissioning, documentation, reliability, user training and maintenance. These are each discussed below.

Although meters are provided for the majority of areas of the new school, there are areas where the strategy does not appear to have been fully considered. There are specific issues which could have been addressed relatively simply had the design strategy been more aligned with the needs of the school in terms of energy management.

Some of the key issues around the design of the metering strategy are:

- Meters are connected to the BMS, which by default only stores about one day's worth of historical data, as is typical, and these are held locally on outstations.
- Although the BMS can be configured to download data from the outstations for long term storage on the controlling PC, this is not possible via the graphical interface, nor is data retrieval. Configuration and retrieval are via the Explorer interface, which is realistically a technical operation for a maintenance engineer rather than site staff. Furthermore, if the PC is switched off (or fails) no data are stored. Historical meter data profiles are an essential part of energy management.
- There is a lack of meters for the gas boilers, meaning that the heat supplied / fuel used by the gas boilers can only be estimated.
- There is a lack of clear descriptive labelling on meters.
- Some meters documented as lighting in the various school blocks in fact meter total energy.

- The definition of IT power and general power (a key distinction in the metering strategy) is not explained in the Log Book.

In addition, there are a large number of problems with the delivery of the metering strategy which are discussed in the next section (7.2.1).

7.2.1 Building Regulations Metering

The site is equipped with extensive submetering of electricity, gas and water, and of heat distribution. In addition to the shortcomings of the BMS that caused problems with reliable data logging, a number of issues were identified with the metering itself.

First of all, water metering is comprehensive and shows good agreement between the incoming meter and submeters. However, the energy metering strategy is not robust in providing a sufficiently complete picture of where energy is used on the site. Whilst it is common for a few minor supplies to be unmetered (e.g. fire alarms, which often have a separate feed from the main switchgear to improve resilience), at the school campus summing the electrical submeter data accounts for only about 66% of electricity consumption registered on the site incoming meter. Supplies to sports pitch lighting, the central IT server, the sprinkler house, the Sound House and central mechanical services in Cade South are unmetered. Temporary monitoring of these supplies reduced the unknown consumption to 2%, as discussed in Section 6.5.

Gas metering suffers from the omission of meters for the gas boilers, understood to be omitted as a cost saving measure. Inference of boiler gas consumption by subtraction is likely to introduce inaccuracies, takes effort and hinders effective energy management. Heat metering is incomplete, with no metering of the Graham Browne building or the output from the gas boilers (which could arguably be estimated from the (deduced) gas consumption).

The metering strategy is poorly documented: meters are not labelled with their function, and the documentation in the building Log Book is sometimes contradictory and inaccurate, referring to a meter that has not been fitted (the gas boiler meter), omitting meters in existing buildings supplied from the same incomer, and incorrectly showing the hierarchy of electricity meters (some 'lighting' meters actually recording total consumption in a block). Cade

Incorrect meter commissioning and operation was encountered. Initially, none of the electricity submeters had been programmed with the correct parameters to record electricity consumption. This was not identified until it was reported by the BPE team and the buildings had by then been occupied for several months. This highlights the need to specify reconciling submeter readings with main meters and the benefit of post occupancy evaluations as part of a Soft Landings approach. The accuracy of submeters in the sports block and primary school remain uncertain, with one meter in the primary school still not properly commissioned. The Austen / Faraday water submeter is located with the dial facing upwards about 2.5 m above the floor amongst other pipework, access is difficult and readings can only be taken using a mirror or small digital camera.

Heat metering was found to be unreliable. One meter had not had the initial setup procedure completed, and one meter was set to record in MWh, whereas all the others report in kWh. Summation of metered heat and comparison to gas and biomass consumption (assuming typical boiler efficiencies) does not give consistent or meaningful results, suggesting that heat was not being reliably metered even when most of the meters were apparently operational.

The school initially decided not to enter into a BMS maintenance contract, however, towards the end of the BPE study, the school procured such a contract. A number of the above faults were corrected, including making final connections to additional meters and correction of software parameters. The maintenance engineer commented that implementation of the system (e.g. programming style) was inconsistent across the three phases of the build.

7.3 Sports Hall

Early on in the Sports Hall's operation the heating through the high level radiant panels was switched off as it was regularly getting too hot even during winter and spring months. This was a particular problem when sports lessons were taking place in the hall. The underlying issues which seemed to cause the unacceptable conditions in the space are related to the BMS and the heating system.

Figure 7.1. High level radiant heat panels in the Sports Hall.

Reportedly, automatic windows were not opening as required and the BMS reports 'nothing connected' when any attempt is made to override through manual intervention. The BMS controls the windows depending on its assessment of whether external conditions constitute either winter or summer. When in winter mode, the windows are automatically closed and heating provided to the radiant panels. Clearly, the decision making within the BMS is not appropriate for this space and while it may work well elsewhere in the school the more specialised nature of the Sports Hall suggests that it should be treated differently. The situation is made more problematic as this area is part of the Phase 2 development over which the FM has less control via the BMS than for the other phases. Despite this, the site FM has found a way to override the controls to open windows when necessary, but there is still a lack of control for the heating as it is either on or off and appears to have no capacity to regulate heat output from the radiant panels. In part, this may be because it is connected to a constant temperature circuit which also serves air handling units. More typically space heating heat emitters are connected to variable temperature circuits allowing for greater control over output.

7.4 Kitchen

Analysis of the BMS electricity consumption profiles for the Kitchen show that generally much of the equipment is switched off shortly after the lunch period ends around 14:00. However, since after about 6 months into operation the Kitchen Supply and Extract AHU fans have been running 24 hours per day all year and the FM team have been unable to switch them off. Although the FM has contacted Schneider and had various controls specialists in to look at the problem it remains unresolved. This is also reflected in the low measured indoor CO_2 concentrations – see Appendix 7.69.

7.5 Biomass boiler operation

Figure 7.2. Biomass boiler (left)with the stain on the floor in front of the boiler indicating blow back and biomass delivery (right).

The FM team and the Finance team seem to have lost confidence in the biomass boiler system. They perceive the maintenance burden to be too large for the FM team to realistically deal with and also consider the boiler to be uneconomic to operate. As a result, since May 2013 they have switched to the gas boilers as the primary means of heat generation for the site. It is clear that the biomass boiler has been a long term issue for the school and since its installation, it has spent significant periods out of operation (the longest being from January 2012 to June 2012).

The biomass boiler was shut down immediately after the 2012 Christmas break due to what was seen as excessive operating costs. The typical usage of fuel prior to the Christmas break had been 3 deliveries of wood chip per week (i.e. 7 days, delivered on Monday, Wednesday, and Friday) at a cost of £750 per load. To cover the period 2nd January and 7th January, i.e. 6 days), two deliveries were ordered, however, both loads had been consumed in six days. This led the Finance team to decide that the cost of the fuel was excessive (despite this use being fairly consistent with previous consumption) and they requested a switch over to the gas boilers.

However, according to FM the very high biomass use straight after Christmas was because the system had been completely shut down and the buffer vessel (of ~10,000 litres) needed full heating to get the system up

and running after the break. The reaction to the high fuel consumption may be due to understanding of the system being solely held by the FM. He was on sick leave during this period and therefore was unavailable to explain its operation to the wider team.
Due to the problems with the heat metering (Section 7.2.1) it was not possible to calculate an approximate cost per kWh for the biomass boiler. However, without RHI it is likely that these costs would be around 2.9p/kWh, making it more expensive than gas per unit of heat delivered which is approximately 2.7p/kWh. Additionally, considering the greater cost and time burden of maintaining the biomass boiler system relative to the gas boilers there is no financial incentive to continue its use. It is therefore unsurprising that since May 2013, the school has effectively 'mothballed' the biomass boiler and no longer receives fuel deliveries. Even though this was still the case during an energy audit on 4th March 2014, it was discovered that the pumps for the heating circuit for both the biomass boiler and the buffer vessel were running continuously.

There appear to be a number of issues underlying the current situation, as follows:

- The lack of a maintenance contract for the biomass boiler and its associated controls for a considerable period after installation meant a long delay in the rectification of an electrical fault in the control panel by the installers, which rendered the boiler inoperable.
- All of the technical and operational understanding of the system is vested in a single person, the FM, meaning that the impacts of any issues occurring when he is away are magnified. Observations by the BPE team of reactions to high fuel use and the consequences of overfilling of the fuel store support this point of view.
- The biomass fuel supply contract provides no means of ensuring the quality of the fuel being delivered both in terms of regularity / quality of wood chip and moisture content both of which have an impact on performance. Oversized woodchips have led to jams in the fuel lift auger and, on one occasion, a burn back (where fuel ignites when it is still in the fuel feed system rather than in the combustion chamber) which was automatically doused by the boiler's systems leading to flooding in the Energy Centre. Contamination in the fuel (pieces of metal have been found in the fuel delivery system) is also problematic and causes issues with consistent fuel delivery from the wood store to the boiler.

The impact that the variable moisture content in the fuel had on heat generation is difficult to establish. The contract that was in place (where fuel was purchased by volume) meant that there was no specification regarding moisture content so it was not recorded, past experience suggests that it is likely that levels were not optimised for efficiency. Elevated moisture content means more fuel is required to generate the same amount of heat, thus, wetter fuel is effectively more expensive than dryer fuel, if purchased by unit volume. There have been attempts by both the fuel supplier and also by the Main Contractor to determine the moisture content of the fuel, however, results from the two experiments did not agree.

The BPE team recommended to the FM team that they could investigate a delivered heat contract and offered to assist, but this was not taken forward. Had this review of the fuel supply contract been pursued, it would likely have resulted in a more consistent level of fuel charges making financial management more straightforward. It would also have provided a means of holding any fuel supplier to account for poor quality fuel.

The discharger arm in the fuel storage pit sweeps in circular motion, but the pit is rectangular so woodchip becomes piled up in the corners. Despite efforts of the FM team it cannot easily be cleared, which could in itself indicate high moisture content with the resins in the wood causing them to coalesce. It is noted this is not a unique problem to this school campus and is found with many biomass storage pits.

Figure 7.3. Photograph showing build up of woodchip in corners of storage pit.

7.6 Ventilation study

A ventilation study was carried out to assess the effectiveness of the natural ventilation strategy. As BMS data logs for indoor CO_2 were incomplete, seven CO_2 dataloggers were fitted around the site. These were set to record a spot reading at least every 30 minutes. In addition, more detailed ventilation monitoring was conducted on four occasions (two in the summer and two in the winter). On these occasions, the reading frequency was increased to every five minutes and teachers were asked to complete a room log sheet detailing occupancy, whether or not windows and vents were opened and comments on air quality. To corroborate the estimated ventilation rates, tracer gas ventilation rates were made in two of the rooms.

The data are useful in revealing the range of indoor air quality (IAQ) experienced in different types of room, whether the design has the potential to offer adequate ventilation, and whether this is realised in practice (most teaching spaces rely to some extent on the manual opening of windows and ventilators). The results can also be compared to the Building Bulletin 101 ventilation design criteria: the maximum occupied CO_2 concentration should not exceed 5,000 ppm and the average concentration over the school day should not exceed 1,500 ppm. In normal circumstances it is expected that these recommendations would be met in classrooms with a minimum ventilation rate of 3 litres per second per person, a daily average of 5 litres per second per person and the capacity to provide 8 litres per second per person at any occupied time.

The rooms monitored were:

- mechanically ventilated classroom C130 in the Cann Bridge special school,

- ground floor naturally ventilated classroom D106 (windows on two adjacent faCades),
- first floor naturally ventilated classroom D215 Humanities (windows on three faCades),
- first floor art room L210 with cross-ventilation via rooflights,
- ground floor science classroom F107 with mechanical extract,
- the upper seating area in the dining room atrium, and
- the catering kitchen.

From the long term monitoring (Figure 7.4), rooms except the dining room atrium and catering kitchen experienced days with an average CO_2 concentration in excess of 1,500 ppm. This accounted for between one third and one-half of school days in D106, D215 and F107. This parameter was breached for less than 10% of school days in L210 and almost never in C130. The maximum concentration of 5,000 ppm was only exceeded in D106, D215 and F107. CO_2 concentrations were lowest in the catering kitchen, with peak concentrations ranging between 800 and 850 ppm each day.

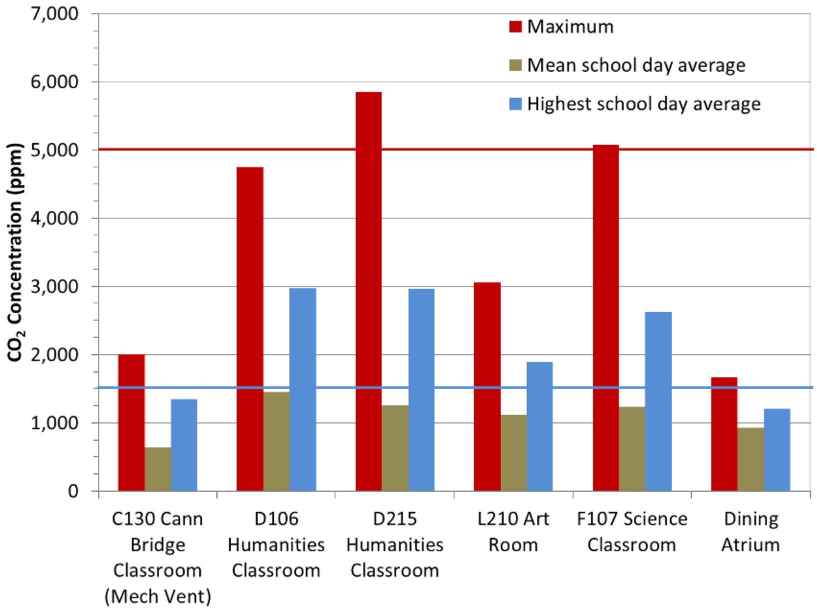


Figure 7.4. CO_2 statistics for the 2013 calendar year, based on long term monitoring.Figures 7.5 and 7.6 depict typical daily CO_2 profiles for each room in the summer and winter respectively. Long term monitoring has shown that the Building Bulletin 101 ventilation criteria (CO_2 concentrations) are frequently not met in many of the teaching spaces. However, detailed analysis of the ventilation rates achieved in specific conditions suggests that this is attributable to the provided ventilation openings not being deployed to the extent necessary to ensure good air quality, rather than a lack of ventilation provision in the design. This finding does not seem to be refDisabling of the roof vents in the art rooms appears to have compromised the provision of effective cross-flow ventilation, but nevertheless the criteria are rarely breached due to the lower levels of occupancy and larger room volume. Further detailed results from each of the four 1-day detailed monitoring periods and statistics for the long term monitoring are contained in Appendix 10.9.

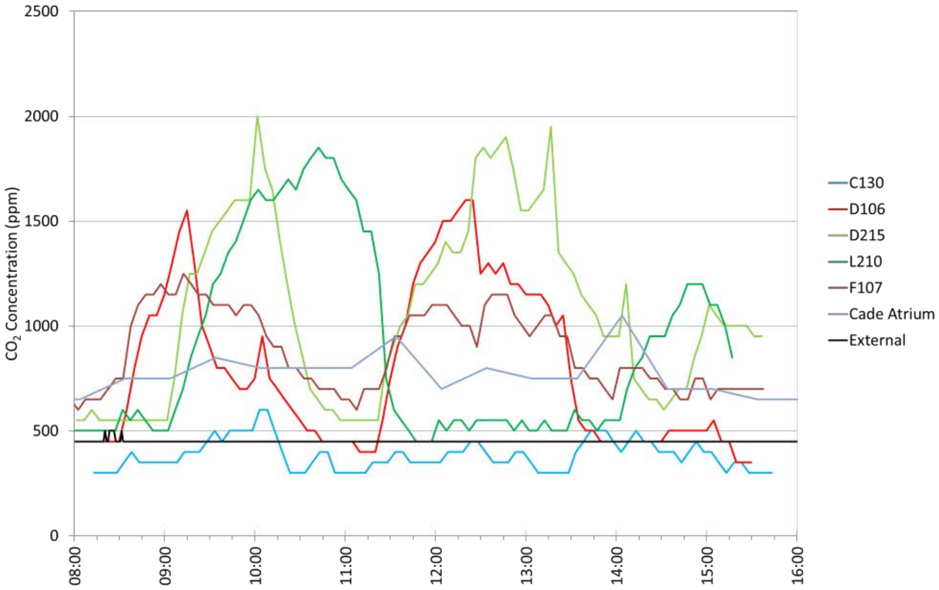


Figure 7.5. Typical CO_2 levels for 10th September 2013 (9th September for the Cade Atrium).

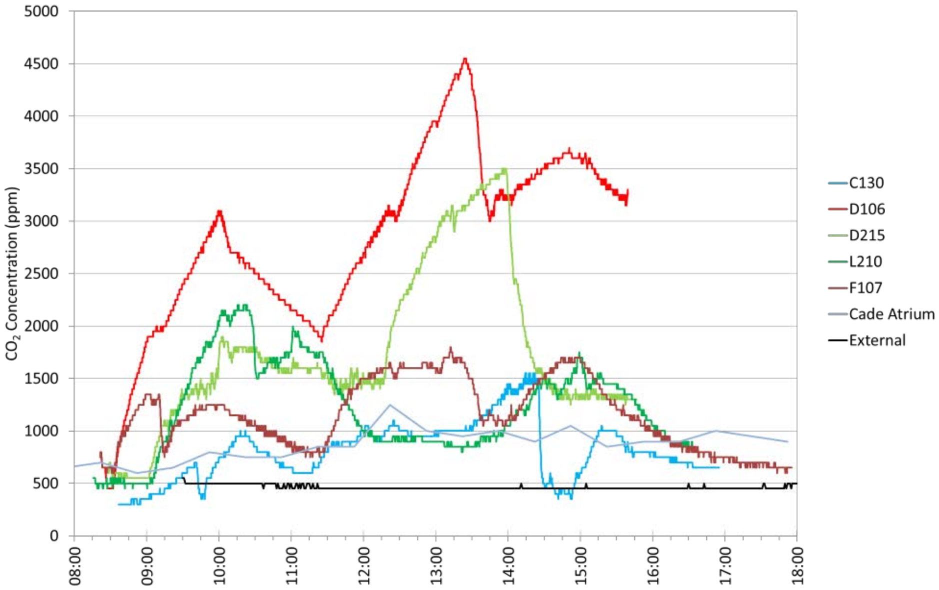


Figure 7.6. Typical CO_2 levels for 17th December 2013.

7.7 Night ventilation

Figure 7.7. Night vents left open overnight in winter.

A significant part of the natural ventilation strategy is the openable window vents provided in each classroom. These provide both ventilation and a means to limit overheating through the introduction of fresh air during warm periods. Some of the openings have the added benefit of being able to be left open overnight due to an externally fixed security grille providing the ability to use a night cooling strategy where the temperature of exposed concrete soffits are reduced overnight. This provides a store of coolth that will off-set heat gains in the space during the occupied period. As outside air is usually cooler than that inside overnight (in naturally ventilated buildings), it will generally be the case that the soffit will be cooled to some degree during this period. While this is beneficial in the summer, this can present significant additional heat load to the space heating system if used inappropriately in the winter, spring and autumn.

An out of hours survey was undertaken on 17th December 2013 and it was observed that several of these night vents were left open overnight (around 5% of classrooms). Considering that one of the design principles for the building was to be highly insulated and relatively airtight, this significantly compromises the design intent and will clearly lead to increased need for heat in the morning to return the room to a reasonable temperature. Addressing this issue is not a matter of technical changes, but rather one of educating building users to operate the ventilation system more appropriately.

7.8 Winter heating and summer overheating

The heating systems are automatically controlled in zones linked to the BMS with temperature sensors and with individual local control within occupied spaces. The thermal zones include variable temperature controls and permit extra-curricular activities, and individual thermostatic control is provided to the radiators in each room or space. Conventional controls are provided with time controls and room thermostats. While this is typical current practice for school buildings, this control strategy is unresponsive to unplanned high or low levels of occupancy.

During the walk through survey it was observed that many radiators, especially those in circulation areas had their TRVs set on the maximum of 5 (Figure 7.8). The FM team report that pupils often turn TRVs up to maximum, particularly in circulation areas. The TRVs are also prone to being kicked off by pupils with the FM team reporting that this happens at least once per week. It is recommended that these are gradually replaced with tamperproof versions. TRVs can also be restricted by setting end stops although it is recognised that this can potentially lead to user complaints. Many radiators in classrooms were found to be blocked by equipment, which will compromise effective operation (Figure 7.9).

Figure 7.8. Radiator in circulation space in Austen block. TRV was set to maximum of 5, which was typical for many radiators in circulation areas.

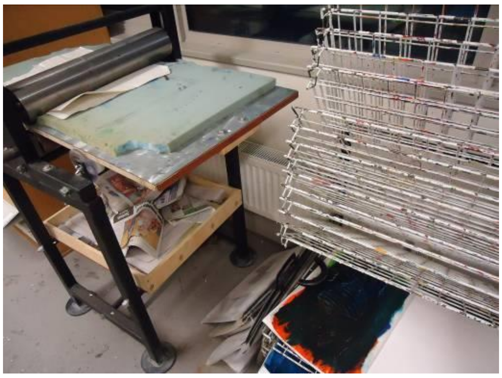


Figure 7.9. Radiators in L210. Art room Cade North obscured by various equipment.

It was also observed that the door in the Sports Block was regularly left open with the heating on (Figure 7.10).

It was initially planned to use the BMS to record room temperatures, however, the data available from the BMS are incomplete. To provide some more reliable data on internal temperatures, 61 Dallas Semiconductor DS1922-F5 "i-button" temperature dataloggers were fitted around the site. The longest data capture was 660 days, from April 2012 to January 2014, although additional monitoring was introduced as the project progressed meaning some areas have data available for shorter periods. In addition, two data loggers were fitted externally.

Figure 7.10. Door to outside in Sports block. Observed during several site visits to be left open for much of the day even though the heating is on.

The data are useful in revealing the range of internal temperatures experienced in different types of room. The results can also be compared to the Building Bulletin 101 (BB101; DfES 2006) overheating design criteria. These state that during a standard school day (09:00 to 15:30) for the period 1st May and 30th September there should be:

- less than 120 hours above 28°C internal air temperature;
- an average internal – external air temperature difference not exceeding 5°C;
- a maximum internal air temperature not exceeding 32°C.

According to BB101, any two of these three criteria should be demonstrated for teaching and learning spaces at design stage. Data capture during over 80% of school days was achieved in 37 rooms. Few of these rooms showed signs of overheating in terms of informal comparisons with the BB101 criteria. In fact, all of the rooms met at least two of the criteria. Only the catering office (A204) could be regarded as of potential concern, which was observed to have an average internal-external temperature difference of 6.5°C, 31.6°C maximum occupied temperature and 75 hours above 28°C.

No room exceeded 32°C during occupied hours. Statistics for rooms in which the occupied temperature exceeded 28°C are tabulated below, along with the other parameters for these rooms.

Table 7.1. Rooms in which internal occupied temperatures exceeded 28°C between 1st May and 30th September 2013.

Room		Hours > 28°C	Maximum °C	Average Internal – External °C
		Statistics 1st May to 30th September 2013 09:00 to 15:30		
A204	Catering office	75	31.6	6.5
A203	6th form common room	48	30.1	6.8
	Cade Atrium upper	47	30.6	6.6
A201	School office	41	30.1	6.3
	Cade corridor outside catering office	30	30.1	5.8
F212	6th Form seminar room	28	30.1	5.2
	Cade atrium lower	17	29.6	5.0
E109	Classroom	9	29.7	4.9
C108	Classroom	8	29.1	4.4
A1	Austen ground floor atrium	6	29.5	4.3
A101	Food tech room	4	28.7	4.4
L219	Office	3	28.6	4.0
C110	Group room	3	28.7	3.9
E102	Classroom	2	28.1	3.8
T2	Tenzing first floor atrium	2	28.1	5.6
	Cann Bridge circulation space	1	28.2	3.8

In summary, summertime overheating does not appear to be a problem generally, with the exception of certain office spaces in Cade with south-facing windows. Air conditioning in the IT server room and IT support office would appear to be controlled to unnecessarily stringent setpoints, which will have an energy penalty. The thermal behaviour of the building is consistent with a modern well insulated, airtight building: heat is retained effectively at night.

7.9 Climate change Impacts

As discussed in Section 7.8, the buildings have been found to perform well with regard to summertime overheating. The effects of climate change are expected to change the frequency of occurrence of warm summer temperatures. Thermal modelling of a selection of the accommodation in the building has been repeated using the current design weather data (Test Reference and Design Summer years) and data representing possible effects of climate change, and the results have been compared to both the Building Bulletin 101 (BB101) and CIBSE TM52 overheating criteria. The results are presented in the report included in Appendix 10.10, in summary:

- Thermal modelling shows that the school as built meets the BB101 criteria for overheating, and taking mid-estimates for climate change assuming a high emission trajectory (A1FI), most spaces would still meet BB101 until the end of the 21st Century. The exception is the ICT classroom due to high internal heat gains. It is not possible to predict how teaching will be delivered by the end of the century, but it is unlikely that ICT classrooms will exist in their current form.

- The success of the scheme at controlling overheating can be attributed to high thermal mass, large ventilation areas that are in operation for long periods, and control of solar gains.
- If more extreme future climate files had been used for the simulations e.g. scenarios under which the climate is “unlikely to be worse than” (66th percentile) or “very unlikely to be worse than” (90th percentile), then it is highly likely there would be extensive overheating, though this was not modelled.
- Whilst there is generally reasonable agreement between the results of the BB101 and the TM52 overheating tests, there are instances where TM52 results in failure, but BB101 is easily passed. This is especially true when the warmer weather files are used, e.g. the Design Summer Year. A key difference is the way TM52 considers the extent of overheating over a single day, which is likely to result in overheating if external temperatures increase rapidly.
- The building has many features that will help to mitigate against overheating, hence both the BB101 and TM52 criteria are in the main easily met. For a building that is less resilient to overheating and so lies closer to the pass / fail boundary, it may be that differences between these two standards becomes more critical.

7.10 Lighting

Lighting for teaching areas is controlled through manual light switches with PIR sensors to automatically switch off lights after a 20 minute period of no presence detection. Lighting for communal / circulation areas is typically controlled through standard manual light switches. During an out of hours walk through it was discovered that in no classrooms had the PIR sensor been disabled at the end of the day. Instead, while all lights were turned off the PIR sensors were still enabled, meaning that lights automatically turned on upon entrance to the room. In two specific classrooms it was noted that the teachers rely on the PIRs to such an extent that they have actually obscured the lighting controls with cupboards (Figure 7.11).

Figure 7.11. Light switch in classroom obscured by cupboard.

The FM team indicated that this situation was typical and that the PIRs were over-sensitive meaning that lights could switch on even when someone passes by outside of a room. Members of the FM team had also been to the school during the night on occasion and found lights in various rooms switched on.

Communal areas and circulation areas are typically controlled through manual light switches. These are switched off by the facilities team / cleaning staff as they complete their final checks in the evening between 7pm and 8pm. The walk through survey was completed before the FM team had finished their final sweep, but in the areas which they had completed, the manual lights had indeed been switched off.

In the Science Opportunity Centre in Faraday block ground floor, a manual lighting control was discovered obscured by a fume cupboard and without any labelling. It was unclear what this control was for (Figure 7.12).

Figure 7.12: Lighting control in Science Opportunity Centre obscured by fume cupboard and PC. Note there are no labels to inform the user which lights the control is for.

7.11 Plant rooms

In addition to the Energy Centre there are smaller plant rooms around the site to house plant for each block or combination of blocks. There are separate plant rooms located in the Sports block, Faraday (for Faraday and Austen), Tenzing, Cann Bridge, Primary school, CADE South (for CADE North and South) and the Sound House. In general these plant rooms are uncomfortably hot. Although the majority of pipe work for the heating circuit is insulated, many of the valves, flanges, and other fittings are not and heat losses from these directly heat the plant rooms (Figure 7.13).

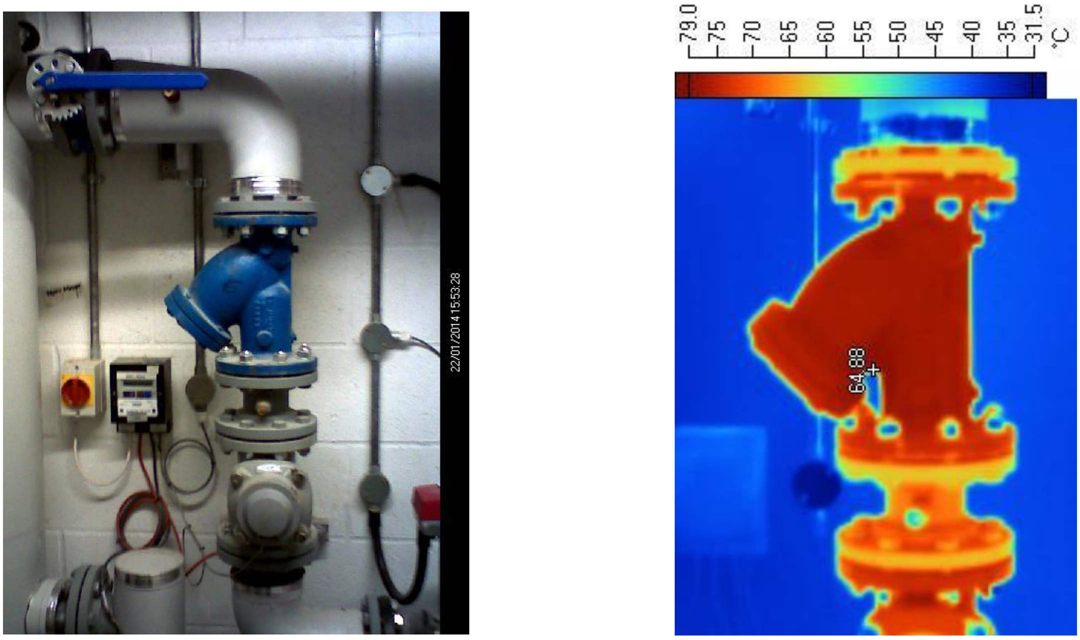


Figure 7.13. Uninsulated pipe joints in Faraday block plant room.

The Energy Centre and these plant rooms also tend to have miscellaneous articles stored (such as pallets of toilet rolls or odd lengths of wood) within them. Plant rooms should not be used as storage space due to health and safety issues.

7.12 Server rooms

The main server room is located on the first floor CADE South. The room contains a number of server racks (totalling around 4.5 kW) and is continuously cooled through two split units. The temperature in the server room was recorded at 19°C.

Additionally, Austen, Faraday, Tenzing blocks, and Cann Bridge have small packet server rooms. These contain one small server rack (rating around 0.5 kW) and are continuously cooled with individual split units typically set at 18°C (Figure 7.24). During the out of hours walk through survey it was observed that some of these units were emitting a grinding sound indicating possible maintenance issues.

Modern IT equipment can function perfectly adequately at higher temperature than was observed in the main server room and the smaller packet server rooms. As a rule of thumb, for every 1°C the cooling set point is increased, 10% of the energy used for cooling is saved. It is recommended that the cooling set points to these areas are adjusted upwards to 27°C as recommended by ASHRAE[ref ASHRAE].

Figure 7.14. Small server room in Tenzing block and 18°C set point.

7.13 Key findings

Key findings of this review of technical issues at the school campus are that:

- Analysis of the BMS has revealed issues with its installation, commissioning, documentation, reliability, user training and maintenance. ***Ensure that the installation, commissioning, documentation, reliability and user training for the BMS are accurate and complete and that a BMS maintenance contract is taken out at handover.***
- The phased construction approach led to different levels of control of systems through the BMS in the different Phases. Phase 2 of the build generally has the least amount of flexibility in control through the BMS. ***If constructing in separate phases ensure consistent level of control over them. Make sure the initial system is flexible enough to easily accommodate subsequent phases.***
- The BMS can only be configured via the Explorer interface rather than the graphical pages, and as such is possibly outside the realistic capabilities of site staff. ***Make sure adequate training is delivered to the FM team not just on how to control building services systems, but also on how to monitor energy performance. Ensure BMS front end is user friendly and provides necessary functionality.***
- The BMS was not specified for full building energy management system (BEMS) functionality, properly configured to act as an energy management tool and record historic consumption data. ***Specify a BEMS and ensure that a high level submeter reconciliation occurs shortly after handover to make sure the BEMS is effective as an energy management tool. See Sections 9.2 and 9.3.***
- During the project the BMS PC failed twice leading to long periods where the FM team could not control the school's systems adequately. As a result only a fraction of the potential submetered energy data has been obtained and analysed. ***Make sure a dedicated PC (with an on site backup***

available) for the BMS is supplied in an appropriate office (not a plant room) and that a maintenance contract for the BMS is in place at handover.

- The school campus has extensive submetering of electricity, gas and water, and of heat consumption. However, there are issues with installation, commissioning, documentation and labelling of meters. For instance, initially none of the electricity submeters had been programmed with the correct parameters to record electricity consumption. This was not rectified until it was reported by the BPE team. ***A high level submeter reconciliation shortly after handover would help to solve this problem.***
- Some of the submeters, in particular the heat meters, are of lower quality which has led to problems with reliability. ***High quality submeters should be specified and these should not be removed or substituted during value engineering, as this will jeopardise monitoring and targeting and result in wasted energy.***
- If the school campus had not obtained funding from the DCSF's low-carbon schools initiative for the biomass boiler, they still would not be eligible to claim Renewable Heat Incentive (RHI) funding for biomass heat generation as one building (Graham Browne) and the gas boilers are unmetered for heat so distribution losses cannot be determined. ***If renewable / low carbon generation is utilised, make sure adequate metering is in place as a priority otherwise funding opportunities may be missed.***
- The thermal behaviour of the buildings is consistent with modern well insulated, airtight buildings: heat is retained effectively at night. Summertime overheating does not appear to be a problem generally, with the exception of certain office spaces in Cade with south-facing windows. ***The construction and design of the school buildings are to a high level.***
- Cooling in the IT server room and IT support office appears to be controlled to unnecessarily strict setpoints. ***If local control for cooling is installed, frequently inspect to make sure that the setpoint is appropriate. See Section 8.10.***
- Although the majority of pipe runs in the various plant rooms situated around the campus are well insulated many joints, pumps, and valves are not. This is leading to high room temperatures in many of the block plant rooms. ***Insulate not only pipe runs, but also joints, pumps, and valves. See Section 8.4.***
- Monitoring has shown that the Building Bulletin 101 ventilation criteria (CO_2 concentrations) are frequently not met in many of the teaching spaces. This is probably due to ventilation openings not being deployed to the extent necessary to ensure good air quality by the occupants, rather than a lack of ventilation provision in the design. ***The natural ventilation strategy is highly dependent on the occupants. More effective ways to indicate appropriate use to occupants are required.***
- Night vents for overnight cooling are an effective strategy and are generally being used appropriately by the occupants. However, there are indications that they are also occasionally being deployed during winter periods resulting in wasted heat. ***Manual control can lead to high occupant satisfaction, but also to inappropriate use and energy consumption.***

8 Key messages for the client, owner and occupier

8.1 Introduction

An essential part of the BPE process is to produce a list of recommendations on which the school campus can act to optimise energy performance at the site. The recommendations are shown in Table 8.1. Ideally these should be carried out in the order shown as the savings are cumulative.

