BRE Scotland Innovation Park Visitor Centre

This document contains a Building Performance Evaluation report from the £8 million Building Performance Evaluation research programme funded by the Department of Business Innovation and Skills between 2010 and 2015. The report was originally published by InnovateUK and made available for public use via the building data exchange website hosted by InnovateUK until 2019. This website is now hosting the BPE reports as a research archive. As such, no support or further information on the reports are available from the host. However, further information may be available from the original project evaluator using the link below.

Innovate UK project number	450086
Project lead and author	BRE Scotland
Report date	2014
InnovateUK Evaluator	Unknown (Contact www.bpe-specialists.org.uk)

Building sector	Location	Form of contract	Opened
Visitor centre	Glasgow	Unknown	2012
Floor area	**Storeys**	**EPC / DEC**	**BREEAM rating**
110 m^2	Single	A / N/A	Outstanding

Purpose of evaluation

The Visitor Centre is a demonstration and test building to determine and display how effectively various products, materials and technologies operate in a live working environment. The BPE study identified a complex array of technologies required to operate together to provide a suitable environment for the occupants.

Design energy assessment	In-use energy assessment	Electrical sub-meter breakdown
Yes	Yes (2013-14)	No

Initial problems with the ventilation and heating systems were not resolved until May 2013. Further problems with the air-source heat pump and gas boiler system were found requiring two 2 kW electric heaters to be used to heat the Visitor Centre over the winter. A consequence of the heating system failure was a reliance on the kitchen kettle for provision of hot water. Although there was a secondary hot water circuit, linked to the solar thermal panel, it provided very little hot water. Users of the Visitor Centre used the kettle to create hot water for washing dishes and to clean the floor. In the second year of monitoring the metered electricity consumption was 72.3 kWh/m^2 per annum (TM22 estimation 104.9 kWh/m^2 per annum).

Occupant survey	Survey sample	Response rate
BUS, paper-based	6 staff, 12 visitors	N/A

The BUS Survey was undertaken over three days in order to capture the views of as many building users as possible. Six-monthly consultations with occupants have been undertaken to gain feedback from building users and identify changes in perception over time due to seasonal differences. The main users of the Visitor Centre, BRE staff who are based at the Centre full-time, were interviewed as a group to facilitate discussion around their experience of operating the building.

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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.

Contents

1 Introduction and overview

Technology Strategy Board guidance on section requirements:	This section of the report should be an introduction to the scope of the BPE and will include a summary of the key facts, figures and findings. Only the basic facts etc should be included here – most detailed information will be contained in the body of this report and stored in other documents/data storage areas.

The BRE Scotland Innovation Park, located on the site of the Ravenscraig regeneration development on the edge of Glasgow, aims to showcase the future of Scottish housing. The single storey, open plan Visitor Centre was the first building to be constructed on the Park and showcases the most innovative technologies and construction methods to a variety of audiences. The Visitor Centre acts as a demonstration and testing building to determine and display how effectively various products, materials and technologies operate in a live working environment. The purpose of the development is to research and disseminate results to inform the wider construction industry.

There are a number of key features that the building showcases, including:

- Highly insulated fabric;
- Airtightness target of 1 $m^3/(h.m^2)$ at 50Pa;
- Electrical energy provided via PV panels;
- Heating provided via an Air Source Heat Pump;
- Hot Water supplemented through Solar Water Heating;
- Mechanical Ventilation with Heat Recovery;
- Low water use specification including, 5/3 litre dual flush WCs, waterless urinals and low flow taps;
- Highly efficient lighting system, including BREEAM compliant zoning and occupant controls;
- Carbon Neutral EPC (A+);
- BREEAM New Construction 2011 ‘Outstanding’ rating at Design Stage.

The key aim of this Building Performance Evaluation (BPE) project is to evaluate the performance of the Visitor Centre, which BRE owns and operates.

From the series of BPE case studies, the Technology Strategy Board (TSB) aim to assemble a substantial body of data for many building types to draw generic conclusions on the performance obtained through various design strategies, building fabric, target performances, construction methods and occupancy patterns, handover and operational practices. These will be shared across the industry with a view to providing reliable information to enable improvements in the performance of new and refurbished buildings through specification, design, delivery and operation. This will help builders and developers to deliver more efficient, better performing buildings.

1.1 Summary of Key Findings

A thorough review of the performance of the Visitor Centre has been conducted, including energy performance, internal environmental conditions and occupant satisfaction. Each of these areas are covered in full in this report. Energy performance data will continue to be collected and analysed to provide two full years of information for comparison across seasons and over time. Occupant views will also be revisited as the building enters its second summer.

A review of the services in the Visitor Centre identified a complex array of technologies which are required to operate together to provide a suitable internal environment for the occupants in relation to temperature, humidity, lighting, air quality and noise levels. Initial problems with the ventilation and heating systems were not resolved until mid-May 2013. Further problems with the heating system were found in October 2013, requiring two 2kW electric bar heaters to be used to heat the Visitor Centre over the winter months.

In addition to a review of services, a series of 'spot checks' and other testing has been undertaken to ensure that the internal conditions are indeed satisfactory. The parameters that were tested including temperature, relative humidity, air quality, lighting levels and noise levels were found to be within acceptable ranges. Tests to confirm the energy efficiency of the Visitor Centre discovered that the 'as built' performance of the walls and roof are in line with the design U-values of the building fabric. However, thermographic surveys identified a number of cracks in the internal finish of the building and air tightness testing highlighted a number of potential air leakage points within the Visitor Centre including various penetrations within the service room. This led to an airtightness value of 4.04 $m^3/(h.m^2)$ at 50Pa being achieved, rather than the design value of 1 $m^3/(h.m^2)$ at 50Pa.

The Visitor Centre utilised a non-traditional procurement method, in that many of the materials and products were donated to the project. This has led to some difficulties with maintenance and warranties for the products used. The heating system and ASHP were replaced in early April 2014, as there was a communication fault identified between the ASHP and the boiler. An attempt was made to contact the manufacturers in order to have the system repaired, but eventually, a full replacement was seen as the best solution.

Feedback from occupants of the Visitor Centre has been gathered using the BUS survey, questionnaire (quantitative and qualitative questions) and interview / focus group workshops. The BUS survey was not found to be entirely appropriate for collecting feedback for the Visitor Centre, mainly due to the small sample of responses which resulted from the small number of potential respondents. The 'open' or qualitative questions in the questionnaire (completed in December 2012) gave occupants more scope for expanding on particular issues. The interview / focus group sessions held with key BRE staff members were useful for identifying specific problems. The main issues highlighted through all three methods related to:

- A lack of training for BRE staff received at handover, with relation to the operation of the building and its various systems.
- Space management, in particular a lack of storage space, was felt to be a problem. There were also problems highlighted with the open plan layout; some occupants felt that a physical division between the main event space and the staff area would be beneficial.
- The temperature within the Visitor Centre was felt to be satisfactory in the winter months, but overheating due to solar gain was identified as a problem in the summer, with glare also being cited as an issue.

- The IT facilities are felt to be poor and staff members cited them frequently as a hindrance to work and an on-going frustration.

Internal environmental performance has also been continually measured throughout the project. The main points to note from this monitoring are as follows:

- Temperature: Low readings (below 18°C) were only seen in quarter one (November – January) while the Visitor Centre presented overheating in the summer months.

- Relative Humidity: The majority of readings taken are within the recommended limits of 40% and 60% in quarters one, three and four (75%, 67% and 95% respectively). In quarter two, there were an unusually high number of low humidity readings, with only 29% within the recommended ranges.

- Air Quality: The mechanical ventilation (MVHR) was not operational until late May 2013, which may be part of the reason for the higher proportion of readings in quarter one which were above 600ppm. Overall, only around 0.5% of readings were above 1000ppm.

Energy consumption over the first 12 months in the Visitor Centre was greater than expected; 5,685kWh (7,380kWh including small power consumption) or 51.68kWh/m^2 compared to a design value of 13.75kWh/m^2. The main factor affecting energy consumption within the Visitor Centre is the presence of security staff overnight and at weekends, which was not considered or expected when initial calculations on energy consumption were determined. This has resulted in much higher consumption figures than were expected. Only considering core office hours (Monday – Friday, 9am – 5pm), the energy consumption over the first year of measurement is 11.78kWh/m^2 (see Figure 145). The second defining factor was the lack of on-going support for commissioning of the heating and ventilation systems in the initial months of occupation.

Related to this are specific problems with the heating unit which is fed by the ASHP and supplies the heating and supplementary hot water for the Visitor Centre. Initially, building users were dissatisfied with the heating and hot water provision and found that the unit presented frequent error codes and often needed reset. Only when new M&E contractors were appointed in May 2013 was it identified that the heating unit was incorrectly configured and was in fact set to run constantly. This was the reason behind the error codes, as the unit was overheating.

Once the M&E contractors had correctly configured the system, the unit worked successfully until a fault was found with the external ASHP unit in early October. This fault, related to the communication between devices, meant that the heating system, once again, did not work correctly. Following attempts to contact the manufacturer of the ASHP and boiler, it was agreed to replace both units in early April 2014.

In addition to the problems associated with the space heating and ventilation, a few other problems were noted including intermittent faults with external and internal lighting.

Air tightness testing also identified that the energy consumption for space heating will be increased compared to the expected values as there is greater air infiltration, causing cool external air to enter the Visitor Centre, and warm, internal air to escape. This will require the space heating to operate for longer to meet the temperature required by the occupants.

Water consumption has been measured in the Visitor Centre, as resource efficiency is an on-going theme within the Innovation Park. Overall water consumption was 267 litres per day, or 2.43 litres per day/m^2. Not including four isolated peak uses, the average water consumption for the other monitored months was 128 litres per day, or 1.25 litres per day/m^2. Monitoring of the water consumption allows for faults to be identified and can track patterns in excess consumption.

The key messages from this building performance review for BRE to consider are the provision of thorough training for all staff who frequently work in the Visitor Centre and user guidance for all services which will help staff operate the equipment and technologies appropriately. Seasonal commissioning and an on-going maintenance schedule will ensure all services work correctly in the future. BRE have found that energy monitoring has helped to identify operational problems. Occupant consultation has also been successful in identifying the key concerns of building users. It would be beneficial if the wider industry was also to adopt these ideas.

It is proposed that the results of this Building Performance Evaluation project are disseminated to encourage learning within BRE and across the industry. In addition, as the building hosts a number of visitors (around 3,000 to date), display boards highlighting the key findings from this research will be produced to disseminate the results as part of wider Innovation Park education and dissemination activities.

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

Technology Strategy Board guidance on section requirements:	This section of the report should provide comments on the design intent (conclusions of the design review), information provided and the product delivered (including references to drawings, specifications, commissioning records, log book and building user guide). This section should summarise the building type, form, daylighting strategy, main structure/ materials, surrounding environment and orientation, how the building is accessed i.e. transport links, cycling facilities, etc – where possible these descriptions should be copied over (screen grabs - with captions) from other BPE documents such as the PVQ. This section should also outline the construction and construction management processes adopted, construction phase influences i.e. builder went out of business, form of contract issues i.e. novation of design team, programme issues etc. If a Soft Landings process was adopted this could be referenced here but the phases during which it was adopted would be recorded in detail elsewhere. If a Soft Landings process was adopted this can be referenced here but the phases during which it was adopted would be recorded in detail elsewhere in this report and in the template *TSB BPE Non Dom Soft Landings report.doc*.

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

BRE Innovation Park @Ravenscraig

The BRE Scotland Innovation Park, located on the site of the Ravenscraig regeneration development on the edge of Glasgow, aims to showcase the future of Scottish housing. It presents innovative construction methods, products and technologies which will help to meet future energy targets and considers the wider themes of sustainability, affordability and community living.

Visitor Centre Design

It was important that the Visitor Centre, as the first building on the site and BRE's home on the Innovation Park, demonstrated high levels of performance in its own right. It was, therefore, designed to meet BREEAM Outstanding at Design Stage. Every effort was made to align with this strategy during construction.

The single storey, open plan Visitor Centre was the first building to be constructed on the Park and showcases its innovative technologies and construction methods to a variety of audiences. The Visitor Centre acts as a demonstration and testing building to determine and display how effectively various products, materials and technologies operate in a live working environment. The purpose of this development is to research and disseminate results to inform the wider construction industry.

The Visitor Centre is an offsite manufactured closed-panel timber frame structure which utilises a high percentage of home-grown timber in its components. All elevations are constructed using timber sourced from the North of Scotland and it demonstrates the successful use of local materials in the construction of a high performance building.

The 110m^2 Visitor Centre is situated at the South-East of the Innovation Park site (see section 10.1). Day-lighting studies were carried out during the design stage to ensure the maximum amount of natural light could be utilised without leading to overheating of the internal space. Full height windows cover the majority of the South-West wall which provides natural light, as well as offering extensive views over the wider Ravenscraig site. The solar gain through these windows also reduces the required additional heating load during the day.

The electric lighting is divided into three zones; the main event space, the adjacent office/kitchen area, and the bathroom and service zone. Within the main event space, the lighting can be further controlled to switch on/off or dim individual rows of lighting. The lighting for the bathroom and service area operates on a PIR detector and timer, ensuring that lights only come on when required and automatically switch off after a set time period.

The expected energy usage for the Visitor Centre was modelled at 13.75kWh/m^2 (1512.5kWh/yr). This figure does not include equipment used within the building.

The building is home to two full-time staff and has hot-desk space for other BRE staff. Many events and meetings have been held; around 3,000 people have visited since the opening in September 2012.

Construction Process

The building was completed with great contribution from the construction industry. Many of the materials and products used within the building were donated by suppliers who were keen to test and showcase innovative new products in a 'real life' setting. Industry partners were able to specify suitable products for all of the renewable technologies, under floor heating system, internal lighting, windows and doors, ceiling and flooring, plasterboard and kitchen furniture.

On-site ground works began in April 2012, while the timber kit was manufactured off-site in advance, ready for erection on site in May. The building was completed in August, ready for an official opening on 5th September 2012.

The cost of the Visitor Centre construction was approximately £250,000. BSW Timber provided home-grown timber from their mills at Fort William and Boat of Garten for the structural frame. Using Scottish timber in this type of non-domestic construction is quite innovative. It is hoped that it will act as a catalyst for the use of this material in the future.

Innovative phase change material, Micronal from BASF, was incorporated into the ceiling tiles provided by Armstrong, to absorb excess heat when necessary and emit it again during cooler spells. BASF also supplied a screed floor which adds thermal mass to the lightweight building.

Knauf Insulation's 'Perimeter Plus' blown fibre insulation, was installed using their 'Supafill' system. This process is normally undertaken on-site but installing it in the factory environment allowed for greater quality control and reduced cost.

Using Fermacell Greenline building board instead of regular plasterboard reduced lifetime costs for the Visitor Centre by reducing maintenance requirements. This product has a longer life span, and will require replacing less frequently during the life of the building, reducing on-going maintenance costs.

The Visitor Centre also features the first commercial use of home-grown FSC cross laminated timber (CLT) designed by Edinburgh Napier University's Institute for Sustainable Construction. The panels are left as an exposed feature wall and are used for structural racking, thermal mass, sequestering carbon and for its hygroscopic qualities.

The design team were keen to demonstrate the benefits of off-site manufacturing. The process within CCG's OSM factory is streamlined and efficient; all individual components are scheduled from the architect's drawings and cut to specification by the factory machinery before being fitted together. A small on-site team oversaw the main kit installation process with exterior walls and roof erected in a single day, allowing follow-on trades to begin work quickly.

Building Access/Transport

The Innovation Park @Ravenscraig is easily accessed from the motorway network, allowing travel from the major cities and population centres. As the wider Ravenscraig site is currently at the early stages of a major regeneration, public transport links are not yet developed. However, a new train station is planned for Ravenscraig, and there are existing railway stations within two miles of the site.

The Visitor Centre is situated immediately adjacent to the car parking facilities in the Innovation Park and cycle storage is also provided.

2.2 Conclusions and key findings for this section

The Visitor Centre utilised a non-traditional procurement method, in that many of the materials and products were gifted to the project. The use of off-site manufacturing was vital to the success of the build and has ensured for a higher quality finished product.

As the wider Ravenscraig area is not yet fully developed the public transport options are currently limited, but it is hoped that the provision will improve as the area continues to grow.

The design intention of the Visitor Centre was to ensure that service needs were reduced, e.g. by having large windows to increase natural light and encourage solar gain. This has been the case, but has also caused problems as can be seen in section 10.7.

The unusual procurement methods, while necessary to ensure the building was constructed, have caused problems around repair and maintenance of equipment as detailed in section 7. This was not foreseen by BRE, but experience in this project would potentially cause for this to be approached differently in the future.

Some of the products and materials were included in the Visitor Centre construction to test and demonstrate their capabilities. It is hoped that BRE will undertake specific testing on some products to determine their performance and impact on the wider Visitor Centre in the future.

As the wider Ravenscraig site continues to develop, it is expected that the public transport provision will improve. Construction of housing in the immediate vicinity has begun in recent months, with some properties now occupied. This will encourage local public transport operators to consider the area.

3 Review of building services and energy systems.

Technology Strategy Board guidance on section requirements:	This section should provide a basic review of the building services and energy related systems. This should include any non-services loads – which would therefore provide a comprehensive review of all energy consuming equipment serving the building or its processes. The key here is to enable the reader to understand the basic approach to conditioning spaces, ventilation strategies, basic explanation of control systems, lighting, metering, special systems etc. Avoid detailed explanations of systems and their precise routines etc., which will be captured elsewhere. The review of these systems is central to understanding why the building consumes energy, how often and when.

3.1 Review of building services and energy systems

The building services at the BRE Visitor Centre include:

Supply

- Air Source Heat Pump (ASHP);
- Photovoltaic (PV) Array;
- Solar Thermal system.

Delivery

- Under floor heating;
- Mechanical Ventilation Heat Recovery (MVHR);
- Energy efficient lighting;
- Water efficient fittings.

The building also features a comprehensive monitoring and control system to achieve optimum performance of all building services. No mechanical cooling system is present.

3.1.1 Low and zero carbon technologies

The BRE Visitor Centre makes full use of low and zero carbon (LZC) technologies. See Figure 1 for the schematic layout of the system.

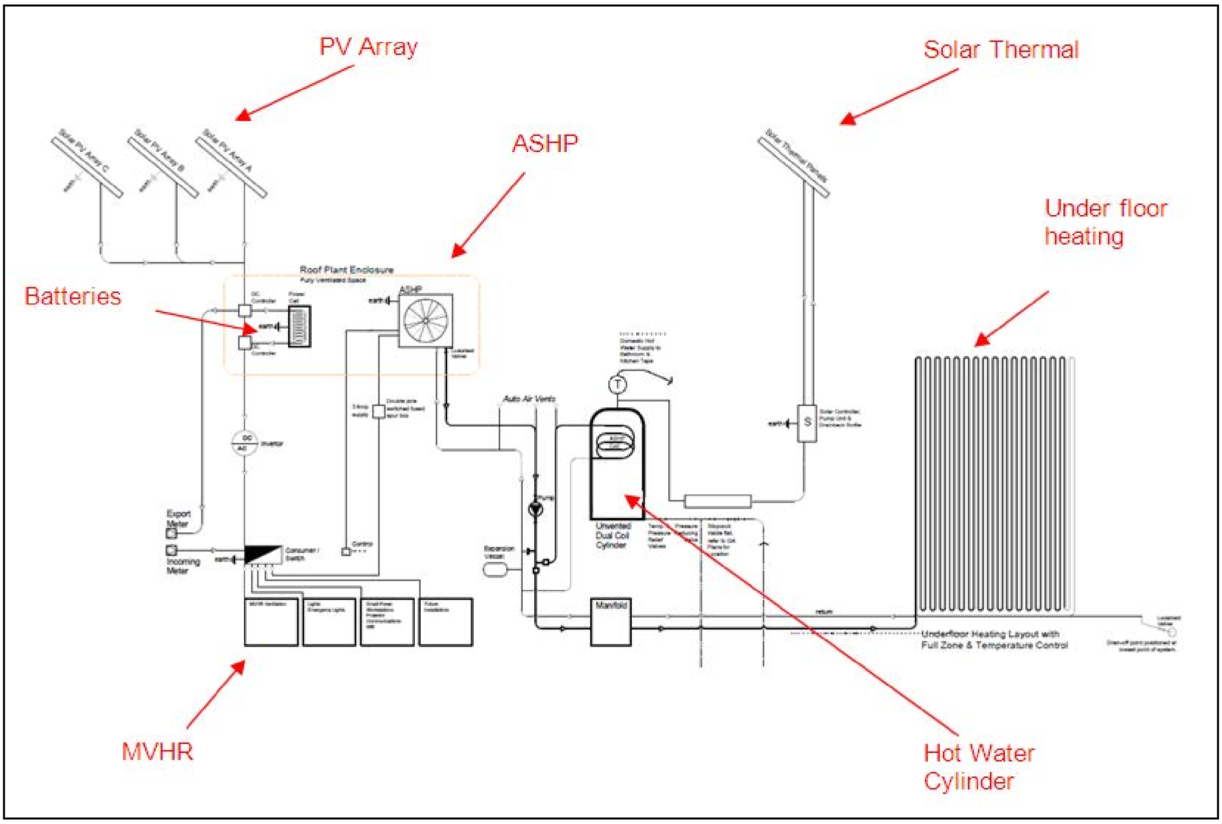


Figure 1: LZC Technology Schematic

3.1.1.1 ASHP and MVHR

The heating system at the BRE Visitor Centre combines an Air Source Heat Pump (ASHP) with under-floor heating and a Mechanical Ventilation Heat Recovery (MVHR) system which serves the whole building.

The original 8.5 kW ASHP (Mitsubishi Ecodan EHPT20X – VM2HA) was located on the roof and was connected to a 210 litre unvented coil cylinder located in the plant room. This distributed heat to the whole building via a manifold to the under-floor heating system which is capable of maintaining a temperature of 21°C in the main space of the building and 18°C in the service area when the outside ambient temperature is -1°C. Below this temperature the electric coil in the hot water cylinder will compensate. The system includes full zone and temperature control.

Following a fault in communication between the Mitsubishi ASHP and cylinder, both were replaced in April 2014. The new ASHP is a Glow worm Envirosorb 5, with a Glow worm Fluryocl$_2$ cylinder and associated hydraulic module. These new units have been commissioned to work as before, providing heating to the Visitor Centre via the underfloor heating.

Figure 2: ASHP Cylinder Unit

Figure 3: Manifold for under-floor heating

Figure 4: ASHP unit on roof

Figure 5: MVHR unit in plant room

The MVHR (Nuaire MRXBox95 – WH1) is located in the plant room at the south east of the building and is installed in accordance with guidance in BRE Digest 398. It has a maximum performance of 110 l/s.

A total of six extract grilles for the system are located as follows: one in the lobby, four in the WC's (one in each) and one in the kitchen area. A total of seven supply diffusers are located in multi-use areas within the Visitor Centre; six in the main area and one in the smaller adjacent area. Each supply diffuser features a volume control damper to adjust the flow of air. The vents are currently set to run at 6 l/s in all areas of the building, except the kitchen, which runs at 8 l/s. The MVHR has a system efficiency of up to 95% (typical MVHR efficiencies vary between 90 – 95%); with a Specific Fan Power (SFP) of 0.4. The SFP is a measure of the electric power that is needed to drive a fan, relative to the amount of air that is circulated through the fan. It is not constant for a given fan, but changes with both air flow rate and fan pressure rise.

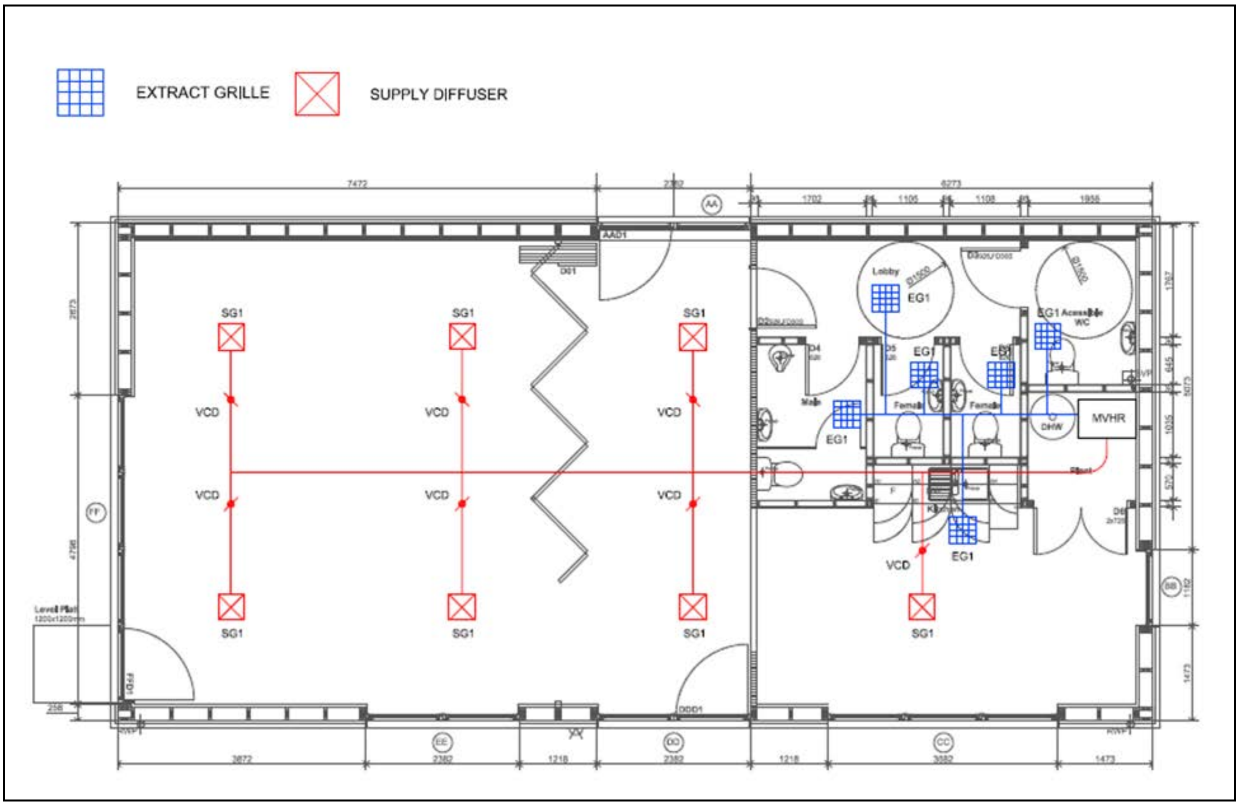


Figure 6: MVHR Schematic

Advantages

The main benefits of an ASHP are the relatively low installation cost, long life expectancy and low maintenance costs. They also generate more energy than they use, and produce no local pollution. MVHR systems improve the indoor air quality and reduce relative humidity and condensation within a building. They can also improve energy efficiency as they recover heat from warm areas of the building and exchange this with fresh air from outside. Underfloor heating has many benefits including the relative ease of installation in a new build and the consistent and comfortable heating provision it affords.

In the Visitor Centre, these technologies will work together to provide effective and efficient heating and ventilation whilst maintaining good indoor air quality.

Disadvantages

A possible disadvantage with ASHP's is that the quoted COP[1] data can differ significantly from the actual design and operating conditions. For example, actual flow temperatures; the surface area of under-floor heating and actual heating requirements can affect the efficiency of the system. At the BRE Visitor Centre these factors have been taken into account to achieve the optimum ASHP system efficiency.

Disadvantages associated with MVHR systems are that the building must be airtight and have thermal efficiency. The system must also be designed specifically for the building (with the correct locations of extractor/supply ducts).

[1] COP: Coefficient of Performance

These issues have been taken into consideration for the MVHR system at the BRE Visitor Centre, with a target of 1 $m^3/(h.m^2)$ at 50Pa for air tightness – a target which was tested (see section 3.1.8).

The main disadvantage of under-floor heating is its slow response to heating up and cooling down. Therefore it is not efficient if used infrequently or if the controls are not correctly understood or used.

3.1.1.2 Photovoltaics

A 4.5 kW photovoltaic (PV) array (south facing, 30° tilt angle) is located on the roof of the Visitor Centre. This consists of 18 Suntech 250 W panels (STP250S – 20/Wd).

Figure 7: PV array on roof

The system features a Victron Energy Phoenix Inverter to convert the DC current produced by the panels to AC current. This can either be used to meet the electrical load in the Visitor Centre or sold back to the grid.

The PV system also features a comprehensive battery facility for storing energy. This features:

- Outback Power Systems Flexmax 80 (FM80 – 150 VDC) Maximum Power Point Tracking (MPPT) Charge Controller;
- Victron Energy BMV 600S Battery Monitor;
- 6 x Surrette Battery Company Deep Cycle Series 5000 Batteries.

It is the purpose of the MPPT Charge Controller to sample the output of the PV array and apply the proper resistance (load) to obtain maximum power for any given environmental condition. The Charge Controller and Battery Monitor are located in the plant room. The batteries are located in an external shed, as seen in Figure 10.

An intelligent monitoring and control system will determine when energy should be stored in the batteries; used to meet the electrical load of the Visitor Centre; or exported to the grid. This monitoring system is part of a separate European research project, which has been run at the same time as this BPE project.

Figure 8: PV Charge Controllers

Figure 9: Battery Monitor

Figure 10: Battery Enclosure

The main benefits of photovoltaics including the flexibility of grid connection or battery storage and low maintenance requirements have been valued in the Visitor Centre. The disadvantage of intermittent energy production has been mitigated in the Visitor Centre by the use of a battery system for storage. The relatively high capital cost of the technology was felt to be worthwhile for the environmental benefits.

3.1.1.3 Solar Thermal

A 3.3 m^2 flat plate solar thermal collector (south facing, 30^o tilt angle) is located on the roof of the Visitor Centre. The pump and control unit (Solar Logic Controller) are located in the plant room.

This is connected to a Willis Solasyphon heat exchanger, and is used to meet the domestic hot water (DHW) demand of the Visitor Centre.

Figure 11: Solar Thermal Flat Plate Collector

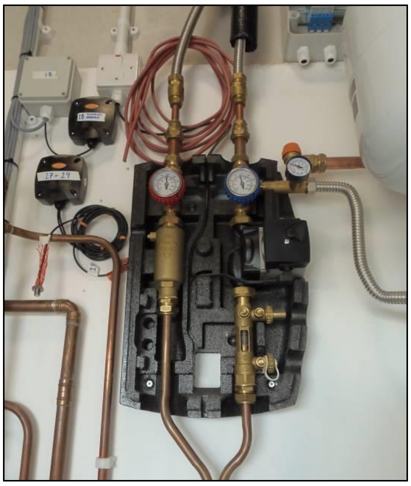


Figure 12: Solar Thermal Pump Unit Figure 13: Solasyphon Heat Exchanger

The main benefits of solar thermal are their generally low maintenance requirements, and their long life expectancy. As they can meet between 50 – 65% of annual DHW demand, using them in the Visitor Centre was vital to reduce grid electricity consumption and associated carbon emissions, despite solar thermal being less effective during the winter. This drawback required the use of a secondary electric coil water heating system.

3.1.2 Controls and Zoning

The Visitor Centre has been divided into two separate under-floor heating zones; with an occupant adjustable thermostat (T) for each zone. The BRE Visitor Centre allows separate occupant control of each perimeter area (within 7m of each external wall).

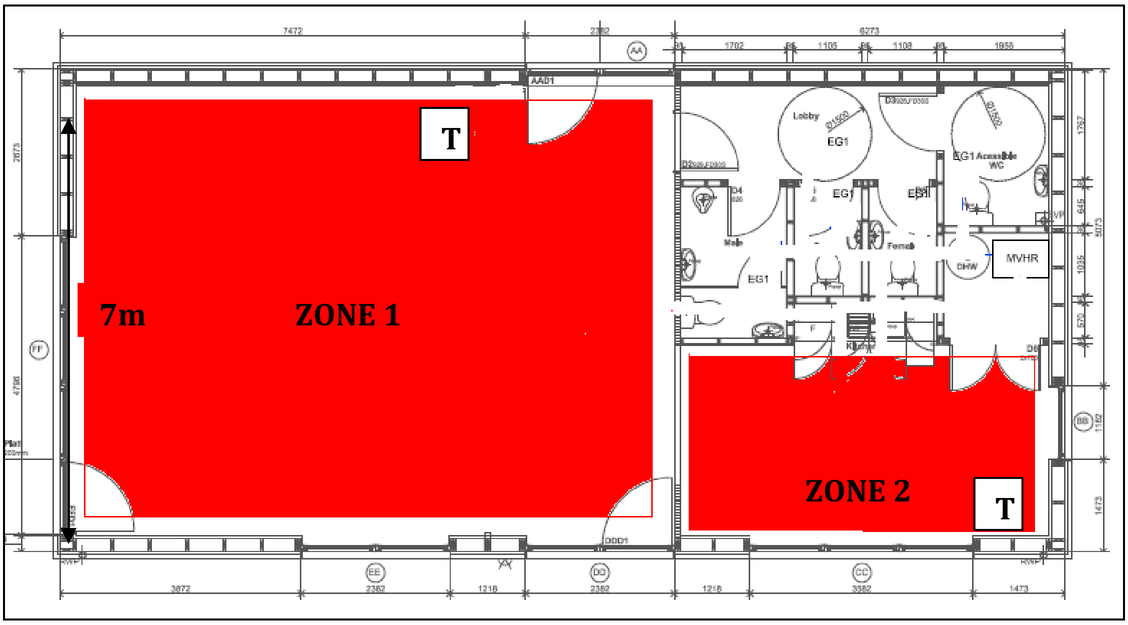


Figure 14: Heating Zones

Figure 15: Heating Zone 1

Figure 16: Heating Zone 2

3.1.3 Lighting

A comprehensive lighting system is installed at the BRE Visitor Centre. See Figure 17and Figure 18 for a detailed plan, schedule and legend. The lighting has been specified in accordance with CIBSE best practice guides both internally and externally. Internally, daylight sensors and occupancy detection devices have also been installed in service and utility areas to help ensure that artificial lighting levels are not surplus to requirements, thus reducing the environmental impact and reducing energy consumption where possible.