Table 8.1. Overall list of recommendations for energy saving at the school campus (Capital costs are one off, while savings values are per year).

Recommendation		**Capital cost**	**Savings Value**						**Payback**
			Electricity		**Gas**		**Total Cost Saving**	**CO_2 Saving**	
Project code	**Detail**	**£**	**KWh**	**Cost**	**KWh**	**Cost**	**£**	**Tonnes**	**Years**
1	Switch off biomass and thermal store pumps	£800	13,300	£1,300	0	£0	£1,300	6	0.6
2	Switch off CT pumps on weekends and holidays	£1,200	25,100	£2,400	60,200	£1,600	£4,000	22	0.3
3	Improve plant & pipework insulation	£13,200	0	£0	163,500	£4,400	£4,400	30	3.0
4	Switch off Kitchen AHU	£900	40,700	£3,700	0	£0	£3,700	18	0.2
5	Recommissioning of BMS & control systems	£28,100	70,600	£6,900	162,300	£4,400	£11,300	62	2.5
6	Keep Sports block side door closed	£900	0	£0	15,200	£400	£400	3	2.3
7	Switch off PCs out of hours	£3,100	32,000	£3,100	0	£0	£3,100	14	1.0
8	Energy awareness campaign	£14,000	26,100	£2,500	92,500	£2,500	£5,000	29	2.8
9	Review IT Server Room Temperatures	£400	11,240	£1,100	0	£0	£1,100	5	0.4
10	Turn off car park lights overnight	£800	3,610	£220	0	£0	£220	2	3.6
	TOTALS -->	**£63,400**	**222,650**	**£21,220**	**493,700**	**£13,300**	**£34,520**	**192**	**1.8**

8.2 CT pump sets for biomass and thermal store

It was observed that the CT pump sets for the biomass boiler and thermal store located in the Energy Centre were running continuously even though the biomass boiler was no longer operational. It is highly recommended that both these pump sets should be switched off at any time the biomass boiler is not operating (notwithstanding any requirement for boiler protection of course). It is a straightforward task to turn these pump sets off and by doing so the school campus could save £1,300 and 6 tonnes of CO_2 per year.

8.3 Switch off CT pumps on weekends and holidays

The LTHW system is constantly pumping hot water around the three heat networks to all blocks on weekends and out of term time. As teaching areas should be unoccupied (at least by the pupils) during these periods theoretically these pumps (except for the Sports Centre) could be switched off. However, it is understood that teachers regularly arrive out of term time with the intention of working in their classrooms, but clearly keeping the entire school supplied with DHW in case a few individuals arrive will result in wasted energy. Management issues for this solution should be considered in terms of pasteurising water stored in calorifiers and so on. It is recommended that a building services engineer should be consulted regarding this measure before implementation. In addition, this could be complemented by arranging limited areas for 'out of hours' working spaces within the campus that would continue to be fully serviced during weekends and holidays. Carrying out this recommendation could result in an additional saving of £4,000 and 22 tonnes of CO_2 per year.

8.4 Insulation for pipe work in plant rooms

As noted in Section 7.11 although much of the pipe work in the Energy Centre and plant rooms is insulated there is a significant quantity of pumps, valves, and flanges in these areas that have no insulation. This means that there are significant uncontrolled heat losses around the heating circuit.

Carbon Trust guide FEB008 "The Economic Thickness of Insulation for Hot Pipes" is the industry standard reference document for evaluating energy savings which are available from improved pipework insulation. To quote the document:

> *"Any surface which is hotter than its surroundings will lose heat. The rate at which heat is lost depends on many factors, but the temperature and area of the surface are dominant; the greater the temperature and area, the greater the loss. Adding an insulating layer to a hot surface reduces the external surface temperature. Although the surface area may be increased if insulation is added to a circular pipe, the relative effect of the temperature reduction is much greater and a reduction in heat loss is achieved ... An uninsulated valve loses about the same amount of heat as 1m of uninsulated pipe of the same diameter. Uninsulated flanges, which have a smaller surface area, lose about half this amount."*

Figure 8.1 is reproduced from Carbon Trust Guide FEB008.

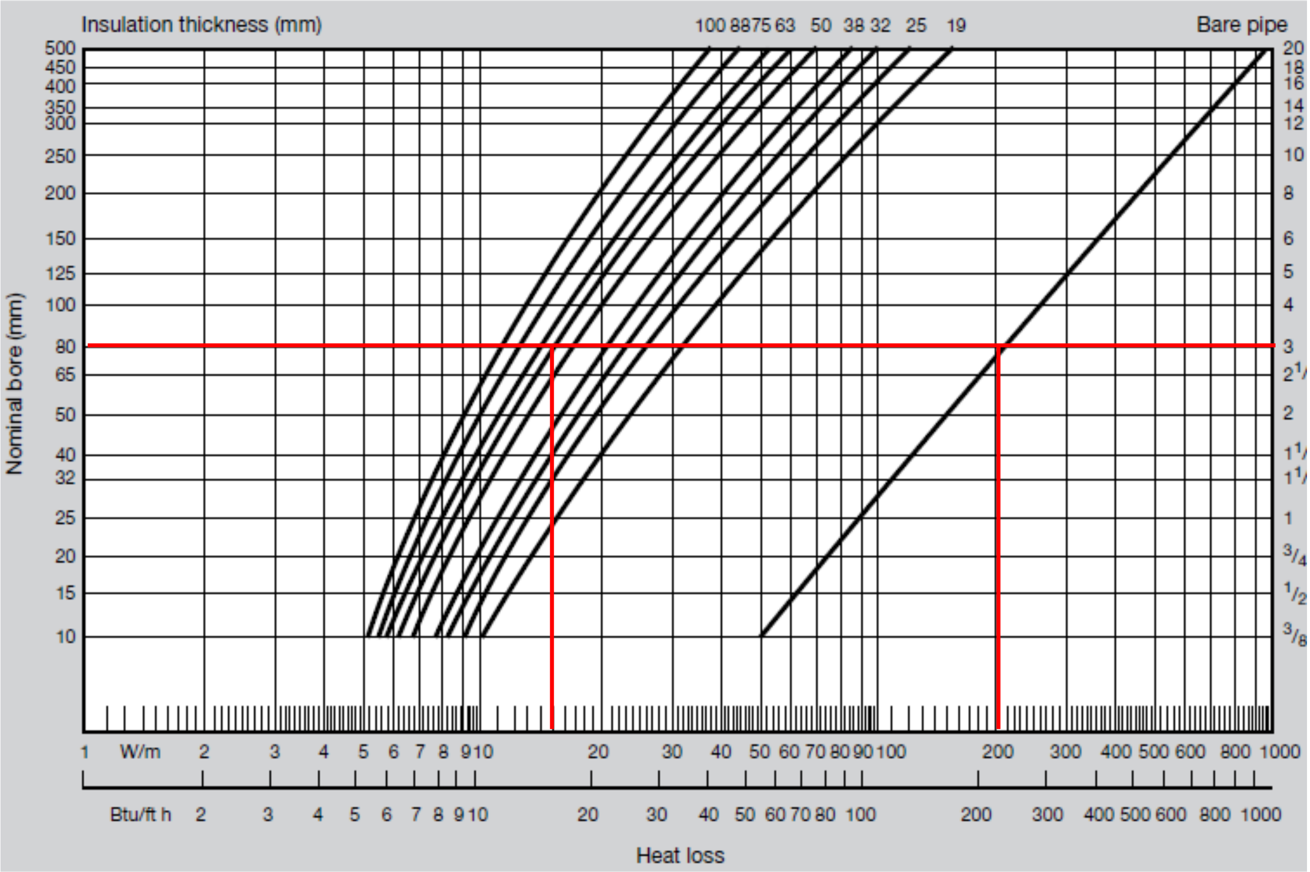


Figure 8.1: Heat loss for pipes with surface temperature of 75°C with varying insulation thicknesses (from FEB008).

The above chart illustrates the effect of installing insulation to reduce heat loss from hot pipes. The straight line which intersects the upper right corner represents a bare pipe at 75°C. For varying pipe diameters indicated on the vertical axes, one can estimate the heat loss for a specific diameter by reading the corresponding heat loss value from the horizontal axis. The curved lines further to the left of the bare pipe line represent the heat loss for varying pipe diameters with differing insulation thicknesses (which are indicated at the top of each line, in mm).

For example, the heat loss for a bare 80 mm pipe is approximately 200 W/m. The heat loss for the same pipe with 50 mm insulation fitted is around 15 W/m – representing a substantial reduction in heat loss of 185 W/m or a 92.5% reduction. This example is indicated by the red lines on the diagram above

Many of the plant rooms visited during the surveys were considerably hotter than would be expected with tens of metres of bare pipework and fittings, all losing heat unnecessarily to their surroundings. This includes not only bare lengths of pipe, but also valves, flanges, and other system components, and represents an unnecessary waste of energy.

It is recommended that all of these are properly insulated. Carrying out this action could save a further £4,400 and 30 tonnes of CO_2 per year.

8.5 Switch off Kitchen AHU when not required

The 5.94 kW rating Kitchen AHU is running 24 hours a day 7 days a week even though it is only scheduled to operate between 5:30 and 15:30 Monday to Friday on the BMS. There appears to be a problem with the BMS control for this piece of equipment. This has been an issue since around 6 months into the site's operation. Adjusting the AHU to only run during the operational hours of the kitchen (Monday to Friday only, 05:30 to 15:30) could save £3,700 and 18 tonnes of CO_2 per year. It is understood that the school campus has attempted unsuccessfully in the past to get this issue resolved, so a capital cost of £900 would be needed to hire the necessary controls expert.

8.6 Recommission controls, optimise BMS and provide training

The BMS problems experienced by the school campus have been documented in Section 7.2. There is significant potential for the use of the BMS to be reviewed, time schedules modified, and controls and sensors recommissioned to optimise performance. The detailed survey of this site indicates the potential for substantial energy savings to be realised if a suitably qualified energy and controls engineer was given sufficient time and authority to systematically test, review, and reconfigure the BMS, providing that a specific focus is made solely on delivering energy savings whilst maintaining required internal conditions.

In the BPE team's experience savings in the region of 10% for both gas and electricity are often achievable. A conservative estimate of 8% savings with 50 days at £500 / day for the energy and control engineer's time and £5,000 capital cost could potentially save £11,300 and 62 tonnes of CO_2 per year. It is also recommended that (i) a dedicated desktop PC is available at all times in an office location for the Facilities Management team to monitor and control the BMS, (ii) this PC should preferably have remote access functionality, and (iii) once the controls and sensors and BMS have been recommissioned, full training should be provided by the energy and control engineer so that at least three members of the permanent on site team have the necessary level of knowledge to monitor and control the BMS. The additional capital cost for the PC is likely to be around £1,000.

8.7 Sports Centre side door

As noted in Section 7.8, the side door to for the Sports Centre is consistently left open even though the heating is on. This situation was observed during each site visit that the BPE team made. Ensuring this door is kept closed during times when the Sports Centre is being heated could save in the region of £400 and 3 tonnes of CO_2 per year. It is understood that the cause of the door being consistently left open is that it has been damaged by students. As a result a £900 capital cost is assumed to procure and fit a new door.

8.8 PC switch off

It is understood that there is IT software in use at the school campus which automatically switches off certain computers at the end of the and during weekends and holidays. However, many computers around the site (such as those in classrooms or IT hub areas) do not seem to run this software and have been observed during several out of hours visits to be left on. Occasionally monitors are switched off but the computer itself is left on. A dedicated behaviour change campaign to turn off these PCs out of hours could save £3,100 and 14 tonnes of CO_2 per year.

8.9 Staff & pupil engagement campaign

As a final step a staff and pupil engagement campaign designed to increase energy conservation could be conducted after the above recommendations have been implemented. Research suggests that successful behaviour change campaigns can offer savings in the region of 5% to 20% for electricity consumption (through lighting and small power appliances) and for gas consumption (through closing windows when the heating is on or not leaving night vents open overnight in winter). Successful energy conservation campaigns in practice are difficult to implement (especially in the initial stages) and require effort and persistence from the management team to realise the savings. To this end, a £2000 budget for equipment for the campaign and 30 days at £400 is assumed in the budget to assist with carrying out the campaign. If successful this could potentially save £5,000 and 29 tonnes of CO_2 per year.

8.10 Review IT server room temperatures

There are one large and four satellite IT server rooms at the school campus. There are a number of energy saving opportunities available for IT servers, including:

- Raise server room temperatures
- Widen temperature set point dead-bands
- Employ night-cooling or free-cooling
- Change the layout and air flow of server rooms
- Switch to newer more efficient equipment, etc.

Incremental savings can also be achieved by applying common sense, e.g.:

- Move equipment that does not require cooling out of the server room

- Remove all unnecessary equipment from the server room – for example, phones, plotters and printers
- Switch off all external devices that are not in use
- Switch off all lights when no one is in the room. Switch off all unused screens. A screen running a screen saver effectively uses full power
- Keep the door to the server room closed if the temperature in the sever room is lower than the surrounding rooms

The main server room and the smaller packet server rooms are all constantly cooled to around 18°C. This is unnecessary and the cooling set point in these areas could be increased to 27°C (as recommended by ASHRAE) with no loss of performance. If this was carried out it could potentially save around £1,100 and 5 tonnes of CO_2 per year.

8.11 Turn off car park lights overnight

During data analysis it was discovered that car park lighting remains on overnight. This is probably not required and there may be the potential to turn these lights off for a certain period, for example from midnight to 4am every day. If this was done this could save £220 and 2 tonnes of CO_2 per year.

8.12 Reinstate biomass boiler

An important aspect of the school campus' design as a low carbon building is the use of the biomass boiler. Although the problems that the school campus has experienced with operating the biomass boiler have been documented in previous sections, the FM has stated that he is still open to using the biomass boiler if the operational problems can be resolved.

One specific issue would be to ensure that the quality of the woodchip fuel was assured. An example of this might be purchasing fuel on a delivered heat basis rather than a volume basis. This ensures that variations in moisture content do not affect fuel costs.

To allow for the extra administration time and the labour to reinstate the biomass boiler a £4,000 capital cost is assumed. This would likely cost the school campus around £13,000 per year compared to using only gas, but would result in a reduction of 282 tonnes of CO_2 emissions per year.

Table 8.2.Table showing potential cost and CO_2 savings associated with reinstating biomass boiler.

Recommendation	Capital cost	Savings Value							
		Electricity		Gas		Heat		Total Cost Saving	CO_2 Saving
Detail	**£**	**KWh**	**Cost**	**KWh**	**Cost**	**KWh**	**Cost**	**£**	**Tonnes**
Reinstate biomass boiler	£4,000	0	£0	1,611,700	£43,200	-1,706,500	-£56,000	-£12,800	282.2

8.13 Discussion and key findings

There are several key recommendations outlined above the school campus can act upon that could see the school save in the region of £34,000 and 192 tonnes of CO_2 per year. The majority of the identified recommendations (except the car park lighting) should all pay back within 3 years. The recommendations should be implemented in the above order as the savings calculations are based on cumulative reductions. Recommendation calculations are estimations only, so it would be important to monitor energy consumption before and after any changes to calculate the exact savings.

The possibility of reinstating the biomass boiler as the primary means of generating heat has also been considered. Although it is likely that this would prove to be a more expensive alternative to the gas boilers, it would save a significant amount of CO_2 per year (282 tonnes) before other savings being realised from other recommendations.

9 Wider lessons

9.1 Introduction

A vital part of the BPE process is to feedback findings from the monitoring not just to the owner of the building(s), but also to the construction industry as a whole. Without this crucial component poor design decisions can be repeated and aspects that worked well potentially overlooked. The following section explores what findings from the school campus BPE study have implications for the wider construction industry.

9.2 Metering

The metering at the school campus was handed over in an unusable state. A significant proportion of time during the 2 year BPE study was spent attempting to disentangle the metering hierarchies and correctly apportion the energy data to the various blocks and subsequent end uses. Key problems included:

- Around 34% of annual electricity consumption is not submetered.
- The gas boilers in the Energy Centre were not separately submetered even though they represent 94% of gas consumption.
- Many of the heat meters and flow meters are not producing reliable readings.

Issues with metering such as those discovered with this BPE could potentially be resolved if a high level meter reconciliation for all energy sources (which is properly audited) takes place during the initial aftercare period (i.e. in the first few months of operation). This would then allow checks to take place that high level submetering is equal to the sum of any incoming Grid electricity and any renewable generation sources. This would identify any discrepancies early on in the project, allowing them to be rectified during the defects period.

Without a high level meter reconciliation shortly after handover issues with poorly installed or commissioned meters will persist in all buildings completely undermining metering and monitoring strategies set out during design and any attempts to identify energy saving possibilities during the building’s operation.

It is also important to have a sensible metering strategy conceived and communicated during the design process. Any generating plant should be separately metered even if they are considered only as back up. Any areas with high loads that are likely to be consistent, such as sports pitch floodlighting, should also be submetered.

9.3 Building management system

The operation of the BMS has been an issue throughout the BPE and continued to cause problems until the end of the BPE study. The amount of data that has been successfully logged has been very small (measurable in weeks rather than months), and the data are of uncertain accuracy. More importantly, failings of the BMS have severely impeded the ability of the FM team to control the heating and ventilation systems, requiring considerable staff effort to circumvent the problems and minimise adverse effects on internal comfort and energy consumption.

At the point of hand-over a maintenance contract was not in place, so when the BMS failed a short time into operation the school was faced with a large repair cost. The school campus does now have a maintenance contract in place that allows for two visits by a controls specialist per year at a cost of £1,200 p.a. The BMS software has been provided on a laptop, which was initially kept in an uninsulated plant room causing the computer to fail during the winter when temperatures dropped. It has now been moved to the FM's office, where the software is regularly used by the FM team.

It is highly recommended that long term maintenance contracts are put in place at handover. There will always be a settling in period for any building and seasonal commissioning is essential to ensure that building service systems are optimised. If the FM does not have expertise with a BMS system (presently a common situation in most new school buildings), then maintenance visits from the BMS installer are crucial. It is also important that a dedicated PC for the BMS software is located in an appropriate location and is regularly assessed to check any alarms and the performance of the system. The majority of BMS have the potential to facilitate dynamic management of the building (i.e proactive setting temperature set points and running hours for the week / month ahead), but the majority of FMs tend to leave the BMS on its default settings. Hence, the situation encountered here for instance, where although the biomass boiler had effectively been mothballed, its CT pump sets and the thermal store were still in operation 24 hours a day.

9.4 Log books need more care

As part of this BPE study, the Log Book for the school campus has been reviewed and while it does contain useful information for the FM team, some of the contained information was inaccurate or incomplete. For example, the Log Book states that the night vents in classrooms should be kept open overnight, but neglects to mention that this action is likely to be inappropriate during winter as it can cause excessive heat loss and an apparent misprint indicates that the biomass boiler is 100% efficient. Perhaps of greater concern for energy monitoring was that the electrical meter hierarchy illustrated in the Log Book bore no resemblance to reality.

In general, log books tend to be rushed as they are compiled towards the end of the project rather than being consistently updated during the design and construction process. It is recommended that the log book should be given more importance during the design process and it can then be added to and modified during construction. It should also be made simpler and avoid any unnecessary technical information. To this end, it is recommended that new ways of engaging with occupants and management in terms of their relationships to their new building(s) are explored. This could include interactive IT to demonstrate how / when / why to use building controls, possibly including Internet hosted video clips or possibly simple flash cards to indicate the appropriate use of building services controls.

9.5 Biomass boilers for schools

The school campus has been beset by operational and logistical issues concerning the biomass boiler. Especially in a single school / campus environment, the suitability of biomass boilers needs careful consideration. Although many of the problems experienced seem to stem from the boiler itself or the quality of the supplied wood chip, the capabilities of the facilities management team needs be considered during the design stages. At this school campus there seems to be a lack of appetite from the FM team to use the biomass boiler due to the perceived added maintenance burden. This reluctance was then reinforced by perceived cost issues and perceived efficiency issues, both stemming from inadequate heat metering. Members of the FM team consider that the old role of 'caretaker' no longer exists and that they are expected to be building service engineers due to current requirements to understand complex building services systems.

This project is not isolated in having significant problems with biomass boiler operation. Use of the Carbon Calculator has (in the BPE team's experience) incentivised the installation of biomass boilers to meet targets as opposed to other technologies. Although the principle of their use is commendable, in practice it leads to a doubling of required plant and there are now believed to be many new schools around the country with large biomass boilers sat idle.

9.6 Building controls

At the school campus the simple nature of the ventilation controls seems to have been successful in terms of the occupant satisfaction. The night ventilation is simple to operate and the teachers get (slightly delayed) feedback on its operation, as not leaving the vents open overnight during warmer months will mean that their classrooms will be uncomfortably warm the next day. However, this has implications for energy consumption if the occupants leave the night vents open overnight during colder periods, as the BMS optimiser will bring on the heating earlier in an attempt to obtain the required temperature in the classroom for the start of the day. High occupant satisfaction with the level of control may have implications for energy consumption.

Although the design intent of the lighting controls is that the occupants disable the PIR sensor at the end of the day by holding down the rocker switch, in practice this action is rarely carried out with occupants relying on the PIR to turn lights off for them. During the out of hours walk through it was found that all classroom lighting had been left with the PIR enabled.

Generally, the industry strategy to encourage occupants to use building controls appropriately is to provide training sessions during the initial handover / aftercare period and supply written details in the log book. However, staff turnover can mean that these training sessions are quickly redundant. Moreover, most occupants do not usually have access to and would rarely (if ever) consult the log book. It is recommended that the construction industry should develop new and innovative ways in which to engage with the occupants to demonstrate the appropriate use of building controls. This could be using flash cards or online video clips rather than gathering occupants for an expensive one off ‘workshop’ to demonstrate how to open and close a window or use a light switch.

It is recommended that controls are kept as simple as possible so that occupants can intuitively obtain the conditions they require. However, there is clearly a complicated trade off between increasing control and potentially increasing energy consumption. There should be some sort of feedback for the occupants (building on the CO_2 traffic light sensors) to help the occupants modify their internal environment without negatively impacting energy consumption.

9.7 Out of term time use for schools

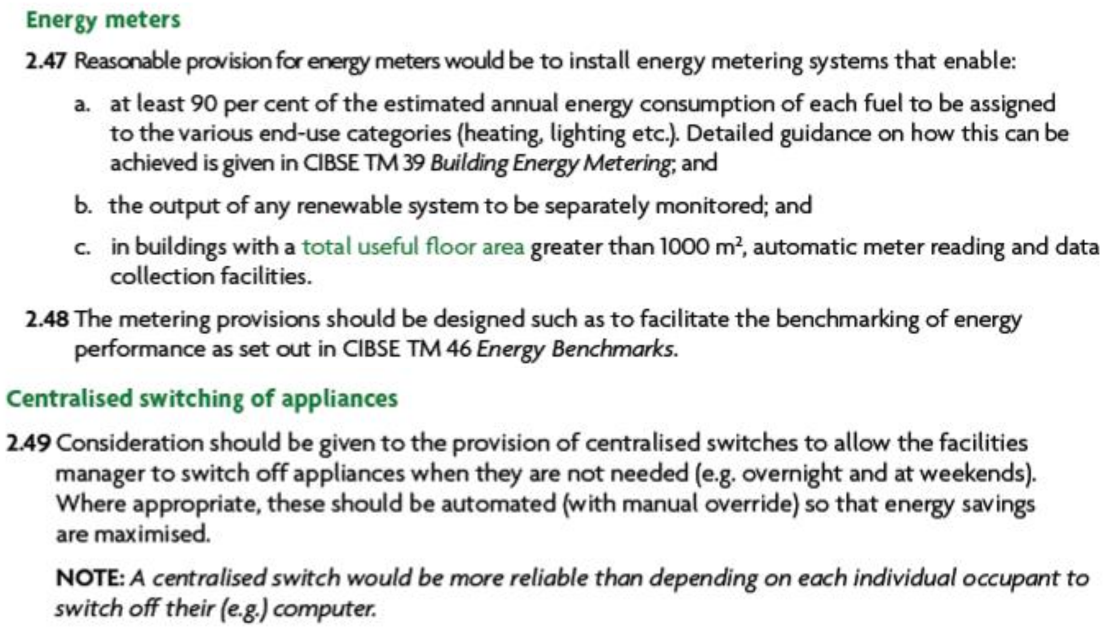
A key factor in the excessive energy consumption at the school campus is out of term time use, particularly heat. The FM team feel that they have to maintain conditions around the whole campus, as teachers sometimes turn up during holiday periods expecting to work in their classrooms. It is clearly a waste of energy to maintain conditions for the whole site on the off chance that a small proportion of the occupants will be present. Presumably, this is a problem for the majority of schools.

Although conditions need to be maintained for the Sports Centre (which is used by the wider community outside term time), space heating in teaching areas could be set back outside of term time. Out of term time, perhaps teachers may be encouraged to only come in on certain days when internal conditions are maintained or they could simply be informed that if they wish to work in isolated classrooms, then certain services will be unavailable. Alternatively, limited areas could be set aside for out of hours working with full space heating and domestic hot water only provided for these spaces.

While energy used to supply domestic hot water is of concern, the FM team have highlighted that Legionella contamination could be an issue if temperatures are not maintained. The risk of Legionella growth therefore needs to be carefully considered and any attempt to turn off domestic hot water services should be risk assessed. It is recommended that hot water to all blocks (apart from Sports blocks) should be turned off during holiday periods. This should also be carried out alongside a careful management plan. Alternatively for future projects, point of use hot water systems could be considered to prevent energy waste arising from this situation.

9.8 Implications and recommendations for various stakeholder groups

The new school campus was developed in line with Building Regulations Approved Document L2A (ADL2A, 2006). However, in the intervening period there have been two further revisions of ADL2A: one in 2010 and another recently in 2013. The latest guidance is shown in Figure 9.2 on reasonable provision for energy meters and centralised switching of appliances in ADL2A (2013). Long term energy monitoring and diagnostics are likely to be more reliably achieved in future new school buildings that are designed, constructed, commissioned, operated and maintained closely following this guidance. To support this, it is recommended to adopt an approach based on ISO 50001 as part of a revised Soft Landings Framework. Figure 9.2 summarises the generic ISO 50001 process. To be effective, such an approach to energy management will also need more robust performance metrics and benchmarks on which to base energy objectives, targets, monitoring, analysis, etc, and corrective action to address any ‘performance gap’. To support this, it is also recommended that industry stakeholders adopt in-use energy modelling based on CIBSE TM54 ‘Evaluating Operational Energy Use at the Design stage’.



Energy meters

2.47 Reasonable provision for energy meters would be to install energy metering systems that enable:

a. at least 90 per cent of the estimated annual energy consumption of each fuel to be assigned to the various end-use categories (heating, lighting etc.). Detailed guidance on how this can be achieved is given in CIBSE TM 39 *Building Energy Metering*; and

b. the output of any renewable system to be separately monitored; and

c. in buildings with a total useful floor area greater than 1000 m², automatic meter reading and data collection facilities.

2.48 The metering provisions should be designed such as to facilitate the benchmarking of energy performance as set out in CIBSE TM 46 *Energy Benchmarks*.

Centralised switching of appliances

2.49 Consideration should be given to the provision of centralised switches to allow the facilities manager to switch off appliances when they are not needed (e.g. overnight and at weekends). Where appropriate, these should be automated (with manual override) so that energy savings are maximised.

NOTE: *A centralised switch would be more reliable than depending on each individual occupant to switch off their (e.g.) computer.*

Figure 9.1: Guidance on reasonable provision for energy meters and centralised switching of appliances in Building Regulations 2010 Approved Document L2A (2013) applicable to new non-domestic buildings.

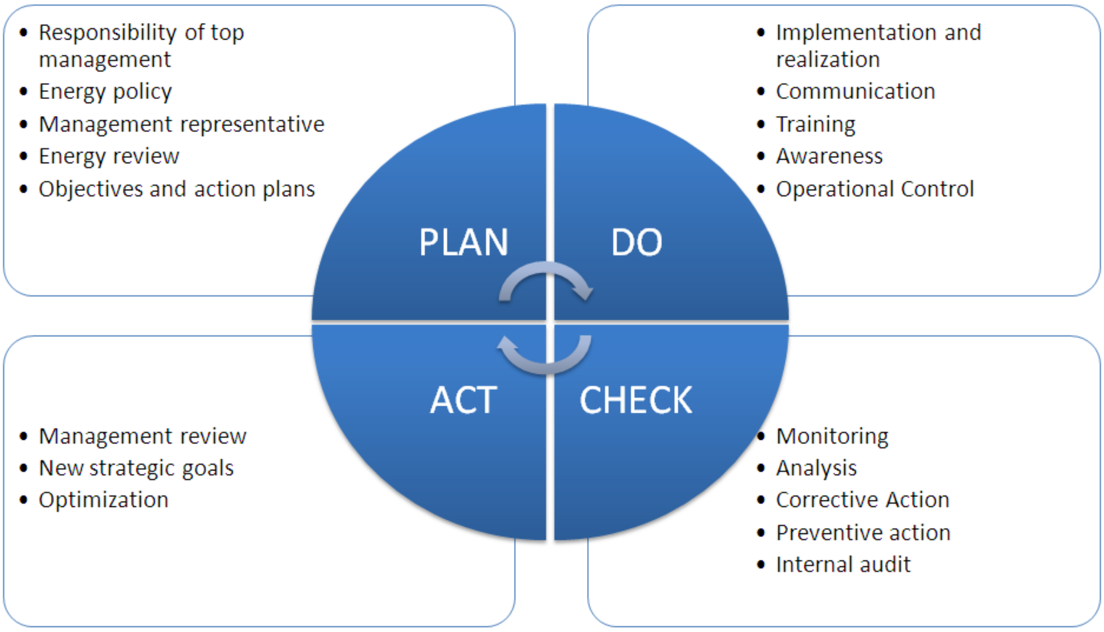


Figure 9.2: The ISO 50001 approach to energy management (Source: Wikipedia)

9.9 Discussion and key findings

The building performance evaluation of this school campus has highlighted certain design strategies that have been correctly implemented and have been observed to work well in practice, both from a quantitative point of view in terms of measurement of the indoor environment and energy use and also from occupant feedback. This is very encouraging.

For future new and refurbished school buildings, it is recommended that close attention should be paid by clients to the correct design, installation, commissioning and operation and maintenance of energy metering and building management systems. To a large extent, the necessary industry guidance, standards and regulations are already in place to achieve this. What seems to be now required is a concerted effort for the entire building construction and management supply chain to better understand their importance in reducing energy use in practice and for vastly improved communications between supply chain organisations to achieve this common goal.

10 Appendices

APPENDIX 10.1: SOFT LANDINGS REVIEW

10.1 Soft Landings review

Although adoption of the Soft Landings (SL) Framework itself was not a formal contractual requirement during construction of the new school campus, a series of interviews were undertaken with key members of the design team, delivery team and client representatives to understand to what extent the principles of the Framework were included in the project and the potential impacts of the approach taken. The findings of the interviews have been reviewed and compared to the principles and various activities of the SL Framework to highlight gaps.

10.1.1 Interview subjects

People in the roles identified in the table below were interviewed as part of the SL review.

Role
Project Architect
Design Manager
Mechanical Subcontractor
Electrical Subcontractor
Mechanical Building Services Designer
Electrical Building Services Designer
Site Facilities Manager
School Campus Business Manager

10.1.2 Other parties

In addition to those interviewed, other key parties to the project overall were as follows:

Role
Main Client (funder)
Client Architectural Consultant
Client Building Services Consultant

Individuals from these organisations have not been interviewed, but are referenced in the text below.

10.1.3 Limitations

This project has carried out a BPE on Phase 1 of the new school campus development, however, the interviews were undertaken some 18 months after the completion of Phase 1. Naturally, some circumstances have changed since the original design period, most significant being that several further phases of the development have been completed, with the new school campus constructed in a total of three principal phases. In addition, the specific individuals within the building services consultant who designed the building services systems of Phase 1 no longer work for the company and have therefore not been interviewed. After considering this situation and discussing the approach taken on Phase 1 (compared to later phases) with those involved throughout, experiences on later phases have been taken as a proxy for Phase 1 where necessary.

10.1.4 Findings

The interviews conducted have been used to inform a comparison between the activities undertaken on the project against the 12 core principles set out within the Soft Landings Framework. As may be expected, the responses to the questions varied according to the interviewee and where there were differences in opinion or recollection, these have been indicated.

Principle 1: Adopt the entire process

The project commenced several years ago and was not procured as a Soft Landings project. It appears that there was no mention of SL in early documentation (such as the PQQ or ITT). There were, however, some limited activities which, whilst not being referred to as such, could be considered to adhere to the Soft Landings principles. Specifically, there was some early engagement with the school and end users as part of the development of the brief and it seems that the outcome of these engagements was carried through to delivery, as the responses indicate that the final outcome is very similar to the original vision.

It seems that the project’s first engagement with the SL Framework resulted from work being carried out as part of a review for the publication ‘Soft Landings for Schools’. This engagement included discussion time with one of the Main Contractor's Site Managers and the Main Client. SL was subsequently discussed and 'informally adopted' during the pre-handover phase.

Despite most of the design and delivery team talking about SL as part of the pre-handover work, the school's representative on the client side had not heard of the Framework before being interviewed. This perhaps demonstrates a failure of the process to properly communicate the nature and purpose of Soft Landings, although that alone does not preclude achieving the desired outcomes.

A key element of Soft Landings is the continued involvement of the professional team and Main Contractor after handover. For Phases 1 and 2, in practice there was a continued presence due to the ongoing delivery of later phases. The Main Contractor typically operates a helpline facility as part of their aftercare process, however, due to the ongoing site presence in this case, a different process of dealing with issues was adopted. But after completion of the final construction phase of the project, it appeared that there was no continuing site presence.

Despite this ‘on-site’ approach during Phases 1 and 2, the BMS, a key building system, only became fully operational following completion of Phase 3. This may not have been the case had this TSB BPE project not highlighted this concern.

Principle 2: Provide leadership

From the responses gathered, it appears that once the initial brief was set, the Main Client and their consultants involvement was mainly to oversee delivery in terms of ensuring all regulatory elements of the brief were met and to ensure the budget was maintained rather than to be an active part of the process. Development of the detail of the design and so on appears to have been led by the Main Contractor and their team through liaison with the school.

During the development of the design, there was a commercial element to the process and responses indicate that there was pressure on the budget, which at times was significant. It should be borne in mind that this is quite common in construction and responsible cost management is essential on all projects. Considering the responses though, there is a sense that this focus on cost may have reduced the effectiveness of the design process. In particular, this included only limited involvement of the original Building Services Designers during installation, commissioning and handover.