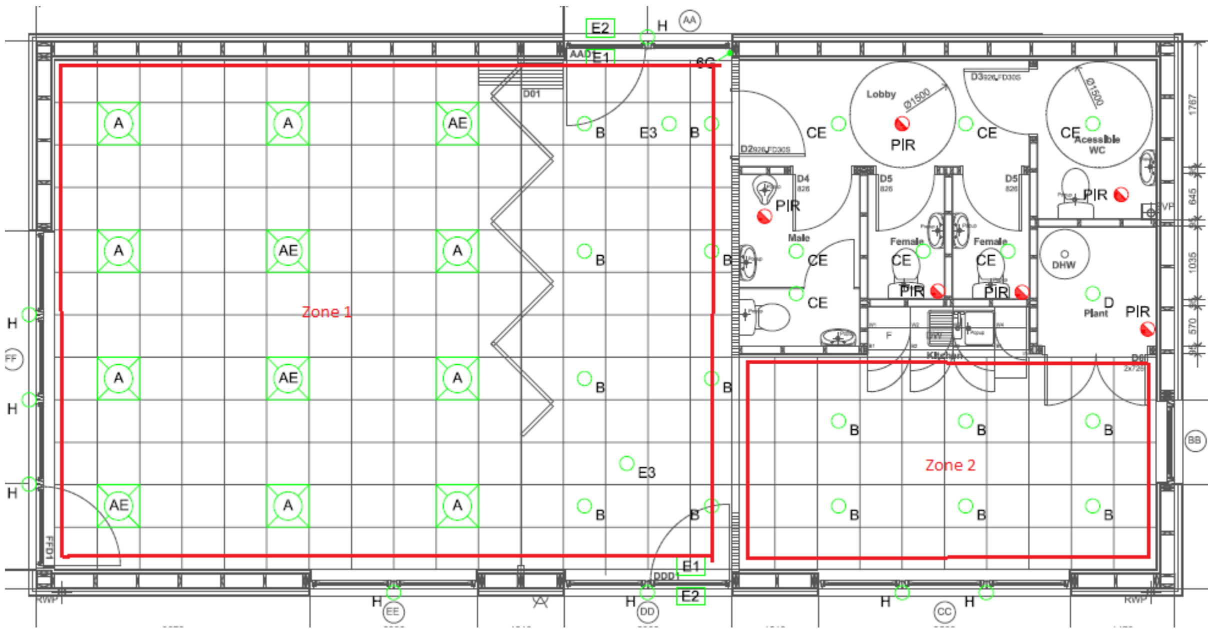


Figure 17: Lighting Schematic

Lighting has been zoned by area and occupant control panels are provided to allow users to adjust levels and arrangements as required. The level of control and zoning varies from space to space depending on the complexity of requirements.

REF	DESCRIPTION	MANUFACTURER	RANGE
A	600mm x 600mm SEMI RECESSED LED MODULE	THORN LIGHTING	ELEVATION LED
AE	600mm x 600mm SEMI RECESSED LED MODULE C/W EMERGENCY CONVERSION KIT	THORN LIGHTING	ELEVATION LED
B	HIGH OUTPUT RECESSED LED DOWNLIGHT	THORN LIGHTING	CRUZ LED
BE	HIGH OUTPUT RECESSED LED DOWNLIGHT C/W EMERGENCY CONVERSION KIT	THORN LIGHTING	CRUZ LED
C	RECESSED LED DOWNLIGHT	THORN LIGHTING	CHALICE LED
CE	RECESSED LED DOWNLIGHT C/W EMERGENCY CONVERSION KIT	THORN LIGHTING	CHALICE LED
D	CEILING MOUNTED VANDAL RESISTANT LED LUMINAIRE	THORN LIGHTING	LEOPARD LED
E1	HIGH PERFORMANCE LED EXIT SIGN C/W RUNNING MAN LEGEND	THORN LIGHTING	VOYAGER SIGMA
E2	IP65 RATED LED EMERGENCY BULKHEAD	THORN LIGHTING	VOYAGER E LED
E3	DISCRETE HIGH PERFORMANCE LED EMERGENCY LIGHT	THORN LIGHTING	VOYAGER LED
H	EXTERNAL HIGH EFFICIENCY FIRE RATED LED DOWNLIGHT	THORN LIGHTING	LIGHT STREAM 2

Figure 18: Lighting Schedule

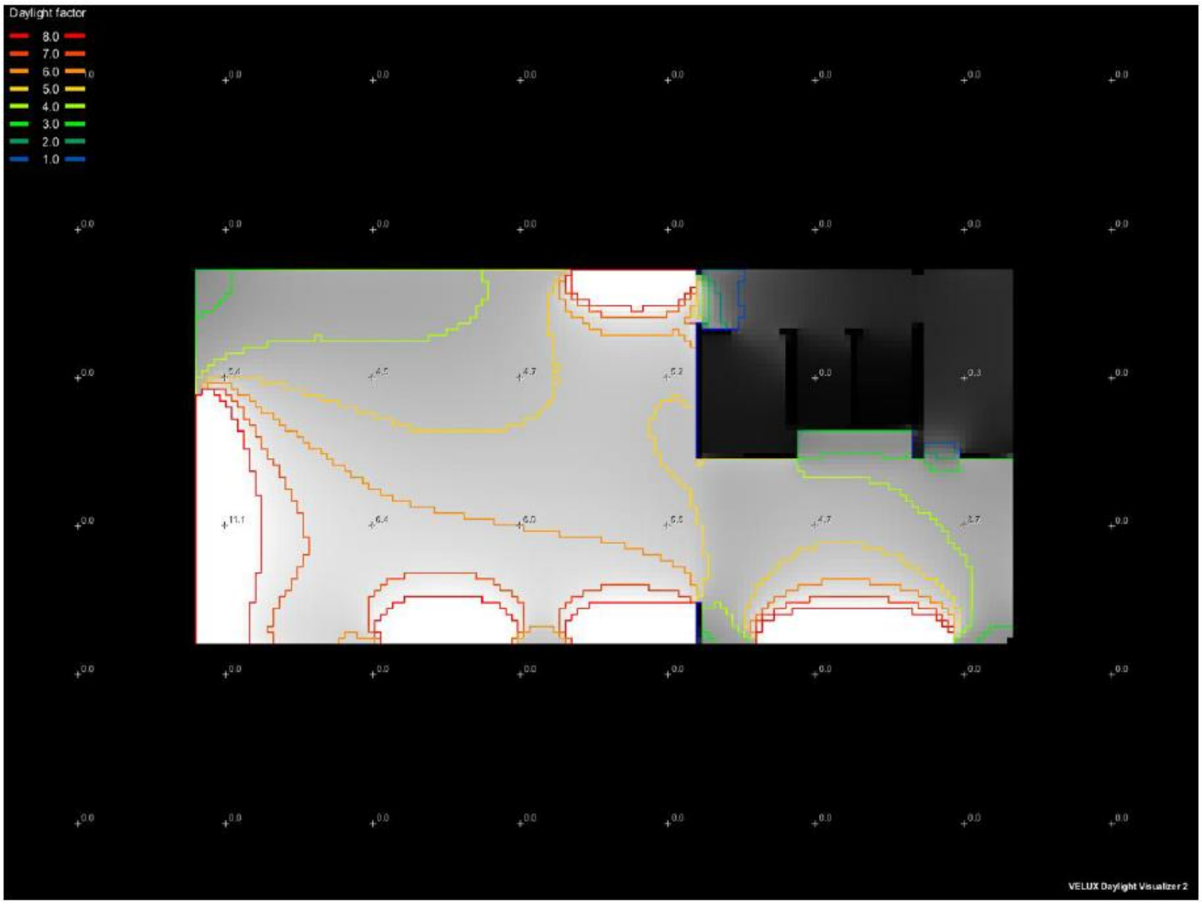


Figure 19: Daylight Study

The Visitor Centre makes full use of daylight to minimise lighting requirements and also features high frequency ballast lighting to maximise user comfort.

BS8206-2:2008 Lighting for Buildings, states that best practice is defined as at least 80% of the floor area with an average daylight factor of 2% or more. From the day-lighting analysis conducted at the Visitor Centre; a total of 100% of the occupied building area was found to receive a daylight factor of 2% or greater with an average daylight factor above 4%.

3.1.4 Water

The following low water use sanitary fittings were specified for the Visitor Centre.

	No. of	Volume / Flow
WCs	4	5/3 dual flush
Urinals	1	Low flow
WHB Taps	5	1.5 litres per min
Kitchen Taps	1	2 litres per min

Figure 20: Water Using Devices

There is a water meter on the mains water supply to the Visitor Centre. The only water consuming areas are a small toilet block and a sink in the staff kitchen area. It is not therefore considered efficient to separately sub-meter these areas given the size and nature of the building. The meter has a pulsed output to enable connection to a Building Management System (BMS) for the monitoring of water consumption.

3.1.5 Scientific Readings

As a part of BRE's Building Performance Evaluation of the Visitor Centre, a number of scientific readings were taken to help to establish the performance of the building in terms of:

- Temperature,
- Humidity,
- Air Quality,
- Lighting Level,
- Noise Level / Acoustic Performance.

These were taken using handheld equipment and effectively provide a 'spot check' for the key issues that create an optimal internal environment for building occupants. The results of these measurements and comparative information are detailed in Appendix section 10.2, with key findings outlined below.

The first 'spot checks' for the Visitor Centre were carried out at approximately 13:00hrs, on Thursday 10th of January 2013. Weather conditions were dry, although cloudy with some fog earlier in the day. The external temperature was slightly above the typical level for that time of year, with a temperature of around 12°C recorded.

Internal temperatures were found to be within the recommended thresholds of 18 to 21°C, however, the Visitor Centre was not fully occupied and if this area was at maximum capacity there would be considerable latent heat gains from the occupants. Generally the level of relative humidity was between 45 to 50%, falling within the recommended limits. There are no concerns regarding the level of humidity within the Visitor Centre.

The level of CO_2 within the internal spaces ranged from between 785 and 834 ppm during the observational site visit to the Visitor Centre. For all areas the CO_2 levels were below the recommended maximum level for comfort and productivity (1000 ppm).[2]

Natural light is plentiful and well utilised within the Visitor Centre. When necessary, artificial lighting can be used to supplement this.

Within the Visitor Centre, noise levels were recorded as being relatively low and generally within the recommended limits for office space, and considerably below the threshold for hearing damage. It is important to note that at the time of the survey, occupancy was minimal, and as such noise levels were expected to be low. External noise levels were reasonably high (58 dB) as construction of the AppleGreen Home was underway adjacent to the Visitor Centre. However, there appears to be little noise transference from external sources to inside the Visitor Centre.

The second spot check measurements were taken at 12.30hrs, on Friday 20th June 2014. Weather conditions were sunny and bright, with an external temperature of 24.2°C.

Internal temperatures during this visit were higher (21.8 – 24.1°C) than the recommended maximum of 21°C, despite windows and doors being open. Relative humidity was generally within recommended levels.

Natural light was again plentiful and noise levels were generally low, though there was a low occupancy in the Visitor Centre at this time. Full details of both spot check visits can be viewed in section 10.2.

3.1.6 Thermography Survey

Infrared thermography is the process of using a thermal imaging camera to view images of the heat patterns emitted from a surface or surfaces. In this context, this information enables BRE to identify particular patterns of heat radiation that indicate faults or areas of interest. These include:

- Continuity of insulation,
- Dampness,
- Air leakage,
- Poor energy efficiency,
- Blocked pipes and ducts.

The closed panel timber frame system was manufactured off-site using advanced technology and an automated production line. In theory, this should enable the insulation to be installed without any breaks or gaps.

To establish if the actual thermal performance of the Visitor Centre relates to the as designed thermal performance, thermal imaging was undertaken. Using a thermal imaging camera, any problematic areas of

[2] In addition, it was later identified that the ventilation system was not in operation at the time the spot checks were carried out. The ventilation system, when operational, would generally work to improve the air quality.

the Visitor Centre are identified by warm spots on the outside of the building fabric or cold spots internally. Details of the thermography testing and the results are shown in section 10.3.

Acceptable continuity of insulation was identified using the thermal camera, with uniform temperatures found across all external surfaces. The highest temperatures recorded on the external surfaces were through the window and door frames, as is to be expected.

A number of areas were identified as having lower surface temperatures throughout the inside of the building, primarily at junctions where some cracks have appeared. The significance of these cracks, when compared with the as designed performance, will be determined through the air tightness testing results, but recorded temperatures are considered to be lower than expected.

3.1.7 U-Value Testing

In practice, the true U-value can be higher than the theoretical calculation, especially when workmanship is poor or when there are unintended or unexpected air gaps between and around sections of insulation.

The presence of mortar snots, wall ties or other debris within cavities could also lead to the actual U-value being higher than the calculated value – although given the nature of the construction of the Visitor Centre this is unlikely.

The thermal imaging allows users to be able to highlight any problem areas in terms of the thermal performance of the fabric; however, to obtain a more accurate conductivity analysis of the building fabric, in-situ U-value testing is required. U-values are a measurement of a building fabrics thermal performance. U-value testing was carried out on the external walls and roof of the Visitor Centre.

Temperature and heat flow measurements were taken for a period of two weeks, then calculations undertaken to establish the measured U-value. The testing gave results in line with the design U-value. Full methodology and results can be seen in the Appendix (section 10.4).

3.1.8 Air Tightness Testing

Infiltration of the cold outside air into warm internal spaces can significantly reduce the internal temperature within a building. Reducing the internal temperature means the heating system will be operating unnecessarily to heat the space to the required temperature. Additionally, heat can be lost directly to the outside.

Infiltration generally occurs through gaps and penetrations of the buildings envelope. Gaps often occur during the construction of the building, however, the off-site manufacturing process used for the Visitor Centre was developed to minimise this. This is also the case for penetrations during the plumbing and electrical fixings.

Air leakage commonly occurs in the following locations:

- Interfaces between materials and building elements, (e.g. windows to wall);
- Penetrations through the building envelope;

- Wall to roof junctions;
- Across cavities.

These causes are generally as a result of:

- Poor design;
- Poor build quality;
- Lack of responsibility for sealing between elements or round penetrations;
- Areas hidden by internal finishes that do not form part of the air line (i.e. suspended ceiling tiles).

The modular closed wall and roof panels of the Visitor Centre were designed to provide a designed air tightness figure of 1 $m^3/(h.m^2)$ at 50Pa. It was expected that the design rate would be achieved.

Air tightness testing was carried out twice within one day, with similar results each time as can be seen in Figure 21.

Test No.	Air Tightness Result
Depressurisation	3.78 $m^3/(h.m^2)$ at 50Pa
Pressurisation	4.35 $m^3/(h.m^2)$ at 50Pa
Average	**4.04 $m^3/(h.m^2)$ at 50Pa**

Figure 21: Airtightness Testing - Test Results

Air tightness testing results showed that the Visitor Centre has an average air tightness of 4.04 $m^3/(h.m^2)$ at 50Pa. This is considerably worse than was predicted, or committed to, by the contractor. The methodology and full results of the air tightness testing are explained in section 10.5.

The key issues which are felt to have affected the airtightness in the Visitor Centre are:

- Hairline cracks between the plasterboard due to differential movement of the timber frame;
- Penetrations in the building fabric within the plant room (partly due to retrofit work).

3.2 Conclusions and key findings for this section

A review of the services in the Visitor Centre has identified a fairly complex array of technologies which are required to operate together to provide a suitable internal environment for the occupants in terms of temperature, humidity, lighting, air quality and noise levels. Problems with the ventilation and heating systems were not resolved until after this review was undertaken. Further details of these specific issues can be seen in section 6.3 and section 10.9.

In addition to the review of services, a series of 'spot checks' and other testing has been undertaken to ensure that the internal conditions are indeed satisfactory. Temperature, relative humidity, air quality, lighting levels and noise levels were all tested and were found to be within industry acceptable ranges.

Tests to confirm the efficiency of the Visitor Centre highlighted the following points:

- 'As built' performance of the walls and roof are in line with the design U-values of the building fabric;
- The thermographic survey identified a number of cracks in the internal finish of the building;
- Air tightness testing highlighted a number of potential air leakage points within the Visitor Centre including various penetrations within the service room. This led to an airtightness value of 4.04 m^3/ (h.m^2) at 50Pa being achieved, compared to the design value of 1 m^3/ (h.m^2) at 50Pa.

There is no BMS (Building Management System) in the Visitor Centre; as it is a very small and simple building, it was not deemed necessary. However, the variety of services and products which operate the Visitor Centre are relatively complex, and perhaps a BMS would have simplified the control of the building. Alternatively, a BMS could have just become another system to be understood by the building users.

Two separate spot check sessions were conducted, one in winter and one in summer, to measure internal temperature, air quality, humidity, luminance and noise levels. The winter spot check presented no issues, while the summer spot check indicated that the internal temperatures were above the recommended maximum, close to the external temperature of 24.2°C. The issue of solar gain is yet to be resolved. External solar shading would ideally resolve the problem; allowing plenty of light in, but reducing the solar heat gain.

During as-built testing, a number of cracks were identified during thermographic surveying. In the air-tightness test, the Visitor Centre was identified to be less air tight than expected (4.04 m^3/ (h.m^2) at 50Pa compared to 1 m^3/ (h.m^2) at 50Pa) and these cracks are likely to have contributed to this, along with unsealed openings in the service / plant room. BRE intends to undertake further testing to identify areas where air gaps exist and allow for remedial action to take place. This is done by repeating air-tightness testing and using a smoke pencil to locate air flow at leakage points.

4 Key findings from occupant survey

Technology Strategy Board guidance on section requirements:	This section should reveal the main findings learnt from the BPE process and in particular with cross-reference to the BUS surveys, semi-structured interviews and walkthrough surveys. This section should draw on the BPE team's forensic investigations to reveal the root causes and effects which are leading to certain results in the BUS survey; why are occupants uncomfortable; why isn't there adequate daylighting etc. Graphs, images and data could be included in this section where it supports the background to developing a view of causes and effects.

4.1 Building Use Studies (BUS) Survey and Occupant Consultations

4.1.1 Building Use Studies (BUS) Survey

Understanding how building users interact with a building is a key stage in maximising operational efficiency and optimising the internal environment. As such, occupant consultation forms an important part of the Post Occupancy Evaluation process.

The initial occupant consultation used a BUS (Building Use Studies) Survey. The BUS Survey was undertaken over three days in June 2013 (5^{th} – 7^{th}) in order to capture the views of as many building users as possible. Building users were informed of the survey a week prior to it by a member of BRE staff and reminded again the day before.

On the days of the survey, the questionnaires were handed out and collected by a member of BRE staff who was also available to answer any queries. Due to the nature of the Visitor Centre, there were a limited number of people that could be asked for their opinion. BRE staff that regularly use the Visitor Centre were surveyed, as were a regular visitor/external contractor and a member of the security team who occupy the building overnight and at weekends. The questionnaires were then passed to Arup for interrogation. A full description of the BUS Survey process and the findings are in the Appendix in section 10.6. A summary of the results from the BUS Survey are detailed below and shown in Figure 22.

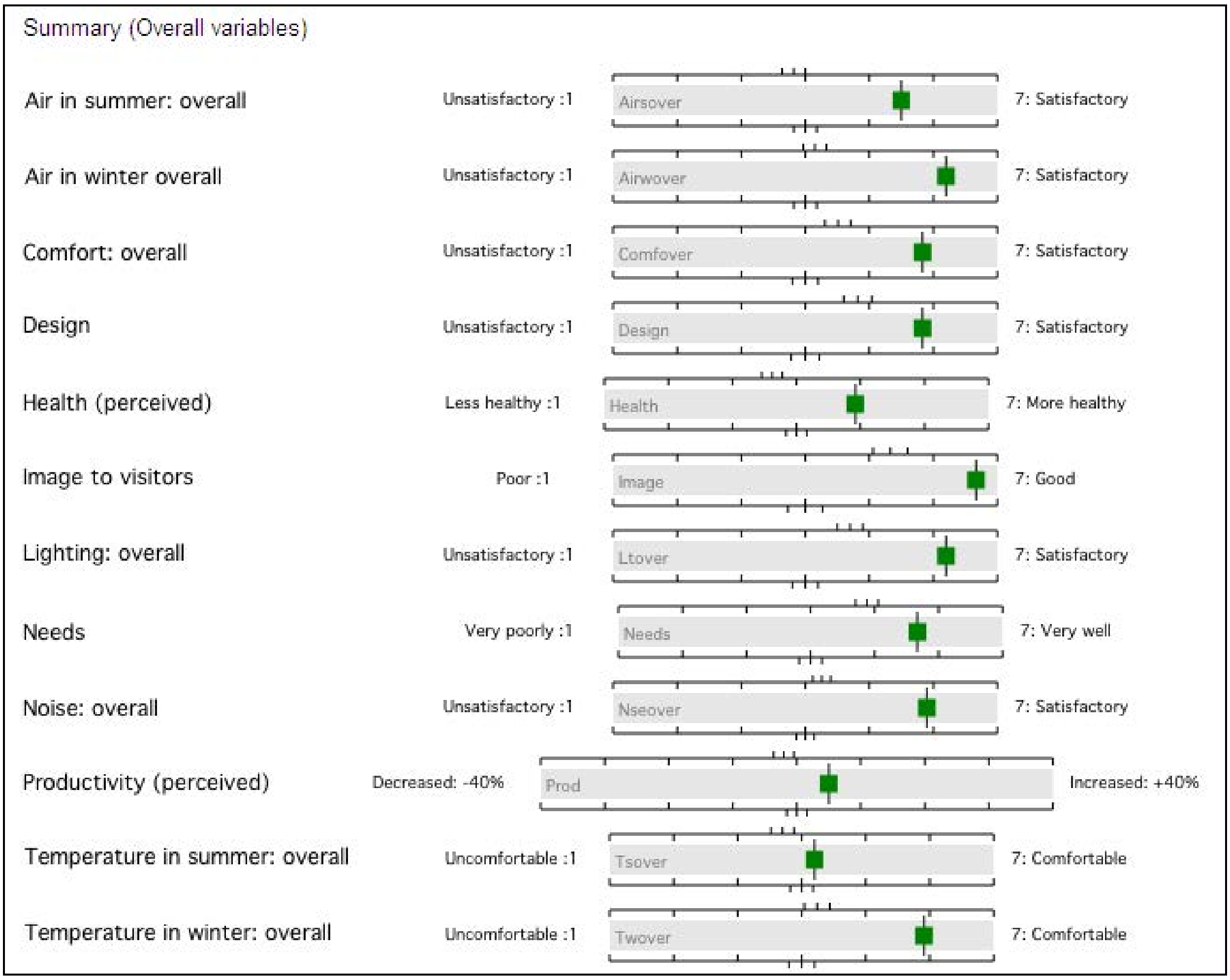


Figure 22: BUS Survey - Overall Survey Results

In particular, things that occupants felt worked well in the Visitor Centre include:

- brightness,
- flexibility of space,
- quietness,
- good quality bathroom facilities,
- flexible furniture.

Occupants also felt that the Visitor Centre was “a generally pleasant environment to work in”.

There were also some comments about things which hinder working within the Visitor Centre, related to IT:

- “better IT facilities would be desirable”,
- “poor internet access”,
- “connectivity”,

- "internet access has been patchy",
- "internet speed".

In addition some comments related to overheating and glare:

- "no blinds on windows [causes] overheating",
- "glare, overheating",
- "heat/light from big windows adjacent to desk – makes it uncomfortable to site and work",
- "overheating … no blinds – glare near computer screens…"

A couple of respondents also noted an issue with the open plan layout:

- "noise",
- "open space means people come and go even when meetings are underway".

Respondents have requested changes in the Visitor Centre including blinds[3] and light intensity (artificial lighting).

4.1.2 Occupant / Building Interaction Feedback

Six-monthly consultations with occupants have been undertaken to gain feedback from building users and identify changes in perception over time due to seasonal differences. These were held:

- Winter (December) 2012/2013: Paper based questionnaire
- Summer (June) 2013 – in addition to the BUS Survey: informal workshop / interviews;
- Winter (December) 2013/2014: informal workshop / discussion session.
- Summer (June) 2014: informal discussion session about building interaction.

In December 2012, users of the Visitor Centre were issued with paper based questionnaires which contained a mixture of 'closed' questions which were answered on a scale of one to five, and 'open' questions which allowed occupants to be more detailed and expressive in their responses. Tabulated results of the 'closed' questions and a summary of the 'open' questions from the questionnaire are contained in the Appendix (see section 10.7.1) of this report.

The Visitor Centre is a small building with both staff members who work there frequently and other transient users who only use the building for short periods of time. As a result of their limited interaction with the building's systems and the short periods of time spent in the building itself, these visitors would not be able to provide an insight into the internal environment of the building.

[3] Blinds were installed on the South-West facing windows in the staff base area in September 2013.

From the staff members, a total of six occupants completed the questionnaire. Although this survey sample is small, the information obtained is valuable and provides an insight into the building from those who use it regularly for longer periods of time.

In addition to understanding how users feel about the building, it is also important to understand how they interact with a structure and its controls. This a key stage in maximising operational efficiency and optimising the internal environment.

The main users of the Visitor Centre, BRE staff who are based at the Centre full-time, were interviewed as a group to facilitate discussion around their experience of operating the building so far. This interview workshop was held in the summer (June 2013), led by a BRE staff member, focusing on the control and operation of the Visitor Centre.

In addition, an informal workshop discussion was held in January 2014, to revisit some of the issues highlighted in the questionnaire a year previously. The key findings are detailed in sections 10.7.2 (summer) and 10.7.3 (winter). Overall user feedback was considered to be positive; the Visitor Centre was considered as a pleasant environment to work in. However, issues were highlighted and these focused on the use of space, operational problems, glare and electric light provision. The problem most emphatically and frequently discussed was the internet and wider IT provision, which is felt to be insufficient and had hindered work efficiency.

In summer 2014, an informal discussion was had between key building users about the interaction they have with the Visitor Centre and the control they have over their internal environment. Positive features included the brightness, and natural ventilation in the Visitor Centre; negatives included summer overheating, noise transference and glare. The key findings from the discussion can be seen in full in section 10.7.4.

4.1.3 Lessons learned workshop

Near the end of the two year TSB Visitor Centre BPE analysis a ‘lessons learned’ consultation was held with all BRE staff members who have used the building in some capacity, whether that is working full time, part time, hosting or attending training sessions, meetings and events. The aim of the session was to identify what, on reflection, could have been done differently in terms of the design, construction and operation of the Visitor Centre.

The lessons learned workshop was held in the Visitor Centre on 18th June 2014 and was attended by twelve BRE staff members. The group were prompted by a series of questions (see section 10.7.5) to help guide discussions.

The general opinion of the group was that the Visitor Centre provided a great space to work in and to bring guests and clients to. However, there was a feeling among some that more consultation with staff at design stage could have been beneficial. A full account of the workshop can be seen in section 10.7.5.

4.2 Conclusions and key findings for this section

This section outlines the feedback from occupants on the Visitor Centre including their opinions of the comfort levels and operation of the building.

Three different approaches have been adopted to gain feedback from the occupants as follows:

- BUS Survey;
- Questionnaire (quantitative and qualitative questions);
- Interview / focus group workshops.

The BUS survey was not found to be entirely appropriate for collecting feedback for the Visitor Centre. This is mainly due to the small sample of responses which resulted from the small number of potential respondents. Until there is a large enough sample of responses, statistically the results may not be significant and a focus on average scores may mask the true trend of responses. In addition, the BUS survey responses are compared to a range of non-domestic buildings, with unknown properties, construction methods and operational practices. These non-domestic buildings are not likely to be all offices, and as such their comparison to the Visitor Centre is perhaps not useful. However, the 'comment style' questions did provide some insight into the particular problems faced by the Visitor Centre occupants.

The 'open' or qualitative questions in the questionnaire (completed in December 2012) gave much more scope for expanding on these issues. The interview / focus group sessions held with key BRE staff were very instructive in outlining specific problems. The main issues highlighted through all three methods are:

- No training for BRE staff was received at handover, with relation to the operation of the building. In part this is due to the problems with the M&E contractor (as described in sections 6.3 and 10.9); but even following the reconditioning work with the new contractors, not all staff were happy with the operation of the services within the Visitor Centre.
- Space management, in particular a lack of storage space, was felt to be a problem. There were also problems highlighted with the open plan layout; some occupants felt that a physical division between the main event space and the staff area would be beneficial.
- The temperature within the Visitor Centre was felt to be satisfactory in the winter months, but overheating due to solar gain was identified as a problem in the summer, with glare also being cited as an issue. Temperature has been explored more thoroughly in section 5.1.2.
- The IT facilities are felt to be poor and staff members cited them frequently as a hindrance to work and an on-going frustration.

In addition, at the 'lessons learned' workshop, BRE staff members were able to comment on things that could have been done differently during the design, construction and operation of the Visitor Centre. The main findings from this session was that the building is well liked and is a popular meeting location, but that more consultation with staff at design stage could have resolved some issues, for example with storage space and division of separate staff and meeting areas. The results of this discussion will be considered in the early stages of future BRE led construction projects.

A BUS (Building User Studies) survey was conducted, to garner the views of the Visitor Centre occupants. Overall results appeared positive, though the small number of respondents (resulting from the small number of regular building users at that time) did not allow for a statistically significant analysis of responses to take place. Much more was gained from the open questions in the later questionnaire, in the informal workshop and interview sessions and in the lessons learned workshop towards the end of the project.

In general, the building is viewed positively by the users, however there are a number of areas which have caused concern, including space management, building system operations, IT facilities and internal temperatures (particularly during summer months).

Space management is due to be resolved by the addition of an external storage space, which will reduce the amount of equipment that must be stored within the Visitor Centre. IT facilities are also due to be upgraded as part of a wider company initiative and the introduction of fibre-optic broadband cabling to the area.

Work is on-going to liaise with M&E contractors to ensure that all systems are operating correctly and are maintained such that they continue to do so. In addition, key staff members plan to spend time with the contractors to fully understand the operation of each piece of equipment. This process will benefit from the increase in external storage, as currently the plant / service room is used for storage which can make accessing equipment difficult.

5 Details of aftercare, operation, maintenance & management

Technology Strategy Board guidance on section requirements:	This section should provide a summary of building operation, maintenance and management – particularly in relation to energy efficiency, metering strategy, reliability, building operations, the approach to maintenance i.e. proactive or reactive, and building management issues. This section should also include some discussion of the aftercare plans and issues arising from operation and management processes. Avoid long schedules of maintenance processes and try to keep to areas relevant to energy and comfort i.e. avoid minor issues of cleaning routines unless they are affecting energy/comfort.

5.1 Operation and management

5.1.1 Sub-metering approach

In addition to metering the energy consumption of the Visitor Centre for Building Performance Evaluation purposes, there are a number of other benefits. Generating awareness of energy and water consumption through regular monitoring and targeting can help to drive down consumption levels.

Energy monitoring also allows an estates manager to identify any areas in which consumption is higher than expected and can prevent wasted energy. For example, if a system or equipment is unexpectedly left on, a building with this facility has the capability to identify the unusual high use, allowing the user to take the appropriate action.

Electricity is used for all end uses within the Visitor Centre. Sub-meters were installed to measure the energy used for specific end uses as follows:

- **Fans:** Energy used for ventilation fans, including recirculation fans and mechanical plant room fans, excluding condenser and cooling tower fans and catering kitchen fans.
- **Hot Water:** Energy used for domestic hot water (e.g. hand washing and drying, showers, manual dish washing in kitchenettes) including electrical consumption of any heat recovery systems, but not pumps and controls. Excludes water heating associated with central catering.
- **Catering – central:** Kitchen (or café) catering preparation and servery equipment including dishwashers, food refrigeration and storage, and water heating associated with catering. Excludes restaurant lighting, ventilation and air conditioning.
- **Lighting (internal)** - three sub-meters, for the open plan area, the office area and the toilet block: All internal lighting including task lights, retail/artwork display or demonstration lighting and emergency lights, but excluding unusual lighting installations with decorative purposes only e.g. laser displays.
- **Lighting (external):** All external lighting associated with the building, including for dedicated car parks and street lighting for dedicated access routes
- **Small Power Equipment** – two sub-meters, for the open plan area and the office area: Decentralised small power uses within the general building space, except for catering equipment and task lighting, including personal computers and phones, electronic point of sale equipment and local printers and

copiers and other plug loads such as cleaning equipment (vacuum cleaning, polishing, etc.), but excluding all servers and central IT equipment and controls.

- **Space Heating:** Energy consumption for space heating (including via ventilation), excluding domestic hot water heating, process heating and unusual end-uses such as swimming pool heating and frost protection of ramps. Electricity input to heat pumps directly associated with space heating is included.

5.1.2 Internal Environmental Performance

As a part of the work undertaken for BRE's Building Performance Evaluation of the Visitor Centre, a number of aspects of the internal environment were monitored to help to establish the performance of the building throughout a full seasonal cycle. This included:

- Temperature
- Humidity
- Air Quality

Unfortunately, due to a broken temperature sensor, accurate monitoring of internal environmental performance only began at the beginning of November 2012. However, seven quarters of data (November 2012 to July 2014) is presented in section 10.8. A summary of the key findings are found in section 5.2.

5.2 Conclusions and key findings for this section

This section initially outlined the sub-metering strategy adopted in the Visitor Centre to ensure accurate and meaningful energy consumption data could be collected. This resulted in a total of ten sub-meters, with suitable energy consumption data analysed in detail in section 6.1.3 and in Appendix section 10.9.

Internal environmental performance has also been measured. A summary of results for temperature, relative humidity and air quality can be seen in section 10.8. The main points to note from this monitoring are outlined below.

Temperature:

- Low readings (below 18°C) were only seen in any great number in quarter one (November – January).
- High readings were noted in all quarters, with 96% of all readings in quarter three (May – July), 85% of all readings in quarter four (August – October) and 88% of all reading in quarter six (February – April) above 21°C.
- The Visitor Centre could be described as overheating in the summer months; this has been identified in both the monitoring results (section 10.8.1) and in the occupant feedback (section 4 and section 10.7.2).

- Unusual temperature profiles in quarter five (November – January) may be attributable to uncontrolled use of electric bar heaters.

Relative Humidity:

- The majority of readings in quarters one, three and four are between the recommended limits of 40% and 60%.
- Quarter two (February to April) had a high proportion of low relative humidity readings; around 70% of readings were classed as ‘low’. In addition, more than 73% of readings in quarter five and 70% of readings in quarter six were classed as ‘low’. Anecdotal evidence is that building users find the Visitor Centre to be very dry.

Air Quality:

- The maximum possible reading was 1023ppm as this is the limit of the CO_2 sensor specified for the Visitor Centre.
- The mechanical ventilation (MVHR) was not operational until late May 2013, which may be part of the reason for the higher proportion of readings in quarter one and quarter two which were above 600ppm. The cooler external temperatures during this quarter may have made occupants reluctant to open windows which will have also had a negative effect on indoor air quality.
- On average, less than 0.5% of readings per quarter were above 1000ppm.