There was not any engagement with the Main Client's team as part of this review process. It appears from the anecdotal evidence provided by others that the Client approached the project in a traditional way. They relied on national standards to set the space and performance requirements of the new school, although there was an exercise of capturing end-user needs through an away day with school staff as part of the early design process.

Principle 3: Set roles and responsibilities
The main project roles and responsibilities were assigned as set out in a Matrix of Responsibilities developed by the Main Contractor and based on the SL Framework document. Again, the Main Client’s principle involvement was to ensure the brief was met in terms of regulatory compliance, delivery of design standards and maintaining the budget.

Principle 4: Ensure continuity
It appears that there were no specific Soft Landings requirements in any of the contracts used on the project - either of the Main Client with the Main Contractor or with their Subcontractors. Whilst this does not preclude the adoption of those SL activities that would normally be carried out during the design and construction of the project, it does severely limit the likelihood that key members of the team would remain engaged after practical completion, at least beyond typical snagging and defect resolution actions.

Despite this, the Main Contractor did engage with the other members of the professional delivery team to explain their approach to SL in the pre-handover phase. One successful outcome of this ‘enhanced’ handover approach was that the building was handed over with 'zero defects' according to the Main Contractor, although there were initially weekly meetings until all 'issues' were resolved. Yet issues such as the BMS not operating correctly and problems with the biomass boiler operation were not considered as defects.

Principle 5: Commit to aftercare
The responses in the interviews indicate that there was no contractual requirement to provide any aftercare services. However, both Phases 1 and 2 benefited from the presence of the Main Contractor and Subcontractors being on-site for the delivery of later phases. This extended to Phase 3 until the demolition of the existing primary school was complete. The design team only had limited presence on site and indeed,

the Building Services Designers were not invited to site at all during the design process, instead transmitting and receiving information through the M&E Subcontractor, to whom they had been separately appointed at a later design stage.

The lack of a coherent approach to aftercare has meant that (prior to the BPE study) robust energy data has never been available to the school to allow them to properly manage the buildings. Also, the biomass system has failed to run without problems for any longer than 6 weeks, which in practice has compromised one of the key design approaches to the reduction of operational carbon emissions from the site.

It appears that the Main Contractor has since further developed their offering around aftercare and now provide two years continuing engagement as a part of their approach to aftercare. This was directly influenced by this project and their involvement as members of the BSRIA Soft Landings User Group and demonstrates a continuous learning approach and the adoption of at least some SL principles into their operating procedures.

Principle 6: Share risk and responsibility
The contract was procured as a traditional two stage design and build contract and therefore risk was transferred to the Main Contractor.

No incentives were put in place other than retention clauses that are common on all major building projects. An environmental target was set based on BREEAM and formed a contractual obligation, which is common on major building projects in the public sector. There were no operational performance targets required as part of any contracts.

Principle 7: Use feedback to inform design
The responses gathered indicate that the later phases of the project were influenced by Phase 1; however, there is no evidence in the responses that suggest other previous projects were formally reviewed as part of the development of this design.

The performance brief was developed from industry standard documentation (Department for Education Building Bulletins and so on), supplemented by input from end users through an independently facilitated engagement process. Anecdotal evidence suggests that the final outcome is very close to the original vision, which is an encouraging finding.

The architects did refer to a process of independently facilitated Design Quality Indicator (DQI) assessments, which would have involved all parties, including end-users and would have highlighted those issues that were important to different sets of stakeholders. The Main Contractor indicated that there was a very active process during the early design that regularly checked the end user wishes against buildability and allowances in the budget to arrive at a solution that could satisfy the operational requirements of the school and be delivered within the contract sum.

Principle 8: Focus on operational outcomes
As the design process continued, there was a significant element of checking with manufacturers, installers and specialists that solutions could be delivered in practice. This may well have contributed to the zero

defects on site, as deliverability was obviously a consideration of the process. Involving subcontractors and specialists early in the process appears to have paid dividends here.

It appears that, apart from the BMS and the biomass boiler, there have been only relatively minor issues with the performance of the building in operational terms. Specific issues like the failure of manually operated mechanisms to open high level vents over classrooms doors were straightforwardly rectified by the schools site team.

Principle 9: Involve the building managers

It seems that the Building Manager had very little involvement in the actual process of developing the design, although the Facilities Manager (FM) was involved in the pre-handover process, as was the school campus' Business Manager. For the latter, this included attendance at regular meetings with the Main Contractor and for the former attendance at scheduled update meetings and an element of training. The Main Client was also represented at these meetings by their consultants who checked that the original brief, etc, was being delivered.s

It should be noted that, whilst not strictly in scope of this BPE, the FM had no involvement in the development of Phase 3 of the campus. This raises issues of how (and if) any feedback and learning from previous phases and their operation were captured, as well as whether the training provided will be sufficient to allow the campus to be operated efficiently.

Members of the building management team were taken to see a previous installation of a biomass boiler as part of the engagement process, as this forms an important element of the building energy strategy. It is understood though, that the FM, the person who would be responsible for managing the biomass system on a day-to-day basis was not invited to attend. Had SL been followed from the start, the importance of his being engaged earlier would have been clear and he perhaps would have had a better understanding of the system he was going to be required to manage.

Training was provided to the FM on the BMS system funded by the school, in addition to the very brief on-site training by the installer. The FM indicated though that he did not learn a great deal from the two day training course, as he had already discovered much of what was taught through trial and error on-site. In hindsight, more comprehensive training at the point of (or perhaps before) handover would have been beneficial.

Principle 10: Involve the end users

End users were involved through an independently facilitated DQI assessment from which their priorities were understood through a series of set questions. This process focuses on the use of spaces and the grounds and also the relationship the buildings have with the local community. It also serves to highlight where there is a difference between the priorities of the end users and the assumptions of the designers.

The M&E Subcontractors also delivered a training session to the end users to explain the principles of the various systems in different rooms – this was generally with small groups of users although the natural ventilation strategy was presented to the entire teaching staff as it was such a significant element of the design. Interestingly, it seems that despite this interaction some end users had issues with correctly operating some of the systems provided, such as the lighting controls, for some time after the school opened. It is unclear if the users experiencing difficulties attended any of these training sessions.

The expectations of the client appear to have been effectively managed, as the Head Teacher suggested that the finished product is very close to the original vision that was developed during early concept sessions. The Facilities Manager was also involved (although he was not employed at the school campus until part way through the first phase) and he was provided with training on some of the systems on site (particularly the biomass boiler), but he felt much of this to be somewhat inadequate. Indeed, a separate two day training course was arranged by the school for the Facilities Manager with the manufacturer of the BMS to ensure he knew how to operate the system.

Principle 11: Set performance objectives

No performance objectives were set for the building. It is difficult to be certain about the consequences, but it is clear that because there were no such targets set, consideration of in-use performance did not form part of the design process. The new construction did however receive over £500,000 of additional funding for achieving a 60% reduction in carbon emissions against Part L 2002 levels demonstrated through the use of DCSF's Carbon Calculator [1]. This represents a design stage target and, whilst operational savings may have been achieved by the measures adopted as a result, this has not been tested in any way and the funding was not dependent on actual emissions reductions.

Interestingly, the designers of the M&E systems, did not complete the building Log Book (See Appendix 10.2), which was instead carried out by the M&E Subcontractor. This means there is very likely to be some degree of disconnect between the thinking about the design and the in-use performance information about annual energy consumption presented in the Log Book. On examination, the energy section of the Log Book is not entirely consistent and would certainly have benefited from being a more integral part of the process.

Principle 12: Communicate and inform

The Architects and Main Contractors were heavily involved in the process of refining and pinning down the brief during the early stages of design to ensure that the required facilities and so on could be delivered within the budget. It emerged during this process that the initial brief prepared by the client’s architects did not exactly match with the school’s needs. This may be due, at least in part, to the fact that the original brief was principally based on generic Building Bulletin 87 requirements.

As part of the process of developing the final Contractors Proposals, there were many meetings with the school including end of stage meetings to sign off the design as well as independent DQI reviews.

There were also very regular meetings (weekly during the design of Phase 1) between the designers at which typical design development issues were discussed.

Regular communication between the delivery team and the client appears to have been a clear feature of the project, although it is notable that the actual Building Services Designers were not invited to meet the

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[1] The Carbon Calculator is a spreadsheet based piece of software which is used solely for the calculation of CO_2 savings against 2002 Part L to determine whether additional funding might be allocated.

client or to visit site during the process – it may be that this did happen during Phase 1, however, it was only possible to interview those working on later phases. As the M&E systems are such a fundamental part of the end-users interaction with the building and the efficient management of the primary systems, this is perhaps counter-productive. The driver for this low level of interaction appears to have been cost.

The Main Contractor has indicated that this project set out to incorporate as much of the SL framework as possible, even if it was not referred to as such. But, it is evident that many of those interviewed did not have a clear understanding of SL and its aims.

10.1.5 Soft Landings activities review

The table below sets out key activities highlighted as part of SL and where the actual project activities overlap. It is assumed that the various activities defined by the RIBA workstages were all undertaken and therefore the SL work constitutes activities additional to a 'standard' project procurement. Comments on the impact of the adopted approach are also provided.

🟩	Fully implemented
🟧	Partially implemented
🟥	Not implemented

RIBA Stage	SL Stage	Soft Landings Activities	Actual activity
A		🟥 Define roles and responsibilities	Client needs principally derived from generic Building Bulletin guidance Roles and responsibilities defined by Main Contractor rather than client
B	Briefing	🟥 Explain Soft Landings to all participants Identify processes and sign-off gateways	SL was not included at the early stages of the project so not explicitly explained even if intent was there. No specific SL gateways etc were used - traditional end of stage sign-off etc adopted
C	Design	🟧 Review past experience Agree performance metrics Agree design targets	End users engaged to envision the end result including drawing on their past experience. No operational performance metrics defined. Environmental design targets included Building Regulations Part L, BREEAM and DCSF Carbon Calculator (linked to additional funding)
D		🟩 Review design targets Review usability and manageability	Design targets achieved through Building Regulations Part L submission, delivery of BREEAM and securing of additional funding from DCSF Carbon Calculator. The Main Contractor managed the process by comparing back to original brief and continuous client engagement and checking forward by

			validating design with manufacturers, installers and specialists
E		Review against design targets Involve the future building managers	Design targets were compliance based (Part L, BREEAM), but were all achieved. Senior building managers engaged through regular meetings, but involvement of site manager could have been more comprehensive
F		Review against design targets Involve the future building managers	See above
G		Include additional requirements related to Soft Landings procedures	Activities included which can be mapped to SL, although perhaps not specifically referred to as such
H		Include evaluation of tender responses to Soft Landings requirements	SL was not a requirement of either the PQQ or ITT
J		Confirm roles and responsibilities of all parties in relation to Soft Landings requirements	Roles and responsibilities matrix used based on BSRIA document, but no specific SL requirements
K	Pre-handover	Include FM staff and / or contractors in reviews Demonstrate control interfaces Liaise with move-in plans	12 week process operated by the Main Contractor included a Soft Landings type approach. The Main Contractor operate a zero defects policy which was achieved although there were some 'teething' issues which were reviewed weekly until resolved although some issues outstanding which were fundamental to efficient operation. The Main Contractor closely involved in post-handover of Phase 1 due to continued on site presence delivering later phases
L1		incorporate Soft Landings requirements	No specific SL requirements although the Main Contractor was on site due to continuing work on later phases of the project so some SL type activities included
L2	Initial aftercare	Set up home for resident site attendance	Site attendance by virtue of the ongoing later phases, but this would not have happened otherwise - no presence from the design team
L3	Year 1 to 3 aftercare	Operate review process Organise independent post-occupancy evaluations	No review process organised as part of ongoing school operation. Unclear whether any review would have happened if TSB BPE funding had not been secured

10.1.6 Conclusions

There were a number of general trends that were observed throughout the design and delivery team interviews, which are summarised below.

Understanding Soft Landings and its function. Whilst activities that could be characterised as SL were evidently included in the project (particularly during the pre-handover period), there did not appear to be a common understanding of the project's approach to Soft Landings or the breadth of a full SL implementation. Responses to additional questions (i.e. in addition to the semi-structured interview templates) suggested that whilst SL was discussed, its limited implementation was likely the source of the lack of full understanding.

Timing of Soft Landings – It appears that SL was not addressed as part of the project until around half way through Phase 1. That said, some of the earlier activities (such as the end-user consultation) could be considered to be SL, despite not being labelled as such.

Other than relatively obvious conclusions drawn from a partial implementation of SL (i.e. that a fully integrated approach to Soft Landings, implemented from day one, would have potentially provided a better overall outcome), there are some specific key findings which come out of the Soft Landings review.

Building Log Book – A number of issues have been observed with respect to the compilation of the building Log Book which means it is less effective than necessary. Specifically, issues such as building areas, energy consumption and so on are not consistently reported making the information confusing for end users. So, sufficient time and budget should be retained for effective completion of the Log Book.

Functionality of metering – Whilst physical meters appear to generally have been operating appropriately at handover, there are issue with the BMS in terms of gathering and recording energy data remotely from the metering installation. Significant effort from the BPE team was required to understand the metering provision on site including the arrangements of submeters, and so on, as the building Log Book was not sufficiently detailed to clearly explain the arrangements.

Ensure training is appropriate and comprehensive – The initial training provided to the Facilities Manager on the use of the BMS was too complex and did not cover the basic operation of the BMS, which would have helped to identify key issues early in occupation. It should not be necessary for the client to fund and arrange additional training for systems installed. Although staff were trained on the operation of classroom ventilation, it has taken some time for users to understand how to use lighting controls effectively. This indicates that training was not as comprehensive as it perhaps could have been.

Ensure maintenance contracts are in place at handover – There needs to be clear demarcation between defects / snags and maintenance issues. This would help users to know who to approach for specific problems and to avoid being left with no one to speak to if the issue is not covered by defects.

Specialist functions - Early consideration of specialist functions is essential, such as ICT – Specialist functions often take a significant amount of design time and can impact on a wide range of other systems, such as lighting, ventilation, cooling and so on. As the specification for ICT was provided very late by the specialist consultants, there was a knock on effect that had a detrimental impact on the design process even though the final outcome was satisfactory.

Cost pressure affected communications – Pressure on overall project budget inevitably also affected professional fees and this appears to have had a knock on effect on communication. The designers did not have access to end users and there was an overall sense of the need to get the work done as quickly as possible. Whilst this is unlikely to impact on the actual work of producing a design in any professional situation, it is likely to have detrimental effect on less design critical activities (such as the production of a robust Log Book) which support efficient operation of the building in use.

APPENDIX 10.2: LOG BOOK REVIEW

10.2 Log Book review

Typically building log books are arranged based on the template set out in CIBSE's TM31 Building Log Book Toolkit document. To provide a structure for this review of the building Log Book, it has been compared against the guidance in TM31 and in particular the ten golden rules set out for a successful document. These are:

1. Ensure the requirement for a log book is included in the client's brief (log books are essential for compliance with the Building Regulations) and include it in the fee structure, so there resources are allocated to develop it.
2. Appoint a single person, e.g. the lead designer or consultant, to be responsible for producing the log book, even if final production is sub-contracted to specialist authors.
3. Start the process early and don't release sub-designers until they have summarised their section of the design and provided the required information to the log book author.
4. Use the distinctive CIBSE style so that it is easily recognisable among the many other manuals likely to be found in the building operations room.
5. Keep the contents list reasonably similar to the template so it retains a common structure that is recognisable to anyone working in the buildings industry.
6. Make it easy to read/use for all facilities managers and building operators. Use simple explanations with minimum jargon, utilising diagrams wherever possible.
7. At handover the log book should be between 20 pages (for a small/simple building of floor area less than 200 m^2) to 50 pages (for a large and/or complex building) in order to make it a useful and easily accessible summary. Buildings/tenancies having a floor area less than 200 m^2 can use the 'small business' template which might give a log book of 5 to 10 pages.
8. The facilities manager should sign the log book at handover as a recognition of taking over responsibility for the log book.
9. Keep the log book up-to-date by undertaking an annual review as part of the quality assurance system, particularly with regard to energy performance, maintenance and alterations to the building.
10. Keep the log book in a designated location in the main building operations room - not to be removed without the facilities manager's approval.

The log book produced for the school campus is examined against each of the golden rules in turn.

1 – Ensure there are sufficient resources to develop the log book

The Soft Landings review found that pressure on the project budget meant that some activities which were secondary to the production of the design may have suffered and the Log Book is an example of that. Several elements of the Log Book are incomplete, indicating that either the document was put together some time prior to handover or required information was not gathered at that time.

2 – Make a single person responsible for producing the log book
This does seem to have happened insofar as a single organisation was responsible for producing the Log Book (the Main Contractor according to page 4 of the document). However, they would obviously have gathered information from other members of the delivery team including the Architect, Building Services Designers and Subcontractors. This means that whilst they might have been responsible for its compilation, they are unlikely to have been responsible for producing all of the source information. Moreover, there does not appear to have been any process for checking the document before issue, as some of the inaccuracies are obvious and would have been spotted in any review.

3 - Start early and ensure sub-designers contribute
It is not clear when the Log Book was started, but TM31 indicates that leaving the development of a log book to a late stage is likely to mean it is produced when fees are squeezed and time is tight. It appears that these issues could have been significant here, implying that it should have been started earlier.

Clearly there has been input from multiple sources, although the principle source of information seems to have been the M&E Designers. Whether contract clauses would have been sufficiently robust to ‘force’ participation in producing the Log Book is unclear.

4 - Use the distinctive CIBSE style
The Log Book has been produced using one of the TM31 templates.

5 - Keep the contents list reasonably similar to the template
The Log Book contents list reflects that set out in the TM31 template.

6 - Make it easy to read, avoid jargon and use diagrams
The Log Book is necessarily technical in some aspects, although there appears to be no attempt to explain the information provided to someone who is not relatively experienced in building design. An example is the results of air infiltration tests – the results are provided with no preceding text explaining what air infiltration is or why it is important. There is, however, a statement confirming that the results indicate compliance with the Building Regulations.

There is a limited number of diagrams throughout and there are several obvious instances of where a diagram would have aided understanding. In addition, some of the diagrams provided are somewhat misleading – specifically, the diagrams illustrating the metering arrangements do not reflect what has been observed to be installed on site.

7 - At handover the logbook should up to 50 pages
TM31 states that for large / complex buildings with a floor area over 2000 m^2, the Log Book should be between 35 and 50 pages. The Log Book provided is only 40 pages and considering the size of the project, the presence of multiple buildings, the inclusion of the biomass boiler and so on, this certainly appears to be insufficient. The Log Book would have benefited from better explanations throughout and more robust data.

8 - The facilities manager should sign the log book at handover
The BPE team has been provided with an unsigned copy of the Log Book. However, having discussed the Log Book with the Facilities Manager as part of the Soft Landings review process, it is clear that he understands it is his responsibility.

9 - Keep the log book up to date
Although the Facilities Manager does keep records of maintenance, energy consumption and so on, these are not kept as part of the Log Book, but are filed separately. No major changes to Phases 1 and 2 have yet occurred, so there have been no changes of this sort to record at this time.

10 - Keep the log book in a designated location - not to be removed without the facilities manager's approval.
The Log Book is kept in the Facilities Manager's office, although this is not reflected on the cover space to record this information. Whether the Log Book could, or would, be removed by anyone without his approval is unknown. In reality, it seems unlikely that anyone else would have reason to remove it.

10.2.1 Specific observations on the log book

The following list sets out specific observations made as part of the Log Book (version 2) review. The observations are intended to highlight issues for attention in future projects.

Page	Observation	Comment
1	No details of log book location (physical or electronic)	
7	No record of whether commissioning certificates are included in appendices	
	Commissioning results indicate there were no issues during commissioning and all systems were operating efficiently	Particularly when considering the performance of the BMS and biomass boiler, this calls into question the extent and effectiveness of commissioning of some systems and the timing / quality of the information provided in the Log Book.
8	Air infiltration section does not include any explanation of terms used or context of information	
	Dates for handover and end of defects are the same for both Phase 1 and Phase 2	
9	The basis of design section makes reference to individual room data sheets,	

	but gives no indication of where they can be found	
	The basis of design section is written in the future tense	This may be a case of simply changing the tense. However, the implication is that the text is copied from briefing / specification / contractor's proposals documents and may not reflect the final situation
18	Key dos and don'ts includes reference to warning lights, but they are not mentioned previously	This situation means that there is no indication of where the warning lights are, what they look like, what to watch for, etc
	Item 3 in the dos and don'ts contradicts itself	
20	Floor areas given are different to elsewhere in the Log Book	
25	Information provided suggests biomass boiler is 100% efficient	
26	System sheet – descriptions of systems would have benefited from the inclusion of simple diagrams	
27	The description of the ventilation system includes a recommendation that the louvres should be opened at the end of each day.	Clearly this advice is dependent on external conditions at the time as this is the summer strategy to avoid overheating, but there is no such caveat in the advice.
29	No details of authorised personnel is provided (with respect to BMS access)	
30	Occupant information on heating describes the installation of system, but has no details of how users should control their local environment. Similar issues with ventilation and lighting.	All of these would have benefited from diagrams or photographs of actual equipment in-situ so that users could recognise what is being described
31	The list of simple dos and don'ts is different to those presented previously	In particular, advice here is to shut windows to prevent heat loss – elsewhere advice is to open windows / vents to reduce peak temperatures
32	Total estimated incoming fuel lists electricity and biomass – assume this should be gas and biomass	

34 & 35	Metering diagrams do not appear to match what is on site	The diagrams do not clearly indicate the hierarchy of metering or indicate locations of meters meaning understanding which meters to aggregate to check readings is very difficult
36	Overall annual energy performance table appears not to include gas	
	No figures in the asset rating which could potentially have been completed from the Energy Performance Certificate	
37	Energy end use comparison table is incorrect – equipment energy (noted as un-regulated) is included in the regulated total. The total energy does not appear to be the summation of any combination of the figures in the table. Also doesn't match figures elsewhere in the log book	
38	Maintenance overview section not completed	The version reviewed still includes a note for others to complete missing information.

10.2.2 Conclusions

The Log Book provided for this project contains some useful information for the Facilities Manager, but is likely to leave the general user somewhat confused about the systems at their disposal and how best to use them. There are also certain inaccuracies and potentially misleading information that is likely to confuse.

APPENDIX 10.3: CIBSE TM22 OUTPUTS

10.3 CIBSE TM22 Outputs

Table 10.1. List of CT pumps for LTHW circuit in Energy Centre from TM22.

Item	End use	No. of units	Rating (kW) per unit	Load Factor	Units	Profile	Annual hours	Usage Factor	Energy consumption kWh/year
Pumps - Buffer vessel	Pumps	1	0.76	0.80	kW	24h flat 100%	8,760	1.00	5,326
Pumps - Sound House	Pumps	1	0.38	0.80	kW	24h flat 100%	8,760	1.00	2,663
Pumps - CADE, Primary	Pumps	1	0.76	0.80	kW	24h flat 100%	8,760	1.00	5,326
Pumps - Sports, F,A,T,C	Pumps	1	1.55	0.80	kW	24h flat 100%	8,760	1.00	10,862
Pumps - Gas boilers	Pumps	2	0.76	0.80	kW	24h flat 100%	8,760	1.00	10,652
Pumps - Biomass boiler	Pumps	1	0.76	0.80	kW	24h flat 100%	8,760	1.00	5,326

Table 10.2. Cooling unit list in the school campus from TM22 model.

Sub-meter	Item	End use	No. of units	Rating (kW)	Load Factor	Units	Profile	Annual hours	Usage Factor	Energy consumption kWh/year
E03 - Austen Power	Daikin VRV	Cooling	1	2.59	0.80	kW	24h flat 100%	8,760	0.20	3629.3
E05 - Faraday Power	Daikin VRV	Cooling	1	2.59	0.80	kW	24h flat 100%	8,760	0.20	3629.3
E09 - Tenzing Power	Daikin VRV	Cooling	1	2.59	0.80	kW	24h flat 100%	8,760	0.20	3629.3
E12 - Cann Bridge Power	Daikin VRV	Cooling	1	2.59	0.80	kW	24h flat 100%	8,760	0.20	3629.3
E12 - Cann Bridge Power	Nuaire spilt	Cooling	4	0.10	0.80	kW	24h flat 100%	8,760	0.80	1166.1
E37 - Sports Hall	Split unit - medium RZQ125B9W1B	Cooling	2	3.70	0.60	kW	Sports Hall	5,371	0.60	10587.6
E37 - Sports Hall	Split unit - small RKS20J2V1B	Cooling	1	2.00	0.60	kW	Sports Hall	5,371	0.60	2861.5
E46 - No sub meter - IT server room	Split - Mitsubishi PUHZ-RP140YKA	Cooling	3	4.30	0.80	kW	24h flat 100%	8,760	0.60	40139.0

E46 - No sub meter - IT server room	Split - Mitsubishi small	Cooling	1	2.50	0.80	kW	24h flat 100%	8,760	0.60	7778.9

Table 10.3. List of AHUs at the school campus from TM22 model

Sub-meter	Item	End use	No. of units	Rating (kW)	Load Factor	Units	Profile	Annual hours	Usage Factor	Energy consumption kWh/year
E37 - Sports Hall	AHU - Dance Supply	Fans	1	2.5	0.80	kW	Sports Hall	3,437	0.80	8593.1
E37 - Sports Hall	AHU - Fitness Supply	Fans	1	2.5	0.80	kW	Sports Hall	3,437	0.80	8593.1
E45 - No sub meter - CADE Plant Room	AHU - Dark room	fans	1	2	0.80	kW	Monday - Friday 7.30 to 7	1,439	0.60	2878.3
E45 - No sub meter - CADE Plant Room	AHU - Library	fans	1	2	0.80	kW	M-F 8-6 part weekend	2,002	0.80	4004.6
E45 - No sub meter - CADE Plant Room	AHU - Dining supply	Fans	1	1.3	0.80	kW	Monday - Friday 7.30 to 7	2,399	1.00	3118.1
E45 - No sub meter - CADE Plant Room	AHU - Dining extract	Fans	1	1.3	0.80	kW	Monday - Friday 7.30 to 7	2,399	1.00	3118.1
E45 - No sub meter - CADE Plant Room	AHU - Kitchen supply	Fans	1	4	0.63	kW	24h flat 100%	5,475	1.00	21900.0
E45 - No sub meter - CADE Plant Room	AHU - Kitchen extract	Fans	1	5.5	0.63	kW	24h flat 100%	5,475	1.00	30112.5
E45 - No sub meter - CADE Plant Room	AHU - Computer room	fans	1	2.5	0.80	kW	Monday - Friday 7.30 to 7	1,439	0.60	3597.9

E47 - Graham Browne	AHU	Fans	1	1	0.80	kW	Teaching	1,460	1.00	1460.0
E50 - No sub meter - Sound House	AHU - above hall	Fans	1	4	0.80	kW	Monday - Friday 7.30 to 7	2,399	1.00	9594.3
E50 - No sub meter - Sound House	AHU - above arena	Fans	1	4	0.80	kW	Monday - Friday 7.30 to 7	2,399	1.00	9594.3

APPENDIX 10.4: CLASSROOM STANDBY LOADS CALCULATION

10.4 Classroom standby loads calculation

In past projects, the BPE team has previously looked at the contribution of equipment on standby to the baseload in schools and has found it to be significant. More recently, the team carried out bottom up calculations of a typical primary school to assess how difficult it would be to achieve a Display Energy Certificate rating of B.

Netbook charging would be about 20W and assuming 2 hours charge time, charged every 2-3 days.

Standby power typical figures from measurement
Desktop PC 20W
Thin client PC 2.3W
Data Projector 20W
19” LCD computer screen 4W
Whiteboard/Speakers 5W (although this could be more at the school campus as audio amps are relatively large)

Estimate of standby power:
1600 pupils/30 per class = 53 classrooms. Say 60 to allow for spare capacity.
Each classroom: 20W PC + 20W projector + 4W screen + 5W whiteboard
Classrooms total 2.94 kW
x (17.5 hours x 190 days) +(24 hours x 175 days) = 22.1 MWh per year

Say 8 computer clusters each with 12 thin client PCs : (12 (2.3W PC + 4W screen)) + 20W projector
Clusters total: 0.765 kW
x (17.5 hours x 190 days) +(24 hours x 175 days) = 5.8 MW h per year

Say 10 computer labs (e.g. MACs in art dept., business studies in Cade North East, Tenzing D204), each with 20 desktop PC: (20 (20W PC + 4W screen))+ 20W projector)
Clusters total: 5 kW
x (17.5 hours x 190 days) +(24 hours x 175 days) = 37.6 MW h per year

Total of all standby = 65.5 MWh per year
cf. about 1 GWh per annum total electricity
=7% of total

APPENDIX 10.5: AN ANALYSIS OF THE PERFORMANCE OF THE BUILDING MANAGEMENT SYSTEM

10.5 An Analysis of the performance of the building management system

10.5.1 Summary

The Building Performance Evaluation (BPE) team conducted site monitoring over two years in Phase 1 of the recently constructed school campus. The original philosophy of the project was to use the meters and sensors installed on site as part of the build, and through the building management system (BMS), record values at frequent intervals. In practice, the operation of the BMS has been very unreliable. The amount of data that has been successfully logged has been very small, and the data are of uncertain accuracy. More importantly, failings of the BMS have severely impeded the ability of the school staff to control the heating and ventilation systems, requiring considerable staff effort to circumvent the problems and minimise adverse effects on internal comfort and energy use.

This Appendix presents an evaluation of the implementation of the BMS strategy. The focus is biased towards the metering systems, since these have been examined in greatest depth for the wider project, but information is also included on sensor placement and information reported by site staff.

The work has highlighted issues with the thoroughness of commissioning, and the specifications of the BMS as implemented. The metering system was handed over in an unusable state, with meters incorrectly configured, BMS readings not synchronised with physical meter readings, mislabelled meter channels, and a significant number of non-functioning meter channels. More widely, there is a lack of clear information on the control strategy and how sensors correspond to zones in the building. Control of the entire system is from a single central computer: This is a real weakness that has left staff without control of the building during two lengthy computer outages. All of the above negate the advantages of what should be a useful energy management tool.

Whilst the multiple control systems provided have the potential to tightly control heating and ventilation and to reduce energy use, the implementation does not appear to offer a satisfactory level of control or manual override. Significant limitations are inherent in the implementation of summer and winter operating modes, which frequently impede manual override operations such as opening ventilation in the sports hall to alleviate high internal temperatures. In this case it is probable that the external temperature sensors are not optimally positioned and at times experience direct solar heat gain.

Control strategies also appear to be inconsistent across different phases of the build. Areas with a greater level of controllability and local manual controls are generally preferred by site staff.

The systems themselves represent a considerable maintenance burden for the school campus, and some have already been removed or simplified where they were perceived to be unnecessarily complicated.

The phased nature of the build has led to staggered snagging periods. This has made it difficult to resolve certain faults, which are more general in nature and not specific to a particular phase.

10.5.2 Introduction

The BPE team conducted site monitoring over two years in Phase 1 [2] of the recently constructed school campus. The original philosophy of the project was to use the meters and sensors installed on site as part of the build, using the BMS to record values at frequent intervals. It was expected that data would be gathered from the system including gas, electricity, water and heat submeter readings, gas, electricity and water fiscal meter readings, internal and external temperatures, internal CO_2 concentrations (indicating ventilation adequacy), mechanically actuated ventilator operation, air handling unit operation, operation of the central heat generation plant, and other heating system parameters such as control override status, flow and return temperatures, and more.

In practice, operation of the BMS has been very unreliable. The amount of data that has been successfully logged has been very small, and the data are of uncertain accuracy. Considerable additional time has been required to service stand-alone dataloggers for temperature and CO_2 - This approach was originally envisaged to be used for a short period to verify the validity of the BMS data. More importantly, problems with the BMS have severely impeded the ability of school staff to control the heating and ventilation systems, resulting in considerable effort on the part of site staff to circumvent these issues and minimise adverse effects on internal comfort conditions and energy use.

The BPE project included a task to evaluate the BMS strategy, which is the focus of this Appendix. Aspects assessed include:

1. installation and commissioning;
2. reliability and in-use performance;
3. user interface, and
4. training and support.

These are considered in Sections 10.5.3 to 10.5.9 below. The focus is biased towards the metering systems, since these have been examined in greatest depth for the wider project, but information is also included on sensor placement and information reported by site staff.

Two different lettering systems exist for the buildings: one used during construction and the other used by the school campus. This is potentially confusing, so wherever possible, building names have been used. The lettering systems are compared in Section 10.5.9.

10.5.3 Installation and Commissioning

One of the main BMS panels is in the first floor Cade plant room and was noted to contain many unterminated sensor cables (some marked with their intended function), and whilst the tidiness of factory-

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[2] For meter reconciliation, meters have been examined site-wide. Where noted, issues extending outside of Phase 1 have been reported.

wired elements was good, the site connections do not give the impression of quality workmanship (Figure 10.1).