The main issue that has been identified through the monitoring of internal environmental conditions is the overheating experienced during summer months. External shading would provide an effective solution but at present there are no plans to implement this. As a result of the overheating, building users open windows to cool the Visitor Centre. It has been suggested that that the ventilation system should be examined to identify how it could be operated more efficiently and also to create guidance to inform building users if and when the system should be switched off if windows are open. Air quality readings have for the most part been well below the recommended maximum, since the ventilation system was fully operational in May 2013.

Anecdotal evidence from occupant feedback is that the Visitor Centre feels dry. Readings show on average the RH is lower than the recommended minimum, confirming these accounts. However, it is likely that the lower RH levels allow occupants to accept higher temperatures than they might otherwise.

6 Energy use by source

Technology Strategy Board guidance on section requirements:	This section provides a summary breakdown of where the energy is being consumed, based around the outputs of the TM22 analysis process. This breakdown will include all renewables and the resulting CO_2 emissions. The section should provide a review of any differences between intended performance (e.g. log book and EPC), initial performance in-use, and longer-term performance (e.g. after fine-tuning and DEC – provide rating here). A commentary should be included on the approach to air leakage tests (details recorded elsewhere) and how the findings may be affecting overall results. If interventions or adjustments were made during the BPE process itself (part of TM22 (process), these should be explained here and any savings (or increases) highlighted. The results should be compared with other buildings from within the BPE programme and from the wider benchmark database of CarbonBuzz.

6.1 Energy Use

6.1.1 Total Annual Energy Consumption (Year One)

Due to additional works being carried out at the Visitor Centre, monitoring of the energy use did not begin until the 17th October 2012. However, it is possible within this report to provide details of annual energy consumption, plus a comparison of some months against second year data.

Energy consumption within the Visitor Centre from 17th October 2012 to 16th October 2013 (a full year), was 7,380kWh. Excluding small power uses, the total energy consumption was 5,685kWh. This amounts to 67.09kWh/m^2/year or 51.68kWh/m^2/year excluding small power use.

The Energy Performance Certificate and the associated BRUKL report for the Visitor Centre approximated annual energy use to be 13.75kWh/m^2. This figure does not compare favourably with the 51.68kWh/m^2 measured. In particular, the areas which have not met the expected 'actual' use (as in Figure 23) are:

- Space Heating: **37**kWh/m^2/year (as opposed to 5.31kWh/m^2/year) – an almost 700% increase.
- Lighting (including external): **8.33**kWh/m^2/year (as opposed to 4.99kWh/m^2/year).

Energy Consumption by End Use [kWh/m^2]

	Actual	Notional
Heating	5.31	136.26
Cooling	0	0
Auxiliary	2.07	2.1
Lighting	4.99	29.75
Hot water	1.38	5.12
Equipment*	41.54	41.54
TOTAL	**13.75**	**173.24**

* Energy used by equipment does not count towards the total for calculating emissions.

Figure 23: Energy Consumption by End Use (values from BRUKL report)

The main reason for the discrepancies between the actual consumption and the expected figures quoted above are that the Visitor Centre was only expected to be occupied during office hours. However, there has been a member of a security team in the Visitor Centre overnight and all weekend since the building was opened. This has greatly increased energy consumption as the building is required to be heated and lit for an additional 6,500 hours (approximately). The security guards operate on a rotating shift pattern, and especially initially, not all members of the security team were appropriately briefed on the operation of the Visitor Centre. On several occasions, particularly in October and November 2012, BRE staff would arrive for work to find that lights had been left on and the thermostats turned up to the maximum, although the security guards shift had finished earlier in the day. Initially the security staff worked from 4pm – 8am during the week, and 24 hours over the weekend. In mid-October 2012 however, the weekday hours were amended to 6pm – 6am. The weekend and holiday cover (Christmas and New Year) hours remained unchanged.

Only considering core office hours (Monday – Friday, 9am – 5pm), the energy consumption over the first year of measurement is 1,296kWh or 11.78kWh/m^2, lower than the design consumption of 13.75kWh/m^2.

The CIBSE Tool TM22 has been used to help analyse energy consumption in the Visitor Centre, as with all TSB's non-domestic BPE projects. The data from the TM22 analysis is shown in Appendix section 10.9.

6.1.2 CO_2 Emissions

CO_2 emissions which arise from the use of grid electricity within the Visitor Centre can be calculated by using a carbon factor. A carbon factor of 0.55kgCO_2/kWh has been used (as specified in the TM22 tool), which results in annual carbon emissions for the Visitor Centre of 4,059kgCO_2 or 36.9kgCO_2/m^2 based on an annual energy consumption of 7,380kWh (see section 6.1.1). Excluding small power use (annual energy consumption of 5,685kWh) the CO_2 emissions for the Visitor Centre are 3,126kgCO_2 or 28.4kgCO_2/m^2.

There only available TSB BPE projects on the 'CarbonBuzz' website for comparison with the Visitor Centre data were education buildings (see Figure 24) so the comparison is not strictly fair. However, as can be seen in Figure 25, the Visitor Centre also compared favourably with other published 'office' projects. The 'CarbonBuzz' report is included as an Appendix in section 10.12.

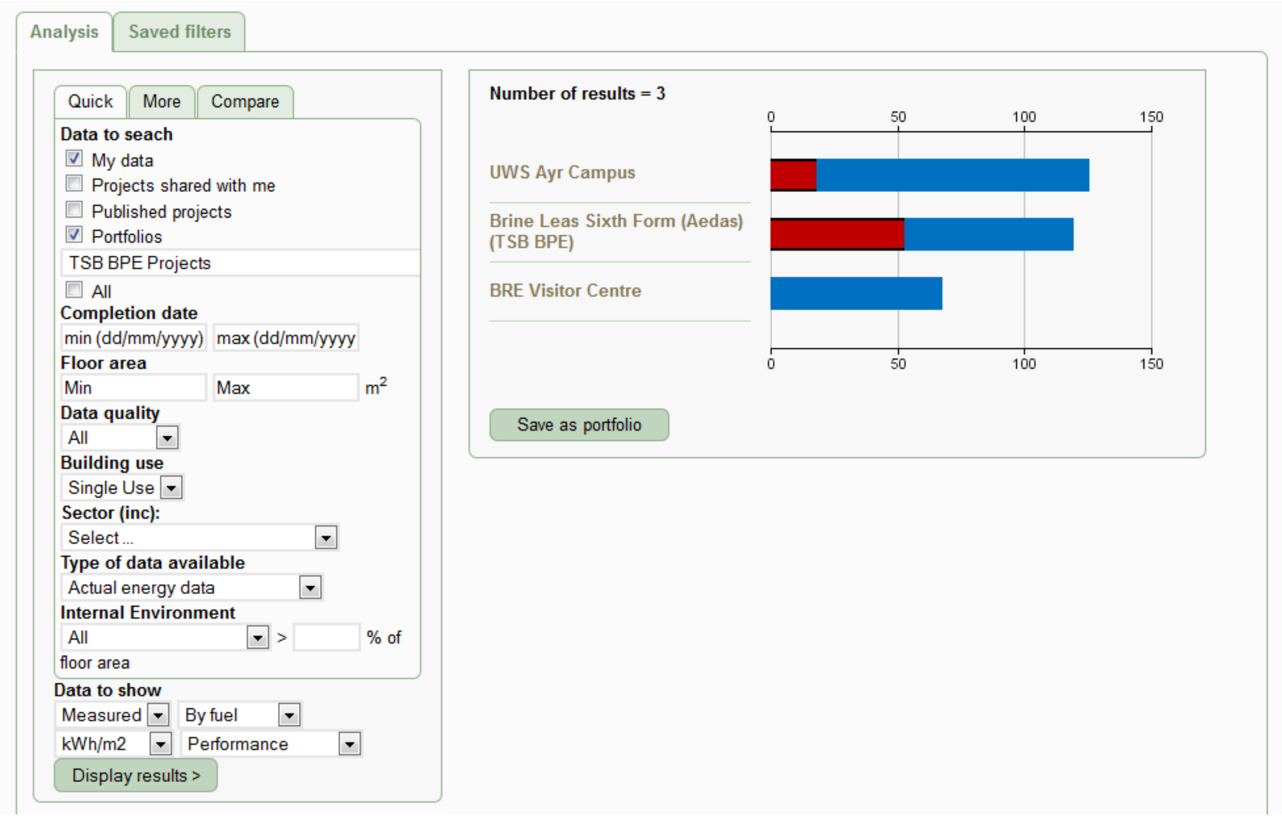


Figure 24: TSB BPE Projects 'CarbonBuzz' comparison ($kgCO_2/m^2$)

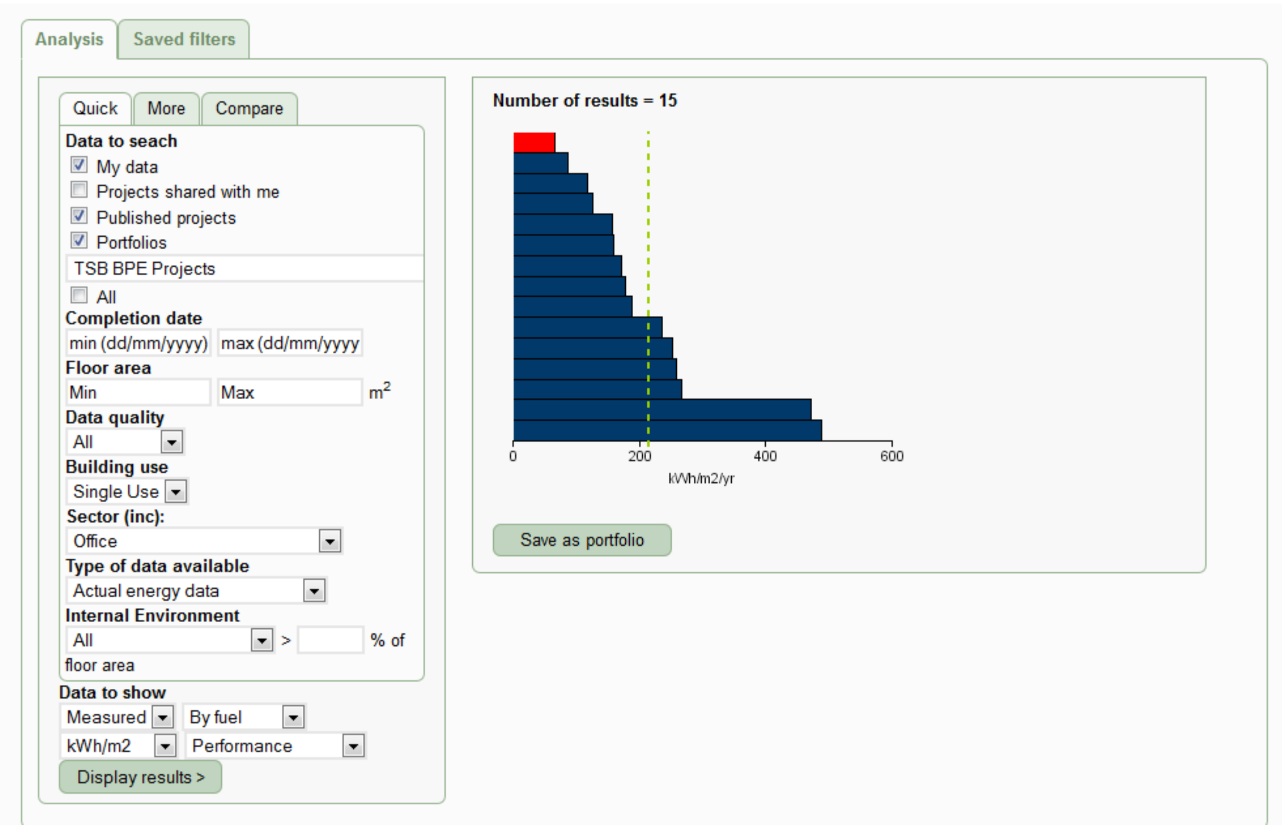


Figure 25: Office Projects 'CarbonBuzz' comparison ($kgCO_2/m^2$)

6.1.3 Energy Consumption by End Use (Year One)

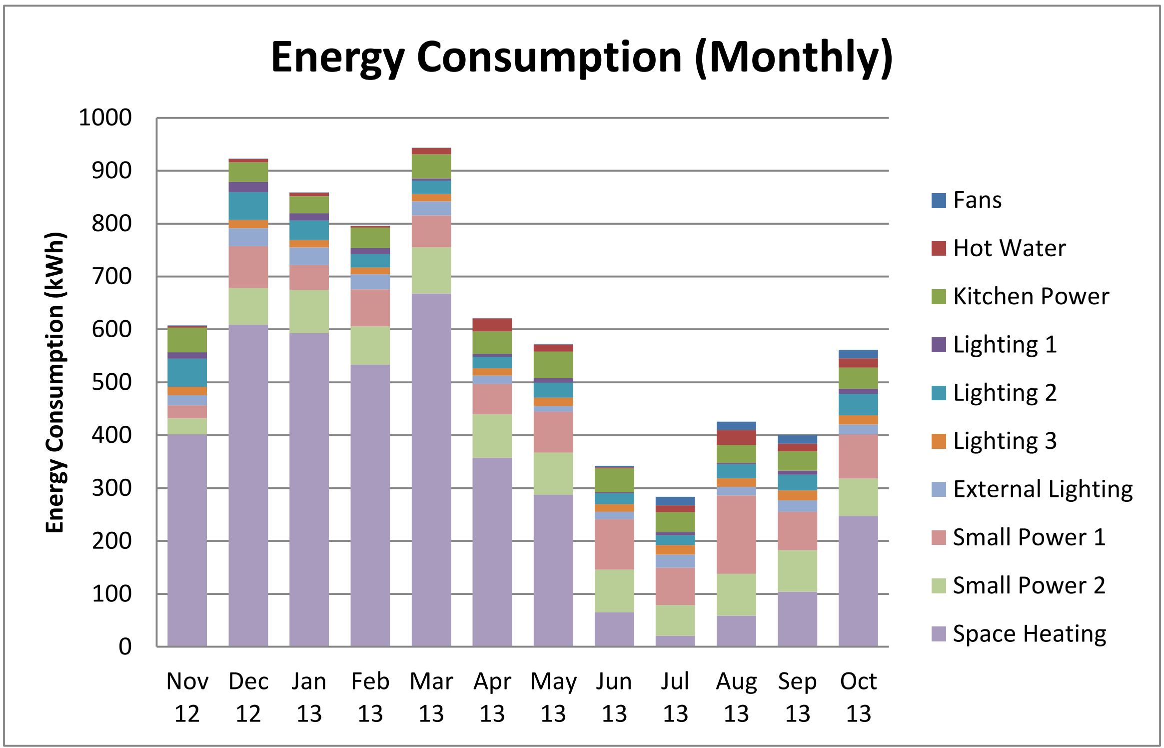


Figure 26: Energy Consumption (Monthly, by end use)

Figure 26 shows the monthly pattern of energy consumption by end use for the year from October 2012 to October 2013. Space heating can be seen as the dominant end use, especially in November to March. To demonstrate more clearly the energy consumption by other end uses, Figure 27 shows the same graph, excluding space heating. Here it can be seen that small power use is greater than other end uses.

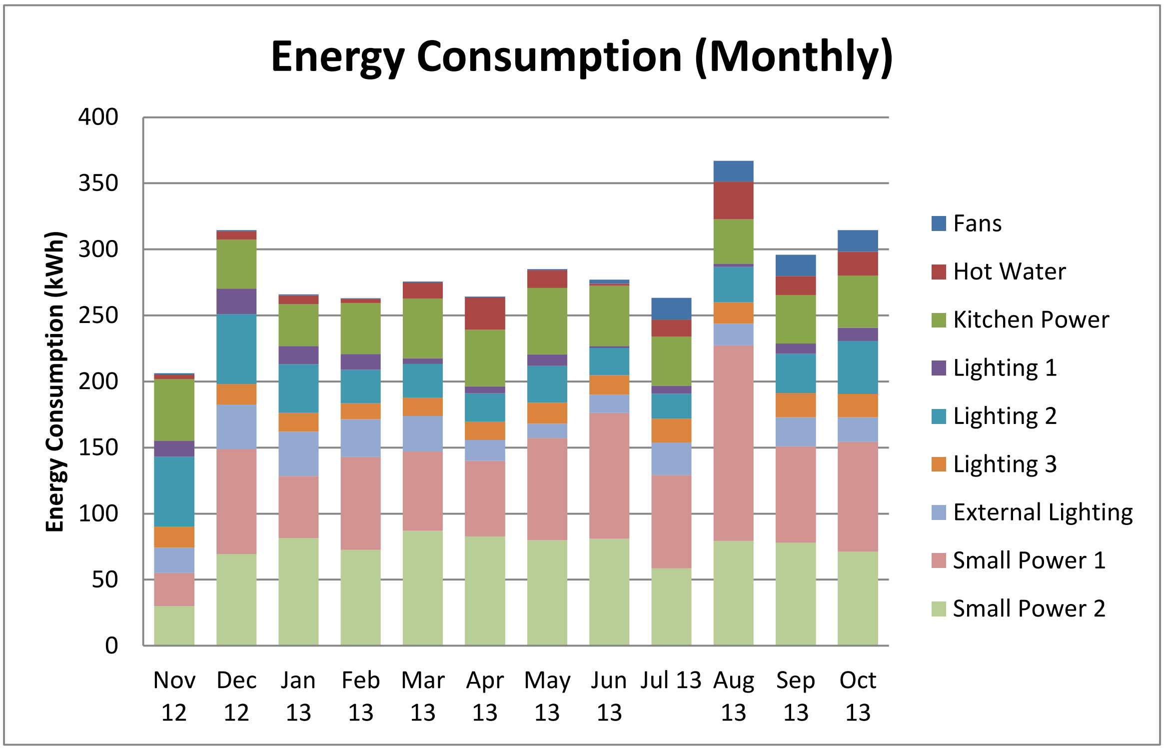


Figure 27: Energy Consumption (Monthly, by end use) (excluding space heating)

Graphs in section 10.9 show for each of the ten sub-meters, the measured energy consumption (overall, weekday core/office hours, weekday non-core hours and weekends) compared to the estimated energy use as determined by BRE staff at the beginning of the BPE project by considering the energy using equipment located within the Visitor Centre and how the building was expected to be used.

6.1.4 Energy Consumption by End Use (Year Two)

Energy consumption data has continued to be collected into year two of the BPE project. The energy consumption from November 2013 – July 2014 can be seen in Figure 28. The profile of energy use is dramatically different to that seen in the first year (in Figure 26) with the dominant energy use now on the small power circuits. This is due to a fault with the heating system which occurred at the beginning of October 2013.

On the 7th October 2013, the boiler unit presented a fault, indicating that the external ASHP unit was not working correctly. Following an investigation by M&E contractors it was found that there was indeed a fault with the ASHP and it would need repaired. The fault related to the communication capabilities between the ASHP and the boiler unit. The unique procurement method adopted by the Visitor Centre construction team meant that no warranty was in place to ensure a quick repair could be made. It was decided that the M&E contractors would instead arrange for a replacement ASHP and boiler unit to be installed.

Temporary electric heaters were provided to the Visitor Centre in the week commencing 4th November, as particularly the security staff were beginning to feel cold as external temperatures fell. These were two, 2kW bar heaters, which had the option to be set at 750W, 1250W or 2kW. There is also a dial on each to increase or reduce temperature. There is no timer control and they have been used profusely, particularly overnight. It has been estimated that the heaters were used for 1,660 hours, using approximately 60.4kWh/m^2 from November to April.

This switch from use of the space heating circuit to electric heaters plugged into the small power 1 and small power 2 circuits can be seen from the change in graphs in Figure 26 and Figure 28. A direct comparison can be viewed in Appendix section 10.9, particularly in Figure 147. In addition, energy profiles for all ten circuits for year one and year two can also be seen in section 10.9.

For a few weeks following the discovery of the ASHP fault, the space heating circuit continued to consume energy, though no heating or hot water was being provided. As such, the entire circuit was switched off on the 5th December. Supply and installation date problems meant that the ASHP and boiler unit were not replaced until 5th April. Further electrical commissioning of the heating system occurred in the following weeks. Over the winter period, the users of the Visitor Centre relied on the electric heaters.

A further consequence of the heating system failure was the reliance on the kitchen kettle for provision of hot water. Although there is a secondary hot water circuit, linked to the solar thermal panel, it provides very little hot water, and generally only in the afternoon. It is possible that this is due to the commissioning, as the secondary circuit was only intended to provide a back-up to the main heating system. Users of the Visitor Centre require to boil the kettle to wash dishes and cleaning staff have to boil several kettles worth of water to clean the floor.

In addition to the fault with the space heating, a fault was discovered on the Lighting Zone 2 circuit. As such, following investigation work, although the lights continue to operate (though are still felt to be too bright by the occupants), the meter for this circuit ceased to take individual readings for the circuit from around the 12th December 2013. Unfortunately, this fault has not been resolved.

A full exploration of the energy consumption in year two can be seen in section 10.9.

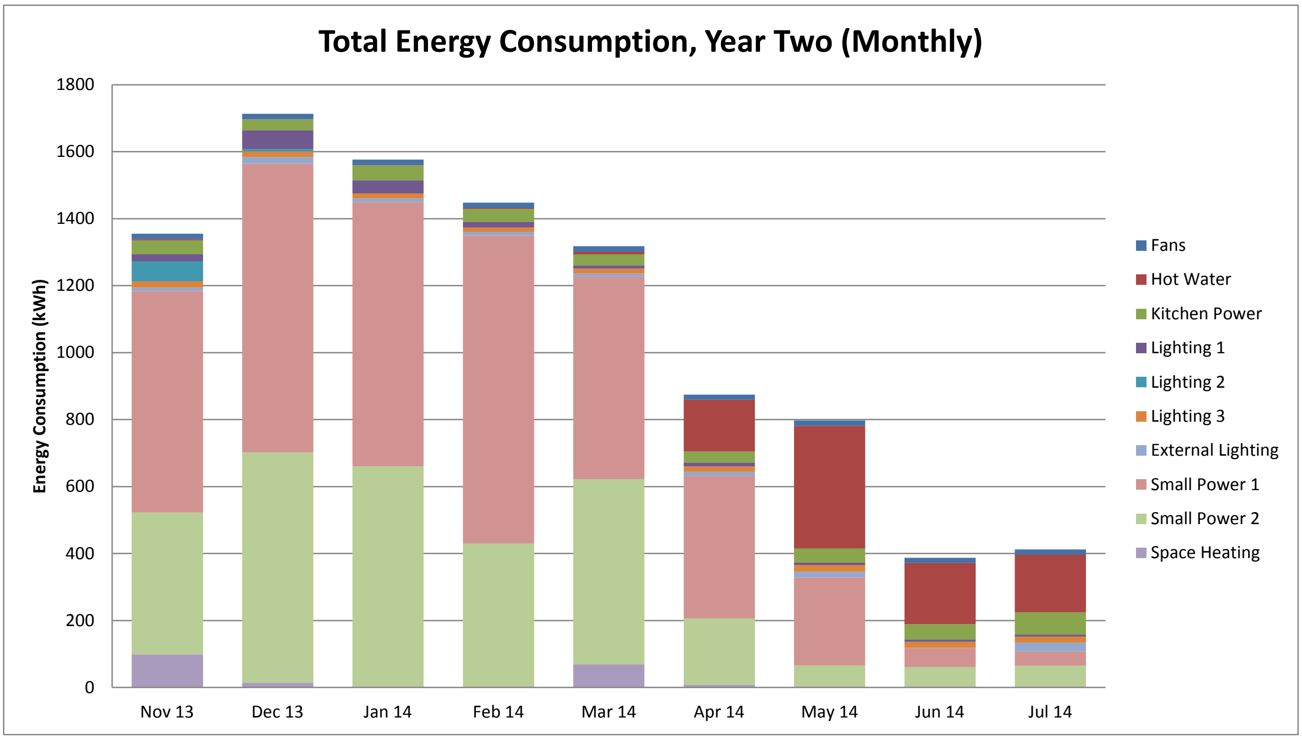


Figure 28: Energy Consumption (Monthly, by end use) Year 2

6.1.5 Renewable Technologies

The renewable technologies installed in the Visitor Centre (ASHP, PV array and solar thermal panel) are currently being monitored through a separately funded research and development project called EnergyWarden. EnergyWarden (EW) is a FP7 project, aimed at the development of tools for the management and control of the renewable technology, deployed in the building domain. As part of this Project, the EW-Controlled was installed and trialled at the Visitor Centre.

The EW-Controller includes data collection, transmitters and sensors to understand the output from the renewable technologies and the energy demand at the Visitor Centre. This real time controller optimises and manages how energy is allocated between being used within the Visitor Centre, being stored within the battery array, and being fed back to the grid.

Unfortunately, at the time of writing the report, there are a number of operational issues with this trial deployment meaning that the data from PV cannot be readily accessed. When combined with the documented operational issues with the ASHP, there is no usable data available for the output from renewable technology.

6.1.6 Effect of Airtightness

Airtightness testing, as outlined in section 3.1.8, provided results which were not in line with the design value. A design value of 1 $m^3/(h.m^2)$ at 50Pa was expected to be achieved, but tests found the airtightness to be 4.04 $m^3/(h.m^2)$ at 50Pa. The likely reasons for this discrepancy are described in section 3.2. The fact that the building is not as airtight as expected will have an effect on energy consumption. Energy consumption for space heating will be increased compared to expected values as there will be greater air infiltration, causing cool external air to enter the Visitor Centre, and warm, internal air to escape. This will require the space heating to operate for longer to meet the temperature required by the occupants.

6.2 Water Consumption

A water-meter with a pulsed output for the building was installed on the 21st November 2012 to ensure that water consumption was monitored and managed to encourage reductions in water use.

As can be seen in Figure 29, water consumption in August, September, November 2013 and May 2014 was extremely high in comparison to other months. The bar shows the total water use, and the red line, the average water use per day.

Figure 30 shows a profile of water use throughout August. It can be seen from the graph that water use began to increase at a greater rate from around the 20th to the 28th. This increase in water consumption can be attributed to a tap in the gent's bathroom which was broken by a visitor on Tuesday 20th August. Whilst the tap was broken it was running constantly and it was not possible to isolate and switch off the supply. A plumber was not able to be arranged until the following week. As can be seen on the graph, water consumption reduced again following the repair on the 28th. Figure 31 shows the consumption in September which shows a jump in consumption on the 27th and 28th of the month. No particular fault has been attributed to this increase in water use, but consumption levels returned to normal and remained so throughout October. Further jumps in water consumption were seen in November (Figure 32) and May 2014 (Figure 33), due respectively, to draining and refilling of the heating system during investigative works and a request from Scottish Water to run taps on a few days to drain the system, as potential contamination was found in a neighbouring site.

These issues contributed to increase the overall water consumption to be 251 litres per day, or 2.28 litres per day/m^2. Not including these months outlined above, the average water consumption for the other monitored months was 138 litres per day, or 1.26 litres per day/m^2. As there is no standard occupancy of the Visitor Centre, water consumption 'per occupant' is unable to be calculated.

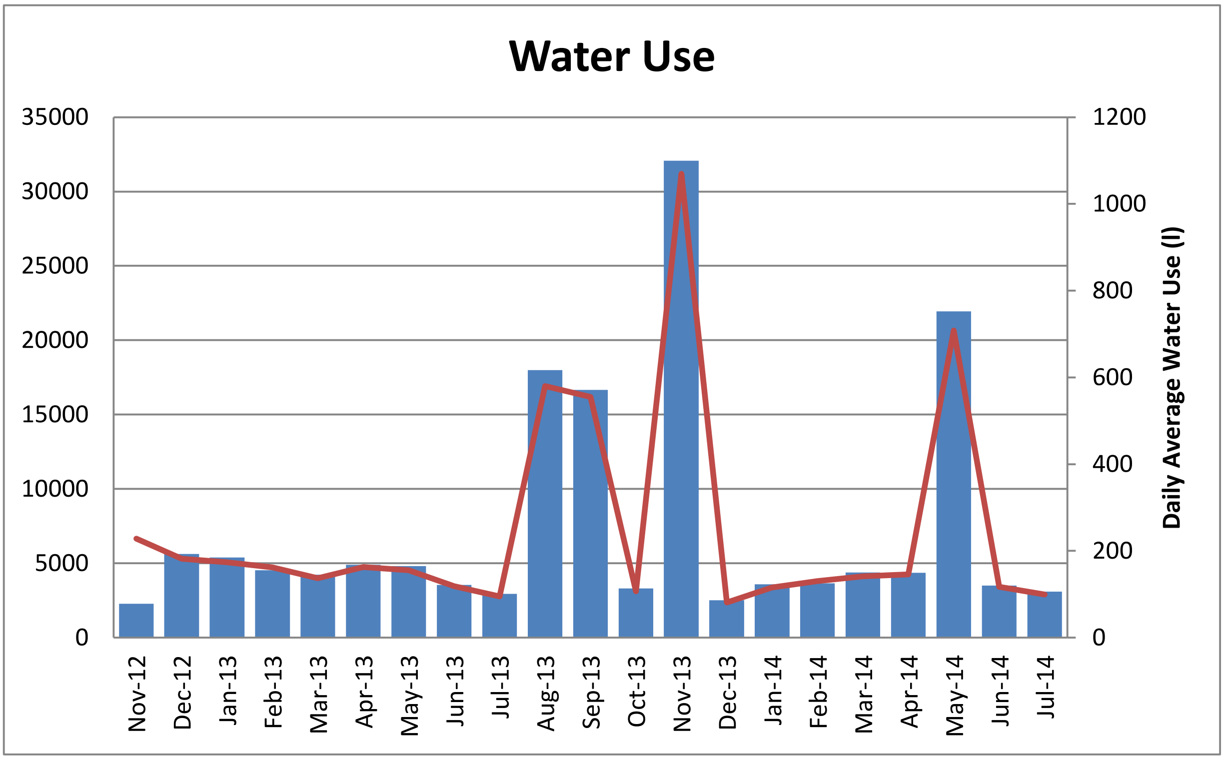


Figure 29: Monthly Water Use

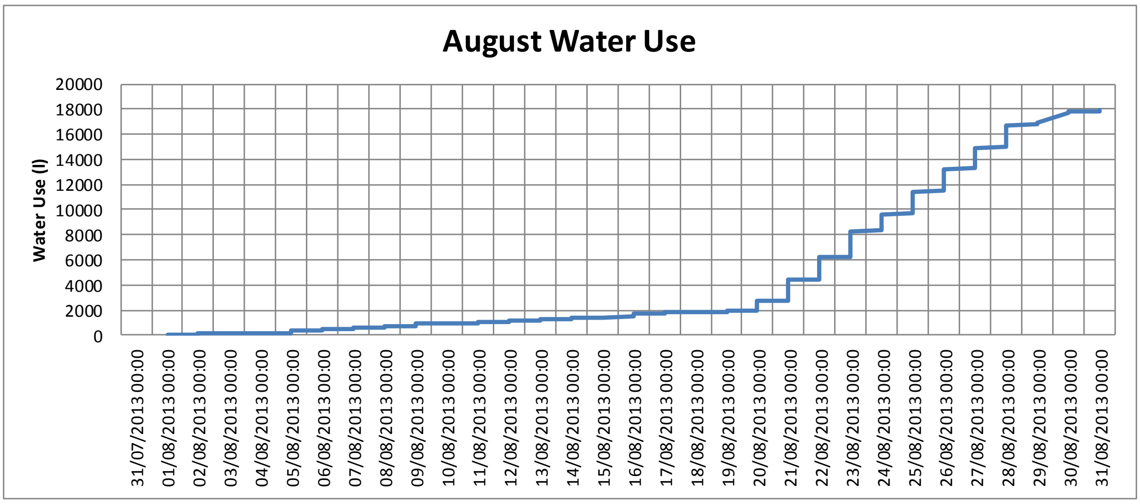


Figure 30: Cumulative August Water Use

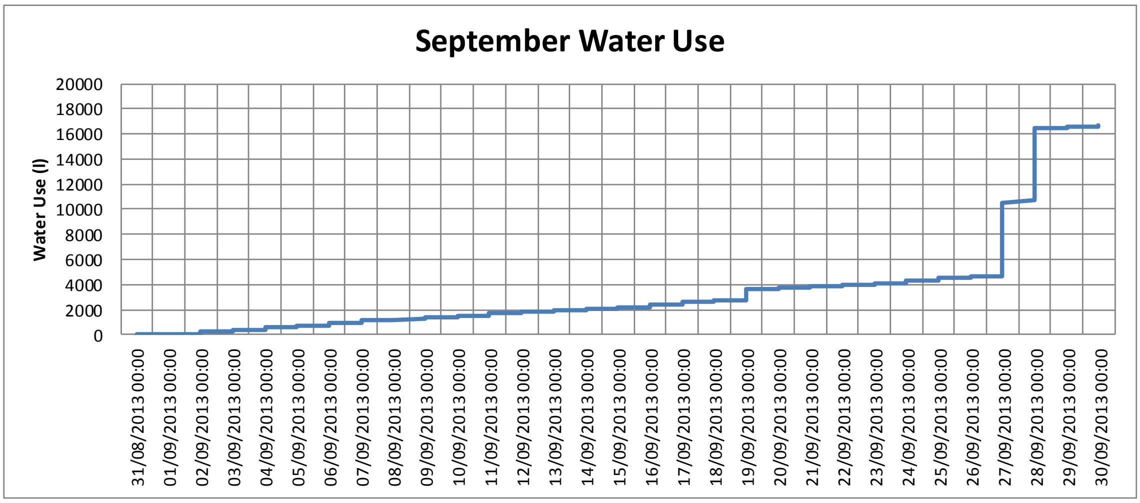


Figure 31: Cumulative September Water Use

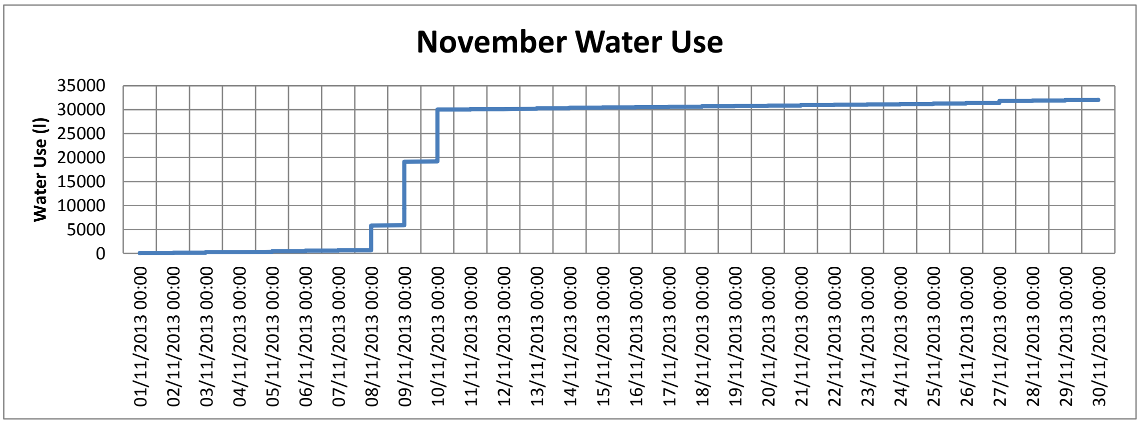


Figure 32: Cumulative November Water Use

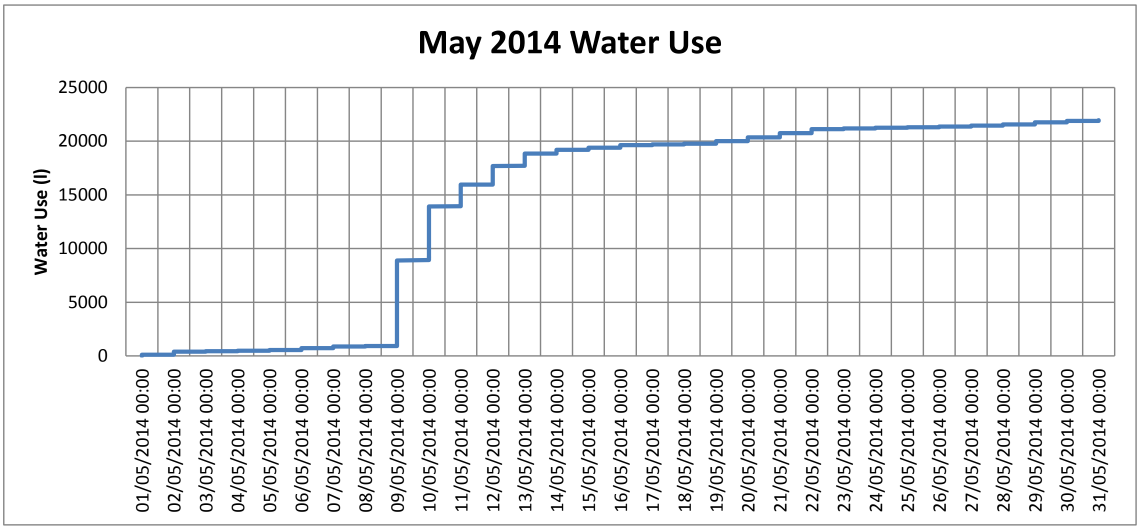


Figure 33: Cumulative May 2014 Water Use

6.3 Conclusions and key findings for this section

Energy consumption in the Visitor Centre was greater than expected; 51.68kW/m^2 (not including small power) compared to a design value of 13.75kWh/m^2. The main factor affecting energy consumption within the Visitor Centre is the presence of security staff overnight and at weekends, which was not considered or expected when initial calculations on energy consumption were determined. This has resulted in much higher consumption figures than were expected. Only considering core office hours (Monday – Friday, 9am – 5pm) however, the energy consumption over the first year of measurement is 11.78kWh/m^2.

A second defining factor was that the M&E contractors who designed and specified the various heating, lighting and ventilation systems for the Visitor Centre went out of business shortly after the building was occupied. This meant that snagging problems were not easily (or quickly) resolved as new contractors had to be found and appointed.

Related to this are on-going problems with the heating/boiler unit which is fed by the ASHP and supplies the heating and supplementary hot water for the Visitor Centre. Initially, building users were dissatisfied with the heating and hot water provision and found that the unit presented frequent error codes and often needed reset. Only when new M&E contractors were appointed in May 2013 was it identified that the unit had not been correctly configured. This was the reason behind the error codes, as the unit was overheating.

It was also felt that the energy consumption on the ‘space heating’ circuit was considerably higher than expected, even considering the additional ‘out-of-hours’ use of the Visitor Centre.

Once the M&E contractors had correctly configured the heating system, the unit worked successfully until a fault was found with the external ASHP unit in early October. This fault meant that the boiler unit did not work correctly and very little heating or hot water were produced, despite the circuit continuing to draw electricity from the grid. This problem was not yet resolved at the time of writing.

Energy consumption has continued to be monitored, but due to the further problems with the heating circuit, it will be necessary to measure consumption for another year to establish whether consumption over the first winter was greater than expected due to problems with the technology or whether the drop in consumption from May to June was simply due to seasonal factors.

In addition, the M&E contractors, when on-site in May 2013, established that the MVHR system was not switched on correctly – this had been suspected as the ‘fans’ circuit was only consuming minimal amounts of electricity from the grid. The change in consumption levels pre- and post- June 2013 can be seen in section 10.9.

To avoid these ‘snagging’ issues it may have been advisable to delay the start of the BPE process until around six to nine months post occupation (as opposed to six weeks); however, this would not have captured the issues associated with settling in.

In addition to the more severe problems associated with the space heating and ventilation, the following problems were encountered during the first year of monitoring:

- External lighting was not installed until 2nd November 2012; hence there was no usage on this circuit during the initial monitoring period. The external lighting was initially switched on and off manually until a timer was installed on the 20th. The timer has had occasional faults and when this occurs, the lights are switched on and off by BRE staff/security staff.

- The energy consumption on the kitchen power circuit is likely to be greater than expected as problems with hot water provision required the kettle to be boiled more frequently to provide hot water for cleaning and dish-washing.
- As can be seen in Appendix section 10.9, the power consumption on the ‘kitchen power’ circuit fluctuates throughout the day. This is due to short, high power loads on the circuit from the use of the kettle, microwave and toaster. A peak around 9am will be from increased use of the kettle as staff arrive at work.
- The energy demand profile for ‘Lighting Zone 3’ (in Appendix section 10.9) also shows fluctuations throughout the day. This is because this bathroom area is not naturally lit, and the lighting is controlled by PIR sensors and timers to ensure lighting is only used when required.
- Consumption on the ‘small power 2’ circuit increased over the year as more equipment was installed in the Visitor Centre. This circuit covers the area used by BRE staff so IT equipment and various items of monitoring equipment are located here.
- At the end of April, a hot water urn was purchased and located in the ‘small power 1’ circuit area to allow guests at events to help themselves to hot drinks. This increased energy consumption on this circuit, but reduced consumption in the kitchen power circuit.
- When the M&E contractors rectified the problems with the heating in May 2013, they also installed a programmable timer for additional control of the system. The programme was originally set for the heating to come on for two hours in the morning, two in late afternoon and two in the evening, if the temperature in the building is below the level set by the room thermostats. In October, the timer was amended to allow the heating to come on for longer overnight, as the security staff had begun to feel cold.
- A drop in consumption in overall consumption in July (see Figure 27) is likely due to the fact that this month is traditionally a holiday period in Scotland therefore the Visitor Centre would be less busy with events, and BRE staff would also likely be on leave. August has greater consumption (excluding space heating) than any other month to date; the Visitor Centre was very busy with events during this month.

The use of electric bar heaters for space heating over the winter in year two has greatly skewed the energy consumption data. It has been estimated that these heaters consumed approximately 60.4kWh/m^2 between November 2013 and April 2014.

Air tightness testing also identified that the energy consumption for space heating will be increased compared to the expected values as there is greater air infiltration, causing cool external air to enter the Visitor Centre, and warm, internal air to escape. This will require the space heating to operate for longer to meet the temperature required by the occupants.

Water consumption has also been measured in the Visitor Centre as resource efficiency is part of a wider sense of sustainability – one of the main themes of the Innovation Park as a whole. Water consumption was seen to be fairly constant, with four exceptions (20th – 28th August and 27th – 28th September, 8th – 10th May and 9th – 13th May). Overall water consumption was 251 litres per day, or 2.28 litres per day/m^2. Not including August, September, November and May, the average water consumption for the other monitored months was

138 litres per day, or 1.26 litres per day/m^2. Monitoring of the water consumption allows for faults to be identified and can track patterns in excess consumption.

Monitoring of the Visitor Centre's energy and water consumption has identified a range of issues, and contributed to rectifying some. It is therefore recommended to allow for monitoring in all new build and major retrofit projects. The specific problems related in particular to space heating have meant that the building has not performed as expected. BRE will work closely with the appropriate contractors to resolve all outstanding issues and to ensure the Visitor Centre is as efficient as possible in the future.

7 Technical Issues

Technology Strategy Board guidance on section requirements:	This section should review the underlying issues relating to the performance of the building and its systems. What are the technical issues that are leading to efficiency results achieved to date? Are the automated or manual controls effective, and do the users get the best from them? Are there design related technical issues which either need correcting/modifying or have been improved during the BPE process? Did the commissioning process actually setup the systems correctly and, if not, what is this leading to?

7.1 Technical Issues

The technical issues faced by the Visitor Centre, are for the most part related to an increase in energy consumption compared to the expected usage (51.68.3kWh/m^2 compared to a design value of 13.75kWh/m^2). The main 'non-technical' reason for this is an increase in occupancy levels, due to security staff being present in the building out with office hours – this has resulted in much high consumption figures than were expected. The technical issues that have affected the performance of the Visitor Centre are outlined below.

A defining factor was that the M&E contractors who designed and specified the various heating, lighting and ventilation systems for the Visitor Centre went out of business shortly after the building was occupied. This meant that snagging problems were not easily (or quickly) resolved as new contractors had to be found and appointed.

Related to this are on-going problems with the heating unit which is fed by the ASHP and supplies the heating and supplementary hot water for the Visitor Centre. Initially, building users were dissatisfied with the heating and hot water provision and found that the unit presented frequent error codes and often needed reset. Only when new M&E contractors were appointed in May 2013 was it identified that the unit had never been correctly configured and was in fact set to run constantly. This was the reason behind the error codes, as the unit was overheating.

Once the M&E contractors had correctly configured the heating system, the unit worked successfully until a fault was found with the external ASHP unit in early October. This fault was related to the communication between the ASHP and the electric coil. This was only resolved in April 2014 when the decision was made to replace both the ASHP and the boiler unit. Electric heaters, plugged into the small power circuits were used to heat the Visitor Centre over the winter months.

In addition, the M&E contractors, when on-site in May 2013, established that the MVHR system was not switched on correctly – this had been suspected as the 'fans' circuit was only consuming minimal amounts of electricity from the grid. The change in consumption levels pre- and post- June can be seen in section 10.9. This may have had a negative effect on internal air quality levels (see section **Error! Reference source not found.**).

In addition to the more severe problems associated with the space heating and ventilation, the following problems were encountered during the first year of monitoring which have had an effect on energy consumption:

- External lighting was not installed until 2nd November 2012; hence there was no usage on this circuit during the initial monitoring period. The external lighting was initially switched on and off manually until a timer was installed on the 20th. The timer has had occasional faults and when this occurs, the lights are switched on and off by BRE staff/security staff and therefore may on occasion have been left on for longer than was necessary.

- As noted above in section 10.9, the energy consumption on the kitchen power circuit is likely to be greater than may have been expected as problems with hot water provision required the kettle to be boiled more frequently to provide hot water for cleaning and dish-washing.

The air tightness of the Visitor Centre has also had an effect on the efficiency of the building. An air tightness value of 4.04 $m^3/(h.m^2)$ at 50Pa was measured, compared to the design value of 1 $m^3/(h.m^2)$ at 50Pa. Further investigation of the air tightness will be undertaken by BRE, but this is out-with the scope of the BPE project at present.

A lack of training at handover was highlighted as a problem in the occupant consultations (see section 4). This has resulted in a lack of understanding of controls by some occupants and potentially the incorrect use of some systems. This is compounded by the fact that, as explained in section 6 the M&E contractor who designed and installed the systems in the Visitor Centre went out of business shortly after occupation. As such there was initially no commissioning of the various systems, and problems (in particular with the heating system) were not resolved until a new contractor was identified and appointed in May 2013.

The majority of these problems (in particular the heating and ventilation issues) could have been prevented had the contractors fully completed pre-handover commissioning and had an on-going maintenance plan been agreed and carried out from the beginning.

In addition, overheating has been identified as a technical issue both in the occupant consultations and also in the internal environmental performance measurements. Solar gain was mentioned as a factor in the temperature sections within the occupant consultations. Blinds have since been purchased; these were installed on the South-West facing windows in the staff base area in September 2013. However, it will be necessary to continue measurements and undertake additional occupant consultations to identify if the blinds have resolved any or all of the overheating issues.

7.2 Conclusions and key findings for this section

The key technical issues as identified in the Visitor Centre are summarised in this section. The main technical issues have combined to increase the energy consumption within the Visitor Centre. This is in addition to the increased occupancy due to security staff occupying the Visitor Centre in non-office hours. The key technical issues are:

- Faults with the heating system and ASHP, causing a lack of heating and hot water provision, plus increased energy consumption on the heating circuit and the kitchen power circuit (required to heat water);

- Problems with the timer on the external lighting circuit may have resulted in increased energy consumption;

- Decreased levels of air tightness, causing increased air infiltration and increased heating requirements;
- Lack of handover training has resulted in staff being unsure how to operate the building most efficiently;
- Lack of full service commission caused a failure to highlight the aforementioned problems in a timelier manner, which could have seen them resolved more quickly, or prevented entirely.

These technical issues combine to result in an increase in energy usage compared to expected consumption.

As the ventilation unit was not switched on until May 2013, this may have contributed to poorer air quality results in quarter one. In addition, overheating (due in part to solar gain), as identified during consultation sessions and monitoring is a technical problem which is impacting on the comfort of occupants.

Faults with equipment, air tightness and a lack of operational guidance have resulted in the Visitor Centre performing less well than had been hoped. In addition, increased occupancy hours have increased consumption levels against what had been expected. Liaising with M&E contractors will resolve the space heating related problems before the next heating season. Further investigation of the airtightness is also planned, and identification of areas where air is infiltrating will allow these to be sealed as appropriate.

8 Key messages for the client, owner and occupier

Technology Strategy Board guidance on section requirements:	This section should investigate the main findings and draw out the key messages for communication to the client/developer, the building owner, the operator and the occupier. There may also be messages for designers and supply chain members to improve their future approaches to this kind of building. Drawing from the findings of the rest of the report, specifically required are: a summary of points raised in discussion with team members; recommendations for improving performance, with expected results or actual results where these have already been implemented; a summary of lessons learned: things to do, things to avoid, and things requiring further attention; a summary of comments made in discussions and what these could be indicating. Try to use layman's terms where possible so that the messages are understood correctly and so more likely to be acted upon.

8.1 Key messages for BRE

BRE are the client, owner and occupier in relation to the Visitor Centre. Key messages for BRE to consider are outlined in the following sections.

Summary of occupant feedback

The main issues highlighted through the occupant consultation were:

No training for BRE staff was received at handover, with relation to the operation of the building. In part this is due to the problems with the M&E contractor (as described in section 6); but even following the reconditioning work with the new contractors, not all staff were happy with the operation of the services within the Visitor Centre.

Space management, in particular a lack of storage space, was felt to be a problem. There were also problems highlighted with the open plan layout; some occupants felt that a physical division between the main event space and the staff area would be beneficial.

The temperature within the Visitor Centre was felt to be satisfactory in the winter months, but overheating due to solar gain was identified as a problem in the summer, with glare also cited as an issue. Temperature has been explored more thoroughly in section 10.8.1.

Summary of lessons learned

The key technical issues as identified in the Visitor Centre are summarised below.

- Additional occupancy due to security staff;
- Non-commissioning of M&E services;
- Lack of handover training;

- Decreased levels of air tightness;
- Overheating (due in part to solar gain).

Recommendations for improving performance

In particular, the issues highlighted in the occupant consultations should be addressed to improve the performance of the Visitor Centre and the experience of those who use the building. In order to do this, the following steps are recommended:

- Training for all BRE staff who regularly occupy the Visitor Centre in the correct and appropriate operation and control of all systems. This will have the added benefit of increasing the feeling of control that occupants have over their environment.
- In addition, user guidance on the various M&E systems and technologies installed in the Visitor Centre would be beneficial.
- Blinds have already been installed on most of the windows in the staff base area of the Visitor Centre but additional monitoring and consultation will be required to establish whether or not they have improved the comfort and temperature levels within the Visitor Centre.

Further to an understanding of the operation of the systems within the Visitor Centre, the promotion of sustainability in a wider sense would be beneficial. It is important to establish a clear and consistent method of communication between staff with regards to the efficient operation of the Visitor Centre. While BRE staff are aware of what sustainability is, they may benefit from more information on the Visitor Centre's sustainability performance, aspirations and what they can do to enhance this.

Resolving technical issues

Seasonal commissioning and an on-going maintenance schedule / agreement would be of benefit to the performance of the Visitor Centre in the longer term. This would ensure that a proactive, rather than a reactive approach would be adopted and problems (such as those experienced with the heating and ventilation systems) could be identified and resolved more quickly than has been the experience in the Visitor Centre to date.

8.2 Conclusions and key findings for this section

The key messages for BRE to consider are:

- Thorough training for all staff who frequently work in the Visitor Centre;
- User guidance for all services will also help staff operate the equipment and technologies appropriately;

- Seasonal commissioning and an on-going maintenance schedule will ensure all services work correctly in the future;
- Continued occupant consultation and on-going monitoring should continue to identify if the issues highlighted with the temperature and overheating are resolved and to see if the installation of blinds has been effective in controlling temperature and glare;
- Identify if air tightness can be improved to improve the efficiency of the Visitor Centre;
- Wider sustainability messaging should be presented to ensure all staff members and visitors are equally aware of the steps they should take to conserve resources;
- For any future projects, identify storage requirements in advance and ensure they are adopted by the design team.

9 Wider lessons

TSB Guidance on Section Requirements:	This section should summarise the wider lessons for the industry, clients/developers, building operators/managers and the supply chain. These lessons need to be disseminated through trade bodies, professional Institutions, representation on standards bodies, best practice clubs etc. As well as recommendations on what should be done, this section should also reveal what not to do on similar projects. As far as possible these lessons should be put in layman's terms to ensure effective communication with a broad industry audience.

9.1 Wider lessons

The lessons that the industry in general should consider are:

- Ensure thorough handover training for all staff who will occupy the building;
- Building user guidance will also help staff operate the equipment and technologies in the building appropriately;
- Seasonal commissioning and an on-going maintenance schedule should be adopted from the start to ensure all services continue to work correctly in the future;
- Continual occupant consultation and on-going energy and environmental monitoring should be adopted as standard to identify any issues and ensure that they can be resolved as quickly as possible;
- As built testing of the complete building will identify any problems which may affect the building efficiency (e.g. U-value testing, air tightness testing);
- Wider sustainability messaging should be presented to ensure all staff members and visitors are aware of the steps they can take to ensure resource efficiency;
- Adopting a sustainability advisor or using BREEAM in the design process will ensure that an efficient building that is suitable for the occupants needs will be delivered. This will also ensure that the building continues to operate in an effective manner throughout its life.

For this particular project, the BUS survey was not found to be entirely appropriate for collecting feedback for the Visitor Centre. This is mainly due to the small sample of responses which resulted from the small number of potential respondents. Until there is a large enough sample of responses, statistically the results may not be significant and a focus on average scores may mask the true trend of responses. In addition, the BUS survey responses are compared to a range of non-domestic buildings, with unknown properties, construction methods and operational practices. These non-domestic buildings are not likely to be all offices, and as such their comparison to the Visitor Centre is perhaps not useful. However, the 'comment style' questions did provide some insight into the particular problems faced by the Visitor Centre occupants.

The ‘open’ or qualitative questions in the questionnaire (held in December 2012) gave much more scope for expanding on these issues. The interview / focus group sessions held with key BRE staff that spend the most time in the Visitor Centre were very instructive in outlining specific problems.

10 Appendices

Technology Strategy Board guidance on section requirements:	The appendices are likely to include the following documents as a minimum: • Energy consumption data and analysis (including demand profiles) • Monitoring data e.g. temperatures, CO2 levels, humidity etc. (probably in graph form) • TM22 Design Assessment output summaries • A DEC – where available • Air conditioning inspection report – where available • TM22 In-Use Assessment output summaries • BUS Occupant survey – topline summary results • Additional photographs, drawings, and relevant schematics • Background relevant papers

10.1 Visitor Centre Plans and Drawings

Included as separate files:

- Location Plan
- Site Plan
- Ground Floor Plan
- External Elevations
- Sections.

10.2 Scientific Testing – Summary of procedure and results

Scientific 'spot checks' were taken on two days, one winter, one summer, to identify how the Visitor Centre performs under different external conditions. The first spot checks were taken on Thursday 10th January 2013, and the second on Friday 20th June 2014.

	Winter – 10 January 2013	**Summer – 20 June 2014**
Temperature (°c)	12.44°C	24.20°C
Relative Humidity (%)	45%	42%
Air Quality (ppm of CO_2)	460 ppm	424 ppm
Noise Level (dB)	55 dB	50 dB
Light Level (lux)	4400 lux	1370 lux (in shade)
General weather conditions	Cloudy with some fog	Sunny

Figure 34: External Conditions during Survey

Figure 35: External Conditions during January spot checks

A number of areas were surveyed within the Visitor Centre to give a full and accurate overview of the buildings performance; these are detailed below in Figure 36 and Figure 37.

Reference No.	Location	Area Description
1	Open Plan Area	Reception Area
2	Open Plan Area	South Corner
3	Open Plan Area	West Corner
4	Open Plan Area	North Corner
5	Open Plan Area	Central Area
6	Staff Base	Desk Area 1
7	Staff Base	Desk Area 2

Figure 36: Areas to be surveyed

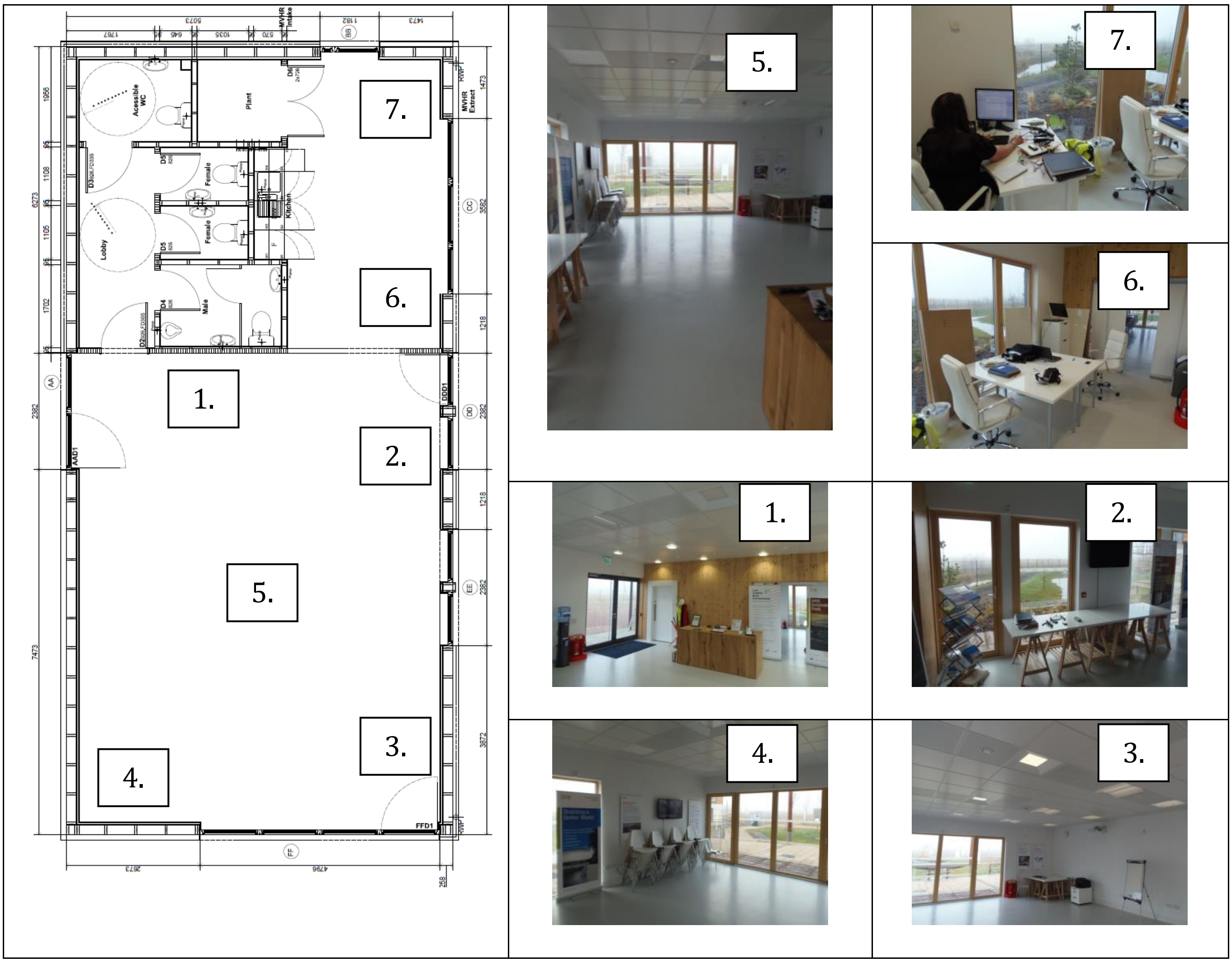


Figure 37: Plan / Images of Areas Surveyed

It is important to consider the impact internal environment conditions or settings will have upon the 'spot check' measurements as these are likely to have the biggest influence over the readings. The general conditions are described below in Figure 38.

	Winter 2012/2013		Summer 2014	
	Staff Base	Open Plan Area	Staff Base	Open Plan Area
Set point temperature	28°C	24°C	-	-[4]
Occupancy	2 staff members	Unoccupied	2 staff members	1 staff member
Lighting	Artificial lighting off, no blinds	Artificial lighting off, no blinds	Artificial lighting off, blinds on 3 SW facing windows	Artificial lighting off, no blinds
Building Services	All systems operational[5]	All systems operational	All systems operational, windows and doors open	All systems operational, windows and doors open

Figure 38: Internal Conditions during Surveys

Temperature and Humidity

Typical thermal comfort levels, in terms of temperature, vary depending upon the building users clothing type and activity. For an office in Scotland, it is assumed that the majority of activities involve sitting and wearing normal to heavy clothing. Therefore, typical comfort levels should range from between 18 to 21°C for most spaces, as can be seen in Figure 39 below.

Clothing Type	**Typical Comfort Levels - Temperature (°C)**			
	Strolling	Standing	Sitting	Sleeping
Light clothing	15	23	25	27
Normal clothing	8	19	21	24
Heavy clothing	0	14	18	21
Very heavy clothing	0	10	14	18

Figure 39: Comparative Temperature Levels

[4] The heating was not switched on during the summer months.
[5] It has since been identified that the MVHR unit was not operational at this time, and there were on-going problems with the heating system (see section 6.1.3).

Generally, in a working environment, the recommended relative humidity level should be between 40% and 60%. When temperatures are higher, humidity should be nearer the lower end of this scale. When humidity is too low there can be a wide range of health implications, including eye, nose and throat irritation, respiratory infections and headaches. Similarly, when humidity is high the internal environment can become very uncomfortable. As the human body feels warmer and cannot cool, overheating can occur and lead to dehydration and chemical imbalances within the body.

		Winter 2012/2013		Summer 2014	
Ref.	**Location**	**Temperature (°C)**	**Humidity (%)**	**Temperature (°C)**	**Humidity (%)**
1	Reception Area	18.88	48.8	21.8	49
2	South Corner	19.50	46.6	23.0	44
3	West Corner	19.00	47.9	22.3	47
4	North Corner	19.11	66.4	23.0	44
5	Central Area	18.94	66.1	22.6	46
6	Desk Area 1	19.94	67.9	24.1	39
7	Desk Area 2	19.83	67.7	23.5	41

Figure 40: Temperature and Humidity measurements

As can be seen from the readings in Figure 40, temperatures in the winter were within the 18 to 21°C threshold recommended. It should be noted that the Open Plan Area was unoccupied at the time of survey, and if this area was at maximum capacity there would be considerable latent heat gains from the occupants. Additionally, the thermostat in this area was set to 28°C (higher than would typically be expected) as the Air Source Heat Pump (ASHP) appears to be struggling to me the specified heat requirement.[6]

During the summer spot checks, the temperatures were higher, and all were above the recommended maximum of 21°C, despite all the windows and doors being open. It should be considered however that the external temperature was 24.2°C and there was a great amount of solar gain.

It should be noted that generally the level of relative humidity was between 40 to 70%, generally falling within the recommended limits. Generally it was drier when the temperature was greater.

Air Quality

Air quality is a measurement of the level of CO_2[7] within the internal environment, and is measured in parts per million (ppm). Typically, 'Good' practice levels should be below 1000 ppm and ideally less than 600 ppm as when CO_2 levels are in excess of 1000 ppm, drowsiness and lethargy are common side effects, with a noticeable drop in productivity and concentration. Levels of between 1,000 and 2,700 ppm have been shown

[6] Again, it was later identified that the heating system was not correctly configured (see section 6.1.3).
[7] CO_2 – Carbon dioxide

have an adverse effect on building occupants wellbeing and up to a 14% reduction in cognitive function. 'Spot check' measurements were carried out for air quality, with results detailed below in Figure 41.

		Winter 2012/2013	Summer 2014
Ref.	**Location**	**Air Quality (ppm)**	**Air Quality (ppm)**
1	Reception Area	808	360
2	South Corner	786	450
3	West Corner	834	400
4	North Corner	810	456
5	Central Area	830	410
6	Desk Area 1	775	480
7	Desk Area 2	785	460

Figure 41: Air Quality Measurements

The level of CO_2 within the internal spaces ranged from between 785 and 834 ppm during the January observational site visit to the Visitor Centre. For all areas the air quality was above the recommended level for comfort and productivity.

Unusually, the level of CO_2 within the occupied staff base was recorded as being lower than the unoccupied Open Plan Area. This is common in naturally ventilated spaces and further investigation in the summer spot check session showed CO_2 levels in all areas were well below the 600ppm recommended maximum. This is to be expected however as all windows and doors were open, providing natural ventilation.

Lighting

Within an office environment it is important to consider the lighting level within each internal space, measured in lux, as specific tasks require varying levels of light. Lighting levels can include both natural and artificial lighting. However, the use of natural light has multiple benefits, including improved occupant health and wellbeing and can also contribute to the reduction of energy consumed for lighting.

Figure 42 details typical comparative lighting levels that would be expected for various space functions or tasks.

Comparative light levels	lux
Precision task lighting	1,000
Drawing boards	750
Kitchen preparation areas	500
General reading	300
Entrance halls	150
Corridors or storage	100

Figure 42: Comparative Light Levels

Similarly to the thermal comfort and air quality measurements, lighting levels were also measured for the Visitor Centre and are detailed below in Figure 43. Readings were taken for both natural light only, and also with artificial lighting in use.

		Winter 2012/2013		Summer 2014
Ref. No.	Location	Lighting Level (Lux)		Lighting Level (Lux)
		Natural (only)	Artificial	Natural (only)
1	Reception Area	230	852	7650
2	South Corner	306	1990	2000
3	West Corner	1700	1790	2000
4	North Corner	197	215	600
5	Central Area	273	430	2000
6	Desk Area 1	480	1140	4080
7	Desk Area 2	920	1340	3950

Figure 43: Lighting Level Measurements

The scientific measurements recorded indicate that within the majority of the Visitor Centre, natural light is plentiful and well utilised. When necessary natural light can be supplemented using artificial lighting as is shown in Figure 44 below. Artificial lighting was not used, or needed during the day in the summer.

Figure 44: Reception desk with artificial lighting on

The North corner of the building had considerably lower levels of daylight than the majority of other spaces; however, this was as expected on the basis of the study carried out at the design stage (see Figure 19).

Noise Level and Acoustic Performance

When considering the acoustic performance of the internal environment, it is important that noise levels do not regularly or consistently exceed the recommended sound levels as detailed below in Figure 45. Generally, constant noise levels of 65 dBA or higher can have a negative impact on the wellbeing of the building occupants, such as experiencing fatigue.

Space function	**Noise Level (dBA)**
Hospital & general wards	55
Small consulting rooms	50
Large offices	45-50
Private offices	40-45
Living rooms	40-45
Small classrooms	40
Large lecture rooms	35
Bedrooms	30-40
Music studios	30

Figure 45: Recommended Noise Levels

The final measurements taken during the 'spot check' exercise were to determine the noise level within the internal spaces. The results of this exercise are detailed below in Figure 46.

		Winter 2012/2013	Summer 2014
Ref. No.	Location	Noise Level (dBA)	Noise Level (dBA)
1	Reception Area	70	54
2	South Corner	60	40
3	West Corner	45	45
4	North Corner	70	44
5	Central Area	60	42
6	Desk Area 1	50	42
7	Desk Area 2	40	47

Figure 46: Noise Level Measurements

Within the Visitor Centre, noise levels were recorded as being relatively low and generally within the recommended limits for office space, and considerably below the threshold for hearing damage. It is important to note that at the time of the surveys, occupancy was minimal, and as such noise levels were expected to be low.

External noise levels were reasonably high during the winter spot checks (58 dB) as construction of the AppleGreen Home was underway adjacent to the Visitor Centre and in the summer (50dB) as a new housing development is being constructed on the next site to the Innovation Park. In general terms, there appears to be little noise transference from external to internal.

10.3 Thermography Testing

Correctly interpreting the thermal images is critical in identifying any areas that are directly affected by poor insulation, thermal bridging and/or poor quality construction. Correct interpretation is particularly important as emissivity, reflections and evaporation can look similar. BRE hold a valid Level 2 certificate in thermography (as defined by the UKTA). The TSB 'Quality Checklist' has been appended to the report, see Figure 54.

Thermal imaging can also be used to identify air leakages within a building; it is unable to quantify air leakage rates but merely show the pathways of the leakages. Ideally the thermal images will be taken when there is at least a 10°C difference between the internal and external temperature, wind speed should be no more that 10m/s and where there is no direct solar gain.