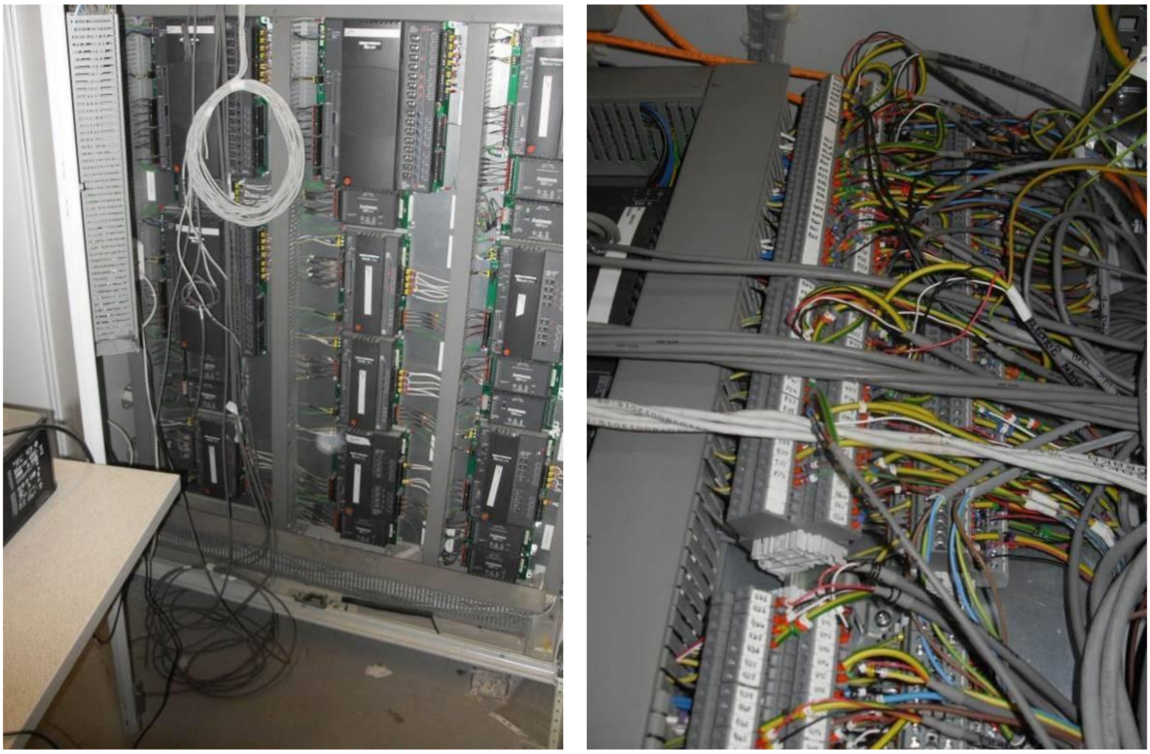
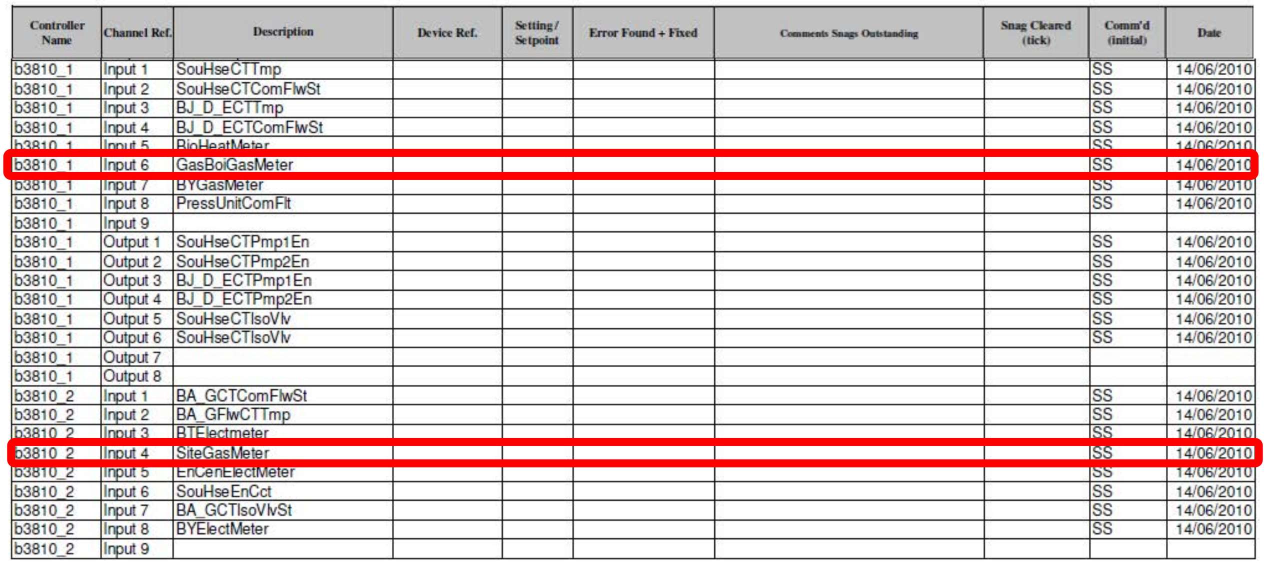


Figure 10.1. BMS panel and connections in Cade room A109.

It is understood that the BMS interface is only available on a dedicated PC, and is not accessible on the school campus network or over the Internet. This is contrary to the statements in the building Log Book [1] that "*the BMS installation is configured such that access to the primary control functions will be available over the ICT LAN for potential three party monitoring. This also allows interrogation by users for an education aid*". The dedicated PC has failed on two occasions causing problems and leaving staff with no control of the BMS for extended periods.

Despite the issues highlighted in this Appendix, commissioning sheets in the operation and maintenance (O&M) manual [2] confirm that all channels in use on Phase 1 have been commissioned (with the exception of one omission and two faults in Austen / Faraday). Each channel is initialled in typeface, but the forms included in the O&M manual are not signed by the Commissioning Engineer and the 'Witnessed By' section is blank. Deficiencies in the commissioning are evident in that, for example, the channel for the gas boiler gas meter is initialled despite the meter itself being omitted. The fiscal gas meter for the north of the site has an unterminated cable for the BMS connection. The relevant section of the commissioning sheet for these two meters is depicted in Figure 10.2.



Controller Name	Channel Ref.	Description	Device Ref.	Setting / Setpoint	Error Found + Fixed	Comments Snags Outstanding	Snag Cleared (tick)	Comm'd (initial)	Date
b3810_1	Input 1	SouHseCTTmp						SS	14/06/2010
b3810_1	Input 2	SouHseCTComFlwSt						SS	14/06/2010
b3810_1	Input 3	BJ_D_ECTTmp						SS	14/06/2010
b3810_1	Input 4	BJ_D_ECTComFlwSt						SS	14/06/2010
b3810_1	Input 5	BioHeatMeter						SS	14/06/2010
b3810_1	Input 6	GasBoiGasMeter						SS	14/06/2010
b3810_1	Input 7	BYGasMeter						SS	14/06/2010
b3810_1	Input 8	PressUnitComFlt						SS	14/06/2010
b3810_1	Input 9								
b3810_1	Output 1	SouHseCTPmp1En						SS	14/06/2010
b3810_1	Output 2	SouHseCTPmp2En						SS	14/06/2010
b3810_1	Output 3	BJ_D_ECTPmp1En						SS	14/06/2010
b3810_1	Output 4	BJ_D_ECTPmp2En						SS	14/06/2010
b3810_1	Output 5	SouHseCTIsoVlv						SS	14/06/2010
b3810_1	Output 6	SouHseCTIsoVlv						SS	14/06/2010
b3810_1	Output 7								
b3810_1	Output 8								
b3810_2	Input 1	BA_GCTComFlwSt						SS	14/06/2010
b3810_2	Input 2	BA_GFlwCTTmp						SS	14/06/2010
b3810_2	Input 3	BTElectmeter						SS	14/06/2010
b3810_2	Input 4	SiteGasMeter						SS	14/06/2010
b3810_2	Input 5	EnCenElectMeter						SS	14/06/2010
b3810_2	Input 6	SouHseEnCct						SS	14/06/2010
b3810_2	Input 7	BA_GCTIsoVlvSt						SS	14/06/2010
b3810_2	Input 8	BYElectMeter						SS	14/06/2010
b3810_2	Input 9								

Figure 10.2. Commissioning sheet showing initials against the omitted gas boilers gas meter and the site (north) gas meter which does not appear to have ever been connected [2].

All of the electrical submeters were handed over with the default configuration settings in place, and hence did not correctly report electricity consumption. These had also been initialled on the commissioning sheets.

It is reported that after handover, the library end of the Cade block was cold, and this was traced to isolation valves being shut. It may be that this part of the system was never commissioned or correctly balanced.

Other systems have also suffered from variable standards of installation and commissioning. A maintenance engineer reported that the sprinkler system was not properly installed and rectification was needs for faults such as resilient packing missing from pump mountings and leaks in the diesel fuel lines.

Many of the temporary temperature dataloggers installed for the TSB BPE project have been located inside the BMS temperature sensor housings, and this allows the BMS temperature data to be verified. In many cases (e.g. classroom C108, C123, E102, F206) there is a good match between the two data sources. There are cases, however, where sensor data are clearly spurious [3], generally being fixed values (possibly indicating faulty or disconnected sensors). This could impact upon the correct control of the building if these channels are being used as setpoints. It is possible that the channels are in fact unused, or represent unused setpoints rather than actual sensors.

Further into the monitoring, during a period when the BMS was logging channels successfully, attempts were made to match physical room sensor locations with the BMS channels and locations of the temporary temperature dataloggers. Many of the BMS temperature and CO_2 sensors are named by the heating zone

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[3] Examples include BGCenZnSpTmp1, BGWstZnSpTmp1, BGHighLevTmp3, BGHighLevCo2_3, WstZnSpTmp2 (const. block B), HWSCalorifierTmp (const. block B), HighLevTmp2 (const. block B), SthZnSpTmp2 (const. block B), HighLevCo2_2 (const. block B), HWSMixFlwTmp (block C), HWSCalorifierTmp (block C), HighLevTmp1(const. block B), HighLevTmp2(const. block B), HLLTmp(const. block B), HRU1ExtTmp(const. block B), HRU1SuppTmp(const. block B), HRU2ExtTmp(const. block B), HRU2SuppTmp(const. block B), BEKAHUExtAirTmp, BEKAHUSupAirTmp, BEKAHUExtAirTmp, BEKAHUSupAirTmp, BuffOutletTmp1, BuffOutletTmp2

rather than a room number. Drawings showing the physical locations of sensors were requested. "As installed" plans were eventually received [3], but had two shortcomings. Firstly, although the locations were marked, the BMS channel name for each sensor was not. Secondly, when surveyed on site, many of the actual sensor locations differed from the supplied plans. The school remain uncertain as to which physical room sensors are represented by many of the BMS channels. Appendix 10.6 compares the surveyed sensor locations with those on the plans. There are implications for the building control strategy if sensors are located inappropriately, for example there will be differing solar gains in north and south zones. It has also been noted that the temperature sensor in the first floor circulation space in Austen is located directly above a radiator, which could lead to incorrect heating control. Figure 10.3 compares temperatures measured using standalone iButton dataloggers inside the BMS temperature sensors, and shows extremely high temperatures were measured on the first floor above the radiator. (This, however, would indicate that the sensor is not currently used to control heating in this zone).

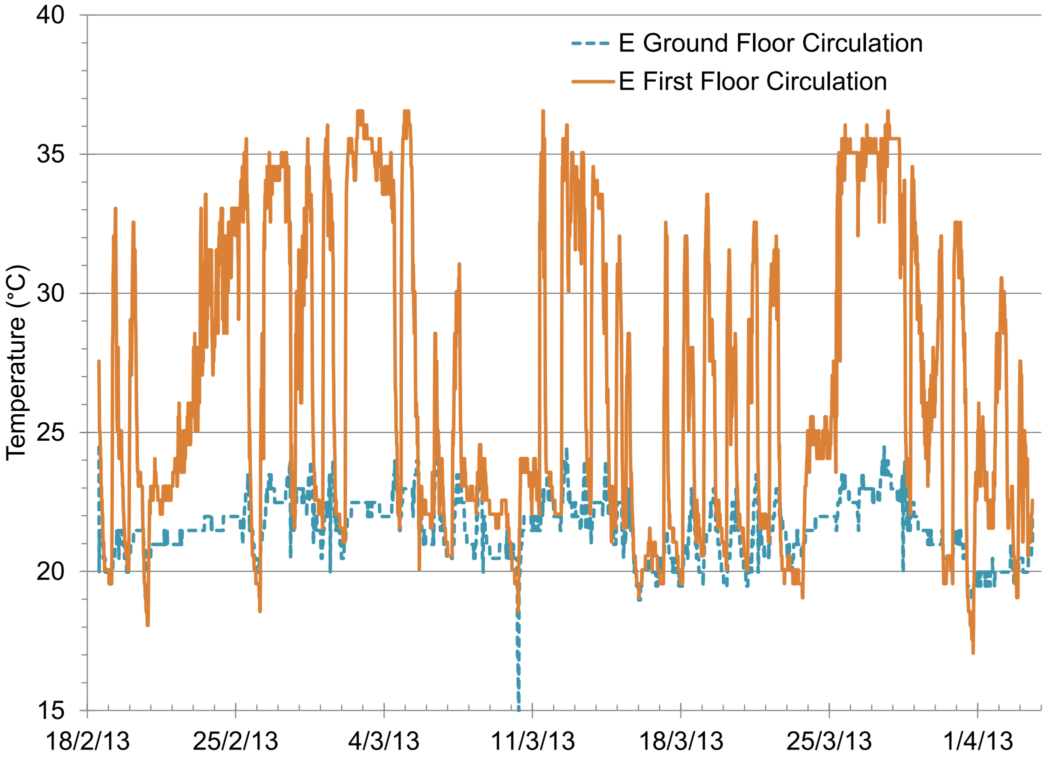

Figure 10.3. Temperatures measured using iButton dataloggers inserted inside BMS temperature sensor housings in Austen, showing the high temperatures recorded on the first floor directly above the radiator.

It is noted that the school was selected as a case study for Stages 3 to 5 of the Soft Landings process [4]. These stages pertain to the construction phase through to practical completion, and post-completion final inspections, handover, and three years of aftercare, monitoring and fine tuning. The case study stated that *"Although there is no contractual requirement to carry out post-completion fine-tuning, [the Main Contractor] felt that benefits would accrue from the school's facilities staff committing to monitoring the building actively, with the environmental data feeding into the school curriculum."* Unfortunately the ability to monitor the building effectively has been compromised due to the poor standard of commissioning of the BMS.

Few of the meter readings reported by the BMS were even close to the physical meter readings. Offsets have arisen owing to the electricity submeters being reset, and meters being installed before or after the BMS. In many cases, a factor or formula needs to be applied to account for the pulse weighting of the meter. The BMS does have the capability to apply an equation to ensure that the pulse weighting is accounted for (Figure 10.4) [5], but this has not always been set up correctly. An offset value cannot be specified since for pulse inputs the equation applies an increment to the channel's current stored value. Any constant specified in the formula would therefore be added or subtracted every time the channel's value is updated. A workaround solution involves temporarily forcing the channel value to match the physical meter reading by entering the numerical value directly in place of the equation, then subsequently re-entering the equation required to interpret meter pulses. BMS readings would then match the physical meter readings. In the primary school, commissioning of the metering channels appears to be more consistent, although in some cases [4] there is a difference by a factor between the values displayed in the user interface and logged data. This suggests that an alternative approach has been taken to data processing in these cases, compared to that described above, and could cause confusion if logged data are used for energy management purposes. Appendix 10.7 lists the factors and offsets that have been determined for the BMS-connected meters.

It would be reasonable to expect the BMS to be configured with appropriate factors and offsets as part of the commissioning procedures. Without correct configuration, the reported readings will appear arbitrary to most users and will be of no use for day-to-day energy management.

It is understood that physical meter readings are currently taken by site staff since the BMS data are not trusted. In late May 2013, an attempt was made to apply factors and offsets to the BMS metering channels using the method described above with the intention of verifying whether the BMS data continue to reflect the physical meter readings. In some cases, the factors deduced from data are not plausible (see Appendix 10.7), possibly indicating further meter and BMS commissioning issues.

The remainder of this Appendix reports specific issues with the metering strategy and implementation thereof.

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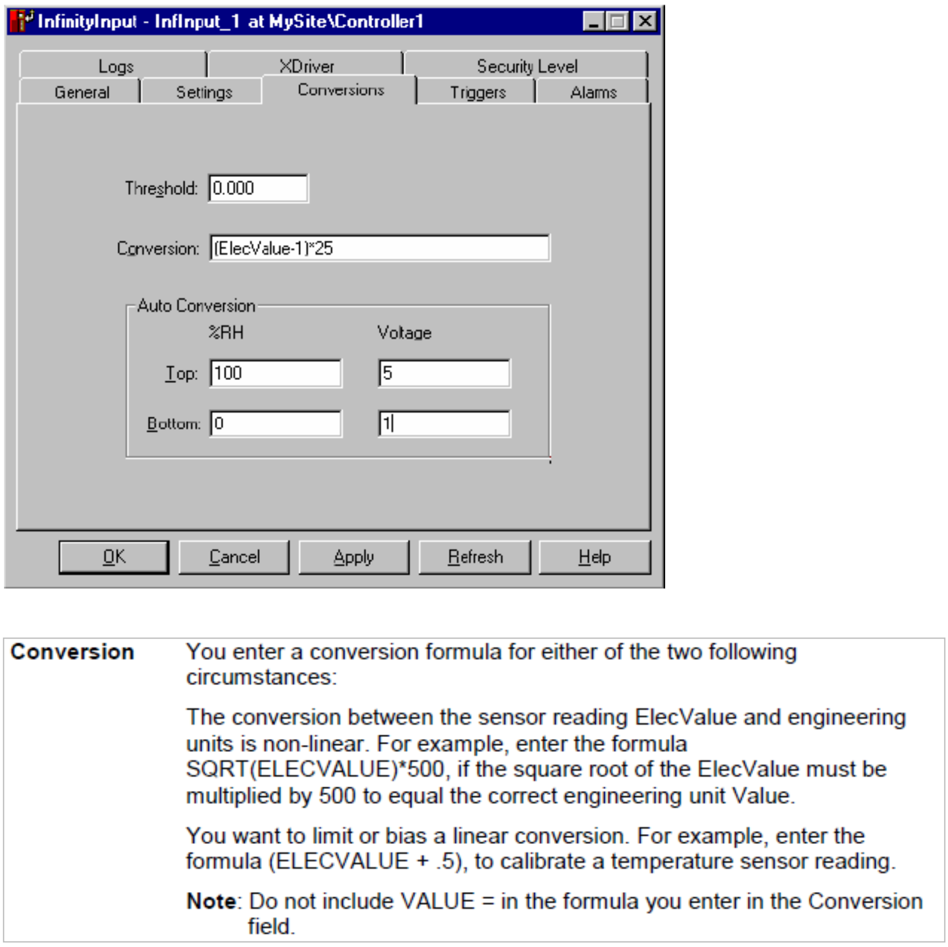
[4] VT and underfloor heating CT heat meters, and water meter.



InfinityInput - InfInput_1 at MySite\Controller1

Threshold: 0.000

Conversion: (ElecValue-1)*25

Auto Conversion

	%RH	Voltage
Top:	100	5
Bottom:	0	1

Conversion	You enter a conversion formula for either of the two following circumstances: The conversion between the sensor reading ElecValue and engineering units is non-linear. For example, enter the formula SQRT(ELECVALUE)*500, if the square root of the ElecValue must be multiplied by 500 to equal the correct engineering unit Value. You want to limit or bias a linear conversion. For example, enter the formula (ELECVALUE + .5), to calibrate a temperature sensor reading. **Note**: Do not include VALUE = in the formula you enter in the Conversion field.

Figure 10.4. Functionality to offset of factor meter readings in the Continuum BMS [5].

Electricity Metering

1. Electrical submeters were all (except the Cade external lighting meter, which is of a different type) recording very low levels of consumption. On subsequent inspection it was found that the current transformer (CT) ratios had not been programmed into the meters. These factors were subsequently set by the M&E Subcontractor [5] and despite requests, meter readings were not recorded at this point. This would have allowed data preceding the reprogramming to be manually factored. Once the factors were set, reasonable consistency has been obtained between most first and second tier submeters (Appendix 10.8 summarises the current state of meter reconciliation across the site).
2. Five electrical submeters in Cade were reading zero until the remedial works above were completed by the M&E Subcontractor.
3. Further investigations involving comparison of current clamp readings in the switchroom with instantaneous current readings on local submeters indicated that most of the submeters are now operating correctly, with the exception of Cade South (meters read 40% of measured current, but supplies to the main mechanical services panel and fire alarm are unmetered), and Faraday (meter reading twice measured value on phase L3). These issues are being investigated further using logging current clamps.

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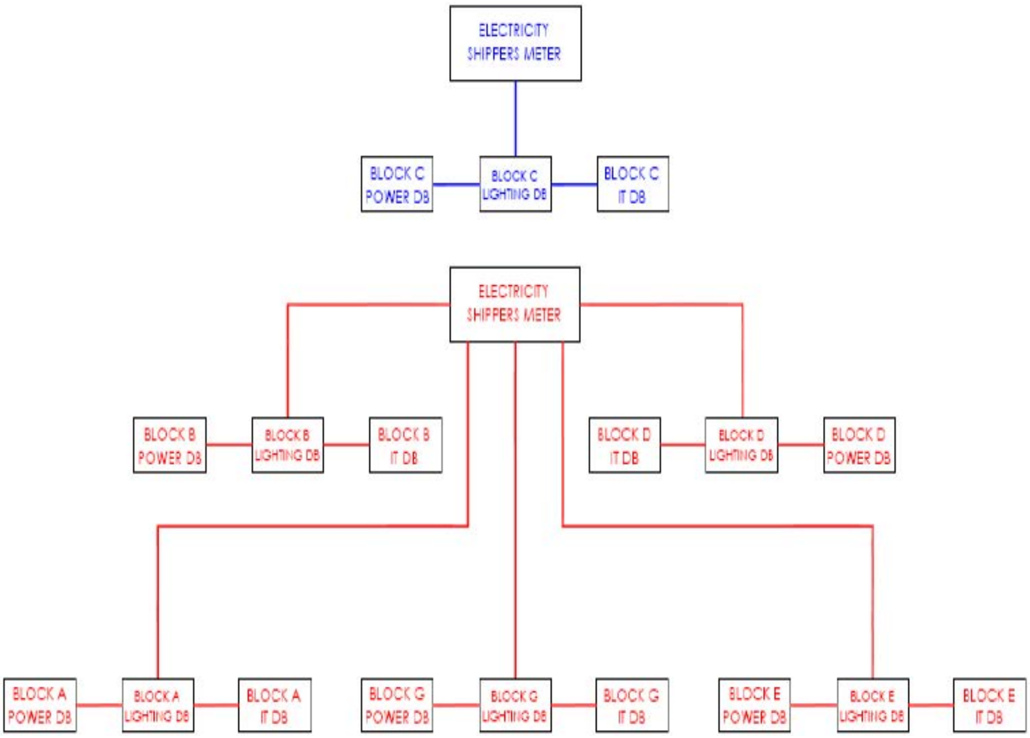
[5] The primary school external lighting meter appears to have been omitted from this remedial action and still has a CT ratio of 1:5 programmed.

4. There is also a discrepancy in the Sports block, where the top level submeter consistently under-reads compared to the sum of the lower level submeters.
5. Site-wide meter reconciliation remains poor when comparing the fiscal and submeters for the secondary school and the primary school (see Appendix 10.8). A good match is obtained for Cann Bridge.
6. Site-wide reconciliation (and ongoing energy management) is compromised by several potentially significant unmetered circuits: the Sound House, central IT servers, sprinkler supply and the MUGA pitch lighting. Ongoing current clamp monitoring is intended to enable full reconciliation of electricity use in the secondary school.
7. The incoming fiscal meters do not appear to be BMS-connected (but half-hourly data should be available from the utility company). There is a BMS channel designated for the Cade electrical incomer (presumably for the secondary school), but all readings are zero.
8. BMS readings are zero for the Cade Block North power circuits meter and the youth centre meter.
9. The Energy Centre and Graham Browne building electrical meters do not appear as channels in the BMS software.
10. Metering channels DBF/MCCB and DBF/L/P West are transposed in the BMS in comparison to the meters actually connected.
11. There is an additional, apparently unused metering channel 'BAElectMeter4' on the BMS for the Austen / Faraday block.
12. In Cann Bridge and Tenzing, the meters labelled as Lighting on the BMS are, in fact, the total for these buildings, the power and IT distribution boards are sub-circuits of the “lighting” board. This relationship between the distribution boards is mentioned in passing in the building Log Book [1], but is not depicted in the diagrammatic representation of the electric submeters (Figure 10.5). It also differs from the approach taken in Faraday, Austen, Cade and the sports block.
13. A hydrotherapy pool is being retrofitted in Cann Bridge, no submetering arrangements appear to have been made as part of this work and the 3-phase electric heater and the pumps may be a significant load.



Electrical Distribution

Two new electric supplies have been installed into the main LV switch room by Western Power Distribution. One supply feeding Block C the other supplying all other blocks on the Campus. From this LV panel board steel wire armoured cables have been installed in trenches or duct systems to the relevant blocks. within each block the cable terminates into the lighting distribution board. From the lighting DB the power and ICT power boards are fed from high capacity output ways. The distribution boards are manufactured by MEM from their Memshield 3 range.

Figure 10.5. Information on electricity submetering from the building log book [1].

Gas Metering

1. The gas meter for the main energy centre boilers has not been fitted, there is a conduit box labelled for the BMS connection to this meter, but a plain piece of gas pipe runs adjacent (Figure 10.6). When reported, the contractor’s reply was that the meter was deemed unnecessary since consumption could be deduced from the incoming meter for the north of the site, the youth centre meter, the Tamar Centre meter and the Faraday labs meter. This, however, is not as robust a solution as a separate meter (e.g. there may be leaks, inaccuracies may be compounded). Additionally, the building Log Book has a diagram of the gas distribution in this area that omits the Tamar Centre meter (Figure 10.7).
2. There was confusion at the school campus regarding the gas distribution network: the incoming meter for the south of the site was stated to be for the nursery supply, and the distribution diagrams supplied by the contractor to clarify gas distribution had so many temporary and redundant supplies marked that it was difficult to interpret [6].
3. Although listed on the BMS, electrical connections have not been made to the Tamar Centre gas meter, nor the two fiscal incomers (although these do have fiscal dataloggers with the potential to provide half-hourly data) (Figure 10.8). The Faraday labs meter is physically wired to the BMS panel, but does not appear as a channel in the software.

Figure 10.6. Intended location of the omitted gas boilers gas meter, with Traffolyte sign adjacent to signal cable conduit box.

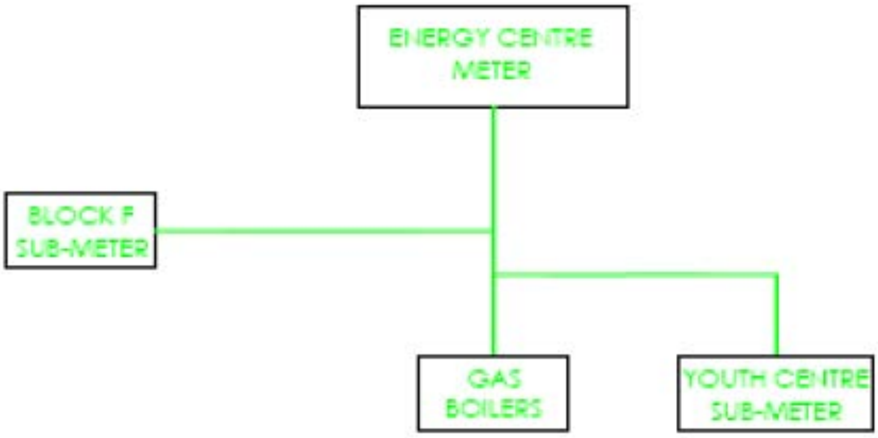


Figure 10.7. Gas distribution diagram from the building log book, omitting the feed to the Tamar Centre [1].

Figure 10.8. Site (north) fiscal gas meter with fiscal datalogger wired and the unterminated BMS data cable.

Water Metering

1. BMS readings are zero for the fiscal site water meter (but data may be available from the utility company). BMS readings for the Cann Bridge and Sports block submeters have not incremented since September (but the actual meters have recorded consumption).
2. The Graham Browne building and Cade boosted cold water meters have unterminated pulse output cables and are not listed on the BMS. The contractor asserted that the Cade meter was not specified in the contract so it appears that the meter was fitted in error and left.
3. The Austen/Faraday water submeter is located with the dial facing upwards about 2.5 m above the floor amongst other pipework, access is difficult and readings can only be taken using a mirror or small digital camera.
4. The Graham Browne water submeter appears to be of a lower quality than the other water consumption meters, and is similar in type to the flow meters for heat metering. The digital register is also difficult to read (see item 7 under Heat Metering).

Heat Metering

1. A major issue with the heat metering strategy is a lack of heat meters on the gas boilers: Any estimate of distribution losses must be made from gas consumption and assumptions of the boiler efficiency. Submetering of heat loads is incomplete since no heat meter has been fitted in the Graham Browne building. This was understood by the BPE team to have compromised Renewable Heat Incentive eligibility for the biomass boiler.
2. The sports building heat meter on the variable temperature (VT) circuit had not had its initial setup completed which should have included selection of MWh or kWh, heating or chilling mode, flow meters in flow or return pipes, and litres per pulse from the flow meter. Connections to the flow meter were incorrect on all three heat meters in the Sports building plant room. A further untraced fault on the VT heat meter prevented any heat being reported until some point between 3/1/2013 and 18/2/2013 (this is most likely due to the flow meter, since a positive temperature difference was being reported between flow and return pipes).
3. The Tenzing HWS heat meter reading is not incrementing on the BMS, whereas the actual meter has indicated some consumption during the same period. This meter is also configured to report in MWh, unlike all the other meters which report in kWh.
4. The Cann Bridge CT and HWS meter reading has not changed throughout the project, suggesting a meter fault.
5. The Sports building CT and VT heat meters are labelled meter 2 and 1 respectively, but the respective BMS channel names are HeatMeter1 and HeatMeter2, potentially causing confusion.
6. There are five Cade heat meters, but seven BMS heat meter channels: BEHtMeter1, BEHtMeter4, heatmeter2, heatMeter_4 and BEHeatMeter. Channels BEHtMeter2 and BEHtMeter4 appear to be unused.
7. Settings on the heat meters cannot be verified or changed without purchasing a special unit. This is apparently to protect the integrity of the meters, but it is unfortunate that the setting cannot be verified in a read-only interrogation.
8. Several of the flow meters have developed noisy bearings or condensation in the dial. (Several similar meters at an unrelated site have developed water leaks through the dial and have been decommissioned as a result.)

10.5.4 Reliability and In-Use Performance

Interaction with the BMS is dependent on a single dedicated computer. This was originally located in the first floor plant space in Cade (room A209), which has large ventilation grilles, is dusty, can be cold and is not an especially hospitable environment for either the computer or the user. The computer failed twice during the first year of the TSB BPE monitoring project. On both occasions site staff were left for several months with no control over the heating or ventilation systems. As a result the system remained in winter mode during the early part of the summer, meaning that mechanically actuated ventilation systems were not active. After the second failure the school ran in summer mode until the end of 2012. The high level vents in some art rooms were taped and boarded over and the actuators isolated with local switches in an attempt to mitigate the lack of control available during the autumn (Figure 10.9). The inclusion of an embedded PC on one of the BMS plant room panels would have provided a backup means of controlling the school campus systems.

After the second failure, a new computer was provided, and software was re-installed by the manufacturer at a cost of about £600. This is located in the site office which is a better environment for monitoring and controlling the school campus systems. However, certain features are unavailable on the newly commissioned system, including alarm reporting and extended datalogging.

The system has summer and winter operating modes; these are said to be automatically selected on the basis of external temperature, with the option of manual override. Automatic summer / winter selection however does not always reflect weather conditions, possibly indicating that the external temperature sensor receives direct solar insolation at certain times of day. Control options are restricted according to the season selected, for example the availability of mechanically actuated ventilation and space heating. These limitations are problematic all year round, but particularly in the spring and autumn shoulder months. A specific example is discussed in Section 4.

Figure 10.9. High level mechanically actuated vents in room L222 / L226, with evidence of them having been blocked up and isolated using local switches when building in summer control mode during the winter as a result of failure of the controlling PC.

The BMS-based automatic metering is not generally used as it is not trusted. The offsets and factors between the displayed values and physical meter readings are problematic and make the data difficult to interpret. Furthermore, a significant number of metering channels are not incrementing at all (see Appendix 10.7).

The system's ability to record half-hourly consumption profiles is potentially a powerful energy and water management tool. For example, baseload electricity consumption can be easily identified, allowing action to be targeted to reduce out-of-hours use, and overnight water consumption data can quickly highlight underground leaks from pipework or dripping taps.

Electricity metering is split into lighting, general power and IT power. The philosophy on which the IT designation is based is not clearly stated, and is not understood by site staff. From distribution board circuit schedules, it would appear that IT power circuits include ring mains in teaching spaces, and supplies to local comms cabinets. General power includes cleaner's sockets (which are said to be unmarked), plant room sockets, and hard-wired equipment such as hand dryers, security systems, door actuators, and fan coil units.

The automatic lighting control operation differs from that described in the building Log Book: "*Upon entrance into the classroom, the lights remain off until the momentary switch is pressed in the down position. This then illuminates all of the fittings. If the momentary switch is pressed again for 3 seconds this will turn the fittings off. If the room is left unoccupied for a set period, the lighting will turn off until such time the switch is pressed again*". In actuality, the lights come on automatically using presence detection. This leads to lights continually switching on when not really needed (e.g. if a teacher enters a room to collect something), and the only way to manually switch the lights off (and avoid a lengthy absence detection period) is to press and hold the momentary wall switch for several seconds. This requirement is not immediately apparent to users or visitors and is potentially wasteful.

In general, the BMS may be overcomplicated and has not been properly commissioned. Many automated systems are provided (lighting, CO_2-controlled ventilation, submetering, biometric security) which should improve the basic functions of the campus buildings and many of the systems should reduce energy consumption. Unfortunately repeated failures in these systems will increase the maintenance burden and lead to the bypassing or removal of systems which are not viewed as being worthwhile (e.g. the biometric student registration system). The capital cost of the system then represents poor value. CO_2 sensors typically require recalibration or replacement after a relatively short period (perhaps every five years). Many of these sensors are for user information only and are not likely to be maintained. Where they do control ventilation, they may be replaced by manual switches rather than being properly maintained (this would be preferable to having a system controlled by sensors that are no longer accurate). The provision of some systems is driven by legislation, e.g. electricity submetering is required by Building RegulationsRegulations and heat metering for eligibility for Renewable Heat Incentive payments for biomass boilers.

The security alarm system is also seen as being overly complex. The original high security classification included PIR and door contacts at each entry point. However, component failures of both PIRs and door contacts has led to the system being downgraded to something simpler with lower maintenance requirements.

Other failures have also become evident. For example, the frost protection heater battery on the kitchen air handling unit has failed every year, causing a loss of pressurisation to the entire heating system. Bypass pipework was not initially provided, although this was retrofitted on the first failure. Another example is the sprinkler system, where a jet of water from a failed pipe joint on the central heating system hit a sprinkler head, and was sufficiently hot to set it off. Local isolation of sprinkler systems to each block has not been provided, so the only way of switching the sprinkler system off is in the main sprinkler house. This led to widespread flooding and damage to the expensive oak floor in the atrium. A further example is the window and ventilation actuators, a number of which have burned out prematurely, possibly because of a lack of a timeout feature on the control system to switch off power to stalled or jammed actuators.

10.5.5 User Interface

The level of control available through the user interface varies considerably between phases of the build. The Graham Browne building, for example, has completely manual control, with local switches and overrides. This is preferred by the site staff. From a metering point of view, it is noted that the electricity and water meters in the Graham Browne building are not BMS-connected and no heat meter has been provided. Phase 2 of the build generally has the least amount of flexibility in control through the building management system. An example of this is ventilation in the Sports Hall which is often required in the winter to alleviate hot conditions. The mechanically actuated windows are only automatically controlled when the system is in summer mode and it is frequently necessary to engage the system into summer mode just to open these windows. Even then the CO_2 and temperature setpoints must be manually adjusted before the windows can be opened.

As noted earlier, control is only available from a single PC, which has failed on two occasions leaving the building’s heating and ventilation systems without manual override capability. Wider BMS access, including off-site access would be useful for site staff and was envisaged during the planning of the project. At some other sites security concerns over school IT systems have precluded network access to the building management system.

The graphical user interface of the BMS is poorly implemented in places, for example, the metering displays are often under-sized so that once the meter exceeds a certain number of digits, the reading can be obscured. The Cann Bridge and Tenzing total electric meters were also misleadingly labelled as lighting.