Results and Discussion

The survey was carried out under the following conditions:

General		
Date	23/01/13	
Camera Type	Flir E50bx	
Camera Specification	Resolution	43,200 pixels
	Temperature Sensitivity	0.045°C
Relative Humidity assumption	50%	
Internal Conditions		
Internal Temperature	20°C (heated for at least six hours)	
Occupancy	2 occupants	
External Conditions		
External Temperature	1°C	
Weather Conditions	Cold, dry and overcast	
Direct sunlight	No direct solar radiation observed in last 24 hours	
Surface Condition	Dry, with no precipitation	
Wind speed	1 to 2 m/s	

Figure 47: Survey Conditions

Continuity of Insulation

Figure 48: External Thermal Image 1

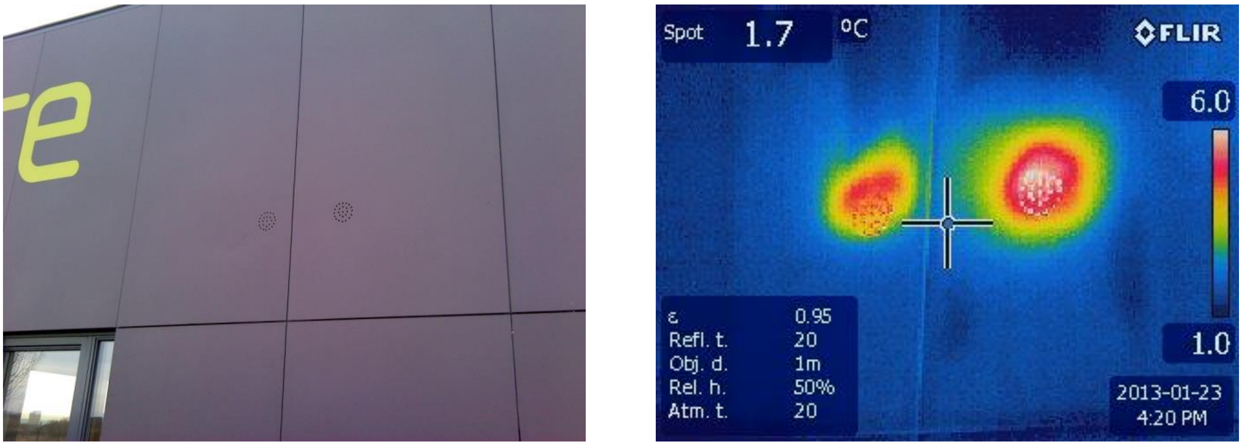


Figure 49: External Thermal Image 2

In Figure 48, a considerably warmer surface temperature was detected at two concentrated points located above the battery shed. This was further investigated and was found to be mechanical ventilation openings, as is shown in Figure 49.

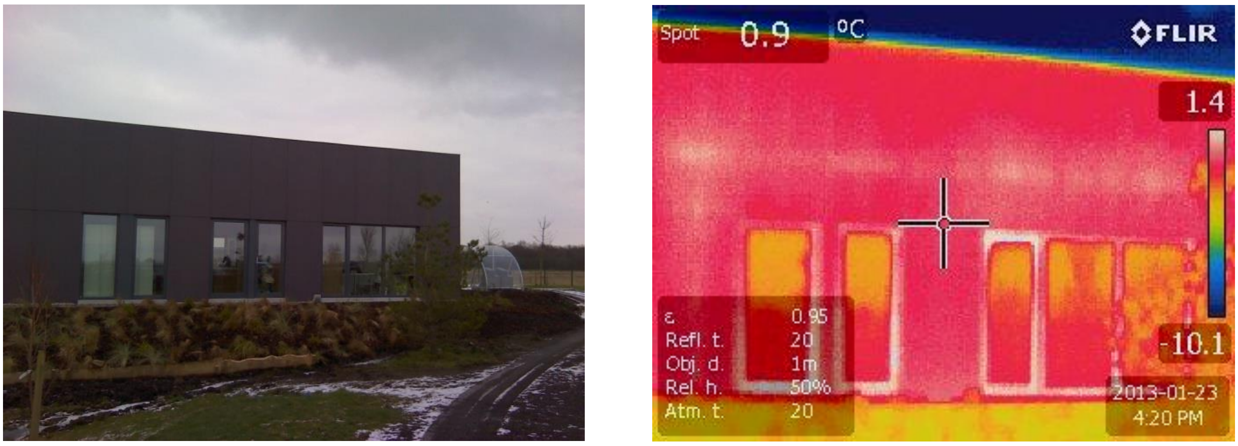


Figure 50: External Thermal Image 3

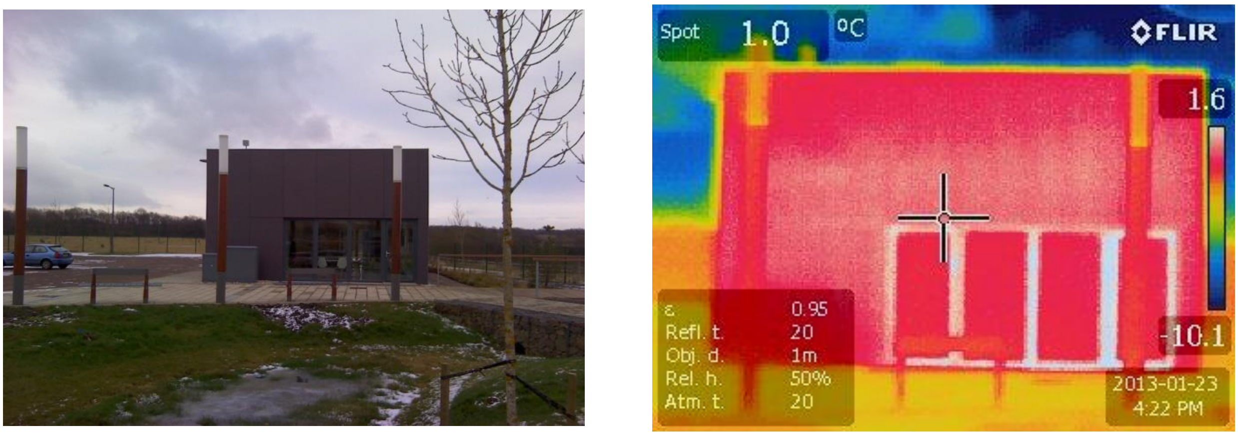


Figure 51: External Thermal Image 4

The above images (Figure 48, Figure 49, Figure 50 and Figure 51) demonstrate acceptable continuity of insulation, with uniform temperatures across all external surfaces. The highest temperatures recorded on the external surfaces were through the window and door frames, as is to be expected.

Insulation levels appear consistent, with no external areas identified with inadequate levels of thermal resistance.

Internal Surfaces

A number of areas were identified as having lower surface temperatures throughout the inside of the building, primarily at junctions where some cracks have appeared. This is particularly clear in Figure 52 and Figure 53. The significance of these cracks, when compared with the as designed performance, will be determined through the air tightness testing results, but recorded temperatures are considered lower than would be expected.

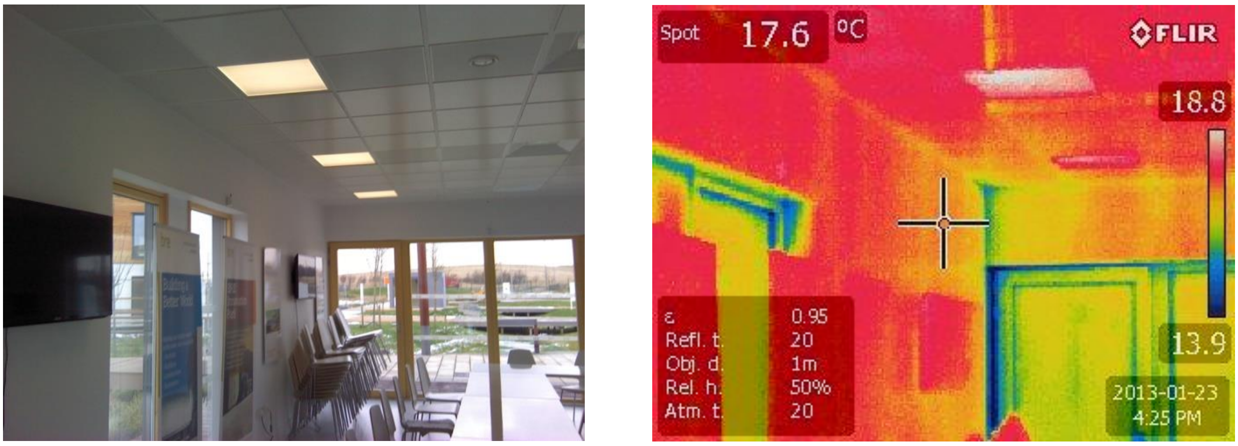


Figure 52: Internal Thermal Image 1

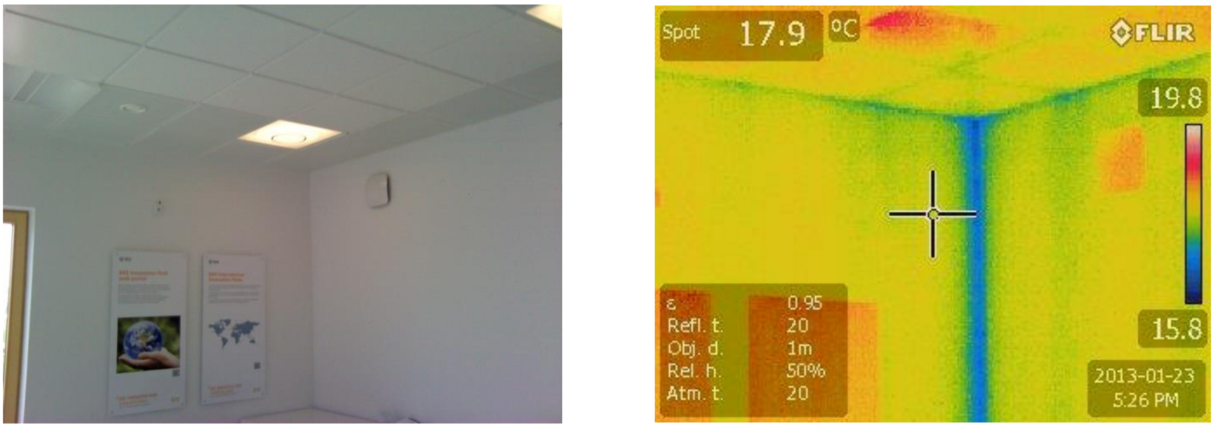


Figure 53: Internal Thermal Image 2

Estimation of thermal conductance by infrared thermography alone is not practical, primarily due to the precise conditions required. It is considerably more accurate to use a heat flux measurement device to measure U-values in-situ, in conjunction with the thermography, to determine any deviation for the as designed specification.

Contents Check	'Y/N'	Mandatory / Preferred	Comments
Introduction provided explaining extent of survey, and scope.	Y	Mandatory	See section 10.3
Is the survey company a member of the UKTA?	Y	Preferred	UKTA – Level 2 Thermographer
Have threshold temperatures been provided in accordance with BRE IP17/01	Y	Mandatory	See Figure 47
Under fCRsi factors – what humidity levels have been assumed?	Y	Preferred	50% RH assumed
Has the report recorded parameters e.g. internal and external conditions at the time of the survey?	Y	Mandatory	See Figure 47
Were ambient/internal conditions in accordance with BSRIA TN 9/2002 (page 14) If 'N' state deviations from these requirements.	Y	Mandatory	See Figure 47
Confirm the spaces tested have been heated at a relatively constant temperature for how many hours and to what internal temperature – state both	Y	Mandatory	20°C for at least six hours
Confirm resolution of camera is at least 40,000 pixels in total pixels and a min. temperature sensitivity in 0.2°C	Y	Preferred	43,200 pixels 0.045°C temperature sensitivity
Confirm a list of issues/ problems been provided?	Y	Mandatory	See section 10.3
Confirm normal digital photos have been provided alongside each thermographic image	Y	Mandatory	Yes.

Figure 54: TSB 'Quality Checklist'

10.4 U-Value Testing

The 'as designed' U-values for the Visitor Centre are as follows:

- Roof: 0.1 W/m^{2}K,
- Floor: 0.1 W/m^{2}K,
- Wall 0.15 W/m^{2}K,
- Windows: 0.9 W/m^{2}K.

The flow of heat internally from the Visitor Centre to the outside was measured by attaching a heat flux sensor to the internal surface of the building fabric, along with internal and external temperature gauges, connected to a data logging device. For each U-value measurement, temperatures and heat flows were monitored over two weeks. The U-value is then derived from the sum of the heat flow readings (expressed in W/m²), with corrections for thermal storage effects, divided by the sum of the temperature difference readings (expressed in K) over the period of the test.

U-value measurement is not a straightforward process. Interior and external temperatures inevitably fluctuate and, in addition to this, there will be times when heat is temporarily stored within the structure of the building and later released. To allow for any temporary storage of heat in any U-value measurement, the heat flows and temperature readings will be carried out over a sufficiently long period to negate the influence of thermal storage (2 weeks).

Due to practical limitations, it is only possible to measure the thermal performance of the walls and roof.

Testing Conditions

The survey was carried out under the following conditions:

Start date	23rd Jan 2013	
End date	13th Feb 2013	
Open Plan Area (Walls)		
Location of Heat Flow Meter (HFM)	**Location 1**	**Location 2**
Height above floor	1.54 m	1.57m
Distance to nearest window or door	2.17 m	1.70m
Distance to nearest wall corner	Over 3.0 meters	Over 3.0 meters
Plant Room (Roof)		
Height above floor	3.2 m	
Distance to nearest window or door	N/A	
Distance to nearest wall corner	N/A	

Figure 55: Testing Conditions for U-value Testing

Heat Flow Meters were fixed to an appropriate location on the internal wall within the open plan area of the Visitor Centre.

An additional Heat Flow Meter was also fixed to the roof of the plant room, as this area has no suspended ceiling and provides access directly to the roof structure.

‘Tiny tags’, to measure temperature were placed at a number of external locations, surrounding the building. These were located in accessible locations at ground level, as access was not available to the roof area.

Figure 56: Heat Flow Meters

Figure 57: Heat Flow Meters

Figure 58: Tiny Tag External Temperature Sensors

Graphical Results

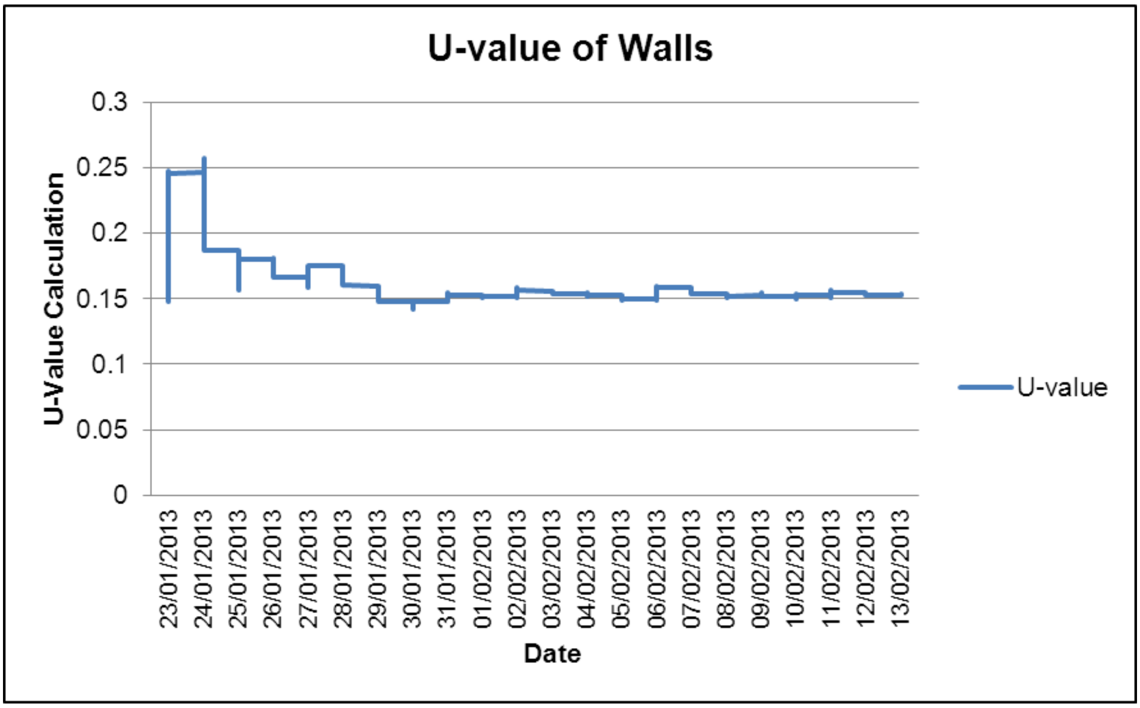


Figure 59: Wall U-Value Calculation

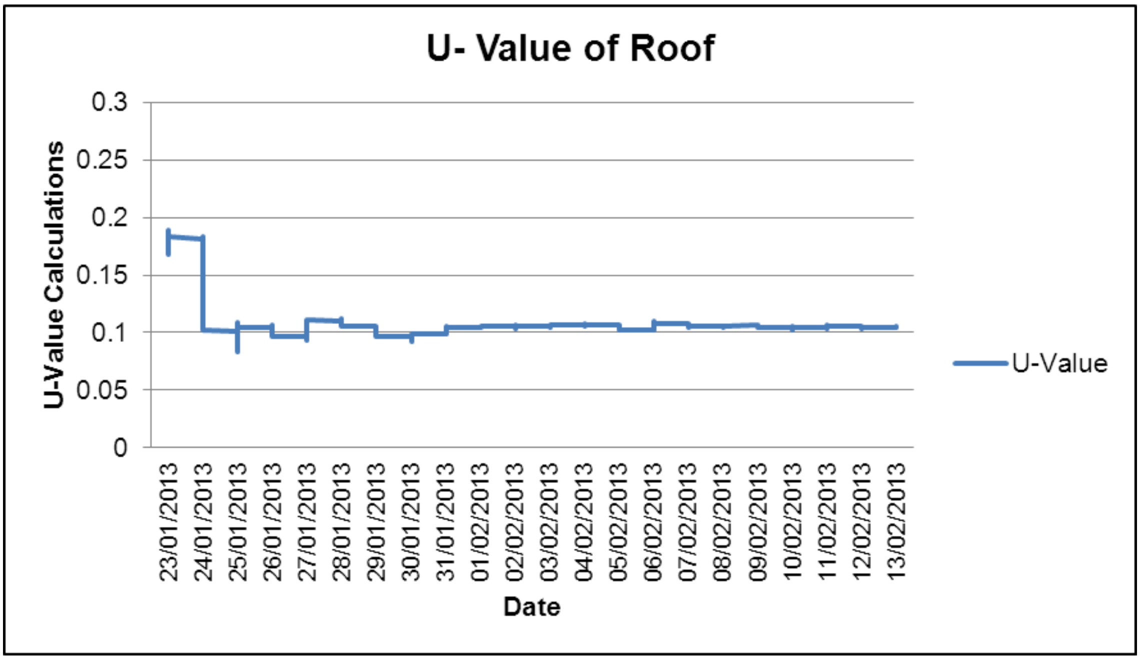


Figure 60: Roof U-Value Calculation

Discussion

Figure 59 and Figure 60 present results from the measurements, derived using the techniques described in ISO 9869. A direct comparison between the measured U-values and the U-values calculated using the methodology in BS EN ISO 6946 is then possible.

	Designed U-Value	Measured U-Value
Wall	0.15 W/m2K	0.15 W/m2K (approx.)
Roof	0.10 W/m2K	0.10 W/m2K (approx.)

Figure 61: Comparative U-Value Results

Within Figure 59 and Figure 60, the heat flow appears to fluctuate following the initial installation of the equipment. After a few days, the U-value measurement appears to reduce to the designed U-value specification. The fluctuation may be due to the effects of thermal mass.

Figure 61 identifies the 'as designed' U-values, which are provided to allow comparison with the measured U-value. As can be seen from the figures, the constructed Visitor Centre fabric (at the tested locations) is consistent with the design specification.

10.5 Air Tightness Testing

To measure the airtightness of the Visitor Centre, the fan pressurisation technique was undertaken. The technique involves the installation of a portable variable speed fan into an external doorway incorporating an airtight seal. All the external windows, doors and vents will be closed, while the vents for the MVHR will be sealed and the internal doors open.

The fan system is set up to pressurise the building (a maximum pressure difference between inside and outside of approximately 50 Pa is aimed for). A set of ten measurements of the building pressure differential and air volume flow rate through the fan are recorded. The speed of the fan is then reduced in steps, and the measurements repeated down to a minimum pressure difference.

After the test is completed, the measured values of pressure difference and air volume flow rate are entered into a spreadsheet where corrections are made for temperature and barometric pressure. A log graph of the parameters Q, air volume flow rate, and ∆P, differential pressure are plotted out for the tests. This graph is shown in the Appendix; see Figure 71and Figure 72. A best-fit power-law trend-line of the form, Q = C ∆Pn is shown within this. The uncertainty of the tests was calculated to be 10%.The test is then repeated for depressurisation.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor of k = 2, which provides a confidence level of approximately 95%, but excludes the effects of wind speeds in excess of 3 m/s.

Once the data has been obtained from the tests, a best-fit power-law profile of the form Q = C ∆Pn where the coefficient C and the exponent n (0.5 < n <1.0) are constants, is fitted to the data. Images of the actual air tightness testing process are shown below.

Figure 62: Variable Speed Fan

Figure 63: Sealed MVHR Vent

Results

Air tightness testing was carried out twice within one day, with similar results each time as can be seen in Figure 64.

Test No.	Air Tightness Result
Depressurisation	3.78 $m^3/(h.m^2)$ at 50Pa
Pressurisation	4.35 $m^3/(h.m^2)$ at 50Pa
Average	**4.04 $m^3/(h.m^2)$ at 50Pa**

Figure 64: Test Results

Air tightness testing results showed that the Visitor Centre has an average air tightness of 4.04 $m^3/ (h.m^2)$ at 50Pa. This is considerably worse than was predicted, or committed to, by the contractor.

In Scotland, all dwellings will require air tightness testing and there is a maximum allowable air permeability of 7 $m^3/ (h.m^2)$ at 50 Pa. In non-dwellings, such as the Visitor Centre, a maximum air permeability value has not been set within the Scottish Building Standards. However, in practice, for the building to achieve the required energy targets, a value of less than 10 $m^3/ (h.m^2)$ at 50 Pa will normally be required. When a value of less than ten is claimed, a test is required to prove this.

The contractor stated that an air tightness figure of 1 $m^3/ (h.m^2)$ at 50Pa, or lower, was expected to be achieved.

There are two key issues related to airtightness, which are often found with timber frame buildings. Firstly, hairline cracks between the plasterboard are generally due to differential movement and general settling of the building. Over time the cracks can expand and result in higher heat loss through infiltration. Structural movement, which is a normal occurrence in new buildings, can also cause or worsen this effect.

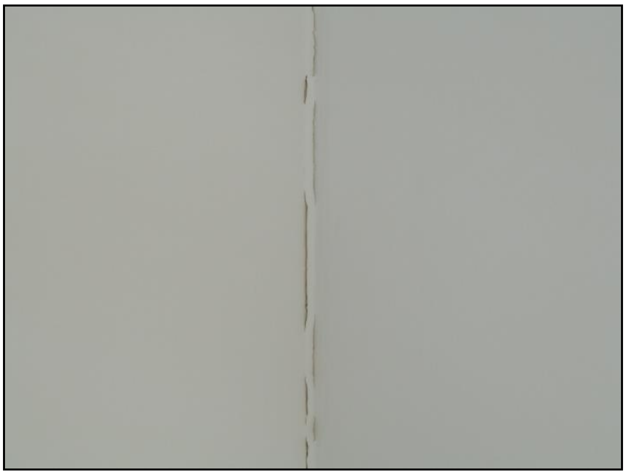


Figure 65: Crack in Wall Joint 1

Figure 66: Crack in Wall Joint 2

The second key issue commonly seen within timber frame buildings is 'popping', where structural movement causes the nails which fix the internal plasterboard to the timber frame to 'pop' out and can leave holes in the internal wall. This has not been the case at the Visitor Centre.

In addition to the possible gaps within the air barrier, there are also a number of penetrations that could be negatively affecting the air tightness performance of the building. While the majority of the building has a fairly clean finish, the plant room has a number of penetrations in the floor, roof and walls. It should be noted that some work in the plant room has been undertaken retrospectively, for various projects and purposes, following handover and therefore the building may have been handed over to BRE with a better level of air tightness than has been measured at this stage in the project. A number of the building fabric penetrations have been documented; see Figure 67, Figure 68, Figure 69 and Figure 70.

Figure 67: Under-floor Heating Connection

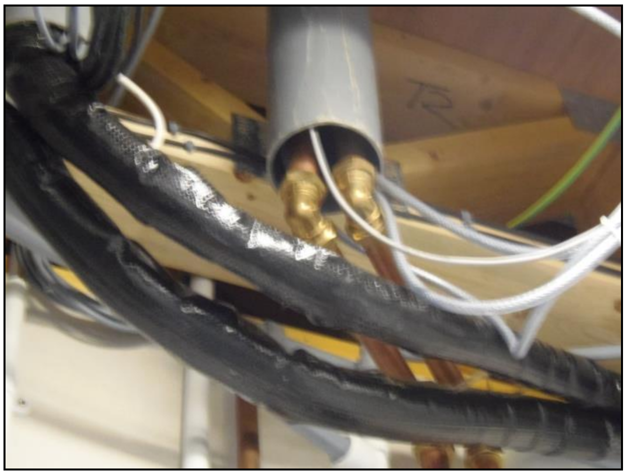


Figure 68: Pipe through Roof

Figure 69: Open Pipe through Floor

Figure 70: Break through Insulation (Wall)

Additionally, full-time staff working at the Visitor Centre have stated that they do not believe that the windows are ‘particularly air tight’. This will be further investigated by BRE, but not as part of the BPE project.

The contractor will now be contacted and asked to review the air tightness testing results and if necessary take remedial action.

Airtightness Test Correction Graphs

A log graph of the parameters Q, air volume flow rate, and ∆P, differential pressure are plotted out for the tests and are shown below.

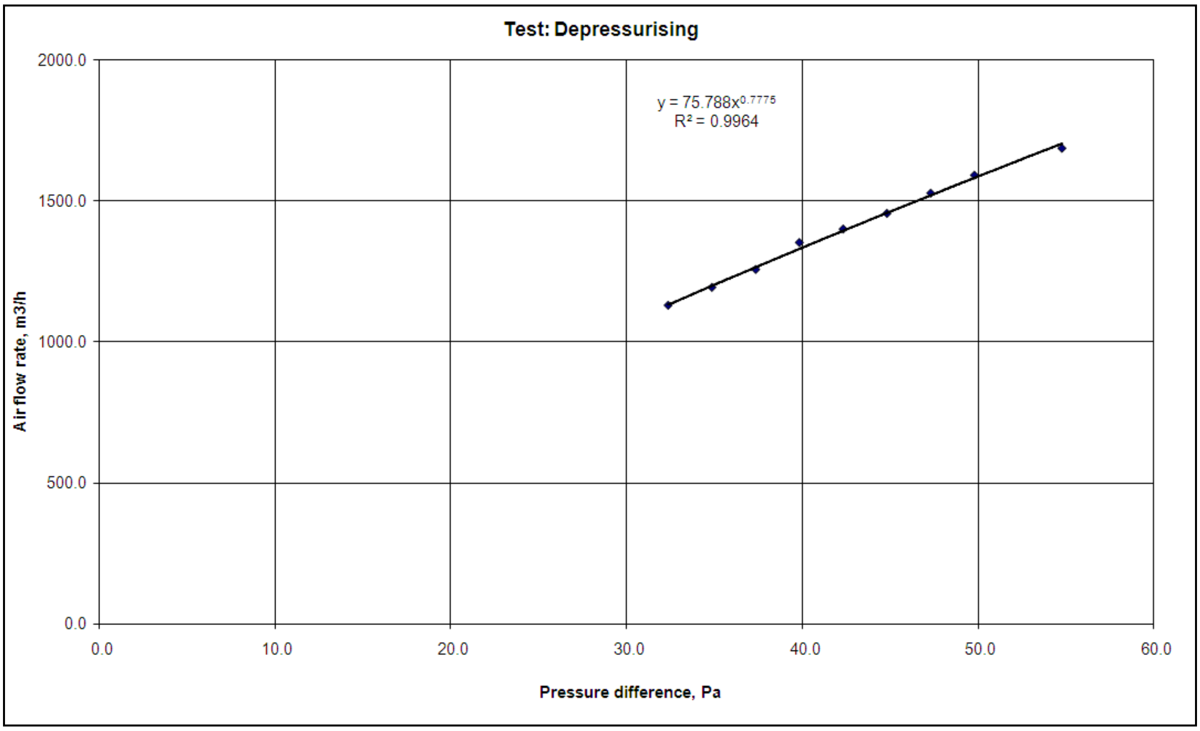


Figure 71: Airtightness Test Correction Graphs (Depressurising)

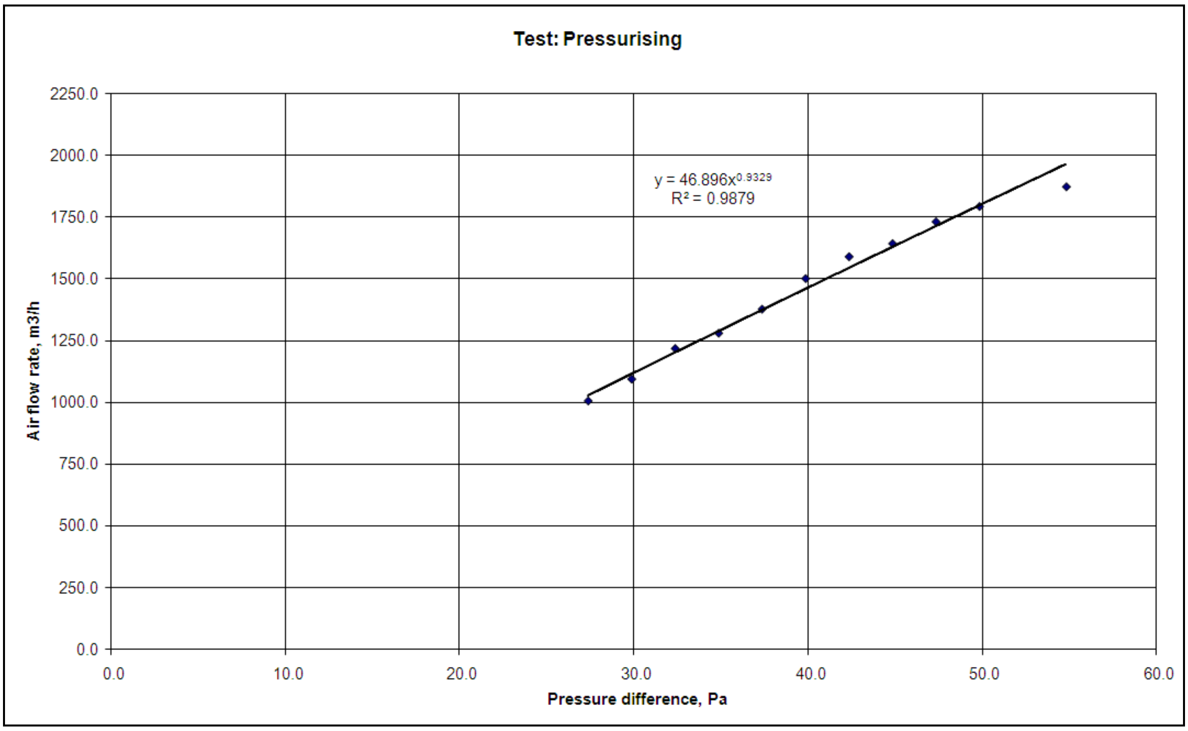


Figure 72: Airtightness Test Correction Graphs (Pressurising)

10.6 BUS Survey

The BUS Survey covers the following areas:

- General design and needs;

- Lighting, noise and temperature;
- Control over heating, lighting, ventilation, cooling and noise;
- Comfort levels (temperature, air quality, air movement);
- Health and wellbeing;
- Space and storage;
- Perceived effects on productivity;
- Complaints and response;
- Background statistics for classification purposes.

A copy of the BUS Survey and the full results report is included as a separate file.

The BUS Survey results are depicted using a scale system. Depending on the scale, either:

- scores that fall between the lower limit of the benchmark and the upper limit of the scale midpoint are considered acceptable and scores that fall between the scale midpoint are considered to be ideal (e.g. for temperature in summer (hot/cold));
- scores that fall below both the lower limits of the benchmark and of the scale midpoint can be considered better than acceptable (e.g. air in summer (odourless/smelly));
- or, low scores below the lower benchmark and midpoint limits can indicate a problem (e.g. control over cooling (no control/full control)).

The benchmark limits (lower, mean and upper) are shown by marks at the top of the images, and the scale midpoint limits are shown by marks on the bottom of the images. For most questions, the scale runs from 1 – 7, so the midpoint (i.e. the average) score would be 4.

A ‘green square’ demonstrates that the conditions are good; an ‘orange circle’ demonstrates that they are average, and a ‘red diamond’ demonstrates that the conditions were felt to be poor. The benchmark results are for all non-domestic buildings in the UK which have been surveyed by Arup. As can be seen in Figure 22, the overall results are positive.

Due to the nature of the Visitor Centre, there were a limited number of building users or regular visitors that could be approached to complete the questionnaire. Twelve responses were received in all. Of the respondents, eight were male (67%), four were female (33%); and four were under thirty (33%) and eight were over thirty (67%). One respondent was an external contractor, and three were usually based in the Visitor Centre. Ninety-two per cent of respondents usually sat next to a window when in the Visitor Centre, but as the building is highly glazed, this is to be expected. As there were so few responses, the results may have little statistical significance, but the responses may still highlight problems or issues as felt by occupants of the Visitor Centre.

Temperature

The graphs in Figure 73 show a summary of results regarding temperature. Mostly the temperature was found to be good in terms of comfort and stability.

Summer

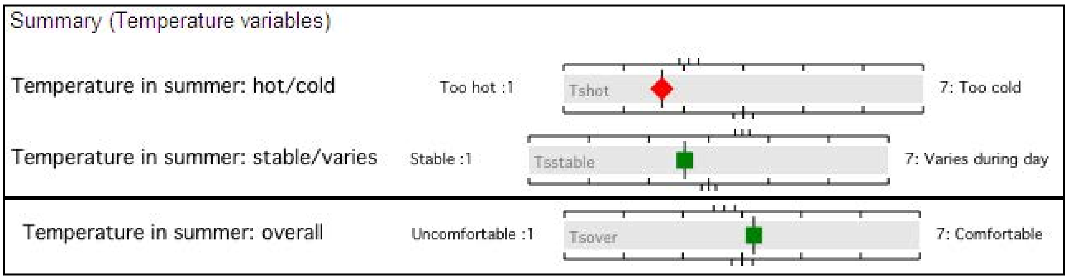


Figure 73: BUS Survey - summer temperature results

The temperature in the summer was toward the 'too hot' end of the scale. As can be seen in Figure 74, all respondents scored the summer temperature as average (4) to 'too hot' (1), with 45% of respondents scoring 1 or 2 and 36% scoring 3.

Results for the stability of temperature were varied, though the average score was 3.6. Overall, the temperature in the summer was found to be good but 40% of respondents noted a score towards the 'uncomfortable' end of the scale. The summer temperature overall was found to be more comfortable than the benchmark data.

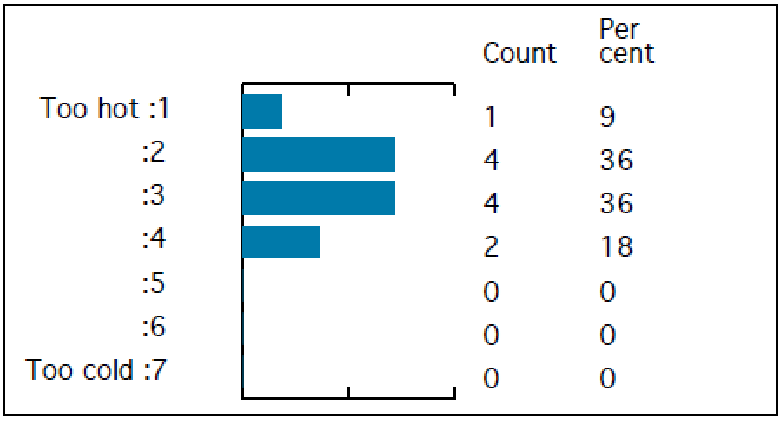


Figure 74: BUS Survey - Temperature in summer (too hot/too cold)

Winter

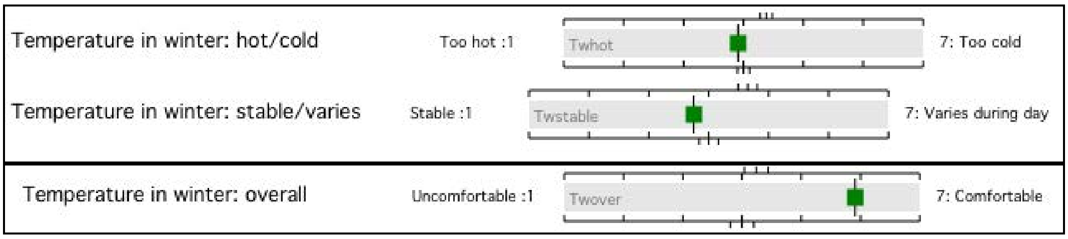


Figure 75: BUS Survey - winter temperature results

The temperature in winter was found to be in the 'ideal' range, with 91% of respondents giving it a score of 4. Results for the stability of temperature were again varied, with an average score of 3.75 in winter. Winter internal temperatures in the Visitor Centre were found to be mostly comfortable, with an average score of 5.91, and no respondents scoring 3 or less.

Air Conditions

The graphs in Figure 76 show the overall results for air conditions within the Visitor Centre.

Summer

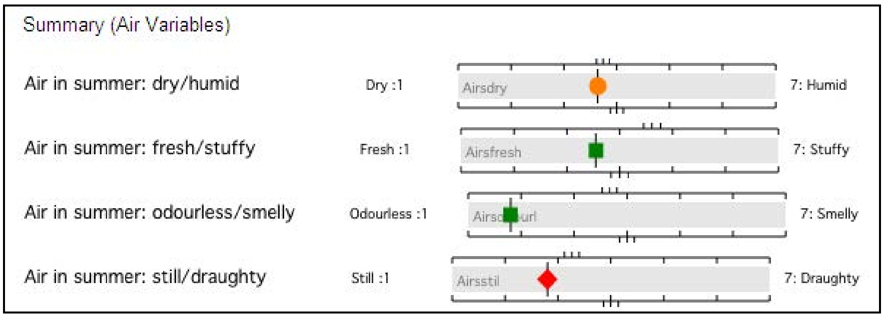


Figure 76: BUS Survey - Summary of Air Results

In Figure 76 above, the air in summer is shown to be average in terms of humidity, but not ideal, though 64% of the respondents found it to be good (gave it a mark of 4, see Figure 77). The air was found to be towards fresh, with 45% of respondents giving a score of 2, however 18% thought it was average, and 36% voted towards the 'stuffy' end of the scale. The air was found to be considerably fresher compared to the benchmark data.

While 60% of the respondents thought the air was neither still nor draughty (a score of 3-5), 40% found the air to be still. This gave an overall score of 2.8, lower than the benchmark average.

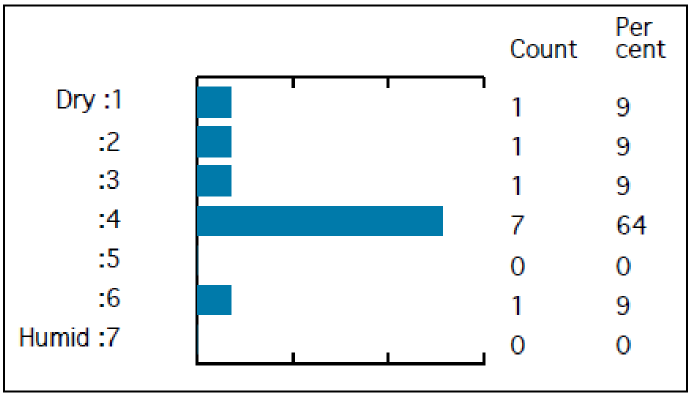


Figure 77: BUS Survey - Air in summer (Dry/Humid)

Winter

Figure 78 displays an overview of the air conditions over the winter months.

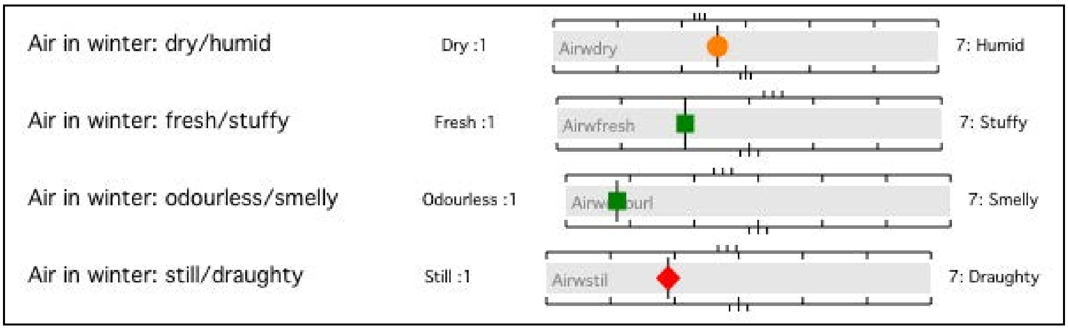


Figure 78: BUS Survey - Summary of winter air results

In the winter, in terms of stillness/draughts, the response was very similar to in the summer (a score of 2.9, compared to 2.8 in the summer). The air was noted as being fresh and odourless. In terms of humidity, the air in winter within the Visitor Centre was noted as being acceptable, with 56% of respondents giving a score of 4, and an average score given of 3.56.

Noise

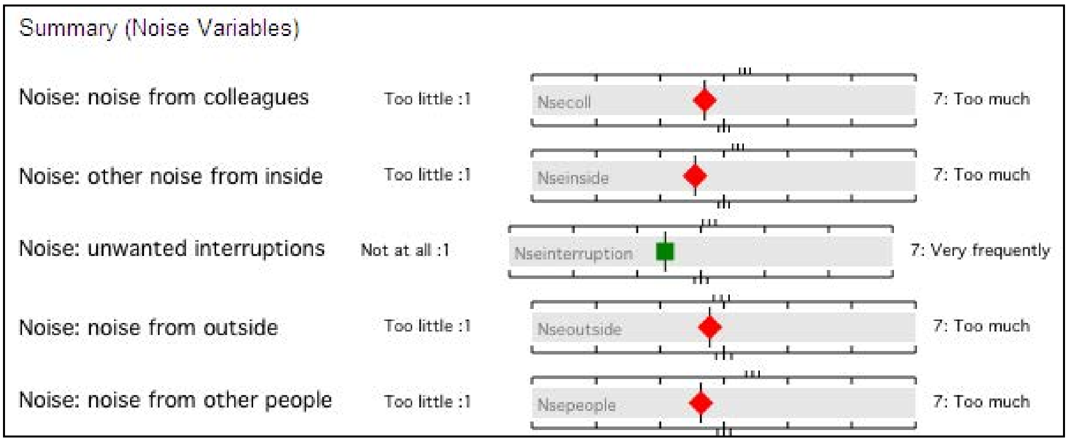
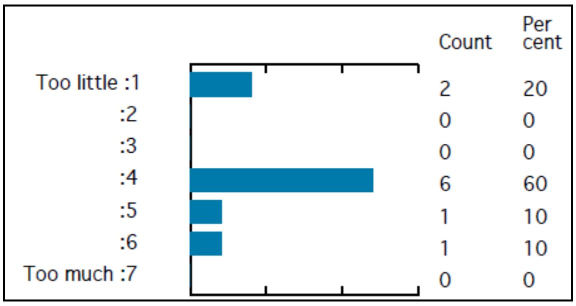


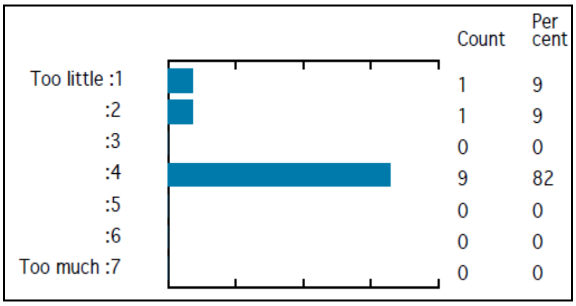
Figure 79: BUS Survey - Summary of Noise Results

With regards to noise, the summary responses can be seen in Figure 79. Four of five of the questions relating to noise (those regarding noise from colleagues, other internal factors, external factors and from other people) have ‘poor’ responses (i.e. they are ‘red diamonds’), however, for these questions the ideal score would be 4 and the feeling of respondents was that the noise levels from these factors was only slightly too little.

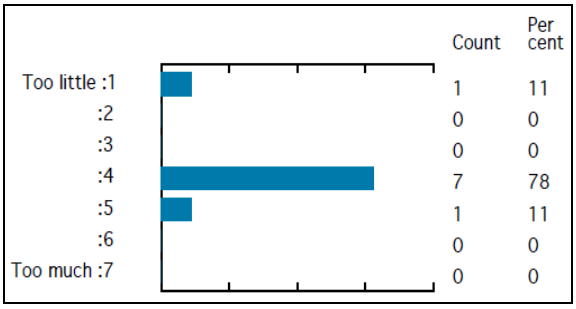
As can be seen from Figure 80, the majority of respondents all felt that the noise levels were satisfactory and therefore the ‘red diamonds’ result from the scores compared to the benchmark data. Overall noise levels were found to be satisfactory, with 90% scoring 5, 6 or 7 but one respondent found the noise levels to be unsatisfactory and scored it 1.



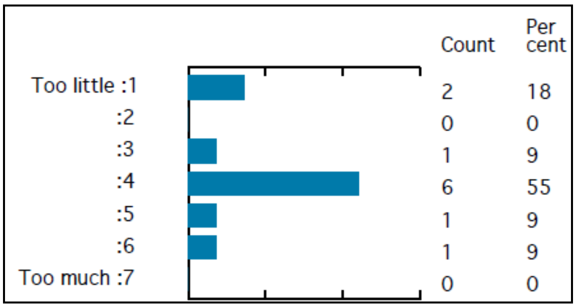
A) Noise from colleagues, score 3.7



B) Other noise from inside, score 3.55



C) Noise from outside, score 3.78



D) Noise from other people, score 3.64

Figure 80: BUS Survey - Noise Results

In terms of unwanted interruptions, the 'ideal' score would be 1 (i.e. no unwanted interruptions). Responses were mixed with an average score of 3.44. None of the respondents stated that there were very frequent unwanted interruptions, but responses ranged from 1 to 6.

Lighting

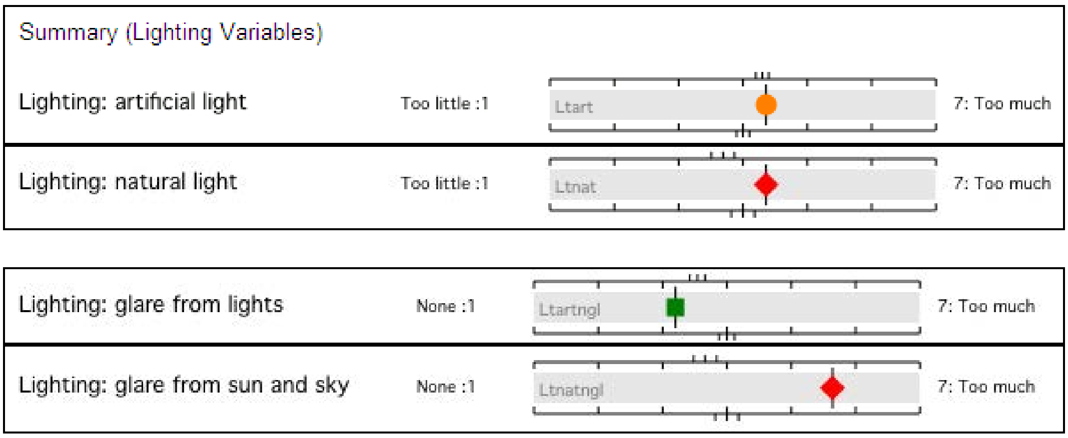


Figure 81: BUS Survey - Summary of Lighting Results

The graphs shown in Figure 81 relate to the lighting within the Visitor Centre. The ideal score for the lighting questions would be 4, and for those which relate to glare, the ideal score would be 1. In terms of artificial light, the respondents found there to be acceptable levels (orange circle) with a score of 4.36 and 64% giving a score of 4 (ideal). For natural light, the average score was also 4.36, with 55% feeling the levels were ideal. When comparing to the benchmark data (for all non-domestic buildings surveyed by Arup), the levels of artificial light were found to be comparable, but the average score for natural light was higher, meaning that there was felt to be too much natural light in the Visitor Centre, compared to other non-domestic buildings (hence the red diamond for this score).

Respondents in general found the levels of glare from artificial lighting to be low (an average score of 3.2), yet two respondents found there to be too much glare (one scored 6, one scored 7). Thirty per cent of respondents found there to be no glare at all from artificial lighting, and the score in general was better than the average of benchmark properties.

In contrast, glare from the sun and sky was found to be an issue. This question scored an average of 5.64, with all respondents scoring 4 or higher and 36% scoring 7, saying there was too much glare from the sun/sky; this was considerably higher than for the comparable benchmark data. Comments related to lighting mentioned this issue of glare:

- “glare is an issue from the …windows next to the desk…”
- “glare is an issue, too warm in summer”.

However, one comment noted that there was good natural light and two comments pointed out that the glare issues could be solved by using blinds in the affected areas.

Lighting overall was found to be satisfactory, with 50% of respondents scoring 7 and no respondents scoring 3 or lower.

Control

Figure 82: BUS Survey - Summary of ‘Control’ Results

Figure 82, shows the results from questions about control within the Visitor Centre. Respondents felt they had some control over all factors, with good control over heating, lighting and ventilation.

Responses to the question “do you have control over cooling?” were entirely mixed; the mean score was found to be 4. However, 27% felt they had no control at all over cooling. More people felt they had control over the heating (mean score of 5.27), lighting (mean score of 5.17) and ventilation (mean score of 4.83). Despite this, 17% of respondents felt they had no control over lighting and 8% felt they had no control over ventilation.

When asked about the level of control over noise, the average score was 3. However, responses were mixed (see Figure 83) with 33% stating they had no control at all over noise levels, and one respondent (8%) saying they had full control over noise levels.

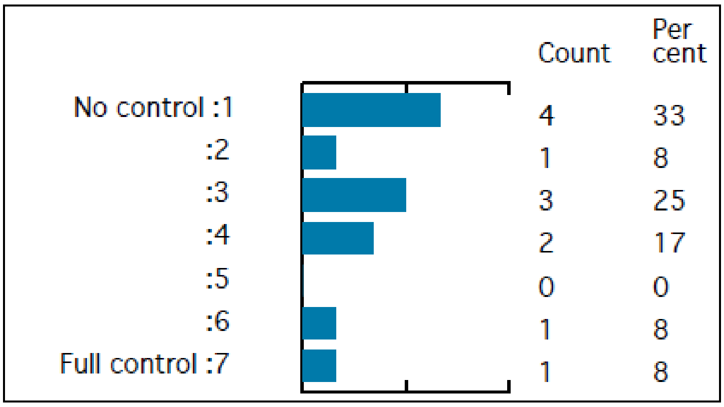


Figure 83: BUS Survey - Control over noise

For all five factors, the average response showed a feeling of greater control compared to the average benchmark data.

Figure 84, shows the percentage of respondents who felt it was important to have control over cooling, heating, ventilation, lighting and noise.

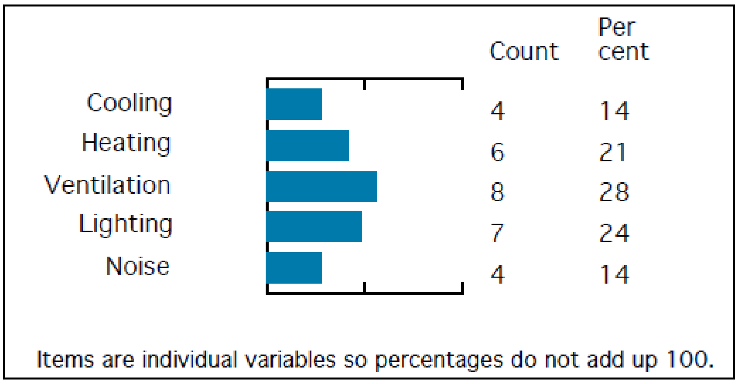


Figure 84: BUS Survey - Importance of Control

Design and Needs

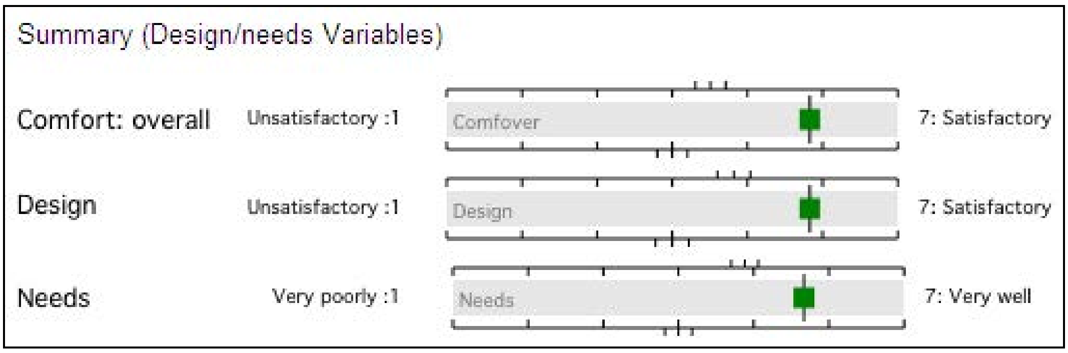


Figure 85: BUS Survey - Summary of Comfort Variable Results

Overall comfort was found to be satisfactory, with 33% of respondents scoring it as 7. Occupants described the comfort levels as “comfortable space, but gets very warm due to solar gains” and “very comfortable place to work”.

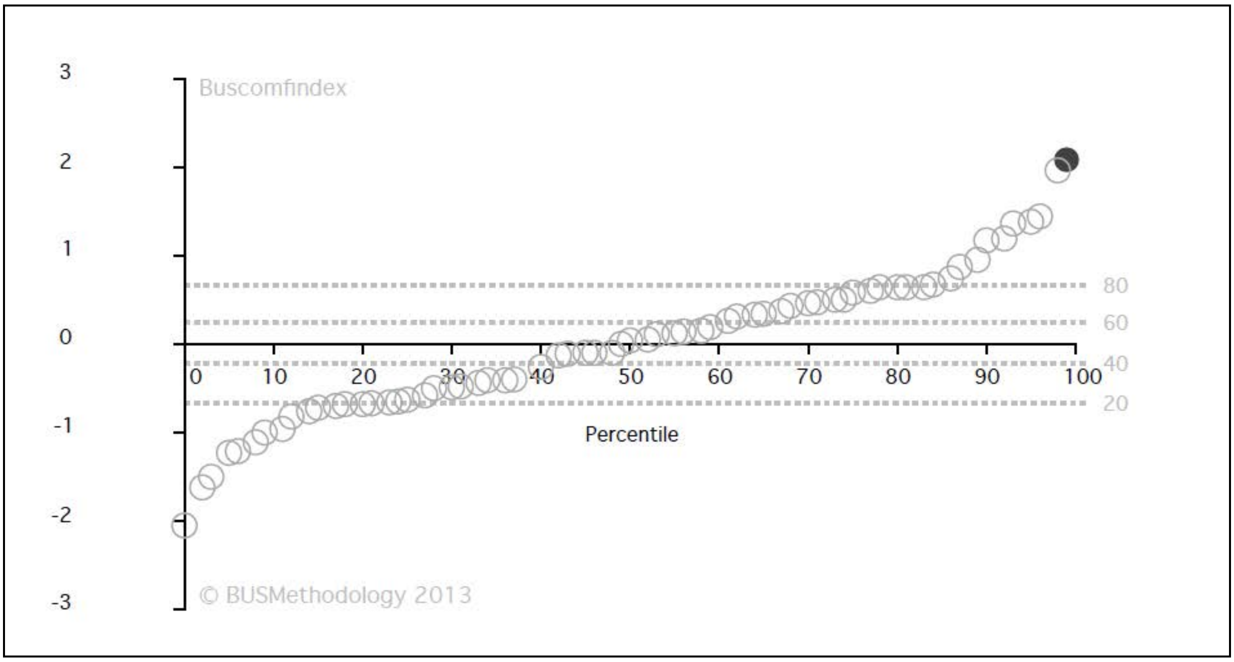
The overall design was found to be satisfactory, with 66% scoring it at 6 or 7. The building was thought to be “well designed”, “simple”, “excellent” and “flexible”.

The facilities provided at the Visitor Centre were found to meet the needs of the occupants very well as 33% gave it a score of 7 and all responses were of 4 or higher. The average score was 5.67. Related comments include:

- “easy to adapt layout to accommodate range of activities”
- “[would like a] method to reduce solar gains”
- “would be nice to have a ‘break’ area”.

There were also comments about the IT system:

- “…connectivity issues”
- “internet connection is poor”.



Indices use standard scores (also called z-scores). Standard scores put variables on a common scale with mean=0 and standard deviation=1.

Comfort index = (ZTSOver + ZTWover + ZAirWOver + ZAirSOver + ZLtOver + ZNseOver + ZComfOver) / 7

Figure 86: BUS Survey - Comfort Index

The graph in Figure 86 shows the overall comfort index for the Visitor Centre in comparison to the benchmark data from all non-domestic properties surveyed by Arup. The Comfort Index is measured as shown in Figure 86.

Facilities Management

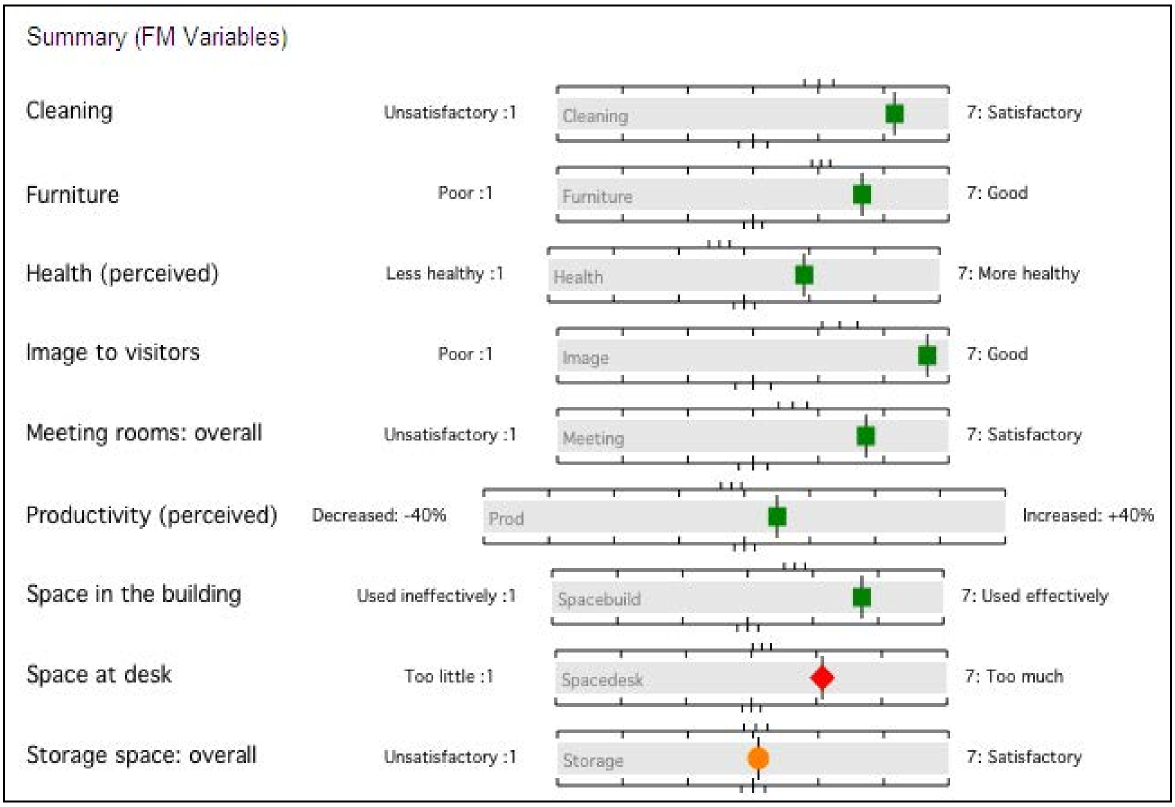


Figure 87: BUS Survey - Summary of FM Variables

In terms of cleanliness, 92% of respondents gave a score of 5 or higher, with 58% giving a score of 7, saying they were satisfied with the levels of cleaning in the Visitor Centre. The average score was 6.17.

Respondents seemed satisfied with the furniture as no-one scored it less than 4, with 50% scoring it 6 and 17% scoring it 7. The average score was 5.67.

In terms of the perceived change to health as a result of working in the Visitor Centre, the general trend was towards feeling ‘more healthy’ as an average score of 4.92 was recorded. However, 17% of respondents scored this question a 3, and 17% scored it as 4 (no change). The daylight provision and the access to natural ventilation were found to be positives in terms of health, while the heat and dryness were cited as detrimental to health.

The Visitor Centre image for visitors was found to be very good, with 83% scoring 7 for this question.

Respondents in general found the provision and availability of meeting rooms to be satisfactory. Sixty-three per cent of respondents scored the meeting rooms either a 6 or 7. Despite this high score, one respondent noted that a separate office space would be desirable, and one said that the meeting space was too small. Others were more positive: “good flexible, open plan space” and “open plan space offers multi-function use”.

Sixty-six per cent of respondents found the space in the building was used effectively (scoring 6 or 7) with an average score of 5.75. However, respondents found that there was ‘too much’ room at desks in the Visitor Centre with an average score of 5.09, where 4 would have been ‘ideal’.

Overall, storage space was found to be acceptable (orange dot), but responses were very mixed (see Figure 88). Perhaps in line with this, the comments regarding storage space were also mixed:

- “Dedicated storage facility for business related operations would be desirable.”
- “Minimal storage.”
- “New storage was recently purchased which helps enormously.”
- “Very little facility in the office.”
- “Very little storage.”

The availability of storage space was found to be in line with other non-domestic buildings, with an average score of 4.08.

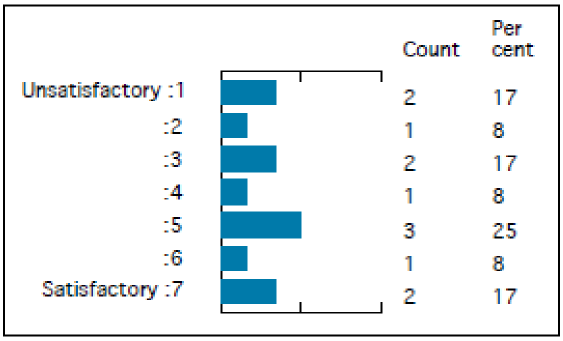


Figure 88: BUS Survey - Storage Space Overall

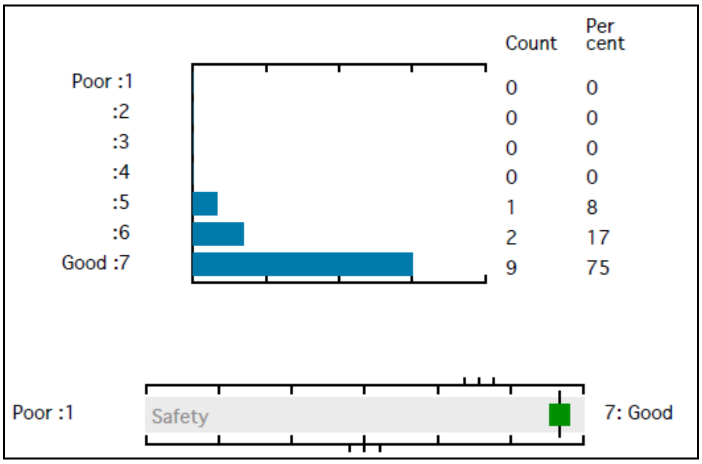


Figure 89: BUS Survey - Personal safety in building and vicinity

As can be seen in Figure 89, all respondents felt fairly safe within the building and in the vicinity, with 75% feeling safety was good.

Conclusions

When asked, "Do you change your behaviour because of conditions in the building?" half of the respondents said yes, and half said no. Some comments related to this question were:

- "[the building] encourages recycling and responsible use";
- "It is a very innovative space, making things clearer";
- "[the Visitor Centre is a] very comfortable place to work, so feel better";
- "[I] work[ing] over lunch as there isn't an alternative area to sit".

A quarter of respondents felt that their productivity was reduced as a result of the conditions in the Visitor Centre, while another 25% felt their productivity levels remained unchanged. No-one thought that there productivity had increased (or decreased) by 40% or more but half felt they were more productive in the Visitor Centre than elsewhere.

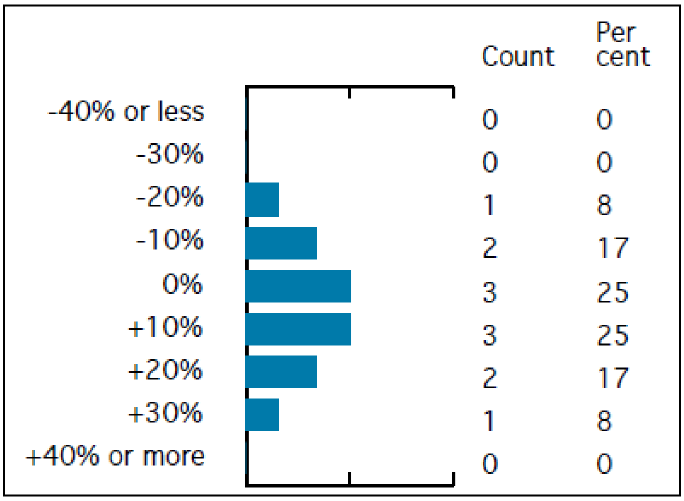


Figure 90: BUS Survey - Productivity

Comments regarding the perceived change in productivity were equally mixed:

- “Decrease [in productivity] due to poor network connections…[t]hough, as there is no breakout area – I tend to work through lunch”
- “Nice working environment. Good use of natural light and very little noise. However, can be warm.”
- “The area is particularly good for events and meeting space. Bright, fresh, exciting, uplifting environment.”
- “The glare from sunlight can make computer screen hard to see.”

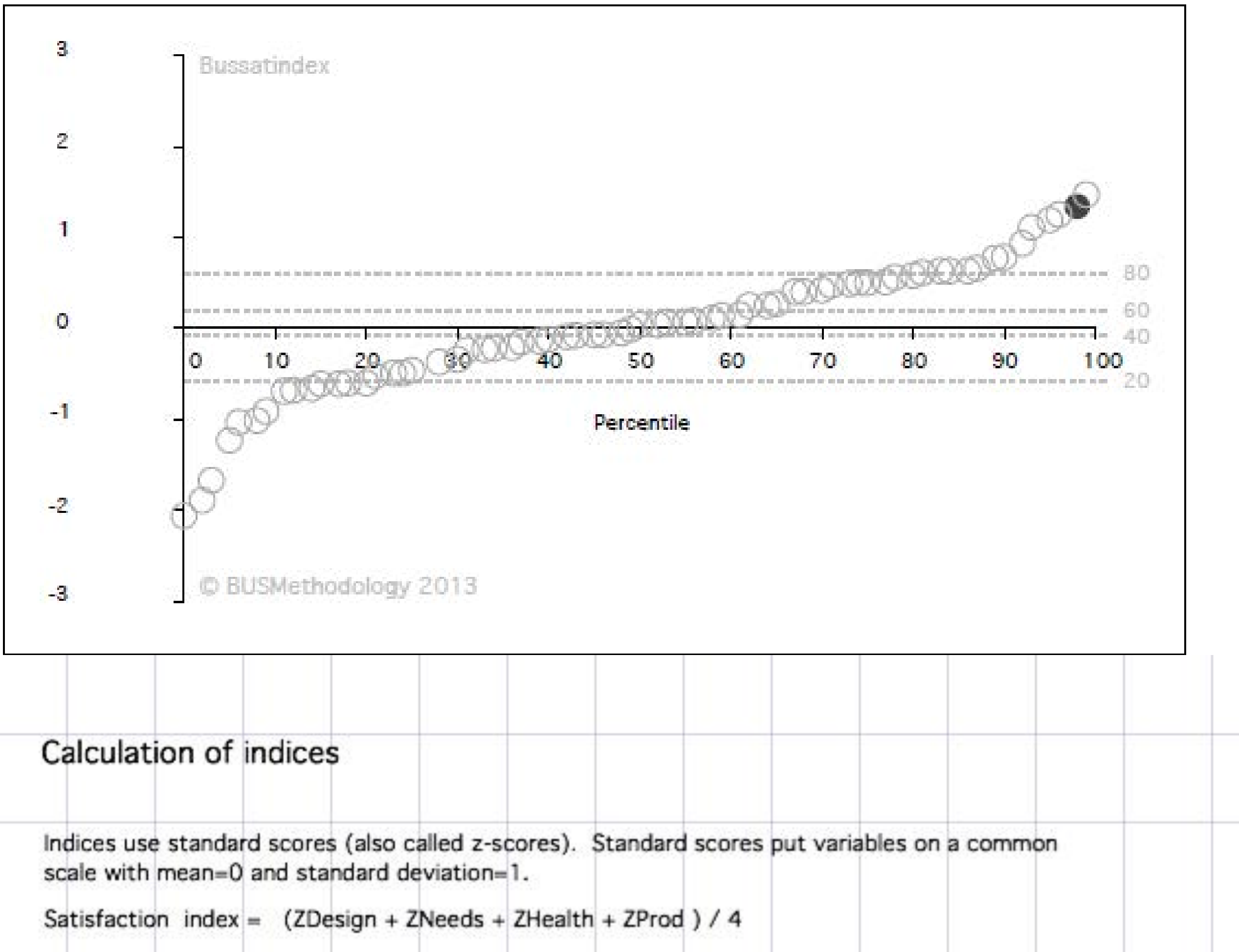


Figure 91: BUS Survey - Satisfaction Index

Figure 91, shows the satisfaction index and the calculation method. This shows the overall feeling of satisfaction with the Visitor Centre (positive), and also how this compares to the last fifty buildings that have been surveyed.