More in-depth programming of the BMS involves direct interaction with the Explorer interface. This has been necessary to set up logging on channels, and to form channel groups to extract the logged data. Each channel must be configured individually and only one channel can be added to a group at a time, making this a laborious process.

10.5.6 Training and Support

On handover, it is reported that very basic training was given covering logging-on to the system, the menu system and changing set points, but with very little coverage of scheduling. The school paid for a manufacturer's training course, but by this time the Facilities Manager was familiar with the basics of operation and gained little additional knowledge.

The phased nature of the school campus rebuild proved problematic for snagging and defect resolution. The defects periods ran for a specified time from the completion of each phase, but for certain items such as the BMS, the cut-off between different phases is less clear since some issues pertain to the system as a whole, and some outstations serve buildings that were split between phases (e.g. Faraday). As reported in Section 10.2, many problems have never been fully resolved and it is said that after the end of the defects period for Phase 1 of the build, the BMS manufacturer felt that in the absence of a maintenance contract it was appropriate to charge for maintenance visits - even though the issues were often unresolved defects from various phases of the build. In the school's view, the defects period for the BMS as a whole should have been based on the completion date for the final phase of the build.

The BPE Team's experience, as part of the TSB project, was that the BMS engineer was happy to explain the operation of the extended logging functions of the BMS during one of his maintenance visits, but in the absence of a maintenance contract was unwilling to address the ongoing issue of extended logging which is no longer functioning on the new computer.

10.5.7 Conclusions

A review of the BMS at the school campus has highlighted issues with the thoroughness of commissioning, and the specifications of the system as implemented. The metering system was handed over in an unusable state, with meters incorrectly configured, BMS channels not synchronised with physical meter readings, mislabelled meter channels on the BMS and a significant number of non-functioning meter channels. More widely, there is a lack of clear, accurate information on the control strategy and which sensors correspond to which zones. Placing control of the entire system in a single computer is a particular weakness that has left staff unable to control the building effectively during two lengthy computer outages.

While the automatic control systems provided have the potential to deliver tight control of heating and ventilation and reduce energy use, the implementation is poor in places and does not appear to offer a satisfactory level of control or manual override. The systems also represent a considerable maintenance burden for the school. The phased nature of the build has presented particular difficulties in defect resolution, since some faults are generic and not specific to a particular phase.

10.5.8 References

1 **Building Log Book. Estover Community Campus.** Version: 2: 28.07.11, Kier Western.

2 **Estover Community Campus. Health & Safety File Incorporating the Operations and Maintenance Manuals.** July 2011.

3 **Estover Community College As Installed Mechanical Services Plans.** M&E Subcontractor Engineering Services (SW Region) Limited.

Drawing REC/1/375/E/L1/M/1 dated 28/6/2010
Drawing REC/1/375/G/L3/M/3 dated 29/6/2010
Drawing REC/1/375/E/L2/M/2 dated 28/6/2010
Drawing 443/M/202 Rev. R dated May '11
Drawing REC/1/375/A/L2/M/1 dated 30/6/2010
Drawing REC/1/375/B/L2/M/1 dated 30/6/2010
Drawing REC/1/375/A/L3/M/2 dated 30/6/2010
Drawing REC/1/375/B/L3/M/2 dated 30/6/2010
Drawing REC/1/375/C/L2/M/1A dated 28/6/2010
Drawing REC/1/375/D/L1/M/1 dated 28/6/2010

Drawing REC/1/375/C/L2/M/1B dated 30/3/2010
Drawing REC/1/375/C/L2/M/1B dated 30/3/2010
Drawing REC/1/375/D/L2/M/2 dated 28/6/2010
Drawing 443/M/205 dated Jun '11
Drawing 443/M/208 Rev. R dated Apr '11
Drawing 486/M/802 Rev. R dated Feb '12
Drawing 443/M/207 Rev. R dated Apr '11
Drawing 486/M/801 Rev. R dated Feb '12

4 **Soft Landings for Schools. Case Studies. BSRIA BG 9/2010.** 2010, BSRIA.

5 **Andover Continuum CyberStation. Configurator's Guide for Version 1.8** December 2006, TAC, Inc.

6 **Mechanical Services. Phase 1 External Gas Layout.** Drawing REC/1/375/M09. 25/9/2009.

10.5.9 Building Names

Construction Ref.	School Ref.	School Name	Faculty
A	E	Austen	Maths, English
B	D	Tenzing	Humanities, languages, social sciences
C	C	Cann Bridge	Special School
D	L	Cade (North)	Art, library, admin
E	A	Cade (South)	Dining, social, food technology
F	G	Sports	Sport, dance, textiles
G	F	Faraday	Science, DT, ICT
H			Primary school
J		Graham Browne	Multi use hall
S	S	Soundhouse	Music
T			Tamar Centre
Y			Youth Club

APPENDIX 10.6: BMS SENSOR LOCATIONS

10.6 BMS sensor locations

The list below compares BMS temperature and CO_2 sensor locations marked on as-installed drawings [3] with actual locations surveyed on site. Red cells indicate a mismatch. Whether or not the CO_2 sensors are BMS connected has not been assessed.

						As Surveyed 3/1/2013		As Drawn [3]		
Block Name	**Room Number (school)**	**Room Number (drawings)**	**Room Description**	**Storey**	**Side of Building**	**Temp-erature**	**CO_2**	**Temp-erature**	**CO_2 (on BMS)**	**Temp-erature &CO_2 (not on BMS)[6]**
Austen	E102	R-A2-006	Classroom	0	North	🟩 1	🟩 1	1	1	
Austen	E103	R-A2-025	6th Form Seminar Room	0	North	🟩	🟩 1			1
Austen	E104	R-A2-007	Classroom	0	North	🟩	🟩 1			1
Austen	E105	R-A2-008	Classroom	0	North	🟩	🟩 1			1
Austen	E106	R-A2-009	Classroom	0	North / East	🟩	🟩 1			1
Austen	E107	R-A2-011	Classroom	0	South / East	🟩	🟩 1			1
Austen	E108	R-A2-012	Classroom	0	South	🟩 1	🟩 1	1	1	
Austen	E109	R-A2-013	Classroom	0	South	🟩	🟩 1			1
Austen	A1	R-A2-022	Atrium	0	Central / West	🟥 2	🟥		1	1
Austen	E202	R-A3-004	Classroom	1	North	🟩	🟩 1			1
Austen	E203	R-A3-005	Classroom	1	North	🟩	🟩 1			1
Austen	E204	R-A3-006	Classroom	1	North	🟩	🟩 1			1
Austen	E205	R-A3-007	Classroom	1	North / East	🟩 1	🟩 1	1	1	
Austen	E206	R-A3-009	Classroom	1	South / East	🟩	🟩 1			1
Austen	E207	R-A3-010	Classroom	1	South	🟩	🟩 1			1
Austen	E208	R-A3-011	Classroom	1	South	🟩 1	🟩 1	1	1	
Austen	A2	R-A3-022	Atrium	1	Central / West	🟩 2	🟥	2	1	
Tenzing	D102	R-B2-028	6th Form Seminar Room	0	North	🟩	🟩			
Tenzing	D103	R-B2-002	Classroom	0	North	🟩	🟩 1			1
Tenzing	D104	R-B2-003	Classroom	0	North	🟩	🟩 1			1
Tenzing	D105	R-B2-004	Classroom	0	North	🟩	🟩 1			1
Tenzing	D106	R-B2-005	Classroom	0	North / East	🟩 1	🟩 1	1	1	
Tenzing	D107	R-B2-007	Classroom	0	South / East	🟥	🟥	1	1	
Tenzing	D108	R-B2-008	Classroom	0	South	🟩	🟩 1			1
Tenzing	D109	R-B2-009	Classroom	0	South	🟩	🟩 1			1
Tenzing	T1	R-B2-018	Atrium	0	Central / West	🟥 2	🟥	1	1	
Tenzing	D204	R-B3-007	IT Room	1	North	🟩	🟩 1			1
Tenzing	D205	R-B3-008	Classroom	1	North	🟩	🟥			1
Tenzing	D206	R-B3-009	Classroom	1	North / East	🟥	🟩 1	1	1	
Tenzing	D207	R-B3-011	Classroom	1	South / East	🟥	🟥	1	1	
Tenzing	D208	R-B3-012	Classroom	1	South	🟩	🟩 1			1

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[6] Combined temperature and CO_2 displays have not been fitted; this column has been compared to the CO_2 displays present on site.

Tenzing	D209	R-B3-013	Classroom	1	South	🟩	🟩 1			1
Tenzing	D215	R-B3-022	Year Leader Base (used as classroom)	1	South / West	🟩	🟩			
Tenzing	T2	R-B3-004	Atrium	1	Central / West	🟥	🟥		1	1

						As Surveyed 3/1/2013		As Drawn [3]		
Block Name	Room Number (school)	Room Number (drawings)	Room Description	Storey	Side of Building	Temp-erature	CO_2	Temp-erature	CO_2 (on BMS)	Temp-erature &CO_2 (not on BMS)
Cann Bridge	C108	R-C2-013	Classroom	0	South	🟩 1	🟩 1	1		1
Cann Bridge		R-C2-020	Classroom	0	South	🟩	🟩 1			1
Cann Bridge	C116	R-C2-023	Classroom	0	South	🟩	🟩 1			1
Cann Bridge	C123	R-C2-029	Classroom	0	North	🟩	🟩 1		1	1
Cann Bridge		R-C2-034	Classroom	0	North	🟩	🟩 1			1
Cann Bridge	C130	R-C2-039	Classroom	0	North	🟩	🟩 1			1
Cann Bridge	Circulation	R-C2-018?	Atrium	0	Central / West	🟥 1	🟩	2		
Faraday	F100	R-G2-023	Science Opportunity Centre	0	Central / South	🟩	🟩			
Faraday	F106	R-G2-014	Science Room	0	East	🟩	🟩 1			1
Faraday	F107	R-G2-013	Science Room	0	East	🟥 1	🟩 1			1
Faraday	F108	R-G2-012	Science Room	0	East	🟩	🟩 1		1	1
Faraday	F112	R-G2-008	Resistant Materials	0	West	🟩	🟩 1			1
Faraday	F113	R-G2-007	Machine Shop	0	West	🟩	🟥			1
Faraday	F114	R-G2-005	Resistant Materials	0	West	🟩 1	🟩 1	1	1	
Faraday	F1	R-G2-024	Atrium	0	Central	🟩 1	🟥	1	1	
Faraday	F205	R-G3-008	Prep room	1	East	🟥	🟥	1	1	
Faraday	F206	R-G3-007	Science Room	1	East	🟩 1	🟩 1	1	1	
Faraday	F207	R-G3-009	Science Room	1	East	🟩	🟩 1			1
Faraday	F208	R-G3-004	Science Room	1	West	🟩	🟩 1			1
Faraday	F209	R-G3-003	Science Room	1	West	🟩	🟩 1			1
Faraday	F210	R-G3-002	Science Room	1	West	🟥	🟩 1	1	1	
Faraday	F211	R-G3-001	Science Room	1	West	🟩	🟩 1			1
Faraday	F212	R-G3-015	6th Form Seminar Room	1	South	🟩	🟥 1			
Faraday	F213	R-G3-018	Staff Work room	1	Central	🟩	🟩			
Faraday	F2	R-G3-017	IT Pod	1	Central	🟥	🟥 1			
Cade	School Library	R-D1-010	School Library	0	West	🟥 1	🟩			
Cade	L114	R-D1-014	Office	0	North / east	🟩 1	🟩			
Cade	L204	R-D2-001	Art	1	West	🟩	🟥 1			
Cade	L205	R-D2-005	Art	1	West	🟩	🟥 1			
Cade	L210	R-D2-009	Art	1	West	🟩	🟥 1			
Cade	L216	R-D2-012	Art	1	West / North	🟩	🟩			
Cade	L218	R-D2-018	Dark Room	1	North	🟩	🟩			
Cade	L219	R-D2-019	IT Room	1	North	🟩	🟩			
Cade	L220	R-D2-020	IT Room	1	North / East	🟩	🟥 1			
Cade	L222	R-D2-024	Art	1	East	🟩	🟥 1			
Cade	L226	R-D2-023	Art	1	East	🟩	🟩			
Cade		R-D2-017	Top of Stairs	1	North / East	🟩	🟥 1			
Cade	A101	R-E1-014	Food Tech	0	West	🟥	🟩 1	1	1	
Cade	A102	R-E1-012	Food Prep	0	West	?	?	1	1	
Cade	A103	R-E1-011	Food Tech	0	West	🟥	🟩 1	1	1	
Cade	Restaurant	R-E1-003	Restaurant	0	East	🟥 2	🟩			

Cade	6th Form Common Room	R-E2-006	Common Room	1	West	1	🟥	1	1	
Cade		R-E2-012	Office	1	South	?	?	1	1	

In summary:

1. Actual provision in Austen matches the drawings with the exception of additional temperature sensors in the first floor atrium and a lack of CO_2 sensors in these spaces.
2. In Tenzing, there is an additional temperature sensor in the first floor atrium, but none in the ground floor atrium. Neither atrium has the specified CO_2 sensor. Sensors are omitted from ground floor classroom D107, first floor classroom D207 and (temperature sensor) in D206.
3. In Cann Bridge, the only discrepancy is that only one temperature sensor, not two, was found in the circulation space.
4. In Faraday, the CO_2 sensor appears to have been installed on the first floor of the atrium, not the ground floor. F113 lacks a CO_2 sensor but F107 has gained a temperature sensor. F205 lacks both temperature and CO_2 sensors, F210 lacks a temperature sensor and F212 has gained a CO_2 sensor.
5. In Cade, not all spaces were surveyed. Discrepancies noted include an additional temperature sensor in the library and two additional temperature sensors in the main atrium (restaurant), but omissions in A101 and A103. A CO_2 sensor has been omitted from the 6th form common room, but sensors are present in L204, L205, L210, L220, L222 and at the top of the stairs in the art department that are not shown on the drawings.

APPENDIX 10.7: BMS METER CHANNEL FACTORS AND OFFSETS

10.7 BMS meter channel factors and offsets

The factors and offsets determined to be necessary to match the BMS metering data and physical meter readings (before factors and offsets applied on 26th April 2013) are listed below.

Colour key

BMS data checked and reconciled with meter
BMS data suspect or unexpected factor determined
Meter issue (e.g. meter zero or not incrementing)
BMS connection or configuration issue
Meter not found on BMS software
BMS channel mislabelled
Out of scope or no action required for TSB project

Meter No.	Supply	BMS Channel	Factor	Approx. Offset	Additional Notes
Gas					
G01	Fiscal Site incomer (north)	SiteGasMeter			All data zero. Signal cable not terminated at meter.
G02	Youth Centre gas	BYGasMeter	0.1	2910	Data in 1/10 m^3
G03	Gas Boilers meter	GasBoiGasMeter			Meter not fitted
G04	Science lab gas supplies				Not found on BMS. Meter has a pulse output cabled to the BMS panel
G05	Tamar Block gas	BTGasMeter			All data zero. Meter has pulse output but not connected
G06	Fiscal Site incomer (south)	GasMeter			BMS reading not incrementing
G07	Kitchen gas	BEKitGasMeter	0.1	412	OK, raw data in 1/10 m^3
G08	Food Tech gas	FoodRoomGas	1	0	OK, no factoring required
G09	Nursery gas				Not found on BMS, separate control system in nursery?
G10	Soundhouse gas				Not found on BMS, separate control system in Soundhouse?
G11	Old Primary School				Meter removed
Heat					
H01	Biomass Boiler Heat	BioHeatMeter	1	516869	OK, no factoring required
H02	VT Heat Circuit Austen / Faraday	VTHeatMeter	4?		Factor about 4, which is strange
H03	CT Heat Circuit Austen / Faraday (HWS)	CTHeatMeter	4?		Factor about 4, which is strange
H04	VT Heat Block Tenzing	VTHeatMeter	0.1	16079	OK, data in 1/10 kW h
H05	CT Heat Block Tenzing (HWS)	HWSHeatMeter			Data all zero
H06	VT Heat Block Cann Bridge	VTHeatMeter	1	0	OK, no factoring required
H07	CT Heat Block Cann Bridge (inc. HWS)	HWSHeatMeter			Meter not incrementing
H08	Cade (Block A (nee E)) HWS	BEHtMeter1	1	106722	OK, no factoring required
H09	Cade (Block A (nee E)) VT	heatmeter2	1	-3.8	OK, no factoring required. Note BMS channel name heatmeter2 NOT BEHtMeter2 (all zero data on latter)
H10	Cade (Block A (nee E)) Kitchen and dining AHUs, FCU, Manifolds (UFH?)	BEHtMeter3	1	119544	OK, no factoring required
H11	Cade (Block L (nee D)) Admin / Community	HeatMeter_4	1	82	OK, no factor required. Note BMS channel name HeatMeter_4, NOT BEHtMeter4 which has all zero data.
H12	Cade (Block L (nee. D)) Art E/W	BEHeatMeter	1	500	OK, no factor required. Note BMS channel name different format from other Cade heat meters.
H13	Sports CT Heat	HeatMeter1	1	1461	OK, no factoring required. Note mislabelling in BMS as meter 1 cf. physical meter label.
H14	Sports VT Heat	HeatMeter2	1	65	OK, no factoring required. Note mislabelling in BMS as meter 2 cf. physical meter label.
H15	Sports HWS Calorifiers	HeatMeter3	1	615	OK, no factoring required

H16	Primary School VT - Radiators	VT_HeatMtrPls	0.1	-1	OK, note GUI values in BMS are already factored correctly (1/10 of logged values)
H17	Primary School CT - UFH	CT_HeatMtrPls	0.1	-6	OK, note GUI values in BMS are already factored correctly (1/10 of logged values)
H18	Primary School CT - Calorifiers	HWS_HeatMtrPls	?		Factor about 0.7, strange

Meter No.	**Supply**	**BMS Channel**	**Factor**	**Approx. Offset**	**Additional Notes**
Water					
W01	Fiscal Site Incomer	SiteWtrMeter			Data all zero - no BMS connection to fiscal meter?
W02	Block Austen / Faraday drinking water	WaterMeter	0.01	65	OK, data in tens of litres
W03	Tenzing drinking water	BlkBWaterMeter	1	473.06	OK, no factoring required
W04	Cann Bridge drinking water	WaterMeter			BMS reading not changing
W05	Cade Blocks A and L total water	BEWtrMeter	10	1973	OK, data in tens of cubic metres
W06	Cade Blocks A and L boosted cold water (drinking)				Not connected to BMS. Reportedly meter accidentally fitted and left in.
W07	Sports block water	WaterSubMeter			BMS reading not changing
W09	Tamar Centre Water				No pulse output unit on meter, not connected
W10	Graham Browne Water				Not found on BMS, pulse output cable not connected to anything
W11	Primary School Water	BlkH_WtrMtr1Pls	0.01	0	OK, note GUI values are 1/100 of logged values, factor applies to logged values
W12	Youth Centre water	BYWtrMeter	1	39	Need to check this is actually the youth centre supply and not energy centre consumption (meter is in energy centre)
Electricity					
E26	Site Incomer for secondary school: Austen, Tenzing, Cade, Faraday	DEMainIncomer			BMS reading not incrementing - no connection to fiscal meter?
E27	External Lighting: main entrance and bus stop				Not found on BMS. Different type of meter from other submeters, probably not connected
E28	Primary School				Not found on BMS. Out of scope of TSB project.
E29	“British Gas” meter				Not on BMS, irrelevant British Gas curriculum meter
E30	Energy Centre	EnCentElecMeter			Not found on BMS
E01	Austen Lights	BALtsElecMtr	0.1?		Factor more like 1/9 which is strange
E03	Austen Power	BAPwrElecMtr	0.1?		Factor more like 1/9 which is strange
E02	Austen IT	BA_ITElecMtr	0.1?		Factor more like 1/9 which is strange
E10	Tenzing Total: Lights (inc. external) (plus IT (on cct 18) and power (on cct 9))	LightElectMeter	0.1?		Factor more like 1/8 which is strange
E09	Tenzing Power (supplied from E10)	PowerElectMeter	0.1?		Factor more like 1/8 which is strange
E08	Tenzing IT (supplied from E10)	ITElectMeter	0.1?		Factor more like 1/8 which is strange
E31	Cann Bridge Total meter in main switchroom				Not found on BMS - no connection to fiscal meter?
E11	Cann Bridge Total: Lights (inc External); IT (cct 6) and power (cct 12)	LightElectMeter	0.1	-497	OK, data in 1/10kW h
E12	Cann Bridge Power	PowerElectMeter	0.1	-584	OK, data in 1/10kW h
E13	Cann Bridge IT	ITBrdElectMeter	0.1	-232	OK, data in 1/10kW h
E14	Cade (Block L (nee D)) Lights GF (& FF)	BDLighting	0.1	0	OK, data in 1/10kW h
E15	Cade (Block L (nee D)) Power GF (& FF)	BDPower			BMS data all zero
E16	Cade (Block L (nee D)) IT GF	BD_GF_IT	0.1	0	OK, data in 1/10kW h
E17	Cade (Block L (nee D)) IT	BD_FF_IT	0.1	0	OK, data in 1/10kW h

	FF				

Meter No.	Supply	BMS Channel	Factor	Approx. Offset	Additional Notes
E18	Cade (Block A (nee E)) Lights GF & FF	DBELGF	0.1	-426	Data in 1/10kW h
E19	Cade (Block A (nee E)) Power GF (& FF)	DBEPFF	0.1?		Factor more like 1/8 which is strange
E20	Cade (Block A (nee E)) Power DB 011	DBEP011	0.1	-87	Listed at level above controllers. Data in 1/10kW h
E21	Cade (Block A (nee E)) Power DB 012	DBEP012	0.1	0	Listed at level above controllers. Data in 1/10kW h
E22	Cade (Block A (nee E)) Power DB 014	DBEP014	0.1	-70	Listed at level above controllers. Data in 1/10kW h
E23	Cade (Block A (nee E)) Kitchen	KitchenDB	0.1	-4340	Listed at level above controllers. Data in 1/10kW h
E24	Cade (Block A (nee E)) IT GF	DBEITGF	0.1	-218	Listed at level above controllers. Data in 1/10kW h
E25	Cade (Block A (nee E)) IT FF	DBEITFF	0.1	-322	Listed at level above controllers. Data in 1/10kW h
E04	Faraday MCCB	BGMainElecMtr	0.1?		Factor more like 1/9 which is strange
E07	Faraday Lights	BGLtsElecMtr	0.1?		Factor more like 1/9 which is strange
E05	Faraday Power	BGPwrElecMtr	0.1?		Factor more like 1/9 which is strange
E06	Faraday IT	BG_ITElecMtr	0.1?		Factor more like 1/9 which is strange
E37	Sports (nee F) MCCB	WestLtg_PwrDB	0.1	-1396	OK, data in 1/10kW h Note mislabelling of BMS channel as West Lights and Power.
E32	Sports (nee F) Lights East	East_Ltg_DB	0.1	-3469	OK, data in 1/10kW h
E33	Sports (nee F) Power East	East_Pwr_DB	0.1	-1702	OK, data in 1/10kW h
E34	Sports (nee F) Lights & Power West	MCCBMeter	0.1	-529	Note mislabelling of BMS channel as MCCB. OK, data in 1/10kW h
E35	Sports (nee F) IT West	West_IT_DB	0.1	-197	OK, data in 1/10kW h
E36	Sports (nee F) Lights West				Meter not found on BMS (or physical meter)
E47	Graham Browne building				Not found on BMS
E45	Primary school level 1 lights	BLKH_ElecMeter1	1	-67	OK, no factor required
E46	Primary school level 1 power	BLKH_ElecMeter2	1	-5	OK, no factor required
E41	Primary school level 1 IT	BLKH_ElecMeter3	1	0	OK, no factor required
E42	Primary school level 2 lights	BLKH_ElecMeter4	1	-112	OK, no factor required
E43	Primary school level 2 power	BLKH_ElecMeter5	1	0	OK, no factor required
E44	Primary school level 2 IT	BLKH_ElecMeter6	?		Factor about 2.5, strange
	Youth centre	BYElectMeter			Meter not inspected. All BMS data zero. Out of scope of TSB project and separate fiscal incomer
E48	Primary School External Lighting	BlkIH_ElecMeter7	?		Factor about 1/16, strange. CT ratio of 1:5 is suspect.

APPENDIX 10.8: METER RECONCILIATION

10.8 Meter reconciliation

The relationship between meters as determined from site observation during the project is indicated below. Meter numbers have been assigned as part of the project (and labelled on site). Reconciliation between consumption recorded on different meters is discussed below, based on data collected up to 26th April 2013.

Colour key to meter hierarchy diagrams below

🟦	Meter supplying Phase 1 of build
▒	Meter supplying buildings other than Phase 1
🟫	Unmetered supply
🟩	Temporary monitoring installed for TSB monitoring project
⬚	(broken outline) Position in hierarchy conjectural and to be confirmed if possible

Electricity

For the Cann Bridge supply, E31 (fiscal meter in central switchroom) closely matches E11 (total meter on local distribution board (DB). By subtraction, typically 50% to 60% of consumption is on lighting circuits.

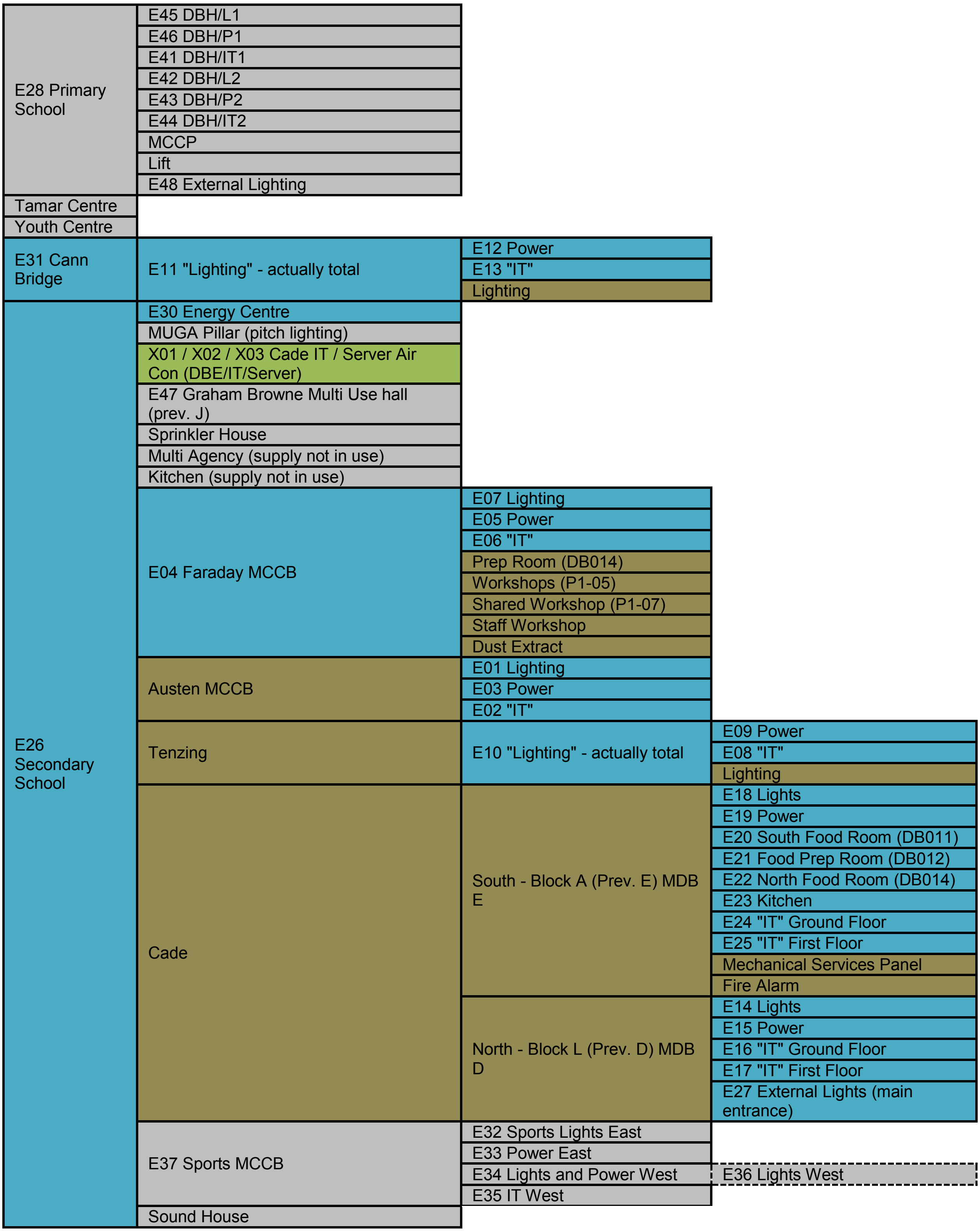
For the primary school, only about one-half of the consumption recorded on E28 (fiscal meter in central switchroom) is accounted for by the seven submeters (E41 … E46; E48). This indicates likely installation problems (e.g. incorrectly installed CTs or incorrect factors set on the meters—either on the fiscal meter or the submeters). E48 is noted to still have a CT ratio of 1:5 programmed, and the incorrect phase sequence annunciator has been noted to be lit on meters E43 and E45 on several visits.

For the secondary school, only about 60% - 70% of the consumption recorded on E26 (fiscal meter in central switchroom) is accounted for by the seven top level submeters (E01 … E04; E10; E14 … E25; E27; E30; E32 … E35; E47). There are some unmetered supplies (central IT server, MUGA pillar, sprinkler house, Sound House, fire alarm and mechanical services panel in Cade). Indications from current clamp monitoring on the unmetered supplies are that the sprinkler, MUGA and server supplies account for about 14% of total consumption. Cade

Further meter reconciliation is possible at distribution board level as follows:

1. In Faraday, about 95% of the consumption recorded on the main submeter E04 is accounted for by E05 to E07. There is additional unmetered consumption on the various workshop supplies, 5% of the total would appear plausible for these supplies. A possible under-read by 50% on the main submeter has been noted from a spot measurement.
2. In Tenzing, about 60% of the consumption recorded on the main submeter E10 is accounted for by E08 and E09, suggesting that lighting accounts for about 40% of total consumption. In the similar Austen block, lighting accounts for about 50% of total consumption, which is reasonably consistent.
3. In the sports block, consumption recorded on submeters E32 to E35 is 10% to 15% higher than that recorded on the main submeter E37. The main submeter has been verified as correct by spot current clamp readings. This indicates likely problems with the metering installation. A further meter, E36, was

listed by the M&E Subcontractor on the report of CT ratio reprogramming, but has not been identified on site; from the description, it is assumed that this is a submeter of E34.



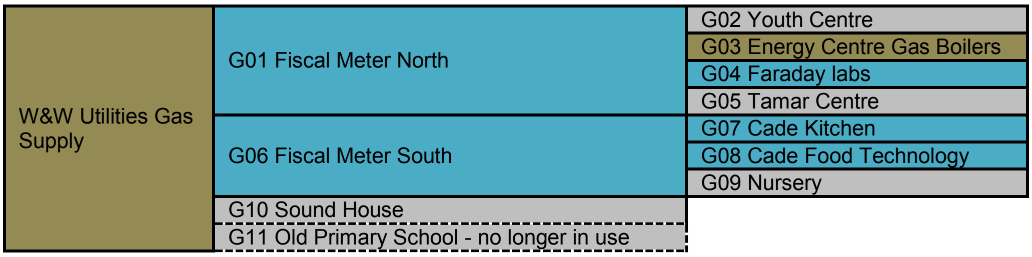
Gas

For the north of the site, 1% to 2% of the consumption recorded on the fiscal meter G01 is accounted for by G02, G04 and G05. The remainder of consumption is attributable to the unmetered supply to the main gas boilers in the Energy Centre. This is not implausible, given that consumption in the Youth Centre, Tamar Centre and Faraday labs will be small compared to the Energy Centre (rated gas boiler power input in the Energy Centre is 968 kW cf. 18 kW each in the Youth Centre and Tamar Centre [1]).

For the south of the site, 100% to 102% of the consumption recorded on the fiscal meter G06 is accounted for by G07 to G09. The slight discrepancy between the main meter and the submeters may have arisen due to slight differences [7] in the times at which the meters were read, or slight inaccuracies in the meters. (Inaccuracy has a tendency to increase if a gas meter is significantly oversized compared to the actual consumption).

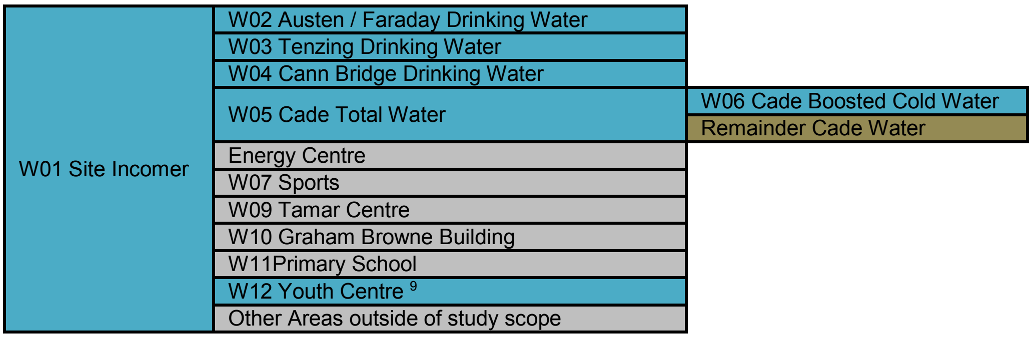
The Sound House is understood to have a separate gas supply and has not been investigated.

The old primary school site has now been cleared and the gas supply removed. Early in the project, this supply was in use and likely had a separate fiscal supply.



Water

93% to 104% of consumption recorded on the fiscal meter W01 is accounted for by the submeters (excluding W06). This is a reasonable match given possible slight meter inaccuracy and the slight differences in times at which the meters were read [8]. It is assumed that the Tamar Centre is connected through the main site fiscal water meter, and the Sound House may also be supplied via the main meter. However, consumption on these two supplies is unlikely to be significant.



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[7] Typically 10 to 12 minutes.

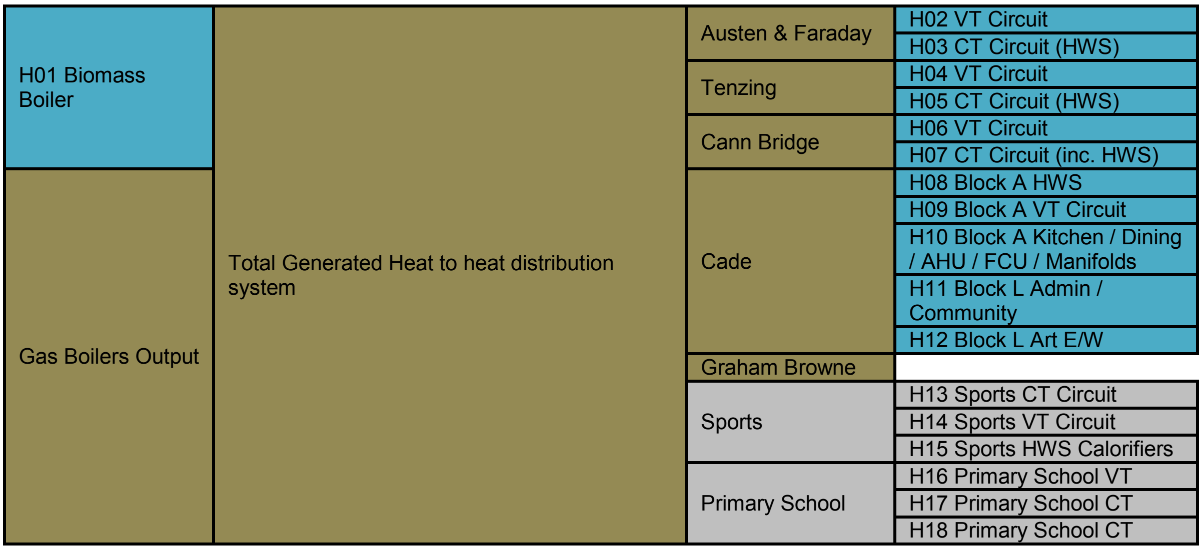
[8] Typically 3 to 4 hours.

[9] Understood to be supplied from the submeter in the Energy Centre.

Heat

To reconcile the heat supply meters H02 to H18 with heat generated, it is necessary to estimate the unmetered heat output from the main gas boilers and add this to the metered heat supply from the biomass boiler. The rated power inputs and outputs for the gas boilers suggest an efficiency of about 93% [1]. Heat accounted for on submeters has been compared to the estimated heat generated by the gas and biomass boilers [10]. This has led to figures between 87% and 141% for the percentage of heat delivered to buildings. Clearly, the figure should be below 100%, and the higher figures suggest inaccuracies in the heat metering.

The hot water supply heat meter in Cann Bridge has not incremented throughout the project, suggesting a fault with either the heat meter or its associated flow meter.



H01 Biomass Boiler	Total Generated Heat to heat distribution system	Austen & Faraday	H02 VT Circuit
			H03 CT Circuit (HWS)
		Tenzing	H04 VT Circuit
			H05 CT Circuit (HWS)
		Cann Bridge	H06 VT Circuit
Gas Boilers Output			H07 CT Circuit (inc. HWS)
		Cade	H08 Block A HWS
			H09 Block A VT Circuit
			H10 Block A Kitchen / Dining / AHU / FCU / Manifolds
			H11 Block L Admin / Community
			H12 Block L Art E/W
		Graham Browne	
		Sports	H13 Sports CT Circuit
			H14 Sports VT Circuit
			H15 Sports HWS Calorifiers
		Primary School	H16 Primary School VT
			H17 Primary School CT
			H18 Primary School CT

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[10] Assuming the gas boiler efficiency in the text, a gas calorific value of 39.2 MJ/m³, 0.278 kW h / MJ, and a temperature correction factor of 1.02664.

APPENDIX 10.9: VENTILATION STUDY

10.9 Ventilation study

10.9.1 C130 (mechanically ventilated classroom in the special school)

This room in Cann Bridge has a lower level of occupancy than classrooms in the secondary school. This will reduce the potential for high CO_2 concentrations to arise. This is evident from the long term monitoring, which show a peak CO_2 concentration of 2,200 ppm and only isolated instances 2 days in a year) where the daily average CO_2 concentration criterion was breached. The mechanical ventilation also has the potential to provide tighter control over ventilation, based on a wall mounted CO_2 sensor. However, the mechanical ventilation system was disabled in the latter period of the study due to complaints of draughts and the unit operating spuriously. It was noted that the CO_2 sensor was at times obscured by clutter.

In winter, ventilation rates were typically 0.5 air changes per hour with windows reported to be closed and between 5 and 20 air changes per hour with windows open. The room was reported as being too hot (the temperature was typically 22°C) and windows were opened at the start of the day to pre-cool the room. Assuming the typical maximum observed room occupancy of 15 people, these rates equate to 3, 17 and 70 litres per second per person respectively. These rates are consistent with the guidance in Building Bulletin 101 of the rates that will control CO_2 concentrations adequately, hence it follows that the long term monitoring showed that the daily average CO_2 concentration requirement was nearly always met in this room.

In summer, similar occupied ventilation rates were deduced (3.3 to 17 air changes per hour, equivalent to 11.6 to 60 litres per second per person).

10.9.2 D106 (classroom with cross ventilation via windows on two walls and a ventilator into the central atrium space)

This classroom in Tenzing has windows on two aspects, but is otherwise typical of the secondary school's naturally ventilated classrooms.

In winter, ventilation rates were typically 1.4 to 5.5 air changes per hour with windows reported to be closed (during lessons), and 0.2 air changes per hour when the room was closed up at the end of the day. Ventilation rates increased to 15 air changes per hour with one window opened. Assuming the typical maximum observed room occupancy of 32 people, these rates equate to 2, 8 and 0.3 and 22 litres per second per person respectively. The significantly lower ventilation rate experienced when the room was closed up at the end of the day are probably attributable to no use being made of the internal door and closure of the fanlight vent into the atrium space. This room experiences average daily CO_2 concentrations exceeding the 1,500 ppm limit for about 50% of school days, and peak CO_2 concentrations just breach the 5,000 ppm limit (on the monitored days, the peak was 4,500 ppm, higher than the other monitored rooms). With windows closed the deduced ventilation rates may fall short of the 5 litres per second per person daily average if windows are not opened. Winter internal temperatures were high, starting the school day at 21°C and increasing to 24°C in mid-afternoon, which was reported as being hit and stuffy.

In summer, similar ventilation rates were deduced with windows reported to be closed; with only the secure vent open the figure was 13 air changes per hour (19 litres per second per person at full occupancy) and with two windows additionally open this increased to 25 air changes per hour (36 litres per second per person). The peak CO_2 concentration was much lower due to the use of windows, and occurred at the end of morning tutor time (1,500 ppm) before windows were opened.

10.9.3 D215 (classroom with cross ventilation via windows on three walls and a ventilator into the central atrium space)

This room experienced high peak CO_2 concentrations both in summer and winter. This is despite its triple aspect layout potentially offering enhanced natural ventilation capability. From the long term monitoring, the 5,000 ppm peak concentration was exceeded by up to about 2,000 ppm and about 30% of school days have average concentrations exceeding 1,500 ppm.

Winter temperatures rose steadily during the day from 17°C to about 22°C, and were reported as being cold initially. Occupied winter ventilation rates ranged from 2 to 6.7 air changes per hour (3.3 to 11 litres per second per person based on maximum occupancy of 32) depending on whether windows were open or not, and even with some windows reported as being open CO_2 concentrations were seen to rise to as much as 3,500 ppm.

In summer, occupied ventilation rates were as high as 10 air changes per hour (16 litres per second per person at maximum occupancy). Temperature sensors located close to windows indicated some instances of the secure night vent being left open overnight, and also direct solar gain through the south-facing windows.

Measurements made at the end of the school day with all windows opened indicate ventilation rates of up to 21 air changes per hour (35 litres per second per person at maximum occupancy). Tracer gas measurements indicated 32 air changes per hour (52 litres per second per person at maximum occupancy) with all ventilation openings fully open, and 1.3 air changes per hour (2.1 litres per second per person at maximum occupancy) with only the night vent open. These results indicate that the design offers potential for high ventilation rates, but that ventilation is not fully utilised (possibly due to the creation of draughts).

10.9.4 L210 (art room with openable windows and mechanically actuated rooflights)

This room has windows on one wall only, and cross-flow ventilation is provided by mechanically actuated grilles in the rooflight well and the corridor fanlight. After a BMS control failure, these rooflight vents were disabled by switching the local isolator switch off (see Figure 10.9 in Section 0.4). This may well have compromised ventilation provision in this room.

This room would be expected to experience lower peak CO_2 concentrations than the standard classrooms due to the increased volume and lower occupancy levels. This is borne out in the long term monitoring results, which show a peak CO_2 concentration of about 3,000 ppm and the daily average CO_2 criterion only being breached on 8% to 10% of school days.

In winter, ventilation rates between 5.5 and 7.2 air changes per hour were deduced, a window, the door or the vent panel were open at various times of day. With the room closed up at the end of the day, this dropped to 0.8 air changes per hour. Assuming the highest observed occupancy of 24 people, these rates equate to 14.6, 19 and 2.1 litres per second per person respectively. CO_2 concentrations peaked at 2,200 ppm mid-morning, after which ventilation was increased. Temperatures were stable (22°C) and reported as stuffy towards the end of the day.

In summer, ventilation rates ranged from 5.5 to 46 air changes per hour (14.6 to 122 litres per person per second at maximum occupancy). Tracer gas measurements with the windows and vent open returned a lower figure (6.2 air changes per hour), and it is thought that the higher rates were achieved with the internal classroom door open and doors and windows open in classrooms on the opposite side of the building. This would provide the cross-flow ventilation that was intended to be provided via the high level vents that appear to have been disabled.

10.9.5 F107 (science classroom with mechanical extract)

Occupancy levels were lower in this room than standard classrooms, the maximum being 26. An extract fan is provided to address the issue of fumes from experiments, and this is understood to normally be left on its auto setting. Long term monitoring revealed that the 5,000 ppm maximum CO_2 concentration criterion was marginally exceeded and the 1,500 ppm daily average was exceeded on between 28% and 35% of school days. This performance is better than the standard classrooms due to the lower occupancy and larger volume.

There was a repeated project issue of non-completion of the room use log in this room, hence assumptions had to be made, leading to possible inaccuracies in deduced ventilation rates.

In winter, ventilation rates between 3 and 9 air changes per hour were deduced (with unknown ventilation opening). With the room closed up at the end of the day, this fell to 0.6 to 0.9 air changes per hour. At maximum occupancy, these equate to 8.9 to 26.6 and 1.8 to 2.7 litres per person per second. The temperature at the start of the school day was 18°C, increasing to 21°C in the afternoon.

In summer, ventilation rates between 6.3 and 20 air changes per hour were deduced (with unknown ventilation opening). When unoccupied and presumably with windows closed, this fell to 1 to 2 air changes per hour. At maximum occupancy, these equate to 18.6 to 59 and 3 to 6 litres per person per second.

19th September 2012

C130
1. Mechanically ventilated room, low occupancy in special school.
2. Lesson periods differ from the senior school.
3. Ventilation rates high during lessons, 13-17 ach^{-1}
4. Lowest (unoccupied) rate 1 ach^{-1}.
5. Ventilation rate could not be calculated for second teaching period (implausibly high) (11:15-11:45) nor during following unoccupied period (zero) (11:45-13:30) – possible inaccuracies in room log.
6. CO_2 concentrations low, < 1000 ppm.

D215
1. Triple aspect humanities room, natural ventilation.
2. No room use log completed
3. First lesson clearly occupied, assuming typical occupancy levels gives 5 ach^{-1}.
4. Subsequent unoccupied period with rapid fall in CO_2, ventilation similar at 4 ach^{-1}.
5. Purge ventilation using all windows and external vent at end of day, gives 21 ach^{-1}.
6. CO_2 peaks at 2300 ppm, falls steadily after first lesson to < 1000 ppm by end of school day.

D106
1. Humanities classroom, natural ventilation. 2 external walls at 90°.
2. Logging data corrupted. Purge ventilation experiment conducted, yielded 5 ach-1 using values from CO_2 display, but can't tell when low value reached so actual ventilation rate could be much higher.
3. Analysed previous two Wednesdays' data, internal temperatures broadly similar to day of detailed monitoring. Occupancy appears similar on 12th from CO_2 trace. Yields 9 or 14 ach^{-1} during lessons and 1 to 3 ach^{-1} unoccupied.
4. On 5th September 1500 ppm not exceeded, on 12th peaks at 2100 ppm after end of second AM teaching period, generally below 1500 ppm.

L210
1. Art studio, natural ventilation, 1 external wall
2. 5.5 to 21.5 ach^{-1}. Some correlation with logged window states. One very high rate (46 ach^{-1}) possibly when door opened.
3. CO_2 peaks at 1450 ppm.

F106 (possibly F107)
1. Science classroom, extract fan, but not used on day of analysis.
2. External door and vent panel used as ventilation as easier to reach handle than windows.
3. 6.3 to 20 ach^{-1} during lessons.
4. CO_2 peaks at 1550 ppm.

30th October 2012

Tracer gas measurements were undertaken to verify the ventilation rates derived from internal CO_2 concentrations, assumed metabolic CO_2 generation rates, external CO_2 concentrations, and documented occupancy and ventilation settings. The decay of the gas was monitored to derive the ventilation rate.

The weather was breezy during the tests; on a still day ventilation is likely to be less effective.

D215
1. With only the secure vent panel open, the ventilation rate was determined to be 1.3 air changes per hour.
2. With all external windows and vents open, 32 air changes per hour was obtained.

L210
1. With all external windows and vents open, 6.2 air changes per hour was obtained.

28th February 2013

C130
1. Mechanically ventilated room, low occupancy in special school.
2. Lesson periods differ from the senior school.
3. Room log not completed, teacher promised to email.
4. Sensors not downloaded.

D215
2. Triple aspect humanities room, natural ventilation.
3. No room use log completed
4. Sharp rise in CO_2 to peak of about 5600 ppm at 13:10.
5. Typical ventilation rates:
    a. 11 to 13 ach^{-1} first two lessons
    b. 2 to 4 ach^{-1} lessons and empty period each side of lunch – during lessons the concentration rose rapidly, but ventilation sufficient to cause rapid fall after occupants left
    c. 6.5 ach^{-1} last two lessons.

D106
1. Humanities classroom, natural ventilation. 2 external walls at 90°.
2. Room use log completed for most periods – from CO_2 trace, appeared to be a lesson first period and low occupancy second period, and unoccupied after lunch (13:00-13:20).
3. CO_2 trace generally shows reasonably linear rises and falls during the different teaching periods.
4. Peak concentration 3200 ppm around lunch time.
5. Typical ventilation rates:
    a. 15 ach^{-1} with 1 window open (tutor time)
    b. 5 ach^{-1} with all windows closed (lessons)
    c. 2.4 ach^{-1} with all windows closed (AS level lesson)
    d. 1.4 ach^{-1} with all windows closed (end of day)
6. Difference between b and c likely to be due to opening of the corridor door

L210
1. Art studio, natural ventilation, 1 external wall
2. Room use log completed comprehensively
5. CO_2 trace matches room use log with rises during lessons and falls when unoccupied.
6. Peak concentration around 2000 ppm, mid-morning.
7. Typical ventilation rates:
    a. 4 to 8 ach^{-1} during day, some correlation (but not perfect) with windows opened-up to 2 windows opened.

F107
1. Science classroom, extract fan generally on auto.
2. Windows closed but internal door open.
3. Room use log completed by teacher in advance at start of day (therefore not completely reliable).
4. CO_2 trace generally matches room use log with rises during lessons and falls when unoccupied.
5. Peak concentration around 2000 ppm, mid-morning and late afternoon.
6. Typical ventilation rates:
    a. 3.5 to 6 ach^{-1} during lessons, higher values in 12:20-13:20 session, lower value similar for first two lessons.
    b. 0.5 to 0.8 ach^{-1} unoccupied

10th September 2013

C130
1. Mechanically ventilated room, low occupancy in special school.

2. CO_2 readings at start of day unfeasibly low, for calculation to work applied +150ppm offset to data.
3. Peak (adjusted) CO2 concentration 750 ppm at 10:00.
4. Trends follow room use log, but due to low occupancy and low peak concentrations, resolution of data are coarse.
5. Ventilation rate 3.3 ach^{-1} for both lesson periods (windows open). 1 ach^{-1} first thing, but no room use information.

D215

1. Triple aspect humanities room, natural ventilation.
2. Sharp rise in CO_2 to peak of about 2000 ppm at 10:00.
3. CO_2 trace generally shows reasonably linear rises and falls during the morning teaching periods, but more varying trends in the afternoon. CO_2 falls rapidly at end of teaching periods.
4. Typical ventilation rates:
    a. 4 to 6 ach^{-1} first two lessons (1 window open)
    b. 7 to 10 ach^{-1} next two lessons (3 windows open)

D106

1. Humanities classroom, natural ventilation. 2 external walls at 90°.
2. Room use log completed for two teaching periods (11:20-12:20 and 12:20-13:20) – from CO_2 trace, appeared also to be used for registration / tutor time 8:25 to 9:15 (with door opened briefly at 8:50).
3. CO_2 trace generally shows reasonably linear rises and falls during the different teaching periods. CO_2 falls rapidly at end of teaching periods, and was close to external concentration after 14:00.
4. Peak concentration 1550 ppm at 9:15 (end of tutor time).
5. Typical ventilation rates:
    a. 3 to 4 ach^{-1} outside of lessons with windows closed (assumed conditions)
    b. 13 ach^{-1} with vent open (RE lesson)
    c. 25 ach^{-1} with vent and 2 windows open (RE lesson)

L210

1. Art studio, natural ventilation, 1 external wall
2. Internal temperature datalogger corrupt, assumed 20°C for analysis.
7. CO_2 trace matches room use log with rises during lessons and falls when unoccupied.
8. Peak concentration around 1850 ppm, 10:45.
9. Typical ventilation rates:
    a. 3 to 6 ach^{-1} with vent and one window open
    b. However, this is not consistent with first and last lessons which appeared to have a greater ventilation rate but logged as having window closed or half open (no mention of vent).

F107

1. Science classroom
2. Room use log not completed, but CO_2 trends match the school's lesson periods.
3. Peak concentration around 1250 ppm, end of morning registration.
4. Typical ventilation rates:
    a. 9 to 11 ach^{-1} during lessons.
    b. 1 to 2 ach^{-1} during periods that appear unoccupied from the CO_2 trend (alternatively, lessons with ventilation rate 30-4011 ach^{-1}).

17th December 2013 (and comparison to previous results)

C130

1. Mechanically ventilated room, low occupancy in special school.
2. Lesson periods differ from the senior school.
3. Mechanical ventilation has been isolated by caretaker in response to complaints from teacher of unit running continually and causing draughts and cold.
4. CO_2 and temperature sensors partially obscured by clutter.
5. Teacher had already opened all windows and vent at start of day.
6. During teaching, ventilation ranges 5 to 20 ach^{-1}

7. Before school about 1.4 ach^{-1} (windows open), after school 0.5 ach^{-1} (windows closed).
8. CO_2 concentrations generally lower and slower rise than other rooms, due to lower occupancy. Peak 1650 ppm (150 ppm has been added to readings as sensor shows an offset).
9. Temperature about 22°C all day. Reported as too hot.
10. No ventilation analysis for February 2013 due to CO_2 sensor failure.
11. Previous summer ventilation analysis showed variable results (Sept 2012 up to 17 ach^{-1}, Sept 2013 3.3 ach^{-1} with windows open.

D215

1. Triple aspect humanities room, natural ventilation.
2. Ventilation rates 2 to 5 ach^{-1}, 6.7 ach^{-1} for lesson with windows open.
3. High CO_2 peak in afternoon, 3500 ppm, surprising given 2 ach^{-1} running up to this.
4. Temperature rose through day from 17°C to 22.5°C. Reported as cold at start and warm at end.
5. Some teaching periods had similar ventilation rates in February 2013, but some were noticeably higher. Again high peak CO_2 concentrations were reported.
6. September 2012: similar rates (4-5 ach^{-1} reported), purge ventilation at end of day gave 21 ach^{-1}. September 2013 showed 4 to 6 ach^{-1} during lessons with 1 window open and 7 to 10 ach^{-1} with 3 windows open.
7. SF_6 tracer gas measurements in October 2012 gave up to 32 air changes per hour with all external windows and secure vents open and the vent to the atrium open. The weather was breezy. 1.3 air changes per hour was obtained in D215 with only the external secure vent open.
8. Additional temperature sensors located above windows and on the internal wall show occurrences in the summer term (2013) where the night vent was definitely left open overnight and internal temperatures subsided. Generally the night vent appears to have been shut at night. Direct solar gain from the south-facing windows is also evident.

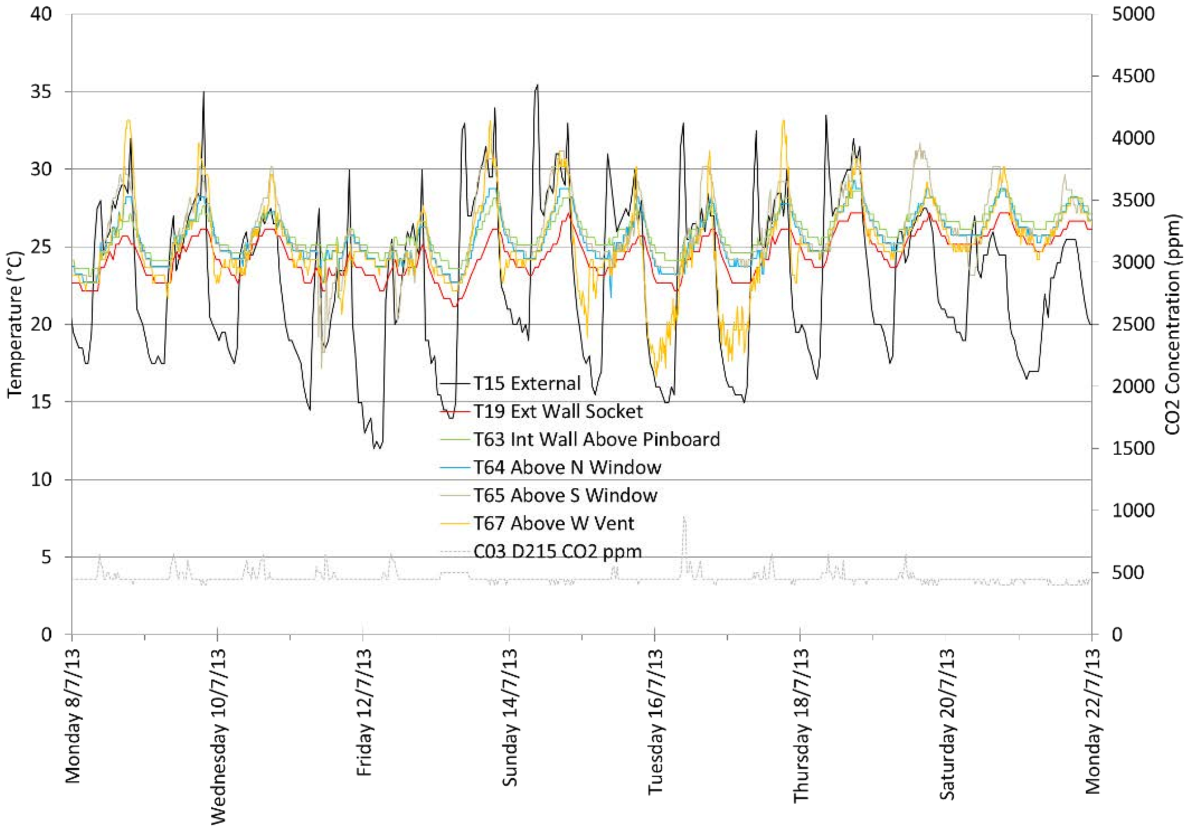

Figure 10.10. Temperature data for room D215. Data from these additional sensors are available from June to August 2013 (file: Temperature CO2 December 2013 v1.xlsx). Temperature sensor T19 has recorded throughout the project.

D106

1. Humanities classroom, natural ventilation. 2 external walls at 90°.
2. Room use log not completed for first two teaching periods (before 11 am).
3. 2.5 to 5.5 ach^{-1} during lessons with windows closed. 0.2 ach^{-1} at end of day with windows closed.
4. The highest peak concentration was recorded in this room for this day, 4500 ppm.
5. Highest temperature also recorded here, 21°C at start of day, 24°C peak during afternoon. Generally reported as OK, noted as being hot towards end of one lesson and stuffy at end of day.
6. February 2013 1.4 to 5 ach^{-1} with windows closed, 15 ach^{-1} with 1 window open, consistent with above.
7. September 2013: 3-4 ach^{-1} with windows closed, 13 ach^{-1} with vent open and 25 ach^{-1} with vent and two windows open. Maximum CO_2 concentration 1500 ppm at end of tutor time. September 2012 estimates (no CO2 data for survey day) are 1 to 3 ach^{-1} unoccupied and 9 to 14 ach^{-1} occupied.

L210

1. Art studio, natural ventilation, 1 external wall. BMS actuated high level vents in rooflights, but noted to be isolated using local high level switch.
2. Ventilation rates 5.5 to 7.2 ach^{-1} during lessons, with variations in window and door opening. 0.8 ach^{-1} at end of day with windows closed.
3. Peak concentration around 2200 ppm, mid-morning.
4. Temperature stable at 22°C. Reported as fresh at first but then as warm and stuffy for most of day.
5. Similar peak concentration in February 2013, similar ventilation rates (4 to 8 ach^{-1}) again with limited correlation with window opening.
6. September 2012 and 2013 both showed limited correlation between ventilation rate and window opening. 5.5 to 21.5 ach^{-1} for September 2012, with 46 ach^{-1} possibly when door opened. In September 2013, 3 to 6 ach^{-1} with vent and one window open, but not consistent with first and last lessons which appeared to have a greater ventilation rate but logged as having window closed or half open.
7. SF_6 tracer gas measurements in October 2012 gave 6.2 ach^{-1} with external windows and secure vent open.

F107

1. Science classroom, extract fan generally on auto.
2. Room use log not completed, this has been a recurring problem in this room.
3. 3 to 9 ach^{-1} calculated during lessons using assumed occupancy levels. 0.6 to 0.9 ach^{-1} in empty room with windows closed.
4. Peak CO_2 concentration relatively low at 1750 ppm.
5. Temperature rose during day from 18°C to 21°C, dropping back to 18°C after end of school day by 16:30.
6. In February 2013, results similar (2000 ppm peak, 3.5 to 6 ach^{-1} during lessons and 0.5 to 0.8 ach^{-1} unoccupied).
7. In summer, 6.3 to 20 ach^{-1} (September 2012) or 9 to 11 ach^{-1} (September 2013) during lessons, with 1 to 2 ach^{-1} unoccupied (September 2013).

10.9.6 Statistics from Long Term Monitoring

Table 10.4. CO_2 statistics for the aCademic year 2012-13.

Location	Max ppm	Mean School Day Average ppm	School Days available	% school days over 1,500 ppm daily average	Highest school day average ppm	Data Capture (% of school days)
C130 Cann Bridge Classroom	2200	705	127	0.8%	1619	68.6%
D106 Humanities Classroom	5050	1527	135	50.4%	2830	71.1%
D215 Humanities Classroom	6750	1370	172	35.5%	3150	90.5%
L210 Art Room	3060	1186	127	10.2%	1978	66.8%
F107 Science Classroom	5070	1315	179	35.2%	2626	94.2%
Dining Atrium	1670	943	117	0.0%	1211	61.6%

Table 10.5. CO_2 statistics for the calendar year 2013.

Location	Max ppm	Mean School Day Average ppm	School Days available	% school days over 1,500 ppm daily average	Highest school day average ppm	Data Capture (% of school days)
C130 Cann Bridge Classroom	2000	641	136	0.0%	1349	71.6%
D106 Humanities Classroom	4750	1450	159	44.7%	2974	83.7%
D215 Humanities Classroom	5850	1252	180	28.9%	2965	94.7%
L210 Art Room	3060	1111	119	7.6%	1887	62.6%
F107 Science Classroom	5070	1238	142	28.2%	2626	74.7%
Dining Atrium	1670	929	187	0.0%	1211	98.4%

Table 10.6. CO_2 statistics for all available data.

Location	Max ppm	Mean School Day Average ppm	School Days available	% school days over 1,500 ppm daily average	Highest school day average ppm	Data Capture (% of school days)
C130 Cann Bridge Classroom	2200	638	229	0.4%	1619	79.5%
D106 Humanities Classroom	5050	1468	237	45.1%	2974	80.9%
D215 Humanities Classroom	6750	1291	274	31.4%	3150	93.5%
L210 Art Room	3060	1116	192	7.8%	1978	65.5%
F107 Science Classroom	5070	1294	204	32.4%	2626	69.6%
Dining Atrium	1670	929	187	0.0%	1211	63.8%

APPENDIX 10.10: CLIMATE CHANGE IMPACT REPORT

10.10 Climate change impact report

10.10.1 Summary

The Building Performance Evaluation (BPE) team simulated the design of the school campus under the projected impacts of climate change. This Appendix describes both the modelling process, and the standards used to assess performance. These include the existing guidance on overheating in schools (Building Bulletin 101, BB101) that was used during the design stage of the new school campus, together with new criteria as described in CIBSE TM52 that have emerged since completion of the new school campus. These new standards represent the most up-to-date thinking on assessing overheating in buildings, and include the principles of adaptive comfort and the time varying severity of overheating within internal spaces. The performance of a sample of the rooms at the school campus was tested against both of these standards. The following broad conclusions were drawn following the simulation exercise:

- The current design of the school meets the BB101 criteria for overheating, and taking mid-estimates for climate change assuming a high emission trajectory (A1FI), most spaces would still meet BB101 until the end of the 21st Century. The exception is the ICT classroom due to high internal heat gains. It is not possible to predict how teaching will be delivered by the end of the century, but it is unlikely that ICT classrooms will exist in their current form.
- The success of the scheme at controlling overheating can be attributed to high thermal mass, large ventilation areas that are in operation for long periods, and control of solar gains.
- If more extreme future climate files were to be used for the simulations e.g. scenarios that are "unlikely to be worse than..." (66th percentile) or "very unlikely to be worse than..." (90th percentile), then it is highly likely that there would be extensive overheating, though this was not modelled here.
- Whilst there is generally reasonable agreement between the results of the BB101 and TM52 overheating tests, there are instances where the use of TM52 results in failure, whereas BB101 is easily passed. This is especially true when the warmer weather files are used, e.g. the CIBSE Design Summer Year. A key difference is the way TM52 considers the extent of overheating over a single day, which is likely to result in overheating if external temperatures increase rapidly.
- The building in question on the campus has many features that will help mitigate against overheating, hence both the BB101 and TM52 criteria are generally easily met. For a building that is less resilient to overheating and so lies closer to the pass / fail boundary, it may be that differences between these two standards becomes more critical.

10.10.2 Background

The Building Performance Evaluation BPE team undertook thermal modelling of the school campus to understand the potential impacts of climate change on thermal comfort within a building on the campus. This Appendix describes the criteria used to assess likely overheating of the building both now and under projected climate change, together with the modelling exercise itself.

10.10.3 Overheating Standards

The likelihood of a building overheating can be appraised through either computer simulation, or through monitoring either using temperature sensors or by interviewing occupants as part of a Post Occupancy Evaluation exercise. This Appendix is concerned only with computer simulation. Most performance criteria pertain to output from computer-simulated analyses of building performance. The current guidance for overheating in school buildings, and the criteria used at the design stage for the school campus, is described in Building Bulletin 101 (BB101) [i]. Within BB101 Section 8, the performance criteria for the avoidance of overheating are stipulated. At the design stage for the school campus, meeting the BB101 overheating criteria was a requirement of Part L of the Building Regulations, though the change to those regulations in 2010 removed this statutory requirement. However, the criteria are still widely used and represent the current industry standard in assessing overheating risk in schools.

There are three criteria within BB101, of which at least two need to be met in order to pass. They are based on simulation of the building using the nearest CIBSE Test Reference Year (TRY) weather file, and Section 8.4 of BB101 states that the period of assessment is Monday to Friday from 1st May to 30th September and during occupied hours from 9.00am to 3.30pm. The performance standards in BB101 relate to internal air temperature. The three criteria are:

- Criterion 1: There should be no more than 120 hours when the temperature in the classroom rises above 28°C
- Criterion 2: The average internal to external temperature difference should not exceed 5°C (i.e. the internal temperature should be no more than 5°C above the external temperature on average)
- Criterion 3: The internal temperature when the space is occupied should not exceed 32°C.

Until recently, the other source of guidance on overheating was within CIBSE Guide A [ii]. It is stated that the same guidance outlined in Guide A regarding offices is applied to schools. This states that an operative temperature (also known as dry resultant temperature) of 28°C should not be exceeded for more than 1% of occupied hours. It is recommended that Design Summer Years (DSY) are used as the basis for computer simulation. It is interesting to note that this guidance differs from BB101 in several ways:

1. As BB101 is based on weekdays from 1st May to 30th September and from 9am to 3.30pm, assuming the spaces are unoccupied for 1 hour at lunch then 120 hours represents 20% of occupied hours. This is clearly significantly more lenient than the Guide A criterion.
2. The BB101 criteria are for use with TRY weather files, which in general are cooler than the DSY files used in the CIBSE Guide A guidance. This represents a further leniency if BB101 is adopted as the performance standard.

3. BB101 performance criteria are expressed relative to air temperatures, whereas Guide A is expressed relative to operative temperature. For a well-insulated building which does not have excessive air exchange, the operative temperature is approximately the arithmetic mean of the air temperature and the mean radiant temperature (i.e. the average temperature of the surfaces of the room). The operative temperature is likely to be a better metric to appraise overheating within buildings.

Guide A is due to be revised soon, and is expected that the overheating guidance will be updated in line with the guidance stated in the recently published CIBSE TM52 [iii]. Within TM52 a series of new performance criteria have been presented. These follow from BS EN 15251 (2007) [iv] the work of Nicol et. al. (2012) [v] which are based on the theory of adaptive comfort. Put simply, it has been observed that people's perception of thermal comfort is strongly influenced by external temperatures, and it has been shown that people have reported feeling comfortable in internal environments below 10°C, and above 35°C. It is important to state that this approach is only valid for "free running" buildings, i.e. in terms of overheating, this excludes comfort cooled spaces as occupants are far less tolerant of changes in temperature. The new criteria described in TM52 are based on a series of additional metrics which are derived from the external temperature. These are:

- Running mean temperature: The running mean temperature is an exponentially weighted running mean of the daily mean outdoor temperature. It is based on the average external temperature of the previous day together with the prevailing running mean temperature, which is influenced by recent external temperature. The running mean temperature for a given day can be simply calculated using the formula given in TM52.
- Comfort temperature: This is the temperature at which people in a building are most likely to feel comfortable. The internal comfort temperature is calculated from the running mean. The relationship between the two is shown in Figure 10.11.
- Comfort range: A range is given around the comfort temperature within which a majority of people will be comfortable. As the range is increased, the proportion of people feeling dissatisfied would increase. TM52 proposes that new buildings are based on Category II buildings, i.e. new buildings with normal expectations. This sets a range of ±3 K around the comfort temperature, and is shown in Figure 0.11. Therefore, temperatures of more than 3 K above the comfort temperature would be classified as overheating. This threshold is termed T_{max}.
- Upper temperature limit: The criteria set out below allow for some instances where T_{max} is exceeded, though set a threshold above T_{max} beyond which the temperature is deemed to be unacceptable high.