10.7 Occupant / Building Interaction Feedback

10.7.1 Winter 2012/2013

An initial occupant feedback session was held in December 2012 to gain the opinions of the individuals who most frequently use the Visitor Centre. The following responses were gathered, under a range of headings.

Social

The social section considers how provisions can enhance the users experience through fit-for-purpose spaces and improved facilities and aims to establish if these features facilitate and enhance the overall user experience.

As the building is newly opened, some users commented that there is no phone or fax provision and that the internet is currently a temporary mobile device which can be quite slow. Users were aware that this was only a temporary situation and were aware that a full phone, fax and internet service is currently being installed.

User feedback also highlighted that the disabled toilet is almost all white with little provision for the partially sighted, and that they felt it would be better if the handrails and potentially one of the walls were a different colour to ensure that the corners can be established easily. Users also commented that the vertical bar for opening the disabled toilet door appears to be in the wrong location as it is situated over the lock mechanism limiting access to the toilet should assistance to an occupant be required.

Finally, users commented that generally the layout of plugs throughout the building is sufficient, although an extension cable has to be used at the reception desk.

Space utilisation

Space utilisation considers the building areas available to assess the efficient use of space for building users.

Some users reported that currently the Visitor Centre does not make best use of the space available as there is no divide between the main area and the ‘hot desk/kitchen’ area. They explained that this means that the building can really only be used for one purpose at a time; and that if an event is being held in the main space, they feel that they are in the way when trying to work in the hot-desk space.

Users also commented that if an event is being held, and others are working in the Visitor Centre, that there is no ‘break-out’ space.

However, users continued to say that they believed the Visitor Centre will be able to hold a variety of group sizes and types in the future, but that a solution to suitably separate the room needs to be identified.

Finally, users commented that much of the storage space has been taken up with monitoring and electrical equipment. They further commented that although a couple of additional items of furniture have been added to try and increase the storage available, there is not enough space to store all the day-to-day items that are needed. Additionally it was reported that there is no storage space available for visiting staff to store items.

Environmental

The environment is a key factor for consideration for all buildings as it can enhance the user experience through the provision of fit-for-purpose spaces and improved facilities.

Some building users commented that there are no recycling facilities available and that they are unsure if any recycling facilities are available locally. Other users commented that a weekly mixed recycling collection is available in addition to the regular waste and that staff have discussed the possibility of getting a food/compost bin in the future. This different user feedback about recycling highlights that there is a necessity for information about the buildings facilities available to be distributed to all users.

Users have suggested that noise transference between the toilets and the main areas could be a problem.

With regards to the external environment, users reported that from almost every location in the Visitor Centre there is a view out and that this makes it a lovely space to work in.

Finally, users were unsure if there was a Green Travel Plan is in place, but confirmed that a cycle shelter is being constructed to allow cyclists to safely and securely store their bikes.

Building Operations

Building operations is a key factor for consideration for all buildings as it can enhance the user experience through the provision of fit-for-purpose systems and the level of user control over these systems.

Where some building users found that the heating is easy to operate and provides a comfortable temperature with easy to use controls, other users found that further information is required on the operation of the heating system. Other users commented that the Visitor Centre can overheat in direct sunlight.

Users also commented that the Visitor Centre is always a pleasant temperature especially in comparison to the external temperatures experienced in this location. They further commented that room thermostats in each area easily allow the temperature to be changed, and that the boiler controls are fairly easy to understand. They did additionally comment that it would perhaps be useful to get a full walk-through of the equipment in the Visitor Centre plant room, as it would be good to know more about what to adjust and when.

The user feedback for the lighting reported that users found the electrical lighting easy to operate and control, and that it was well zoned with plenty of natural light. They further commented that as a result of the high amount of natural light that the electric lighting only has to be used on very dull days. Positive comments were also reported with regards to the lighting in the plant room/service cupboard and the bathrooms, which are on a sensor should they forget to switch them off.

Users reported that glare can be an issue as there are no blinds on the windows. If users are affected by glare when using a laptop, the only option is to reposition their work space to avoid it.

Users reported that they were unsure whether the MVHR was operational and at present they ventilate the building by opening windows which will not be practical in winter. Whilst some users commented that the ventilation appears to be adequate, others reported that they are unsure how to adjust ventilation, therefore highlighting that further instruction is required in this area to allow users to make more educated adjustments.

Likes and dislikes

To understand what is important to building users and gain a further insight into building user interaction, occupants were asked what they particularly liked and disliked about the building. When asked what occupants liked about the building the following was reported:

- It's light and airy;
- There is a high quality of materials and finishes;
- It is bright;

- It is sustainable;
- It is a nice environment to work in; and
- The view and landscaping around the building are pleasant.

When asked what occupants disliked about the building the following was reported:

- The lack of DDA facilities in the disabled toilet;
- The chairs, desks and flooring;
- Lack of proper IT facilities;
- The lack of separate functional working areas; and
- The issue of glare on computer screens.

Occupant Consultation (Numerical Results)

This section contains the numerical results from the winter occupant consultation which should be considered in addition to the qualitative data outlined above.

Social							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The building provides good access and is accessible to everyone	Strongly agree	67%	0%	17%	0%	17%	Strongly disagree
The building has the space and facilities to support and integrate individuals with physical disabilities	Strongly agree	33%	50%	17%	0%	0%	Strongly disagree
The building has flexible opening hours to accommodate visitors	Strongly agree	0%	33%	67%	0%	0%	Strongly disagree
The level of communication and IT systems in place is satisfactory, i.e. phone, fax, and internet etc.	Strongly agree	0%	17%	33%	33%	17%	Strongly disagree
The provision and layout of electrical cabling and plug points are satisfactory	Strongly agree	17%	50%	33%	0%	0%	Strongly disagree
The building has specific facilities to enhance the overall user	Strongly	17%	50%	33%	0%	0%	Strongly disagree

experience	agree						
Space Utilisation							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The building is making the most efficient use of space	Strongly agree	17%	33%	50%	0%	0%	Strongly disagree
The layout of the building utilises space to its maximum potential and can accommodate all activities that take place	Strongly agree	17%	33%	17%	33%	0%	Strongly disagree
Building users were consulted and completed/influenced room data sheets during the design stage	Strongly agree	17%	0%	33%	50%	0%	Strongly disagree
The building provides flexible spaces/areas to accommodate various activities and group numbers	Strongly agree	33%	33%	33%	0%	0%	Strongly disagree
There is an adequate provision of social space available to staff and visitors for break-out sessions between periods of work	Strongly agree	17%	17%	33%	33%	0%	Strongly disagree
Adequate storage facilities are provided for all	Strongly agree	0%	0%	17%	33%	50%	Strongly disagree
The building is safe and secure	Strongly agree	67%	17%	17%	0%	0%	Strongly disagree
The external grounds have been developed in such a way that they can be enjoyed and easily maintained	Strongly agree	33%	50%	17%	0%	0%	Strongly disagree
Environmental							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The building is sustainable and environmentally friendly	Strongly agree	50%	33%	17%	0%	0%	Strongly disagree
There is a Green Travel Plan in place for the building	Strongly agree	17%	17%	67%	0%	0%	Strongly disagree
Recycling schemes are operational at a local level	Strongly agree	0%	17%	50%	33%	0%	Strongly disagree
Noise transference between different building areas is minimal	Strongly agree	0%	17%	50%	33%	0%	Strongly disagree

The level of noise that can be heard from outside the building is satisfactory	Strongly agree	17%	67%	17%	0%	0%	Strongly disagree
Occupants can enjoy a 'view out' from internal, occupied spaces	Strongly agree	83%	0%	17%	0%	0%	Strongly disagree
The quality of materials and internal finishes is of a high standard	Strongly agree	33%	50%	17%	0%	0%	Strongly disagree
Building Operations - Temperature							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The temperature level in the building is satisfactory	Strongly agree	33%	50%	0%	17%	0%	Strongly disagree
The stability of the temperature is satisfactory	Strongly agree	17%	50%	17%	17%	0%	Strongly disagree
The response time when changing the temperature is satisfactory	Strongly agree	17%	17%	50%	17%	0%	Strongly disagree
The level of control over the temperature is satisfactory	Strongly agree	17%	33%	33%	17%	0%	Strongly disagree
Building Operations - Lighting							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The level of daylight in the building is satisfactory	Strongly agree	17%	33%	33%	17%	0%	Strongly disagree
The level of artificial light in the building is satisfactory	Strongly agree	50%	50%	0%	0%	0%	Strongly disagree
The level of control over daylight is satisfactory, i.e.to prevent glare, to provide shade etc.	Strongly agree	0%	0%	33%	50%	17%	Strongly disagree
The control over artificial light is satisfactory, i.e. for performing everyday tasks and more specific tasks such as using a projector etc.	Strongly agree	17%	50%	33%	0%	0%	Strongly disagree
Building Operations - Ventilation							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The ventilation level in the building is satisfactory	Strongly agree	33%	33%	33%	0%	0%	Strongly disagree
The stability of ventilation is		17%	33%	33%	17%	0%	Strongly

satisfactory	Strongly agree						disagree
The level of control over ventilation is satisfactory	Strongly agree	0%	50%	33%	17%	0%	Strongly disagree
Building Operations - Water							
Question	**Scale End**	**1**	**2**	**3**	**4**	**5**	**Scale End**
The hot water provision is satisfactory	Strongly agree	0%	33%	50%	0%	17%	Strongly disagree

Figure 92: Occupant Consultation (Numerical Results)

10.7.2 Summer 2013

Level of control / satisfaction with controls

- The level of control of the building was considered to be is generally acceptable (in terms of lighting, heating, natural ventilation) but additional controls (blinds) to negate solar gain would be welcomed;
- It was noted that often the doors slam shut when left open for ventilation to combat the increased levels of solar gain;
- Users feel confident in the operation of controls, though not so confident in the operation of the systems themselves, particularly the complex plant and renewable technologies.

Building operation

The building was considered to be easily operated, though an in-depth knowledge is required regarding the operation of some systems.

Level of training at handover

- Users confirmed that there was virtually no handover training, and that the operation of the building was essentially self-taught;
- Staff are hopeful of receiving full and proper handover relating to the M&E services once reconditioning work has taken place, which is scheduled for the coming months.

Quality of space / quality of materials

- User confirmed that there was plenty of space to work/carry out required tasks in, and that the space was considered to be of a good quality;

- In addition to this, the quality of materials was also praised, although issues were raised with regards to the floor and cross laminated timber wall;
- The issue of privacy between the meeting space and the office area was raised as an issue.

Positives / negative aspects of the building

Positive features:

- Location
- Quietness
- Brightness
- Natural ventilation / good air quality

Negative aspects:

- Overheating
- Glare

Recommendations from users for future projects

- Increased storage space to ensure a 'clean' workspace;
- Increase space available in plant room area;
- Roof access for maintenance purposes;
- Further consideration of the implications of open plan layout;
- Ensure handover training and commissioning are carried out;
- Undertake energy monitoring / BPE as it can reveal operational inefficiencies.

10.7.3 Winter 2013/2014

The occupant workshop discussion on 16th January 2014, aimed to revisit the issues highlighted in the questionnaire completed in winter 2012/2013 (see the results in section 10.7.1). This session was held with three BRE staff members who work most often at the Visitor Centre; two are there full-time and one part-time. The topics discussed are outlined below.

Social

The building occupants had the following comments on social aspects of the Visitor Centre:

- IT: the occupants feel that there has been no improvement in IT facilities, although an apparently improved system has been installed since the previous interview. The occupants feel that the facilities are not sufficient and that they can hinder working. In addition, at the time of the discussions, the telephone line had been damaged some weeks previously, and a loud buzzing was heard when using the phone.

- Toilet facilities: the occupants were happy with the toilet facilities and noted that tape had been added to the disabled toilet to help those with visual impairments differentiate between surfaces.

- Catering facilities: the occupants felt that the kitchen was too small, especially when hosting events in the Visitor Centre. In particular, the occupants noted a lack of worktop space and added they would like to have a dishwasher and potentially a small hob and freezer to increase catering options. There is no room available for any of these additional appliances.

- Flexibility of space: the occupants felt that the space was not very flexible – that each area has its defined use.

Space Utilisation

The occupants didn't feel that there was an improvement in storage space. In addition, they felt that the lack of a physical divide between the staff and event spaces was a problem.

Environmental

A variety of comments were received in relation to the environmental factors affecting the Visitor Centre. In particular, they felt that the building was not airtight, so less sustainable in winter; and too hot in summer, due to solar gain. Other comments included:

- The recycling facilities were found to be adequate. The occupants have considered getting a food waste bin. There were concerns there would be an additional cost for carriage of this waste, so the occupants are discussing composting facilities.

- No major problems were noted in relation to noise. There was said to be no noise transference from external factors to inside, and in general there were no internal noise nuisances. However, it was mentioned that noise does transfer from the kitchen into the event space, which limits the use of the kettle and microwave if there is an event in progress.

- There is still no public transport available to the Innovation Park. Local train facilities remain as before.

- The external view has changed considerably in recent months due to construction work on-going on the ground surrounding the Innovation Park. However, the occupants said the view out from their desks was still appreciated.

- In terms of security, the occupants said they felt safe in the building and were pleased that the main entrance door had been fixed to prevent it automatically locking when shut. This means that staff cannot be locked out of the Visitor Centre. The building occupants however, did note that they found it to be very dark at the entrance gate, particularly when closing and locking the gate in the winter evenings. They noted that they didn't feel very safe when locking up alone.

Building Operations

Comments related to building operations included:

- The occupants still don't find the building easy to operate as they still have not received a full operation manual or any handover training.
- The temperature within the Visitor Centre has been cold over the previous months. This is because the heating system has not been operational since October (see section 6).
- Blinds have been installed which has considerably reduced the glare experienced by building users.
- Staff often work in 'semi-darkness' in the office/kitchen area as they find the electric lights to be too bright, and there is no dimmer available on the circuit.

Likes and Dislikes

The building occupants were also asked what they liked or disliked about the Visitor Centre. Occupants liked that the building looks bright, modern and clean and found it to be a pleasant place to work. They also noted that the external environment was nice. The most pressing issue the occupants highlighted about the Visitor Centre was the poor internet capabilities.

Finally, the occupants were asked if they would change anything about the Visitor Centre. They highlighted the following:

- More storage space
- Truly separate office area from kitchen and event space.
- 'Unsightly' monitoring equipment on the wall (would prefer it relocated into the cupboard).

10.7.4 Summer 2014

In summer 2014, an informal discussion was had between key building users about the interaction they have with the Visitor Centre and the control they have over their internal environment.

Level of control / satisfaction with controls

Users are happy with the level of control they have over ventilation – though this is through opening windows, rather than changing settings on the MVHR system.

The addition of blinds in the office area has been welcomed by staff, as this prevents much of the glare that was a problem during the summer months, however, it does not reduce the solar gain as much as had been hoped.

The temperature in the Visitor Centre during the summer months is felt to be far too hot, but there is little that can be done to resolve this – windows and doors are left open throughout the working day, but often this does not satisfactorily reduce temperatures.

The control of the lighting in the main space is felt to be good, but in the office/kitchen space building users would prefer more control, particularly the ability to dim the lighting levels.

Building users feel they have no control over noise transference, which occurs between the office/kitchen space and the main meeting/seminar space as there is no way of solidly dividing the two areas.

Though the heating is not required during the summer, building users commented that since the new system was installed, they have not had any information on its operation, and would not be able to operate it, if it was needed.

Building operation

Some building users still wished for more detailed information on the operation of the various systems within the Visitor Centre.

This could be resolved through training from the M&E contractors, which has not been available to date.

Quality of space / quality of materials

Building users felt the Visitor Centre offered a light, bright and welcoming place to work.

Defects which have become apparent in the floor finish and the CLT wall have not detracted from this impression.

The open plan space is felt to be not appropriate, particularly if a private meeting or training session is being held in the main space – BRE staff then feel ‘in the way’, or disruptive if working in the office area. This is when noise transference is a particular issue.

Positives / negative aspects of the building

Many of the positive and negative issues that were previously highlighted remain.

Positive features:

- Location
- Brightness
- Natural ventilation / good air quality
- While in addition, the provision of external space is seen as being beneficial.

Negative aspects:

- Overheating
- Noise transference
- Visibility of office area from main door
- Glare.

Glare was cited as an issue in the review the previous summer. In the main office space, blinds have been added which has solved the glare issues there. However, glare continues to be a problem in the main event area, particularly when viewing presentations.

10.7.5 Lessons learned workshop session

Near the end of the two year TSB Visitor Centre BPE analysis a 'lessons learned' consultation was held with all BRE staff members who have used the building in some capacity, whether that is working full time, part time, hosting or attending training sessions, meetings and events. The aim of the session was to identify what, on reflection, could have been done differently in terms of the design, construction and operation of the Visitor Centre.

The lessons learned workshop was held in the Visitor Centre on 18th June 2014 and was attended by twelve BRE staff members. The group were prompted by a series of questions to help guide discussions.

The general opinion of the group was that the Visitor Centre provided a great space to work in and to bring guests and clients to. However, there was a feeling among some that more consultation with staff at design stage could have been beneficial.

The main areas of discussion were: general design, layout (flexibility and adaptability), space (including external space), personal comfort (temperature, lighting, noise and indoor air quality), transport, safety and facilities (including the impact on productivity).

General design

Overall, the workshop attendees agreed that the Visitor Centre was a good space to work and learn in. It is a popular location for meetings and events. Comments included: 'there is a nice, bright, positive feeling about being in the Visitor Centre' and '[I am] happy to be here'.

Some members of staff felt that there had been a lack on consultation at design stage, and that there had been a reliance or dependence on the abilities of the architect to create a building that was as required by BRE. Others felt that as the building was intended to be a demonstration of new technologies and materials, that it is perhaps not surprising that some elements have not been found to be fit for purpose for office accommodation.

It was also felt that had there been more consultation with staff during design stage and through into construction, there might have been things that could have been done differently to improve the Visitor Centre. These included the location of main entry and fire exit doors, the interaction between the main office space and the main entrance and the division of event, working and kitchen spaces. However, it is difficult to identify whether these suggested changes are due to hindsight, or whether they would have been presented during design stage discussions.

Layout (flexibility and adaptability)

The attendees agreed that division of the different spaces is something they would like to see considered in any future BRE projects. In particular, the transference of noise was seen as an issue, which limits the flexibility of the various spaces. In addition, the location of the front door, opening straight into the event space is something that would ideally have been avoided, with access into a staff or separate area, to avoid distractions during meetings and training sessions.

Personal comfort

There were a number of suggested improvements for future projects in terms of the comfort levels of individuals using the Visitor Centre. The first comment was that there were too many windows, or not enough external shading. Solar gain is seen as a problem in the Visitor Centre, increasing temperatures to uncomfortable levels. The natural brightness in the Visitor Centre, and the inability to control it in the main event space was also presented as a problem. The light levels can make it difficult to easily view the projector. In contrast however, the natural brightness was praised by others who felt it contributed to the energy saving principles of the building by reducing the requirement for electric lighting. In future projects, some control over natural light should be incorporated.

The electric lighting in the staff office space was felt to be too bright, and would benefit from dimmable control. It is possible that in design stage, this area was not intended to be a work space, but only a kitchen area, in which case the lighting would be appropriate.

Noise is found to be a distraction sometimes during meetings, when staff are working elsewhere in the building, and also from the kitchen to all areas of the Visitor Centre. This would be rectified in future projects by permanent division of spaces. The lack of soft surfaces (carpets/curtains/furniture) was also felt to exacerbate the noise transference problems.

Air quality was generally felt to be adequate, with staff happy to open windows to provide fresh air. However, it was felt that it would be more efficient to install a CO_2 sensor ventilation system in any future BRE buildings, which would ensure it only operated when required.

Space

A severe lack of storage space was highlighted by the BRE staff members at the workshop. This was strongly felt to be an area which should have more focus and attention in any future BRE projects. The lack of storage space was also felt to impact on comfort levels, as 'uncomfortable' chairs are being used as they stack easily into a smaller space than larger, more comfortable chairs would do. The external space was praised by all attendees.

Facilities

The lack of space in the kitchen has resulted in a lack of facilities that would be of use, particularly when catering for larger events. Ideally, the kitchen would contain more workspace, more storage space and a dishwasher and oven.

IT facilities have been an on-going frustration for BRE staff and currently limit the number of people who can work at the Visitor Centre at one time and affects productivity. The 'hot desking' situation in the Visitor Centre was praised by some staff members, but others find it difficult to adapt to not having personal space and room to store work. There is no separate 'break out' space within the Visitor Centre; in a future development, a mix of open plan work space and private break out spaces would be preferable to BRE staff.

Safety

Some members of staff highlighted issues with lone working, as frequently only one member of BRE staff is present in the Visitor Centre at a time. This was felt to be exacerbated by the lack of a secure gate. It was also discussed that staff sometimes don't feel safe locking up the building and site on their own in the winter evenings when it can be dark.

A policy to reduce the amount of lone working time is being introduced for the Visitor Centre, and this should be adopted by all BRE working facilities in the future.

Transport

The provision of public transport was still felt to be poor, due to the undeveloped nature of the area. This is something that should be considered by BRE in the future.

The BRE staff members who attended the workshop session were on the whole positive about the Visitor Centre but highlighted several key issues which they hoped would be addressed should BRE plan to construct office facilities in the future. These included early consultation, division and flexibility of space, increased storage facilities and improved control over environmental conditions.

10.8 Internal Environmental Performance

10.8.1 Temperature

Typical thermal comfort levels, in terms of temperature, vary dependent upon the building users clothing type and activity. For an office in Scotland, it is assumed that the majority of activities involve sitting and wearing normal to heavy clothing. Therefore, typical comfort levels should range from between 18 to 21°C for most spaces, as can be seen in Figure 93.

Clothing Type	Typical Comfort Levels - Temperature (°c)			
	Strolling	Standing	Sitting	Sleeping
Light clothing	15	23	25	27
Normal clothing	8	19	21	24
Heavy clothing	0	14	18	21
Very heavy clothing	0	10	14	18

Figure 93: Comparative Temperature Levels

To better understand and analyse the temperature readings from the Visitor Centre, it is vital to consider the external temperatures also as they will greatly affect the internal temperatures. Data from the British Atmospheric Data Centre (BADC) was used initially, as there was no external temperature sensor located in the vicinity of the Visitor Centre until January 30th 2014, when a weather station was installed on site. The nearest weather stations to the Visitor Centre, 980 – Strathclyde Country Park, and 982 – Salsburgh, and their location in relation to the Visitor Centre are shown in Figure 94.

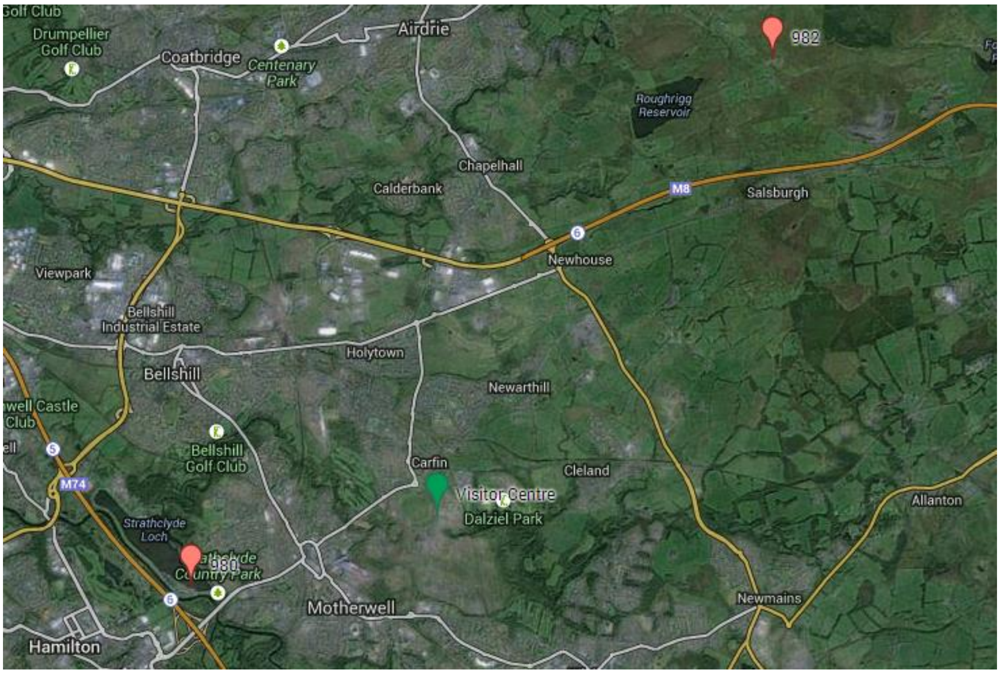


Figure 94: Location of Weather Stations (red) relative to Visitor Centre (green)

Internal temperature graphs for each of six quarters are shown below, with external temperature graphs from the weather stations for comparison. It should be noted that the nearest weather station (980), did not have a full data set for air temperature; hence the data from the weather station at Salsburgh (982) has been used.

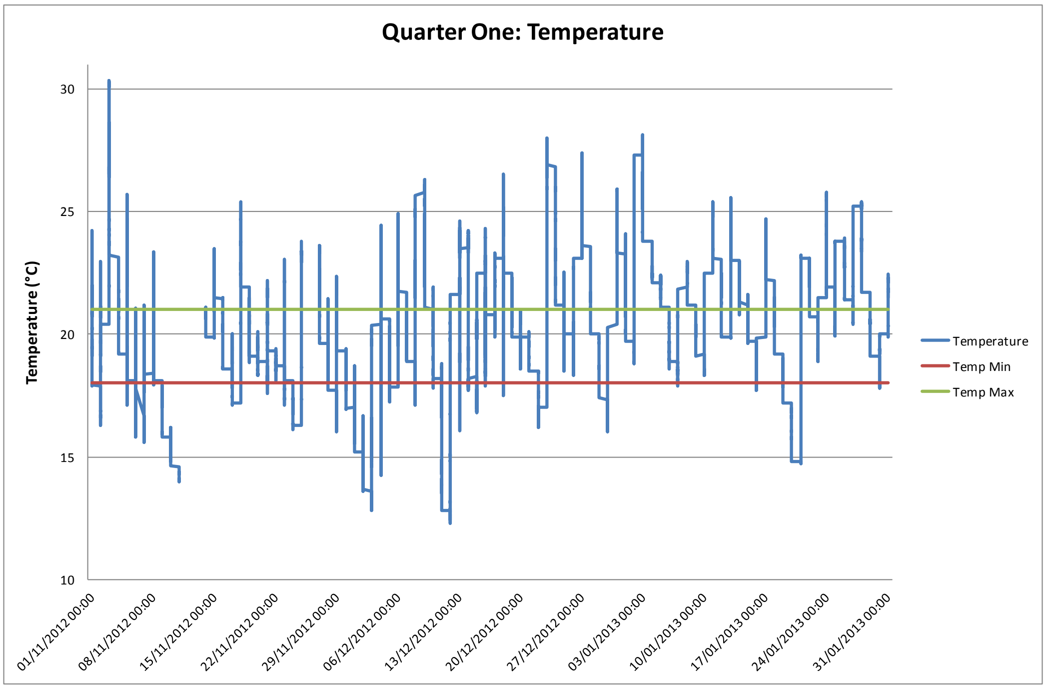


Figure 95: Quarter One Temperature (Internal)

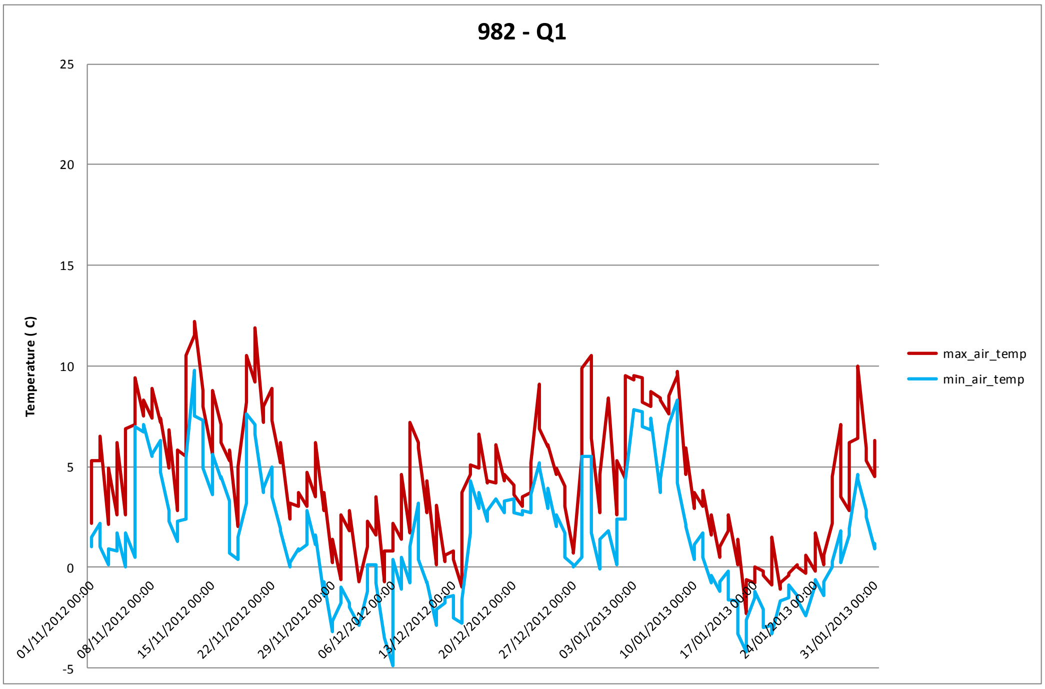


Figure 96: Quarter One Temperature (External)

Temperatures within the Visitor Centre during quarter one, which covers the winter months from the beginning of November to the end of January, varied widely from a peak of 30.3°C on the 1st November to a low of 12.3°C on the 12th November. For almost 40% of the time, the temperature was above the suggested maximum, and for almost 18% of the time it was below the suggested minimum. The average temperature over quarter one was 20.34°C.

The general trend of the external air temperature (see Figure 96) can be seen in the internal temperature in the Visitor Centre – peak around 22nd November, low temperatures (6th December, 13th December), peak early January and a low mid-January.

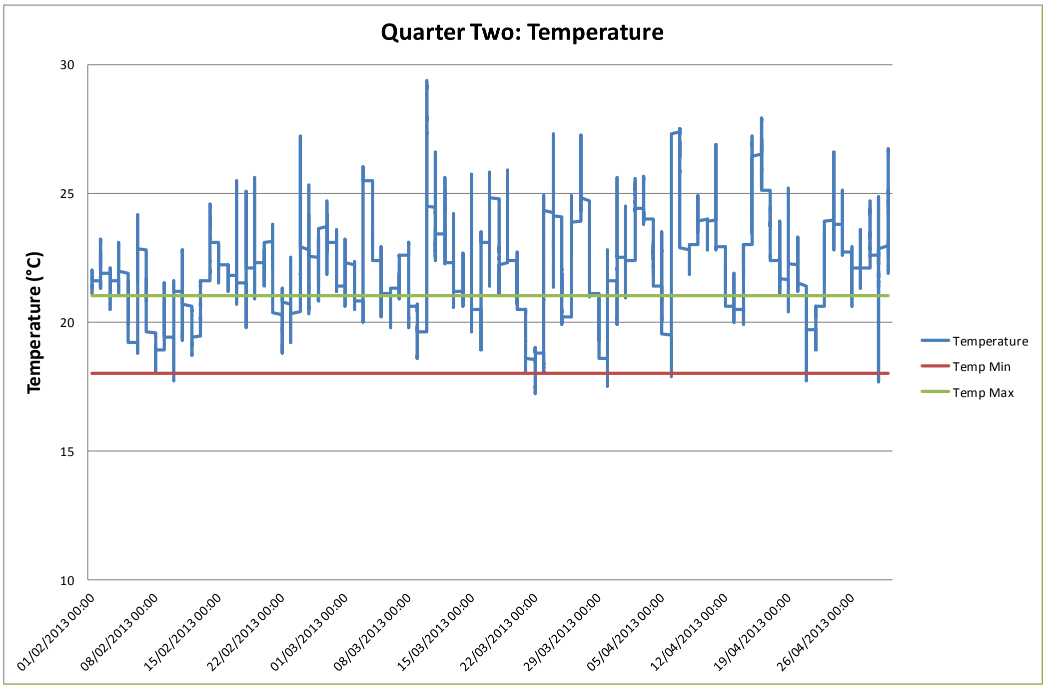


Figure 97: Quarter Two Temperature (Internal)

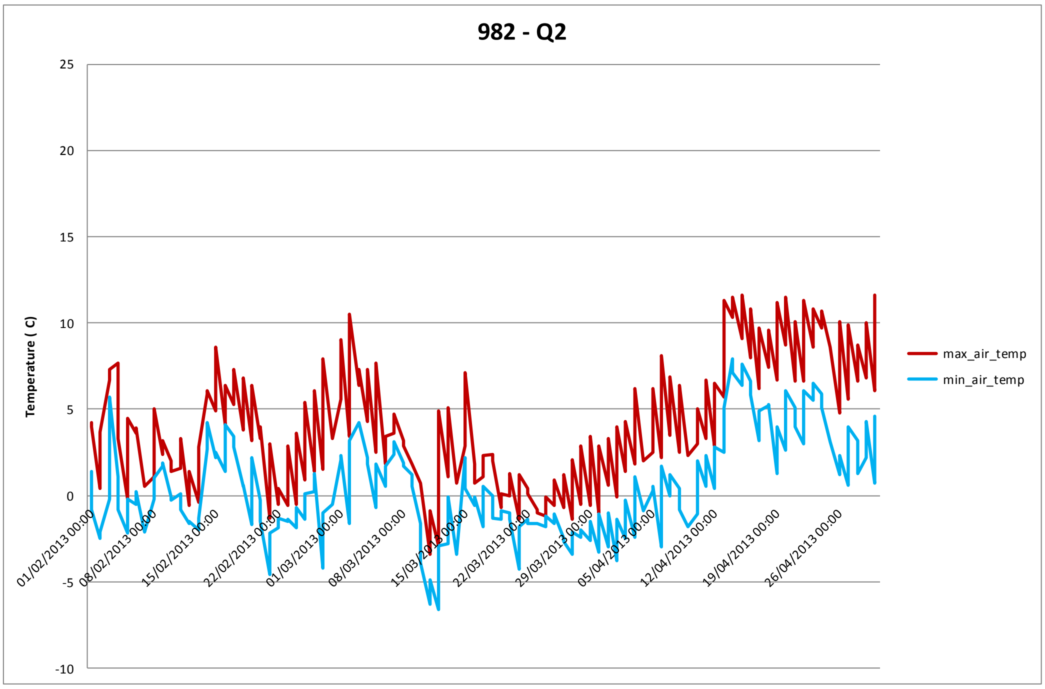


Figure 98: Quarter Two Temperature (External)

For more than 70% of the time, the temperature in the Visitor Centre in quarter two (February to April) was greater than the recommended maximum. The external temperatures (as seen in Figure 98) don't correlate with the internal temperatures in the same way that they did in quarter one. A maximum external air temperature of 11.6°C was noted at Salsburgh, but temperatures frequently dropped below 0°C and the Visitor Centre was able to maintain an average temperature of 22.1°C.