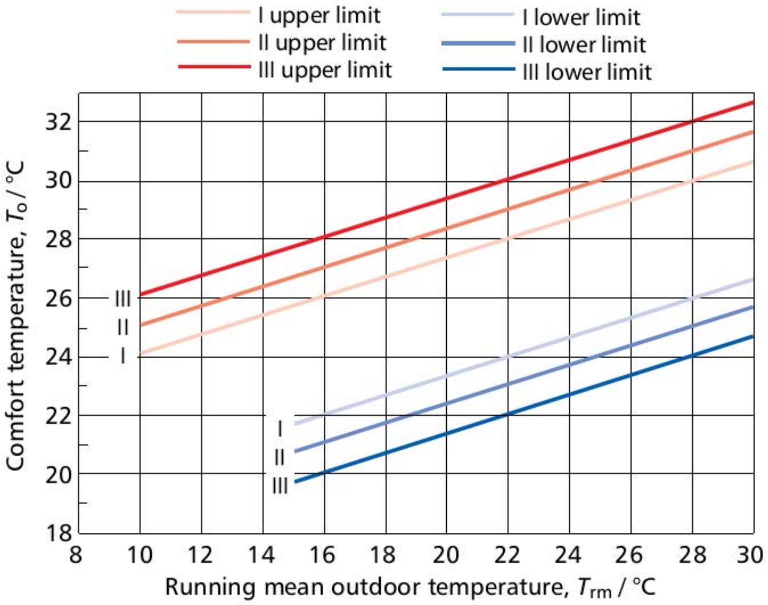

Figure 10.11: The relationship between running mean outdoor temperature, comfort temperature and upper and lower limits for different class of building. TM52 proposes Category II buildings are used for the design of normal new buildings. (Source:CIBSE TM52)

Performance criteria are then set using these metrics. They are valid for occupied periods from 1st May to 30th September, and it is stated that the DSY file should be used. All three criteria must be met for the building to pass, and it is stated that that there may be circumstances where stricter limits are appropriate, though looser limits are not recommended. The three criteria are as follows:

- Criterion 1: The proportion of occupied hours where T_{max} is exceeded should be lower than 3%. It is interesting that this is more lenient than the existing CIBSE Guide A guidance of 1% above 28°C, though for schools much stricter than the 20% implied by BB101.
- Criterion 2: In order to account for the magnitude of overheating, a weighted approach is taken to quantify both the length and severity of overheating. This is a similar approach as is used in degree day analysis. A maximum amount of overheating of 6 degree-hours is allowed on any one day. For example, in a room where T_{max} is exceeded by 2°C for 4 hours, the total weighted exceedences for the day would be 8 degree-hours and therefore the room would fail the criterion. For any given hour, the difference between the room temperature and T_{max} is rounded to the nearest integer.
- Criterion 3: The temperature in the room must not be greater than 4°C above T_{max} (i.e. for a Category II building, 7 °C above the comfort temperature).

In simulating the school campus building, the results have been compared to both the existing BB101 requirements, and the TM52 guidance.

10.10.4 The Model

The building was modelled in the *IES Virtual Environment* software using the model of the building that had been constructed by the design team at the design stage to check for overheating compliance. Importantly, this differs from the energy model used for Part L compliance which necessarily used fixed occupancy profiles and ventilation rates as described in the National Calculation Methodology (NCM). The model used to check for overheating allows more flexibility and is based on attempts to model occupancy and crucially, implementation of the ventilation / passive cooling regime in a more realistic manner. It must be stated that due to the complexity of real buildings, especially where user engagement is required, e.g. to open a window, the computer modelling processes commonly used in practice are not sophisticated enough to capture the likely uncertainty and variability of human behaviour. These simulation exercises should therefore be viewed as guidance tools rather than as an attempt to accurately predict reality.

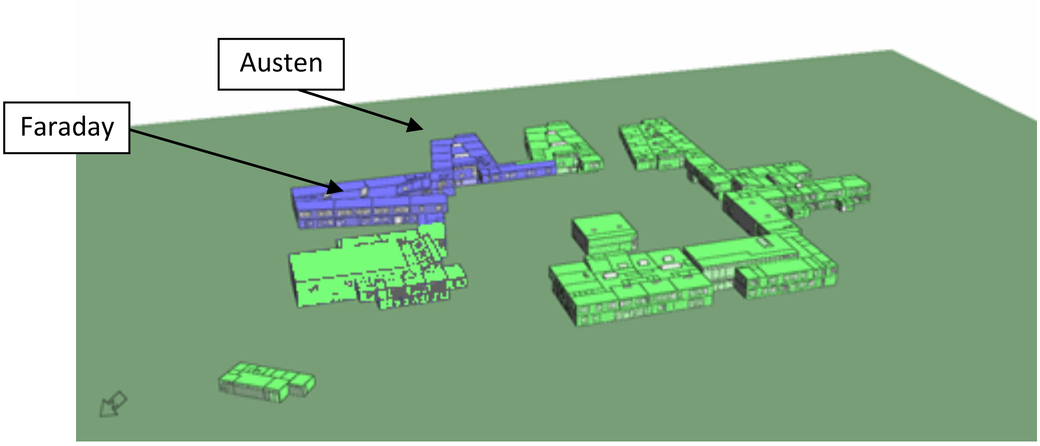

Figure 10.12: View of the modelled building in IES. In order to reduce calculation efforts, only the area of the site shown in blue was simulated – the remainder was retained in order to account for any shading offered by those blocks.

This modelling exercise aimed to look at the performance of typical spaces in the school both now and under projected climate change. In order to reduce simulation times and file sizes, only part of the campus was simulated (shown in blue in Figure 10.12). The results from the simulations were then interrogated to establish which spaces were representative of the building as a whole, and results from only a few spaces presented.

The building was modelled with current TRY and DSY weather files for Plymouth, as well as modified TRY files for 50th percentile (mid-estimates within a much wider range of possible outcomes) 2030, 2050 and 2080 climate for Plymouth based on the UKCP09 A1FI scenario (high emissions). These weather files were created through the EPSRC *Prometheus* project [vi].

The full input parameters are not presented in this report. As stated above, the model was originally formulated by the design consultants to demonstrate compliance with the then mandatory overheating criteria, so it is reasonable to expect that the assumptions regarding occupancy levels, ventilation openings, and constructional form are reasonably accurate. The key assumptions made within the model which are pertinent to its thermal performance and potential to overheat are as follows:

- Classrooms generally have a number of openable windows, with a significant area that may be opened to provide ventilation (e.g. a typical classroom has three large openable windows with a total opening area of approximately 0.5 m^2). These windows were assumed to be fully open once internal air temperature exceeded 22°C from 8.15am to 4pm.
- In addition, each classroom has a large vent which is assumed to be open all the time for the purposes of thermal modelling. Internal openings (in reality mechanically actuated internal fanlight windows) allow air to circulate into the central cores in each block, from where it can

exhaust from high level openings which again were assumed to be continuously open (i.e. day and night).
- There are a number of additional rooflights and vents around the building.
- External facing walls (plastered dense concrete block inner leaf) have high thermal mass, though internal partitions (plasterboard) and the ground floor (carpet over insulated slab) were of lightweight construction. Classrooms have ceilings with exposed thermal mass (concrete slab), though this mass was covered by ceiling tiles to the core and circulation areas.
- Glazing to the north facing rooms was modelled with glass having a g-value of 0.48, with glazing to all other orientation having a g-value of 0.44.
- It was assumed that there was approximately 2.5 kW of sensible heat gain from people and a further 1 kW from lighting and equipment during normal school hours per classroom.
- The building was modelled in pure free running mode (no artificial heating or cooling).

The building was modelled from 1st May to 30th September calculating every 10 minutes and storing results on an hourly basis.

10.10.5 Results and Discussion

The overheating results from a selection of typical occupied spaces are shown in Table 10.7. These spaces include classrooms facing in each direction and on both ground and first floors. In addition, they include an ICT classroom. The first observation to make is that all the spaces examined met the requirements of BB101, when using the TRY weather file. In general, when based on BB101 together with the TRY file, the design of the school managed to meet the overheating criteria when considering the potential impacts of climate change to the end of the 21st century. The good performance can be attributed to the inclusion of many design measures that have been incorporated to combat the potential for overheating, namely large ventilation areas that can be opened for long periods, including overnight, a relatively high amount of exposed thermal mass, and reduction of solar gains using glazing that offers solar control.

The future climate files used were the 50th percentile scenarios i.e. if 100 equally probable scenarios were taken, the files used here would be the midpoint (median) in terms of temperature (the mean dry bulb temperature for each month would be the median of the range of 100 scenarios). Scenarios that happen at the upper ends would result in significantly warmer external climates, and in the experience of the BPE team [vii] are likely to result in a much more significant overheating risk. While the 50th percentile scenario was modelled in this project, there is a one in two chance that overheating under future climate could be worse in practice.

Table 10.7. Overheating results expressed relative to both BB101 and TM52 criteria for a selection of typical occupied rooms in the school.

Room	**Climate File**	***BB101***				***TM52***			
		Number of hours >28°C	**Average internal-external temperature difference (K)**	**Maximum internal temperature (°C)**	**Pass ?**	**% hours above maximum temperature**	**Weighted exceedences on worst day**	**Maximum temperature difference above T_{max} (K)**	**Pass ?**
Austen Ground floor North facing classroom	TRY	0	5	27	**PASS**	0.0%	0	0	**PASS**
Austen Ground floor North facing classroom	DSY	13	5	31	**PASS**	1.2%	10	3	**FAIL**
Austen Ground floor North facing classroom	2030s	2	5	29	**PASS**	0.1%	1	1	**PASS**
Austen Ground floor North facing classroom	2050s	16	5	30	**PASS**	0.8%	5	2	**PASS**
Austen Ground floor North facing classroom	2080s	125	5	31	**PASS**	3.5%	6	2	**FAIL**
Austen 1st floor South facing classroom	TRY	0	4	26	**PASS**	0.0%	0	0	**PASS**
Austen 1st floor South facing classroom	DSY	7	5	30	**PASS**	0.7%	5	2	**PASS**
Austen 1st floor South facing classroom	2030s	4	5	28	**PASS**	0.0%	0	0	**PASS**
Austen 1st floor South facing classroom	2050s	11	4	30	**PASS**	0.7%	4	2	**PASS**
Austen 1st floor South facing classroom	2080s	93	4	31	**PASS**	2.1%	4	2	**PASS**
Austen West facing ICT room	TRY	0	4	28	**PASS**	0.1%	1	1	**PASS**
Austen West facing ICT room	DSY	18	4	32	**PASS**	1.4%	14	4	**FAIL**
Austen West facing ICT room	2030s	9	4	30	**PASS**	0.7%	3	2	**PASS**
Austen West facing ICT room	2050s	27	4	31	**PASS**	2.0%	8	3	**FAIL**
Austen West facing ICT room	2080s	138	4	33	**FAIL**	5.1%	13	4	**FAIL**
Faraday Ground floor East facing science lab	TRY	0	4	26	**PASS**	0.0%	0	0	**PASS**
Faraday Ground floor East facing science lab	DSY	7	4	29	**PASS**	0.7%	3	1	**PASS**
Faraday Ground floor East facing science lab	2030s	0	4	27	**PASS**	0.0%	0	0	**PASS**
Faraday Ground floor East facing science lab	2050s	8	4	29	**PASS**	0.0%	0	0	**PASS**
Faraday Ground floor East facing science lab	2080s	91	4	30	**PASS**	0.9%	2	1	**PASS**
Faraday 1st floor West facing science lab	TRY	0	4	25	**PASS**	0.0%	0	0	**PASS**
Faraday 1st floor West facing science lab	DSY	4	4	28	**PASS**	0.1%	1	1	**PASS**
Faraday 1st floor West facing science lab	2030s	0	4	27	**PASS**	0.0%	0	0	**PASS**
Faraday 1st floor West facing science lab	2050s	0	4	28	**PASS**	0.0%	0	0	**PASS**
Faraday 1st floor West facing science lab	2080s	30	3	29	**PASS**	0.0%	0	0	**PASS**

A further observation to make is that whilst in the case of this building there was reasonably good agreement between assessments using BB101 and TM52, there were instances where there were differences. Considering that BB101 is assessed using the TRY and TM52 the DSY, even under the present climate it can be seen that two of the six rooms would have failed TM52 (Block A north facing classroom, and ICT room). The reason for this is criterion 2 of TM52, the daily weighted exceedences. This can be seen when considering the ICT room (Figure 10.13). Firstly, it is important to note that the ICT room is more at risk from overheating compared to a standard classroom as whilst it has the same occupancy patterns, it has additional heat gains from the ICT equipment (total sensible heat gain to normal classrooms is about 3.5 kW, and close to 6 kW in the ICT room). When observing the temperatures it can be seen that the number of hours above 28°C is low – certainly not 20% of the year (120 hours) – and that the maximum temperature does not exceed 32°C. Hence the BB101 criteria are met, even using the DSY file.

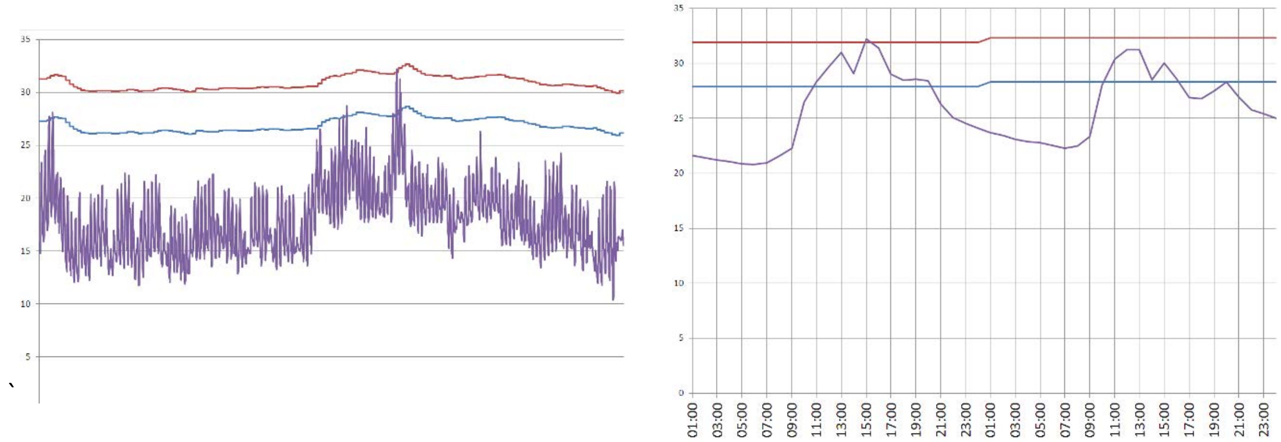

Figure 10.13. Thermal performance of the ICT room when simulated using the current DSY file. The purple line shows the room operative temperature, the blue line is the maximum comfort temperature threshold and the red line is the upper allowable temperature. The graph on the left shows the entire summer period (May-September) with the graph on the right showing the two peak days in August only.

However, when considering TM52, it can be seen that there are two days at the beginning of August when the maximum comfort temperature is exceeded for significant parts of the day in the ICT room. This occurs from around midday and into the afternoon, due to a combination of the increased heat stored in the thermal mass, coupled with solar gains as the room is oriented west. On the first of these days, at midday the exceedence is 2°C, and in the following hours it is 3°C, 1°C, 4°C and 4°C respectively up to 5pm. The weighted total exceedence is therefore 14 degree-hours – significantly above the criterion limit of 8 degree-hours. The next day, the weighted exceedence is 10 degree-hours. It is interesting to observe the external temperature in the week leading up to those peak days (Figure 10.14). The mean external temperature over each 24 hour period was typically around 17°C - 18°C. This rose quickly to about 23°C - 24°C for the peak days in question. As this increase occurred rapidly, the exponentially weighted running mean (from which the comfort temperature is derived) cannot rise as fast as it included the history of the cooler period. Therefore, even though the internal temperature on the peak days is actually similar to the external temperature – not a bad result considering the high internal gains to that space – the space would still not meet the TM52 overheating requirements. It is also interesting to note that the most recent external temperature used to calculate the running mean is yesterday's temperature. This is because the daily average for the same day is not known until the entire 24 hour period is elapsed. This means that rapid increases in temperature are likely to make this criterion of TM52 more challenging to meet.

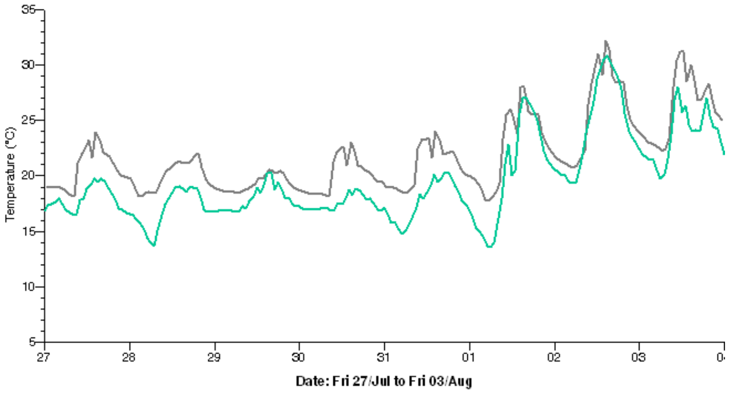

Figure 10.14. Operative (grey line) and external (green line) temperature for the week leading up to the peak temperatures for the ICT room.

The following broad conclusions can be drawn from the simulation of the building on the school campus:

- The current design meets the BB101 criteria for overheating, and taking mid-estimates for climate change assuming a high emission trajectory (A1FI), most spaces still meet BB101 until the end of the 21st century. The exception is the ICT classroom due to high internal heat gain. It is not possible to predict how teaching will be delivered by the end of the century, but it is unlikely that ICT classrooms will exist in their current form.
- The success of the scheme at controlling overheating can be attributed to high thermal mass, large ventilation areas that are potentially openable for long periods (e.g. secure external vents), and control of solar gains.
- If more extreme future climate files had been used for the simulations e.g. scenarios that are “unlikely to be hotter than...” (66th percentile) or “very unlikely to be hotter than...” (90th percentile) then it is highly likely that there would be extensive overheating, though this was not modelled.
- Whilst there is generally reasonable agreement between the results of the BB101 and TM52 overheating tests, there are instances where the use of TM52 results in failure, but BB101 was easily passed. This is especially true when the warmer weather files are used, e.g. the DSY. A key difference is the way that TM52 considers the extent of overheating over a single day, which is likely to result in overheating if external temperatures increase rapidly.
- The comparison of BB101 and TM52 has been undertaken on a building that has taken many steps to mitigate against overheating, and so in both cases the criteria are generally easily met. For a building that was less resilient and so closer to the pass / fail boundary, it may be that differences between these two standards become more critical.

APPENDIX 10.11: BUILDING USE STUDIES OCCUPANT SATISFACTION SURVEY

10.11 Building Use Studies occupant satisfaction survey

10.11.1 Data Tables

[See attached PDF]

10.11.2 Comments

[See attached PDF]

APPENDIX 10.12: OUT OF HOURS WALK THROUGH SURVEY

10.12 Out of hours walk through survey

10.12.1 Purpose

The BPE Team carried out a walk through survey on 17th December 2013. The walk through commenced at 4pm when all pupils had left and teachers were beginning to leave and was completed by 7:30pm. Weather on the day of the survey had been partly cloudy with occasional sunny spells and rain showers. The temperature was around 7°C. It was dark by 4:30pm.

Although the walk through was unaccompanied by a member of staff, a meeting was held with the Facilities Manager prior to the survey (addressing the sections of TSB's Walk Through Report template) to identify potential areas of interest.

The walk through had the specific purpose of establishing what appliances were left on out of hours that could account for the base loads identified during analysis of the half hourly electrical data.

The school campus was constructed in 3 separate phases. The BPE study in general considered only Phase 1 buildings as shown below:

Block name	Purpose
Austen	English
Cann Bridge	Special school
Cade North	Art, Administration offices
Cade South	Dining hall, Home economics, 6th form common room
Faraday (North)	Science, Design & Technology
Tenzing	Humanities

The survey concentrated on these areas, however, where appropriate other parts of the site such as Faraday (South), Graham Browne, and the Sports Hall were also visited to provide context and to shed light on common issues.

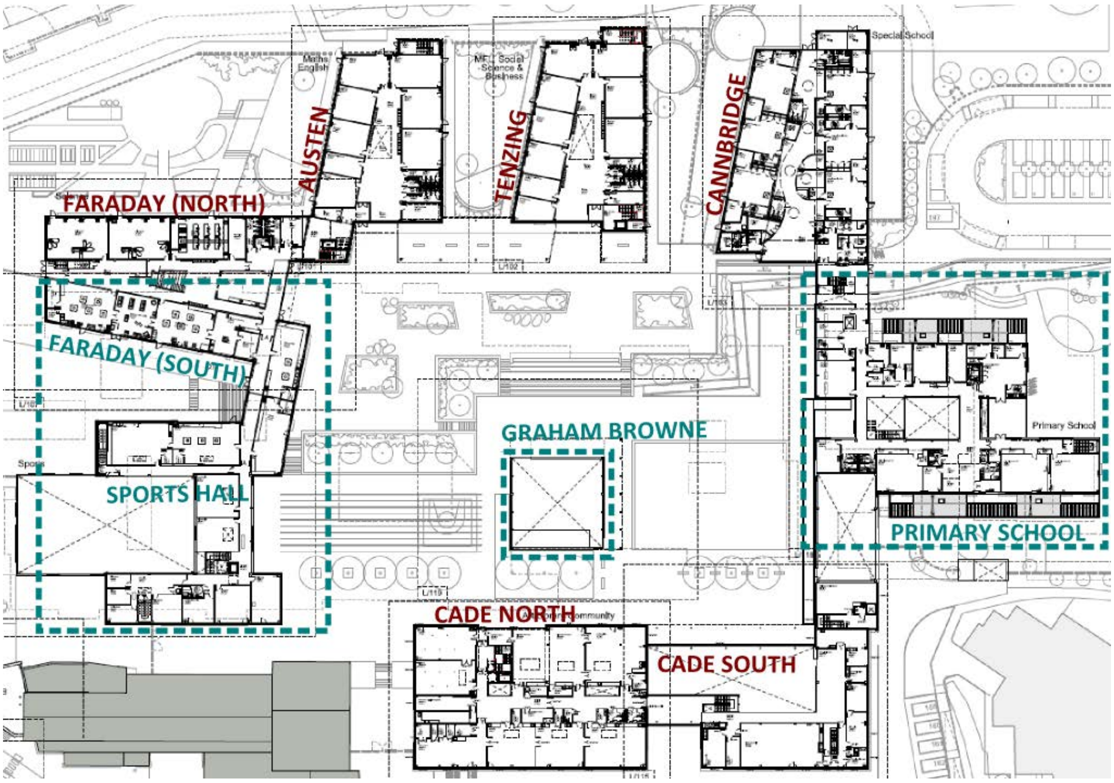

Figure 10.15. The school campus site plan, red labels indicate Phase 1 buildings included in the TSB BPE study and green labels indicate Phase 2 and 3 buildings that were not.

10.12.2 General user experience, building performance and architectural issues

The full results of the BUS survey carried out on 10th December 2012 are given in Appendex 10.11 and indicate that in general staff members seem to be pleased with the new school campus. During the walk through, one teacher who was working late in their classroom was asked about their experience of the school. They stated that '*the rooms tend to heat up very quickly*' and that the pupils sometimes operate the thermostatic radiator valves (TRVs) when they are not supposed to. The night ventilation system worked well during the summer and was easy to use. They also stated that they '*liked*' the buildings on the whole.

In the initial meeting prior to the walk through, the Facilities Manager highlighted a number of concerns with the school buildings especially with regards to the fit out. During the week prior to the site visit, a large bench in the Science Opportunity Centre had falling off the wall after several students had sat on it, fortunately without injury. Examination revealed that the bench had only been attached to the wall with around 10 No. 2' rawl plugs.

Figure 10.16. Fallen bench in Science Opportunity Centre in Faraday block.

In addition, other maintenance issues have arisen which are no longer covered by the defects period, but which may not necessarily be caused by the normal expected level of use. These include hand rails which are not secured to 'noggings', but screwed straight into the wall, bent door openers caused by pupils hanging on doors (causing them to be jammed open while a nearby radiator is on), loose bolts on fittings in plant room which can be rotated by hand, and building service pipes which have burst causing water to leak on to the floor.

Figure 10.17. Clockwise: Loose hand rail, bent door opener, loose bolts on pump fitting, and floor damage from burst water pipes in plant room.

The Facilities Manager (FM) has commented that in general there is too much automation at the school and as a result many of the automated systems have been disabled. For instance, the automatic windows in the

Sports Hall have been disabled and are now constantly shut while the radiant high level panels have been turned off. The school considers that the Sports Hall can be adequately heated by the occupants playing sport inside. If the FM does need to open the windows, he manually adjusts the set point for the Sports Hall on the BMS to ‘fool’ the system into opening them.

As a further example, the Graham Browne building which provides a lecture / performance space was completed in Phase 3. At this stage of the project funding for controls was limited and consequently the final installed controls were much simpler than those found elsewhere on the site and completely manual. The FM has commented that the occupants operate this room a lot more effectively due to the simple nature of the controls. However, it was noted during the walk through that the manually operated lights were on even though the room was locked and not in use.

Figure 10.18. Building service controls in the Graham Browne building: rocker switch for opening / closing high level windows and analogue thermostat for controlling under floor heating.

Building performance

Although the various buildings for Phase 1 are highly insulated (with low U-values), analysis of the energy data so far has revealed an unexpectedly high heat demand at the site. It was conveyed to the BPE team by the facilities staff that this could be due to teachers leaving night vents open during winter months. Although the night ventilation has been a particularly successful and usable feature during the summer, leaving them open during the colder winter months could lead to a high heat demand as the BMS adjusts the room conditions up to the required temperature. This may also occur without the occupant necessarily realising, as when they arrive in the morning the heating would have already achieved the expected temperature.

Some of the heat demand may also be explained by heat losses from pipes in the plant rooms in each block. Although the main pipes have been insulated, the joints have not and these are radiating heat directly into the plant rooms causing them to become very hot.

Figure 10.19. Un-insulated pipe joints in Faraday block plant room.

Heat demand

Energy analysis for the BPE has indicated that there is a high non-weather dependent heat demand at the school. This can be seen on Figure 10.20 where the months of June, July, and August have a similar heat demand even though they have low degree days. This is particularly interesting as the school is not open during the most of July and the whole of August. Indications are that the heat demand may be caused by the calorifiers for each block which provide domestic hot water. Discussions with the Facilities Manager revealed that the hot water needs to be kept running as teachers tend to come in over the summer to work in their classrooms. On some days 30 – 40 staff members could be present even though there are no pupils. This provides the facilities team with a problem as they need to provide services to the whole school even though it is only partially and sporadically occupied.

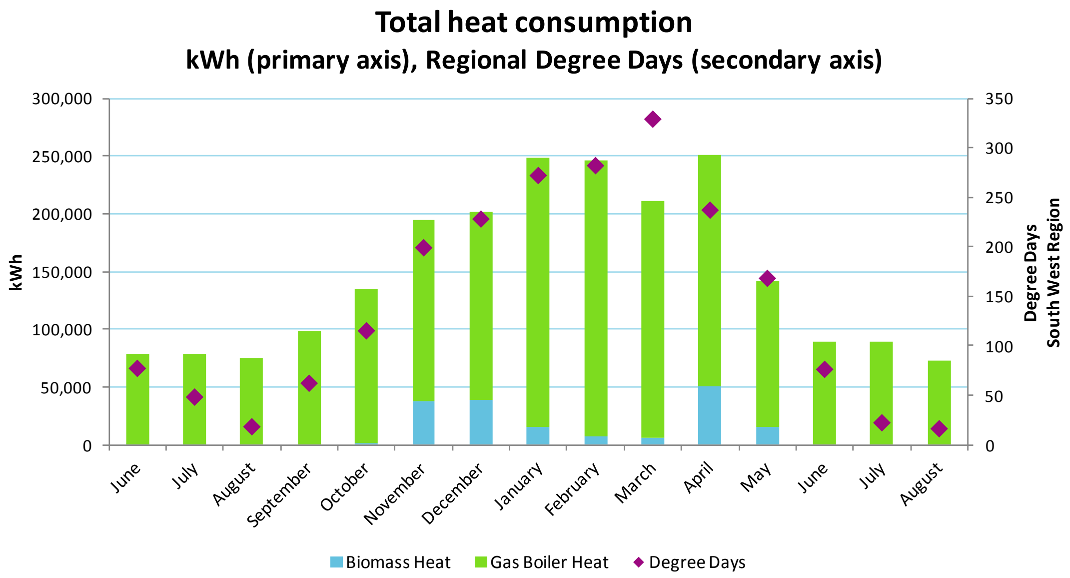

Figure 10.20. Total heat consumption for the entire school campus.

Electricity base load

One of the main motivations to carry out the walk through out of hours was to detect any electrical equipment that was being left on and what could account for the relatively small base loads seen in the daily electricity profiles for each block.

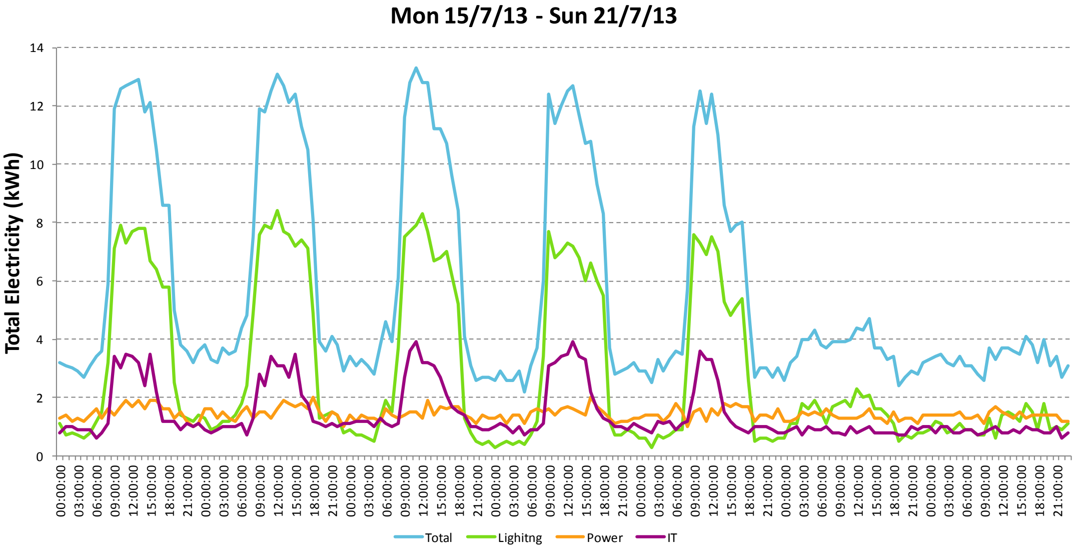

*Figure 10.21. Weekly electricity consumption profile for **Austen Block**, note the 1 kW base load for IT submeter (purple) and the 1.5 kW base load for Power submeter (orange).*

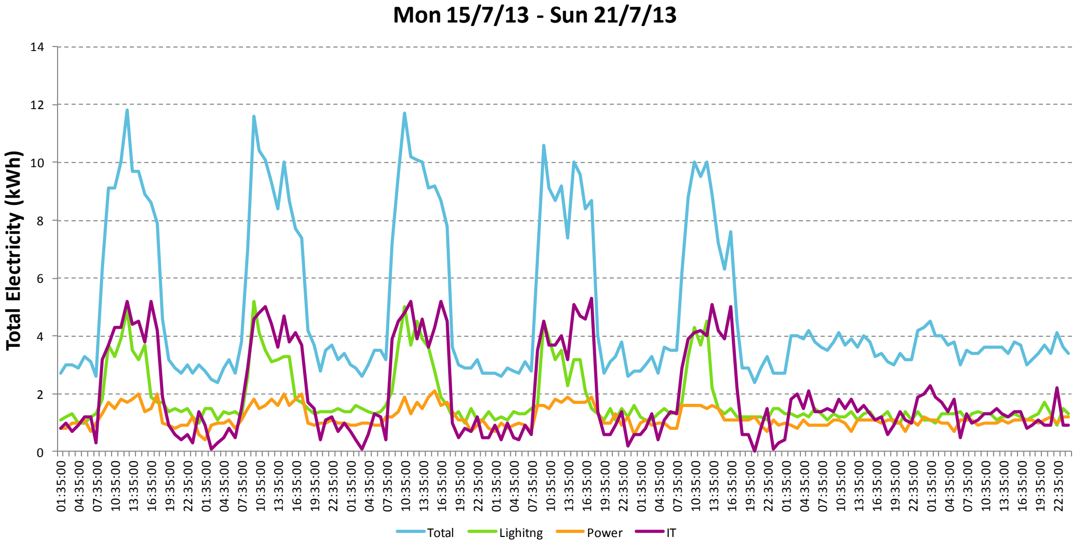

Figure 10.22. Weekly electricity consumption profile for ***Tenzing Block****, note base load for IT submeter (purple) is slightly less than 1 kW and the 1kW base load for Power submeter (orange).*

Figures 10.21 and 10.22 show the electricity consumption profiles for Monday 15th July 2013 to Sunday 21st July 2013 for Austen and Tenzing respectively. They show that some IT equipment is being left operational out of hours and both have a similar base load for the Power submeter (shown in orange). This situation is also typical of all the other blocks.

During the walk through it was discovered that computers located in the IT hubs for each block were often left in sleep mode as well as netbook stations left charging. Additionally, every classroom that was visited had at least one laptop or PC left in sleep mode and the majority had a whiteboard and projector left on stand-by (Figure 10.23). Some rooms also had additional PCs which were typically left on (Figure 10.24). Although these loads are individually small, when combined they are likely to be the cause of the base loads seen on the IT submeters for the various blocks.

Figure 10.23. Projector left on stand-by, this was common to all classrooms.

Figure 10.24. Art room L210 with four out of five PCs left in sleep mode.

Examination of items on the Power submeters for the various blocks revealed that these are mainly cleaning sockets. However, there are some pieces of equipment hard-wired into supplies monitored by the Power submeters. These include alarm and fire systems, BMS communications (Figure 10.25) and Premier PSU200XP power supplies (Figure 10.26). These items are present in each block and seem to account for the base load for each Power submeter.

Figure 10.25. Alarm and fire systems, and BMS communications systems.

Figure 10.26. Premier PSU200XP power supplies.

Additionally, in the Staff room Tenzing block Level 1 there is a 2.2kW water boiler, 2 fridges, 3 microwaves and a toaster, the supplies to which are all connected to the Power submeter for Tenzing block. This may explain why the Power submeter daily profile for Tenzing (see Figure 10.22) seems to follow occupancy more closely than Austen's Power submeter daily profile which is flatter (Figure 10.21).

Figure 10.27. Kitchen appliances in Tenzing's Staff Room. These are all wired into supplies monitored by the Power submeter.

Architectural issues

The Facilities Manager has suggested that the architectural layout at the main entrance creates a 'wind vortex' which has previously caused the large heavy doors at reception to slam shut damaging them.

Figure 10.28. North West facing entrance to school, U-shape can cause wind vortex to occur

The Head Teacher has commented that behaviour of the pupils has improved markedly from the previous school, with the open and light areas seeming to help prevent bullying from occurring. This observation is confirmed by teacher comments from the BUS survey:

> '...students behave more calmly in new open spaces.'
>
> 'Calmer as movement around the building is safer.'

The overall building design is appreciated by the staff especially the high levels of space and light. While the large amounts of glazing are provided to maximise daylight within the building, this can occasionally result in overheating from solar gain. To reduce this, solar control glass is used to the east, south, and west faCades, which cuts down the amount of solar radiation entering the building through the glazing. However, during winter solar gain can be beneficial and may help to reduce the demand for heating. During the walk through, it was observed that many classrooms had their blinds in the closed position preventing natural light and solar gain. This may be as a consequence of the large windows increasing the possibility of glare, particularly when teachers are using whiteboards. It should be noted, however, that glare was only mentioned as an issue by one respondent to the BUS survey.

10.12.3 Heating, Ventilation, cooling, lighting, and other services

Space conditioning

Heating is predominantly delivered through perimeter radiators with integral TRVs. Deeper plan areas such as the dining hall, the library, Graham Browne, and the central cluster space of Cann Bridge block are heated through underfloor heating.

The heating systems are automatically controlled in zones linked to the BMS with temperature sensors, with individual local control within occupied spaces. The thermal zones include variable temperature controls and permit extra-curricular activity, and individual thermostatic control is provided to radiator to each room or space.

During the walk through it was observed that many radiators, especially those in circulation areas had their TRVs set on the maximum of '5' (Figure 10.29). Many radiators in classrooms were blocked by various equipment preventing heat flow (Figure 10.30).

Figure 10.29. A radiator in a circulation space. The TRV was set to maximum of '5', which was typical for many radiators in circulation areas.

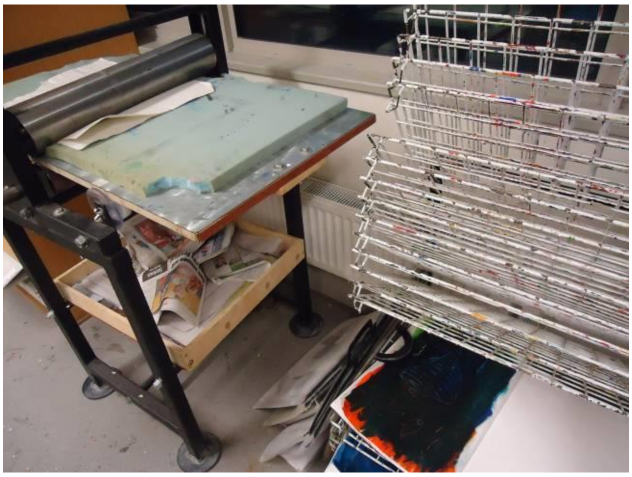

Figure 10.30. Radiators in L210 Art room Cade North obscured by various equipment.

In room F112 design and technology in Faraday block the night vent was left open while the radiator was switched on and running even though it was 6pm. Although the TRV was set to '1', the radiator was still hot to the touch. During the walk through all radiators seemed to have ceased outputting heat by 7pm.

Domestic hot water

Domestic how water is supplied by calorifiers for each block situated in the relevant plant room. The Facilities Manager indicated that showers are only rarely used by pupils or adults using the sports facilities. There seems to be a large amount of hot water being stored for this purpose.

Figure 10.31. 2 No. Hoval calorifiers in Austen block plant room and temperature dial on one. Note the temperature is being kept over 75°C.

Ventilation

The ventilation of the building generally relies on users manually operating opening vents in the external faCade. This creates cross ventilation when the fanlights above the doors are also open and is important in summer to aid night time cooling. Anecdotally, the ventilation system appears to be operating satisfactorily in most areas with positive responses from the BUS in terms of air quality in the summer and the control of cooling.

Although the majority of the Phase 1 buildings are naturally ventilated, some classrooms such as the science laboratories contain extract fans for supplementary ventilation. In Faraday Level 1 rooms F205 to F2011 all have this feature. However, there is no interlock, meaning that if a night vent is left open the mechanical ventilation will still continue to operate.

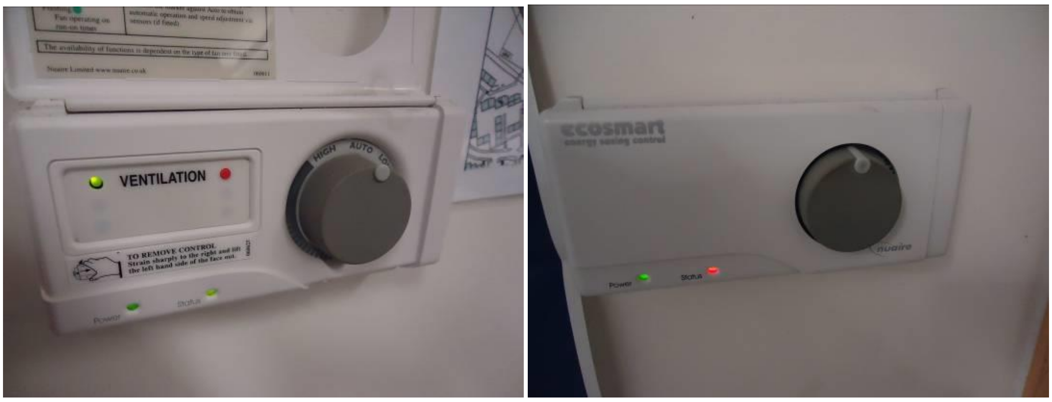

Figure 10.32. Supplementary ventilation control in Faraday science laboratories with the shutter open and closed respectively. Note that when this is closed the user cannot see the labels which indicate what mode it is set on.

This situation was witnessed in room F209 Faraday block. Although the majority of rooms have only one night vent this science lab had two which were both left open while the mechanical ventilation was left on high. The room was exceptionally cold. In science labs F207 and F211 the mechanical ventilation had also been left on high meaning it was running continuously, although the night vents were closed. It was also noted in a several classrooms that the night vent although apparently closed was not properly secured and could easily open in the wind.

Figure 10.33. One of the night vents left open in F210 Faraday block while extract ventilation left on high.

In most classrooms small CO_2 sensors provide feedback to the occupant about the CO_2 concentration in the room through a traffic light system. It was noted however that this display is somewhat small and blends into the proliferation of other items attached to the wall.

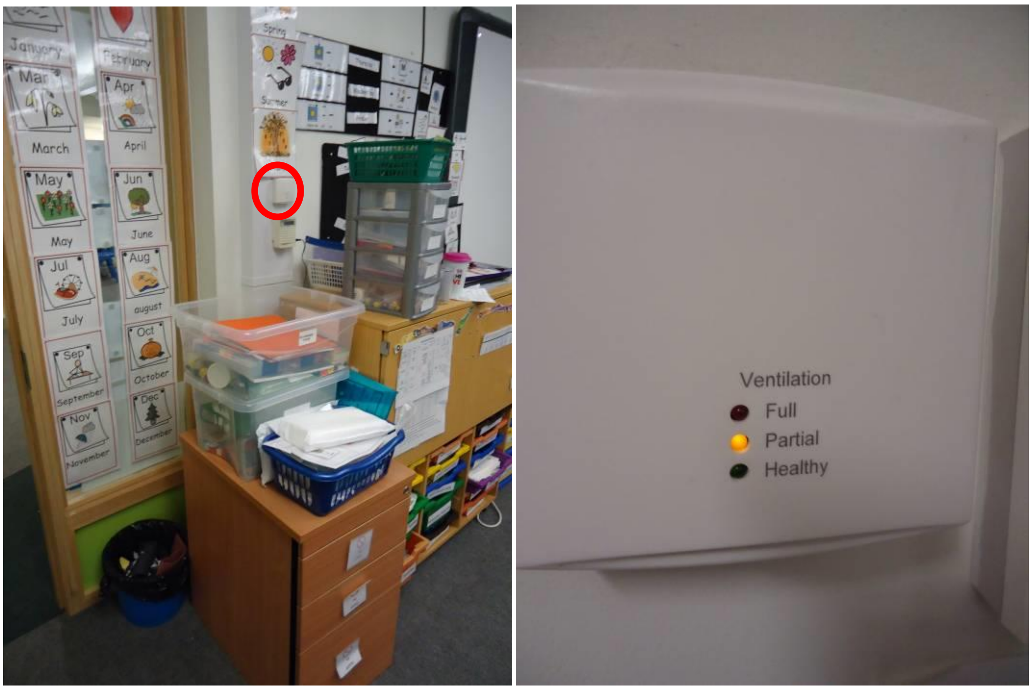

Figure 10.34. CO_2 sensor on wall in room C130 Cann Bridge block highlighted in red and close up. Note that its design does not make it stand out on crowded wall.

The building Log Book indicates to users that night vents should always be left open at night time and makes no mention that this action is inappropriate during winter. It also says the fanlight above the door should also be left open to aid night time ventilation. It was observed though that only 2 classrooms actually completed this action (Figure 10.21).

Figure 10.35. Fanlight vent above door leading to corridor in open state.

Lighting

Lighting for teaching areas is controlled through a manual light switch with PIR sensors to automatically switch off lights after a 20 minute period of no presence detection. Lighting for communal / circulation areas is typically controlled through standard manual light switches.

According to the building Log Book, lighting to teaching areas can be controlled in the following manner:

> *Upon entrance into the classroom, the lights remain off until the momentary switch in pressed in the down position. This then illuminates all of the fittings. If the momentary switched is pressed again for 3 seconds this will turn the fittings off. If the room is left unoccupied for a set period, the lighting will turn off until such time the switch is pressed again.*

The above passage adequately describes how the light switch system should work, but the situation described assumes that the occupant has held the light switch down when leaving the room which turns the lights off AND disables the PIR sensor. However, the walk around revealed that no classroom at all had carried out this action. Instead while all lights were turned off the PIR sensor was still enabled meaning that lights automatically turned on upon entrance to the room. In two specific classrooms it was noted that the teachers rely on the PIRs to such an extent that they have actually obscured the lighting controls with cupboards (Figure 10.36).

Figure 10.36. Art room L210 Cade North, note the light switch obscured behind a cupboard

The Facilities Team indicated that this situation was typical and that the PIRs were overly sensitive meaning that lights could switch on even when someone passes by outside of a room. Members of the facilities team had also been to the school during the night on occasion and found lights in various rooms switched on.

Communal areas and circulation areas are typically controlled through manual light switches. These are switched off by the facilities team / cleaning staff as they complete their final checks in the evening between 7pm and 8pm. The walk through survey was completed before the facilities team had finished their final sweep, but in the areas which they had completed, the manual lights had indeed been switched off.

In the Science Opportunity Centre in Faraday block ground floor, a manual lighting control was discovered obscured by a fume cupboard and without any labelling. It was unclear what this control was for (Figure 10.37).

Figure 10.37. Lighting control in Science Opportunity Centre obscured by fume cupboard and PC, note there are no labels to inform the user which lights the control is for.

Domestic cold water

Incoming cold water temperature to the various blocks has apparently been measured by the Facilities Team and found to be relatively high. The Facilities Manager has recorded it as high as 24°C during the summer, although it has reduced somewhat over winter. The water incoming to the Sound House was recorded at 18°C, so it seems that the water pipes to the various other blocks are picking up heat over a relatively short distance. The Facilities Management team have suggested that the cold water pipes have been laid in trenches alongside the heating flow and return pipes which are transferring heat to them. Cold water arriving at this temperature is problematic as it increases the risk of Legionella breeding (typically 30°C - 40°C). There were traces of Legionella bacteria detected over the summer months at the school leading to a shutdown. However, this occurred during the holidays so no pupils were present. This situation requires further investigation.

Figure 10.38. Location of incoming cold water supply pipes close to heating flow and return pipes in plant room Faraday block. This could possibly the cause of the elevated cold water supply temperature.

10.12.4 Catering, IT, specific processes and other systems

Kitchen

The school campus has catering facilities on site. Breakfast is served to some pupils from 7:30am until 8:30am, and then the main lunch service runs from 12:30pm till 2pm. The kitchen is shut and catering staff have all left from 3pm. Kitchen appliances are mainly electrical, although there is a large 12 ring gas hob and 2 gas fryers. The survey team arrived at the kitchen at around 4pm on the day of the survey to investigate what state the kitchen is typically left in after service.

In general, all kitchen appliances were found to be switched off. A washing machine was running and a coffee vending machine was also on. There were two large electrical Brat pans, which although off were still on standby (Figure 10.39).

The kitchen extract system (Figure 10.40) was running continuously which the Facilities Manager had already explained would be the case. It is understood this is the result of a fault with the BMS and there is no local control to switch the extract system off. This has been the situation since the start of the school year in September 2013.

Figure 10.39. Brat pans in the kitchen turned off, but red lights indicate they are still on standby.

Figure 10.40. Kitchen extract fan which is on continuously throughout the day.

As expected the walk-in and standard fridges and freezers were all switched on. (Possibly, food could all be stored in the walk in fridges overnight allowing bench fridges to be used only during the day as a way to reduce energy consumption.)

IT hubs

Each block has an IT hub located in the central area. These typically have around 10 thin client PCs and 1 photocopier. When visited during the walk through about two thirds were left in sleep mode in total.

Figure 10.41. IT hub in Faraday block, note 8 out of 12 PCs were left in sleep mode.

Figure 10.42. IT hub in Tenzing block, here 8 out of 10 PCs were left in sleep mode.

Server rooms

Each block has a small server room. These are cooled with individual split units. During the walk around it was noted that these are on continuously and are typically on a set-point of 18°C (Figure 10.43). It was also observed that they were making a grinding noise indicating possible future maintenance issues.

Figure 10.43. Small server room in Tenzing block and 18°C set point.

Computer rooms

There are dedicated computer rooms scattered around the school campus. These contain a high density of PCs which are typically thin client. During the walk through it was observed that the majority of these were switched off. The Facilities Manager indicated that there is software in place to automatically turn off these computers when they are not needed. However, this software does not seem to extend to other PCs on the site.

Figure 10.44. Computer room in Faraday block, all PCs were switched off.

Netbook charging stations

Classrooms in Tenzing and Austen blocks each contain a netbook station (Figure 10.45). These contain netbooks which can be easily accessed and distributed to pupils in the classroom when required. There are between 15 and 20 netbooks in each charging stations roughly equating to 1 for every 2 pupils. During the walk around it was observed that all of the netbook stations were left charging continuously. (Although the individual chargers do not draw much power, it is recommended that timer controls are fitted to these.)

Figure 10.45. Netbook station in Tenzing block and chargers plugged in, note that only two of the adaptors are on and charging.

Chemical store

Room F201 is a chemical store located in Faraday level 1. The room is small (around 6 m^2) and has various bottles kept in tubs on the left hand side. When the room was entered at around 7pm it was found that the night vent was open and the room was being mechanically ventilated. The room was fairly cold. It was also noted that heating pipes ended abruptly which may be related to the phased nature of construction or possibly an indication of change of use.

Figure10.46. F201 Chemical store Faraday block, note open night vent and mechanical ventilation panel which was extracting.

10.12.5 Energy and metering systems

Biomass boiler

The Facilities Team and the Finance Team seem to have lost confidence in the biomass boiler. They perceive that the maintenance burden is too large to practically deal with and have switched to the backup gas boilers as the primary means of heat generation. The Facilities Team have commented that they have to ‘baby-sit’ the biomass boiler when it is running and are regularly having to remove ash resulting from miss-fires. They have also had a problem disposing of the ash that the system creates: With no one willing to purchase it from them they were faced with unanticipated bills for disposal.

Preliminary findings from the BPE study may also have inadvertently contributed to the management team stopping use of the biomass boiler. Preliminary calculations were conducted and reported that indicated that the biomass boiler was only operating at 51% efficiency. However, the BPE team eventually concluded that this was not actually the case, rather the heat meters were probably reading incorrectly. It seems that the apparent 51% efficiency has been used as partial justification for not using the boiler. This highlights that BPE teams should be careful about relaying provisional information back to the client, as it can be used in making key decisions about building operation.

Figure 10.47. Biomass boiler, note the stain on the floor in front of the boiler indicating blow back.

10.12.6 Operation, maintenance and management

Operation of the various building services and systems around the school are under the control of the Facilities Manager. Day to day operation of fixed building services such as lighting and ventilation is generally controlled by the users although in some cases (such as the high level Sports Hall windows) specific items of equipment are controlled by the BMS (or in practice, manual override of the BMS by the FM). The Facilities Management Team comprises of a Facilities Manager and four full time caretakers, with a planned additional team member.

Cleaners start at the school around 4am, caretakers arrive from 7am, teachers and pupils from 7:45am. Pupils leave from 3pm, teachers can remain on site until 6pm - 7pm. The last caretaker leaves around 8pm.

The Facilities Management Team is capable and experienced. They tend to react to problems as they occur and they have many small maintenance tasks to carry out throughout the day. During the initial meeting with the Facilities Manager, team members returned from unblocking toilets and were then called out to change light bulbs. One member commented that there job role is no longer that of a caretaker. They have to be full time plumbers and electricians. They have commented that the level of complexity of the systems in schools has increased greatly since they started their careers.

APPENDIX 10.13: TEMPERATURE STUDY

10.13 Temperature study

It was initially planned to use the BMS to log room temperatures. However, available data from the BMS were incomplete. To provide some more reliable data on internal temperatures, 61 Dallas Semiconductor DS1922-F5 “i-button” temperature dataloggers were fitted around the campus. The longest data capture was 660 days, from April 2012 to January 2014, although additional monitoring was introduced as the project progressed meaning some areas have less data available. In addition, two dataloggers were fitted externally.

These data are useful in revealing the range of internal temperatures experienced in different types of room. The results can also be compared to the Building Bulletin 101 (BB101; DfES 2006) overheating criteria, with the caveat that these are design stage criteria rather than intended to assess performance in use. BB101 states that during a standard school day (09:00 to 15:30) for the period 1st May and 30th September there should be:

- less than 120 hours above 28°C internal air temperature;
- an average internal – external air temperature difference not exceeding 5°C;
- a maximum internal air temperature not exceeding 32°C.

Data capture during over 80% of school days was achieved in 37 rooms. Few of these rooms showed signs of overheating in terms of informal comparisons with the BB101 criteria. In fact, all of the rooms met at least two of the criteria. Only the catering office (A204) could be regarded as of potential concern, which was observed to have an average internal-external temperature difference of 6.5°C, 31.6°C maximum occupied temperature and 75 hours above 28°C. This room is further discussed later in this section.

No room exceeded 32°C during occupied hours. Statistics for rooms in which the occupied temperature exceeded 28°C are tabulated below, along with the other parameters for these rooms.

Detailed consideration of indoor temperature variations can reveal much about the success of the heating control strategy, in particular in the heating season when the effectiveness of optimum start / stop algorithms is revealed. Figures 10.48, 10.49 and 10.50 show typical weekly temperature profiles both in and out of term time in summer and winter, for the rooms in which the ventilation studies have been conducted (summertime data are not available for the art room L210).

In summer term time, Figure 10.48 shows a warm week in July (external temperature spikes are attributable to direct solar insolation on the sensor, which was located between Cade and the Sound House). Temperatures remain below 28°C in all of the rooms plotted except the Cade dining atrium.

Figure 10.49 is taken from the end of the summer holidays. External and internal temperatures are cooler during this period.

Table 10.8. Rooms in which internal occupied temperatures exceeded 28°C between 1st May and 30th September 2013.

		Statistics 1st May to 30th September 2013 09:00 to 15:30		
Room		**Hours > 28°C**	**Maximum °C**	**Average Internal – External °C**
A204	Catering office	75	31.6	6.5
A203	6th form common room	48	30.1	6.8
	Cade Atrium upper	47	30.6	6.6
A201	School office	41	30.1	6.3
	Cade corridor outside catering office	30	30.1	5.8
F212	6th Form seminar room	28	30.1	5.2
	Cade atrium lower	17	29.6	5.0
E109	Classroom	9	29.7	4.9
C108	Classroom	8	29.1	4.4
A1	Austen ground floor atrium	6	29.5	4.3
A101	Food tech room	4	28.7	4.4
L219	Office	3	28.6	4.0
C110	Group room	3	28.7	3.9
E102	Classroom	2	28.1	3.8
T2	Tenzing first floor atrium	2	28.1	5.6
	Cann Bridge circulation space	1	28.2	3.8

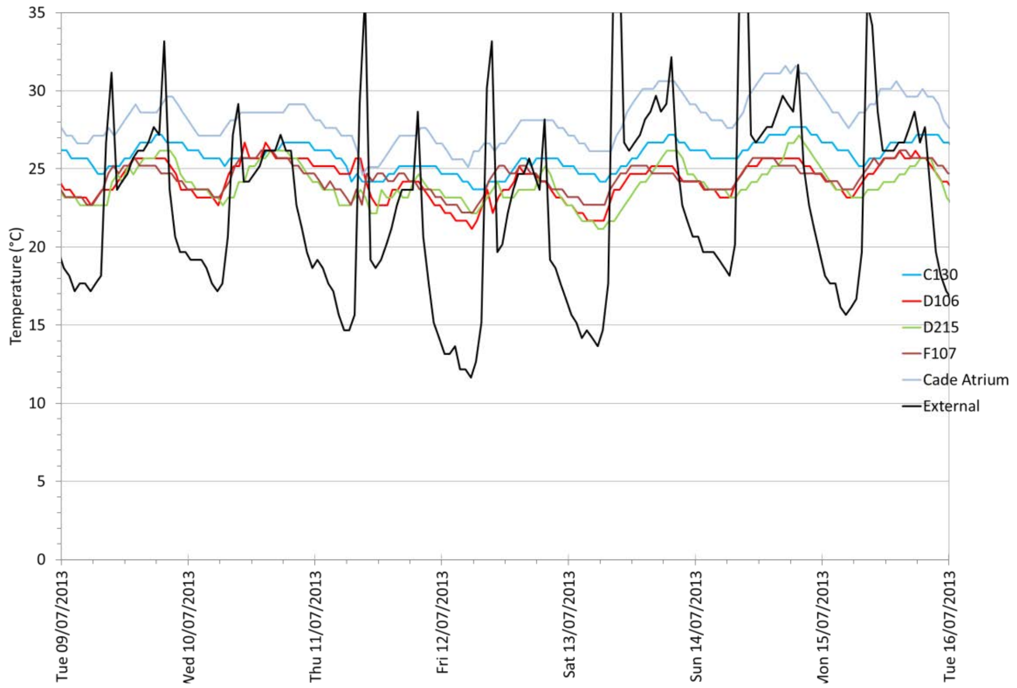

Figure 10.48. Typical temperatures for term time, summer 2013.

Figure 10.50 is for the end of the autumn term in 2013. External temperatures are relatively mild. The cooler rooms (F107 and D215) are seen to reach acceptable occupied temperatures of 18°C to 19°C at a reasonable time (08:30 to 09:00). Internal temperatures outside of occupancy are seen to be stable, indicating high standards of insulation or airtightness (assuming the heating system was not operating).

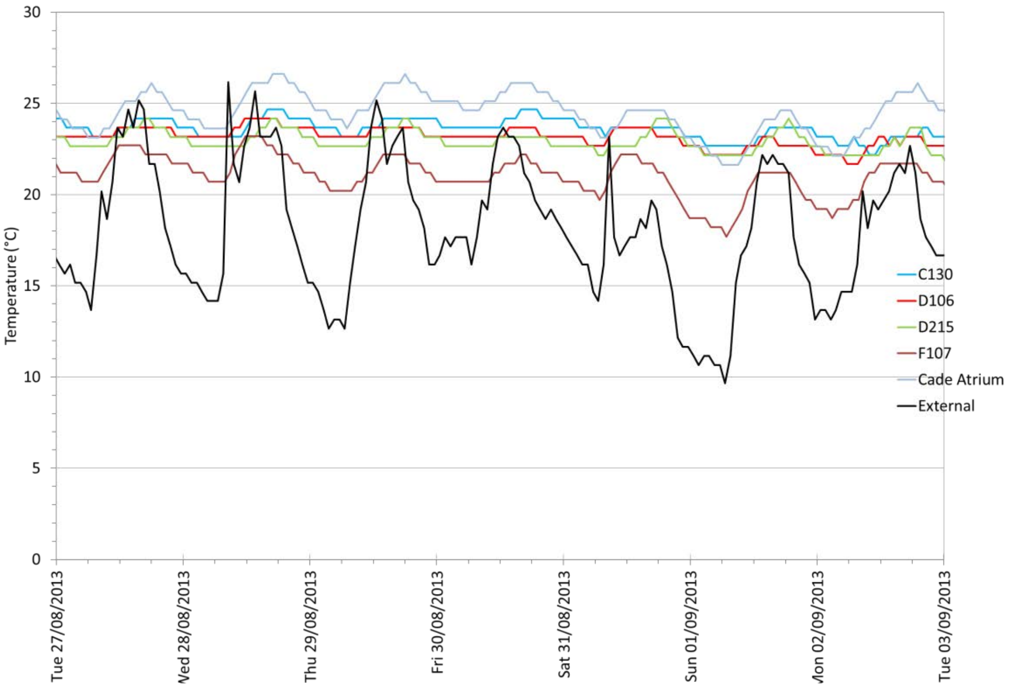

Figure 10.49. Typical temperatures for school holiday, summer 2013.

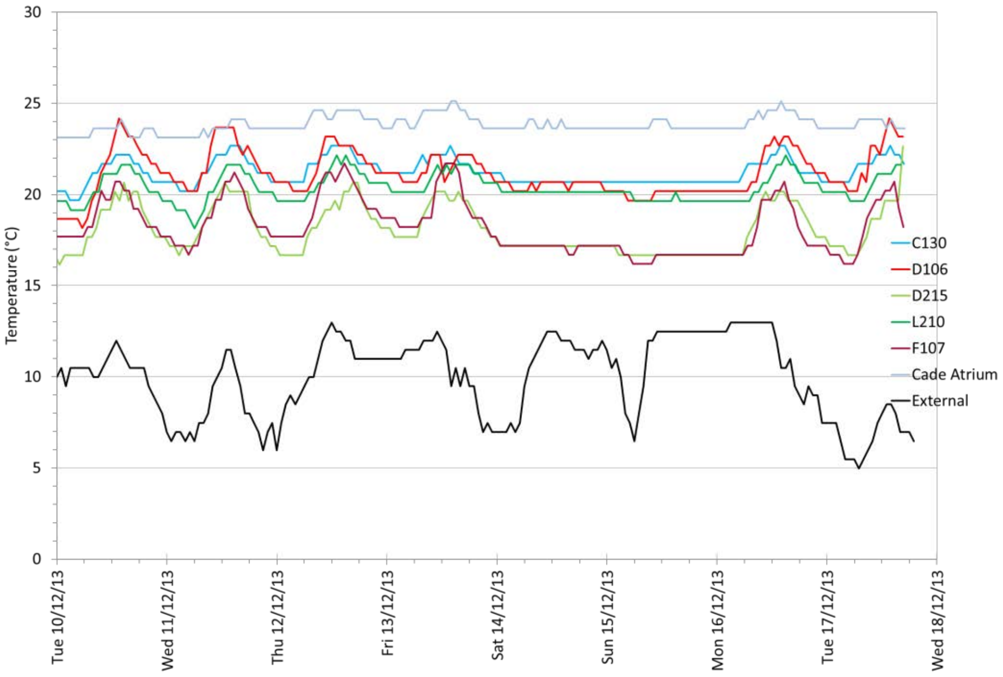

Figure 10.50. Typical temperatures for term time, winter 2013.

Figure 10.51 is taken during the Christmas holidays in the previous year (temperature monitoring ended in these rooms in December 2013). External temperatures were again relatively mild. Temperatures have not decreased below acceptable occupied levels even in the heavily glazed atrium. Solar gain is evident in many of the rooms.

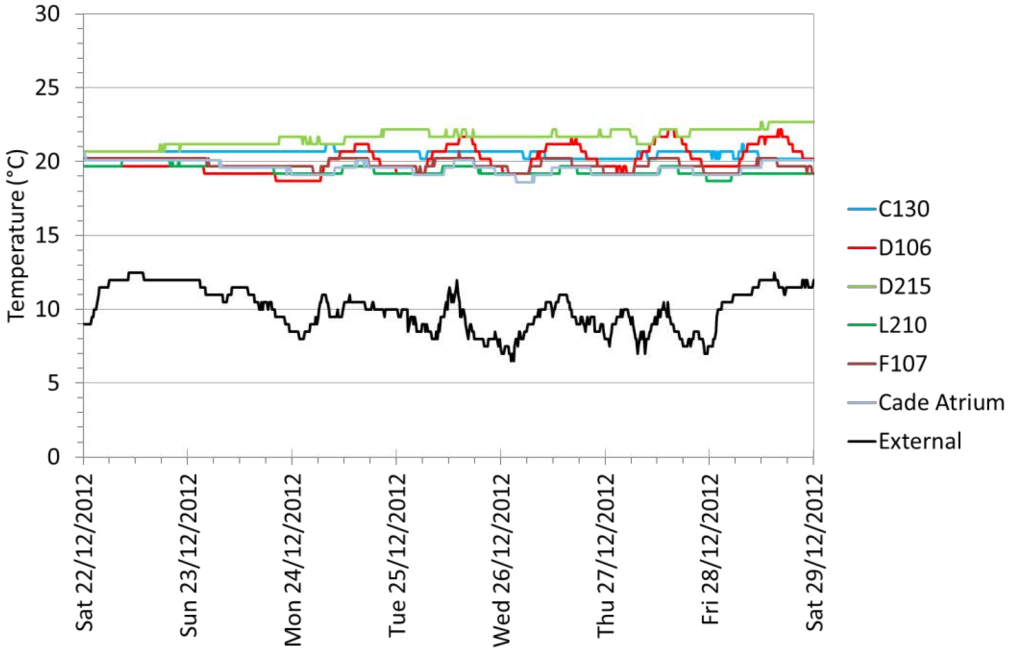

Figure 10.51. Typical temperature traces for school holiday, winter 2012.

One area that is reported to experience high internal temperatures is the first floor office space on the south façade of the Cade building. Air conditioning has been retrofitted in the IT support office, but not in the catering office, A204). Figure 10.52 shows the internal temperatures in these spaces in summer 2013. Extremely high temperatures are evident in the catering office, not dropping below 28°C during this hot week in summer. The air conditioning controls temperatures more than adequately in the IT support office: temperatures peak at 23°C, higher temperatures are likely to be tolerable. Temperatures in the server room are closely controlled to within tight limits (17.5°C to 19°C). Modern server equipment is likely to tolerate a more moderate cooling regime and current temperature guidance for server rooms suggests that cooling to a 19°C setpoint is no longer necessary (CIBSE Knowledge Series 18, 2012, states that 20°C to 25°C is appropriate, while ASHRAE suggests 18°C to 27°C). It is thought that a 1°C reduction in temperature may save between 4% to 5% of the cooling energy costs. The less stringent cooling requirements can often be met using passive or mixed mode systems.

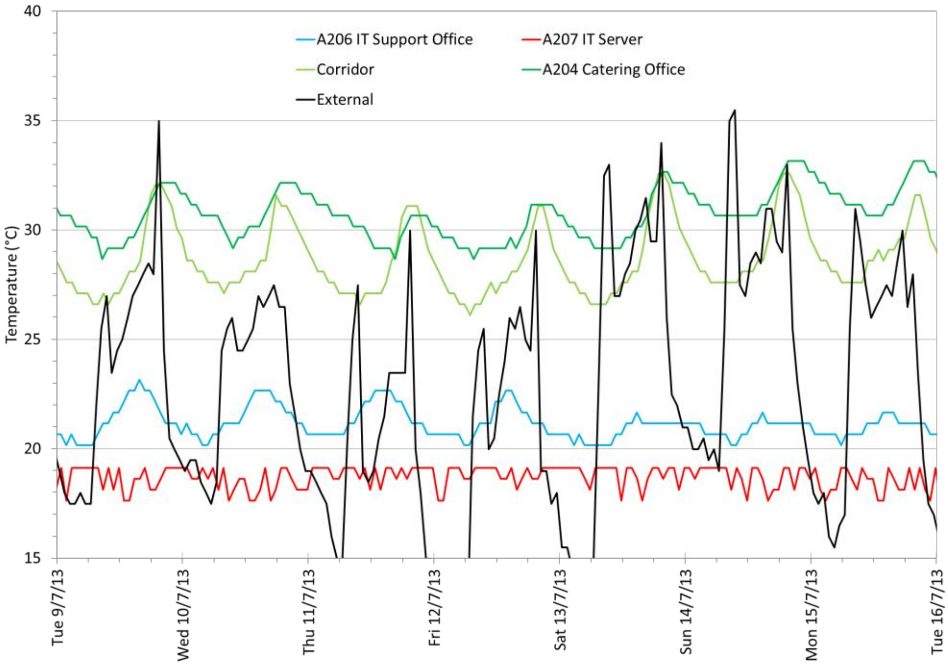

Figure 10.52. Typical temperatures for the office area in the south of the Cade building.

Degree day analysis is useful in revealing the base temperature—the external temperature above which space heating is not required. This is easily determined by plotting daily fuel consumption against daily mean external temperature and determining the temperature above which energy consumption is not temperature dependent. In the absence of daily fuel data (due to the incoming gas meter supplying the boilers not functioning on the BMS and the biomass heat meter being deemed unreliable), an alternative method of analysis has been applied. A performance line is obtained by plotting gas consumption between meter readings against degree days for each period. The base temperature used to calculate the degree days is adjusted until a straight line relationship is established between fuel consumption and degree days. The method is described in Section 5.3 of CIBSE TM46 (2006). The method returns the following base temperatures:

- 10°C for the Energy Centre;
- 11°C for the Sound House;
- 13°C for the nursery.

All of these base temperatures are relatively low as would be expected for well-insulated modern buildings. That for the Sound House may be low due to lower temperature setpoints being appropriate for performing arts (compensating for the lower insulation standards), and the higher base temperature in the nursery is likely to be a consequence of the higher internal temperatures required by the building’s use.

In summary, summertime overheating does not appear to be a problem generally, with the exception of certain office spaces in Cade with south-facing windows. Air conditioning in the IT server room and IT support office would appear to be controlled to unnecessarily stringent setpoints, which will have an energy penalty. The thermal behaviour of the building is consistent with a modern well insulated, airtight building: heat is retained effectively at night.

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[iii] CIBSE: The limits of thermal comfort: avoiding overheating in European buildings (2013).

[iv] BSI (2007) BS EN 15251: 2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (London: British Standards Institution).

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[vi] M. Eames, T. Kershaw and D. Coley *Building Serv. Eng. Res. Technol.,* 32 127-142 (2011)

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