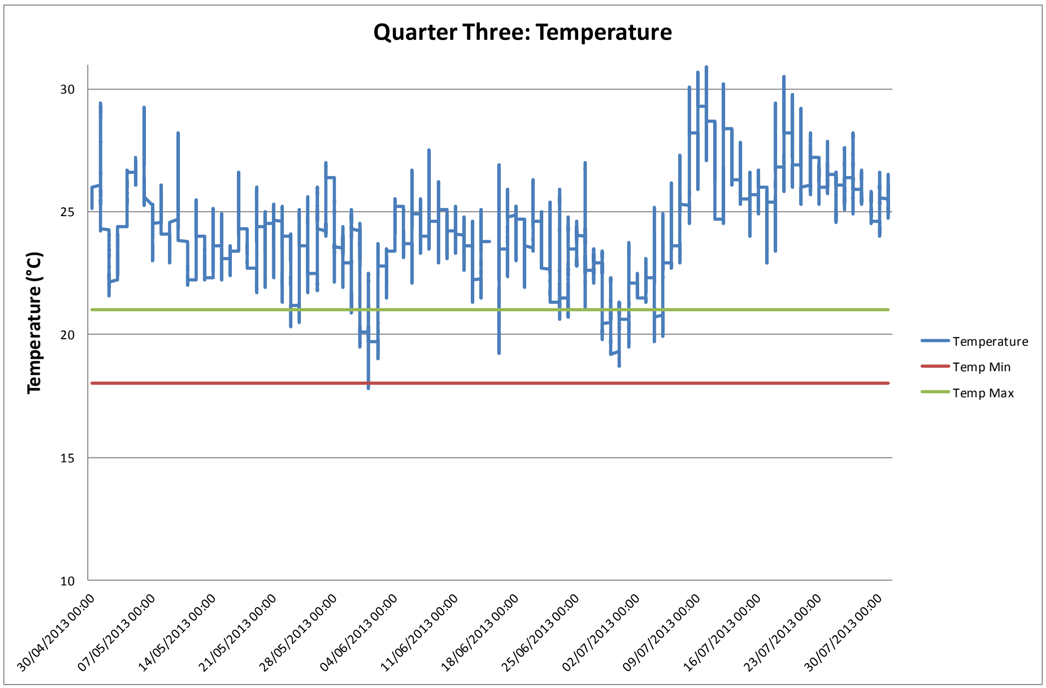


Figure 99: Quarter Three Temperature (Internal)

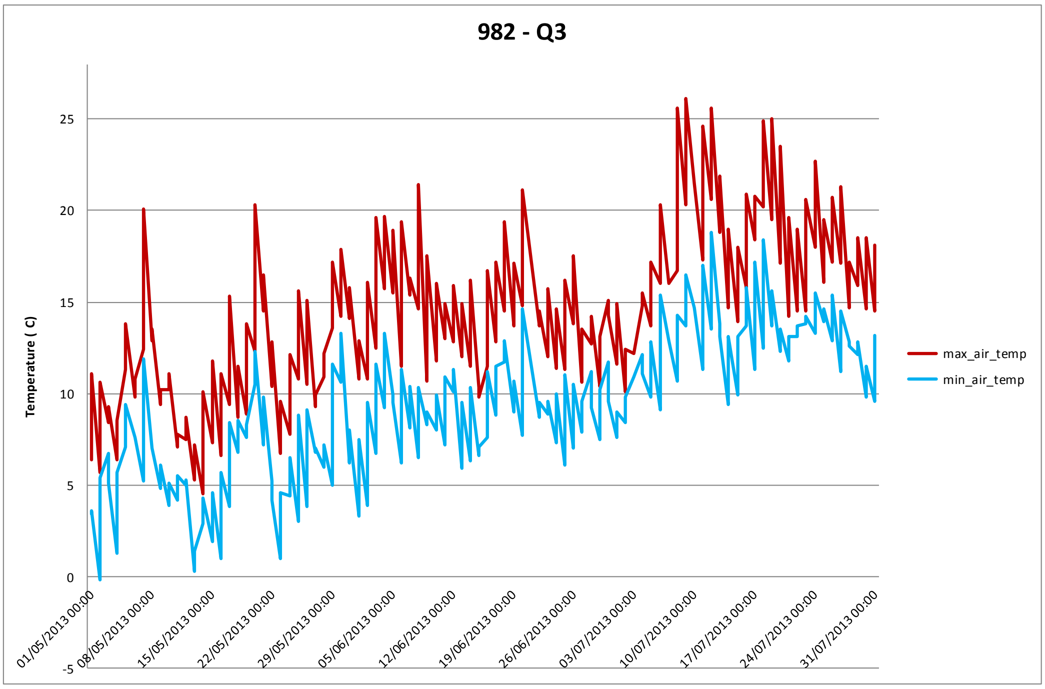


Figure 100: Quarter Three Temperature (External)

In quarter three, for almost 95% of the time, the temperature was above the recommended maximum of 21°C. The temperature is recorded every five minutes and 101 recordings (0.39%) were above 30°C. A maximum temperature of 30.88°C was recorded. The average temperature was 24.39°C.

In June and July, the temperature profiles from the Visitor Centre (internal) and the weather station (external) follow a similar pattern with a slight dip at the end of June and then a rise in early July. The maximum external temperature recorded during this quarter was 26.1°C. This peak temperature occurred the day before the peak temperature recorded in the Visitor Centre.

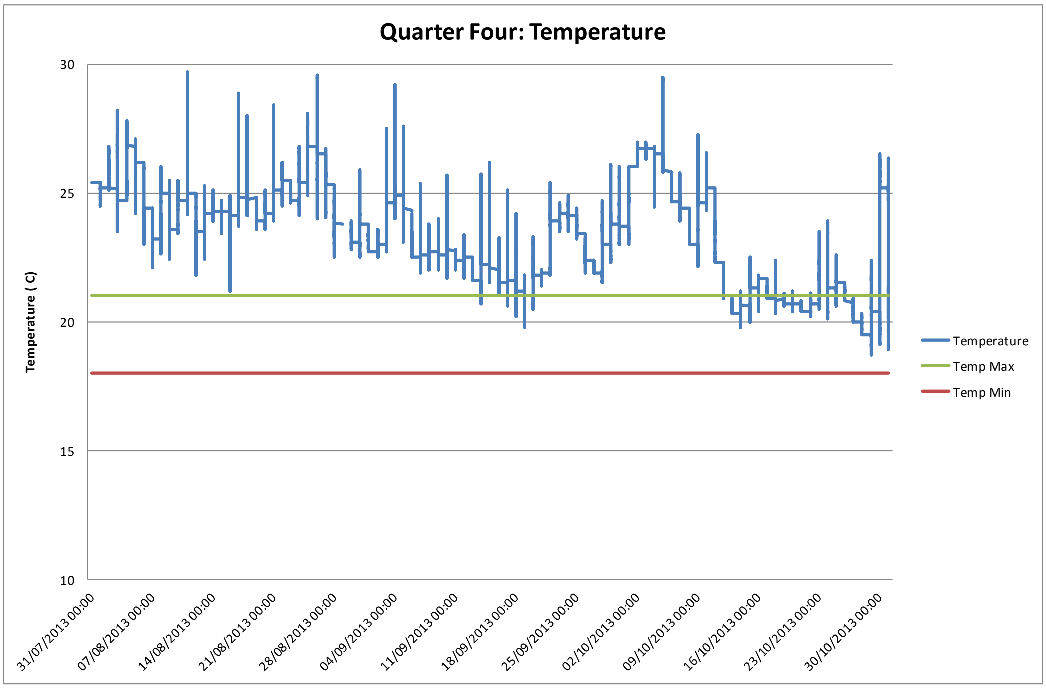


Figure 101: Quarter Four Temperature (Internal)

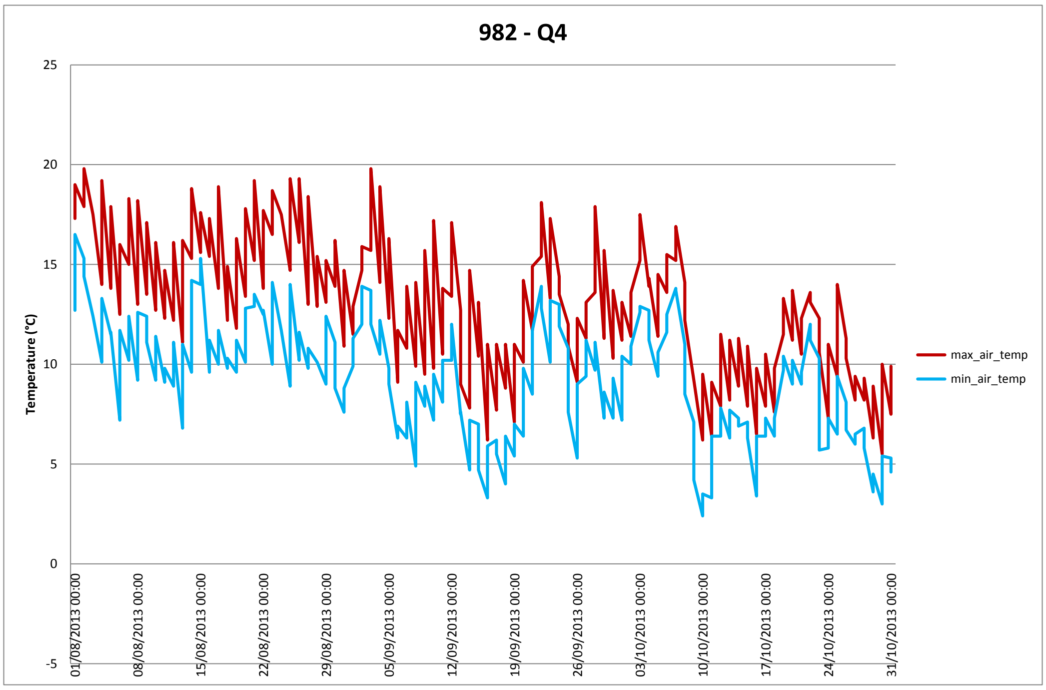


Figure 102: Quarter Four Temperature (External)

In quarter four, which covered the months from August to October, the average temperature was 23.33°C; almost 85% of readings were above the recommended maximum of 21°C, with a maximum temperature recorded of 29.71°C.

The profile of external temperature data for this month does correspond to the temperatures noted within the Visitor Centre – 19.8°C was the maximum external temperature measured in August.

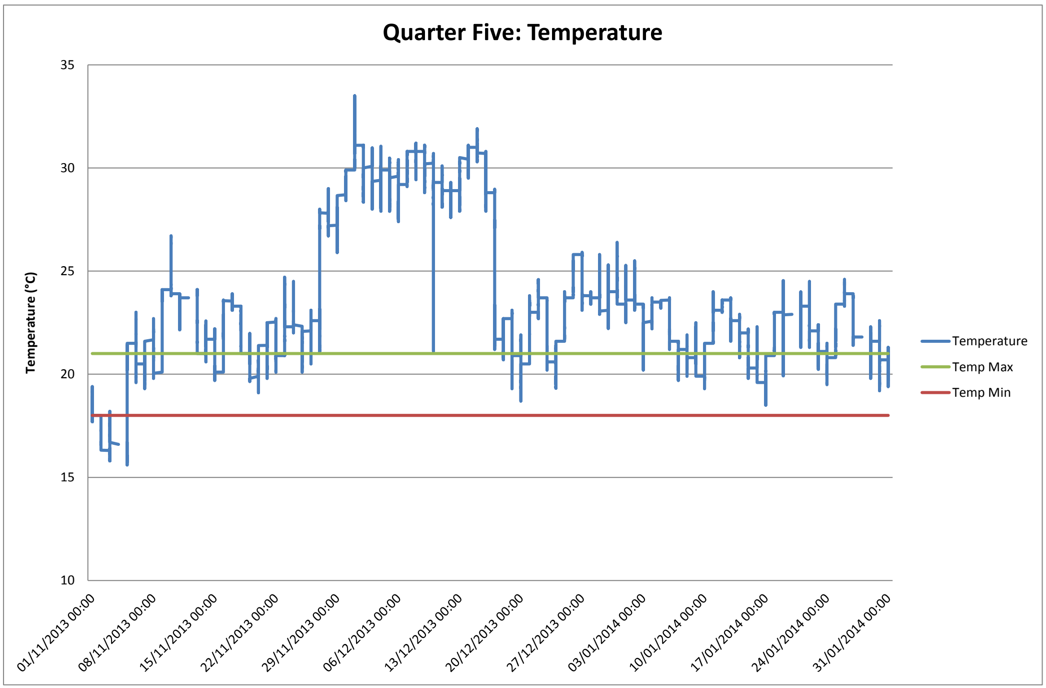


Figure 103: Quarter Five Temperature (Internal)

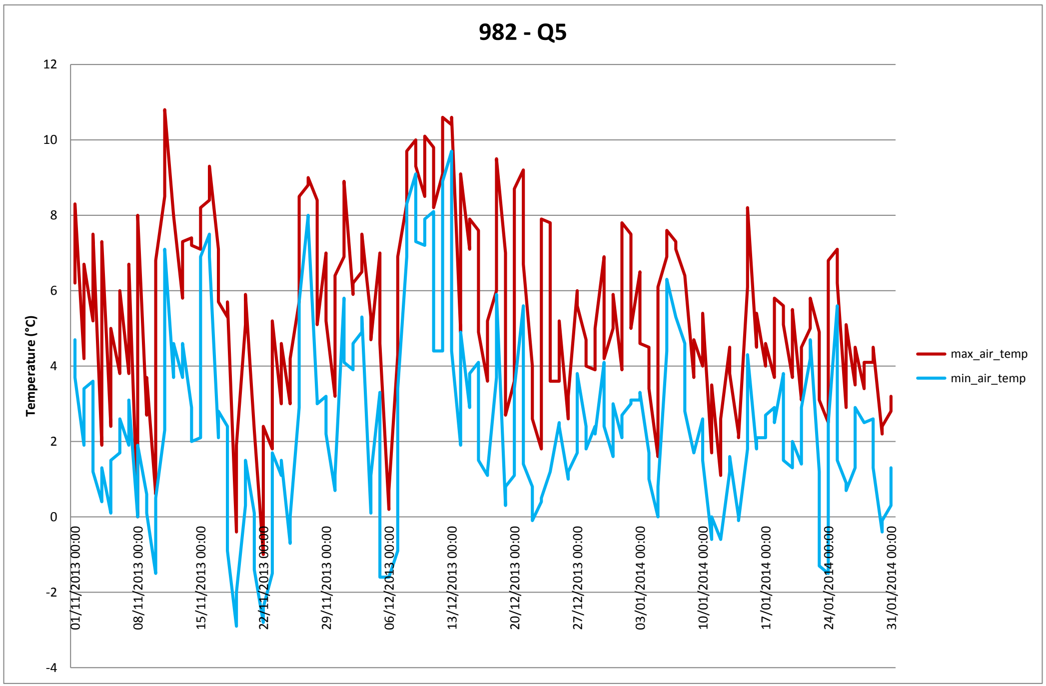


Figure 104: Quarter Five Temperature (External)

The temperature profile in quarter five is quite different to the other quarters with a defined period of increased temperatures from the 27th November, when the Visitor Centre heated up rapidly in the evening, to the 17th December, when it cooled quickly in the morning. Given that the energy consumption on the power circuits (used during this time to power electric bar heaters) totalled over 800kWh, it can be assumed that the heaters were used profusely during this time. As the average external temperature in quarter five was 3.94°C, some heating would be necessary, but there was no control over the use of the electric heaters.

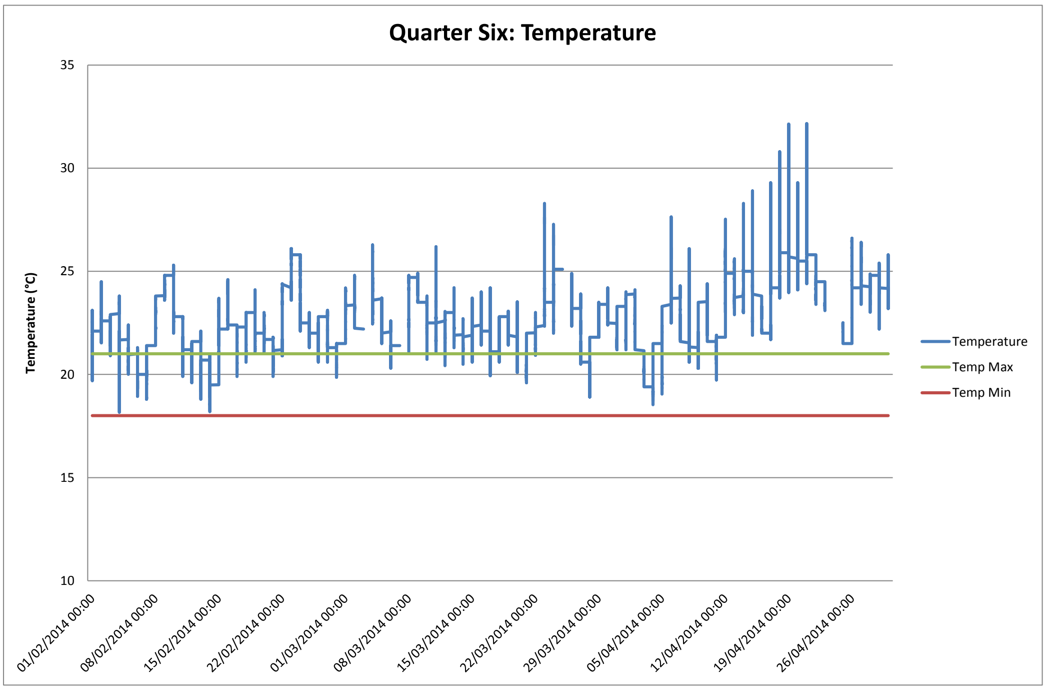
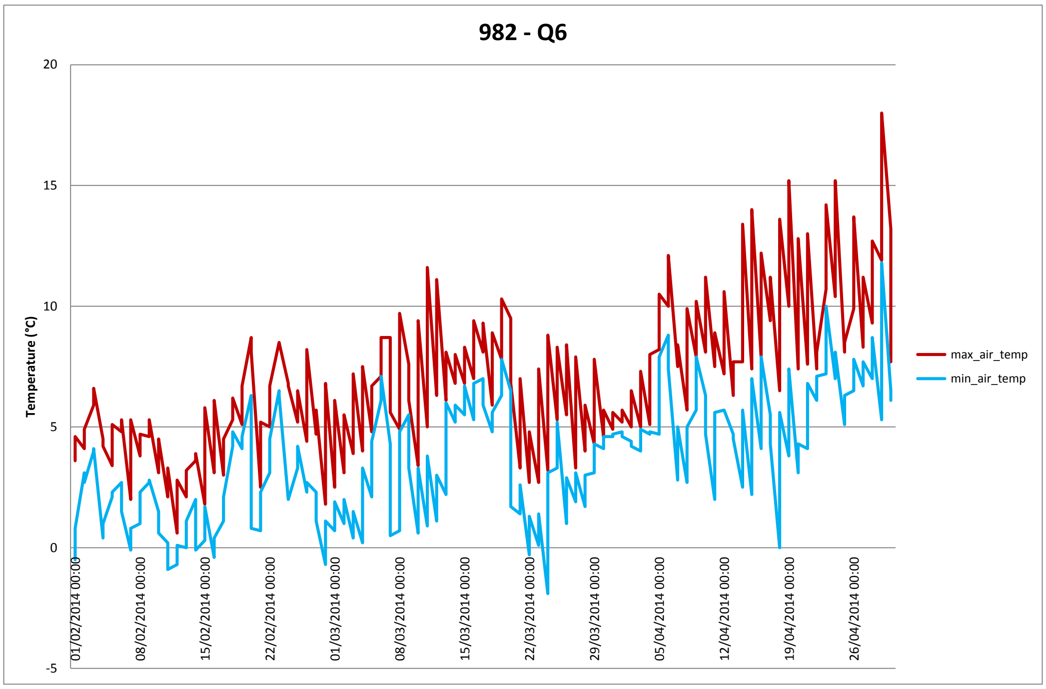


Figure 105: Quarter Six Temperature (Internal)



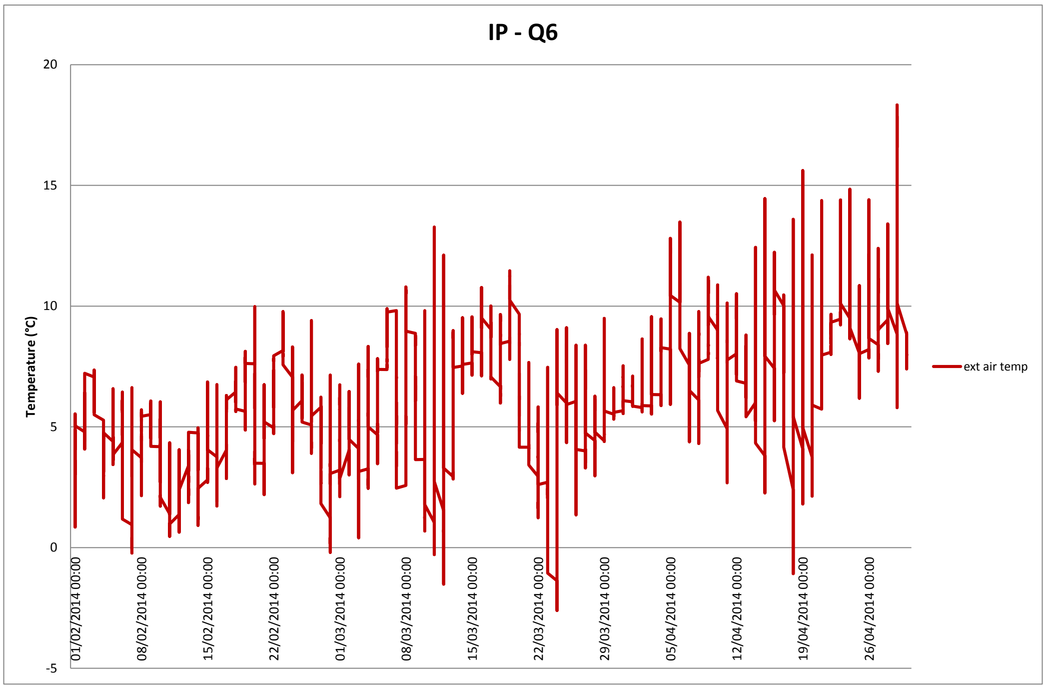


Figure 106: Quarter Six Temperature (External) – Met Office (982) and Innovation Park Data

The internal temperature during quarter six, were much more stable than the previous quarter. Temperatures were still high, with more than 80% of readings above 21°C, but they more closely followed the external profile, increasing towards the end of the quarter, at the end of April.

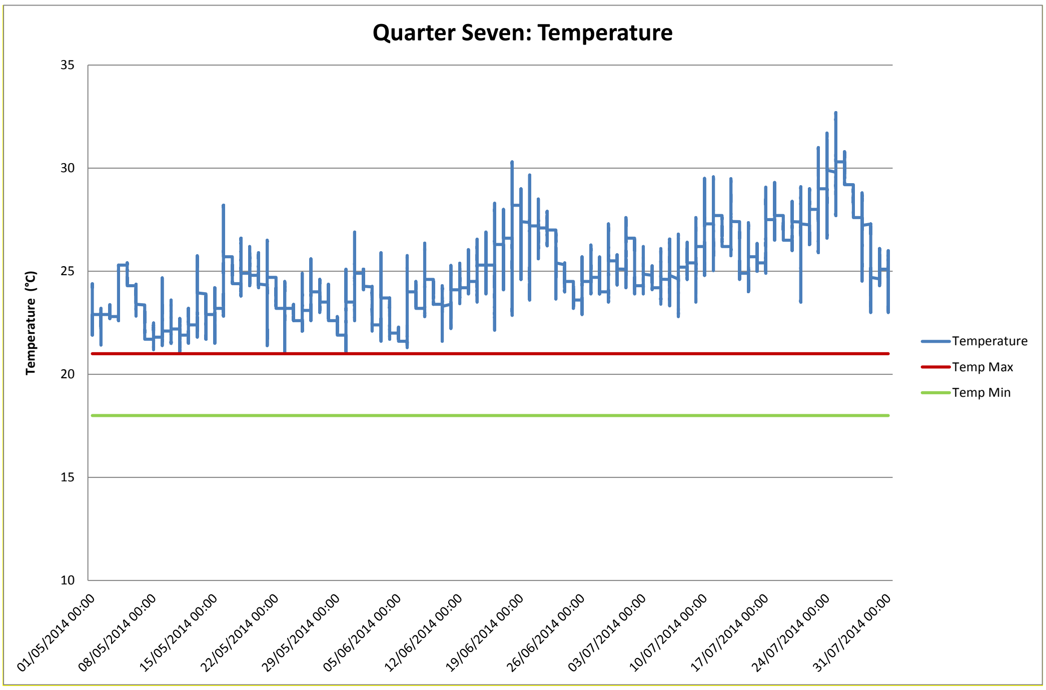
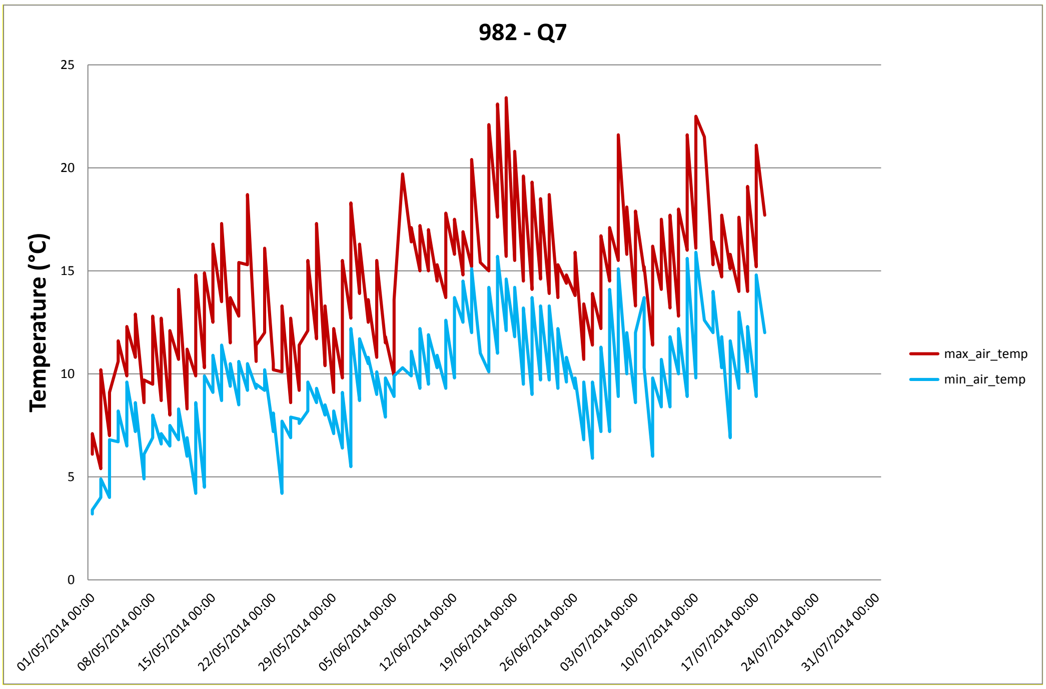


Figure 107: Quarter Seven Temperature (Internal)



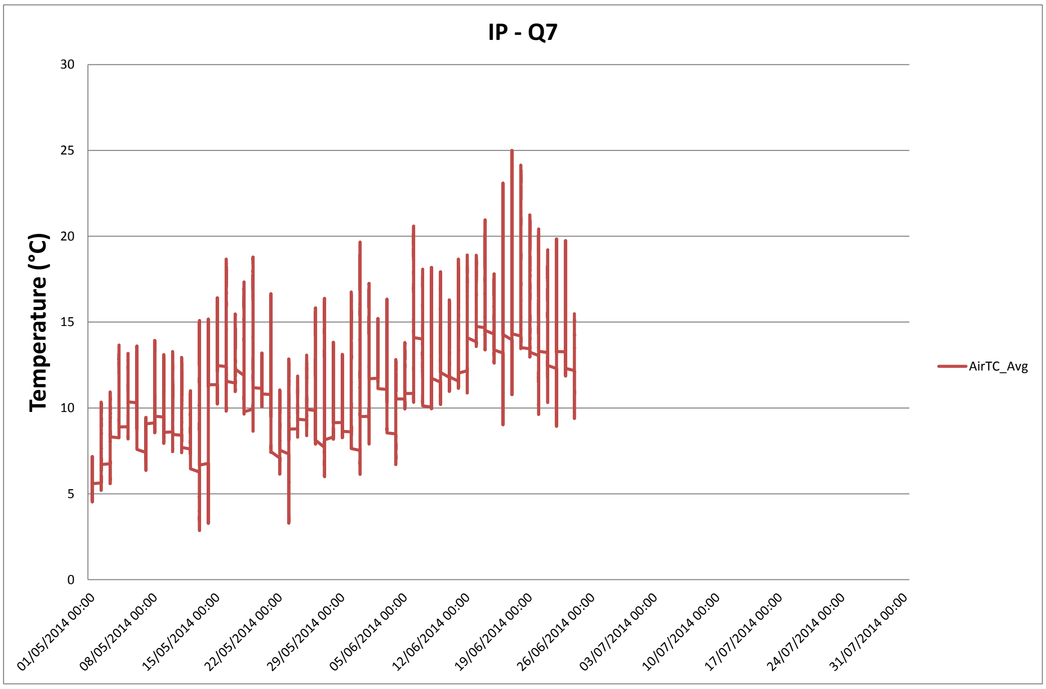


Figure 108: Quarter Seven Temperature (External) – Met Office (982) and Innovation Park Data

All of the internal temperature readings for quarter seven were above the recommended maximum of 21°C. Although the Met Office data is only available until 18th July, the general trend of external temperatures to this point, match the internal temperatures in the Visitor Centre.

A summary of the key figures from the temperature measurements are outlined in Figure 109. The high and low readings are presented as a percentage of the total number of readings.

		Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7
Visitor Centre	AVERAGE	20.34	22.10	24.39	23.33	23.51	22.55	24.83
	MAX	30.34	29.37	30.88	29.71	33.50	32.16	32.69
	MIN	12.30	17.20	17.80	18.70	15.60	18.17	21.00
	High Readings (%)	38.11%	71.70%	94.70%	84.21%	74.20%	82.70%	99.99%
	Low Readings (%)	17.41%	0.96%	0.02%	0.00%	2.82%	0.00%	0.00%
External	AVERAGE	2.99	2.32	11.90	11.19	3.94	5.35	11.98
	MAX	12.2	11.6	26.1	19.8	10.8	18	23.4
	MIN	-4.9	-6.6	-0.2	2.4	-2.9	-1.9	3.2

Figure 109: Key Figures (Temperature)

In quarter six, a weather station was installed at the Innovation Park. This has been used to confirm the Met Office data, as can be seen in Figure 106. For further clarification, the average, maximum and minimum values have also been checked and they correlate with the Met Office readings in Figure 109 (Max: 18.33, Min: -2.61, Ave: 6.56). The data from the Innovation Park weather station was only available up to the 24th June 2014, but the pattern up to this point follows the Met Office data. The maximum (25°C), minimum (2.78°C) and average (12.39°C) temperatures also relate to the Met Office readings as shown in Figure 109.

CIBSE guidance (TM52: 2013) presents that the best way to identify if a building is overheating is to 'ask the occupants'. This has been done as part of the BPE project and the results can be seen in section 4. Previous CIBSE guidance (TM52: 2006) indicated that a building could be considered to be overheating if the internal temperature was greater than 28°C for more than 1% of the occupied hours of the building. As the Visitor Centre is only unoccupied for around one to two hours per weekday, the Visitor Centre is occupied for approximately 94% of the time; 1% of the occupied time (in on year) would be around 82 hours. The temperature readings for the Visitor Centre identified that the temperature was above 28°C for around 104 hours over the year from November 2012 to October 2013, therefore it can be said to overheat. In addition, 18.86% of internal temperature readings were above 28°C in quarter 5. This is likely due to the uncontrolled use of electric heaters by the building occupants, as described in section 6. The external temperatures at this time were generally above average for the season (November to January), with an average external temperature of 3.94°C.

However, the CIBSE guidance (TM52: 2013) also highlights that occupants are more likely to cope with high internal temperatures when the external temperatures are high; the majority of 'above 28°C' internal temperature readings were found in quarter three, when the external temperature was also frequently high (see Figure 100). The temperature readings should therefore be considered in conjunction with the occupant feedback (section 4) as ultimately it is this that will identify the true comfort levels felt by occupants.

10.8.2 Relative Humidity

Generally, in a working environment, the recommended relative humidity level should be between 40% and 60%. When temperatures are higher, humidity should be nearer the lower end of this scale. When humidity is too low there can be a wide range of health implications, including eye, nose and throat irritation, respiratory infections and headaches. Similarly, when humidity is high the internal environment can become very uncomfortable. As the human body feels warmer and cannot cool, overheating can occur and lead to dehydration and chemical imbalances within the body.

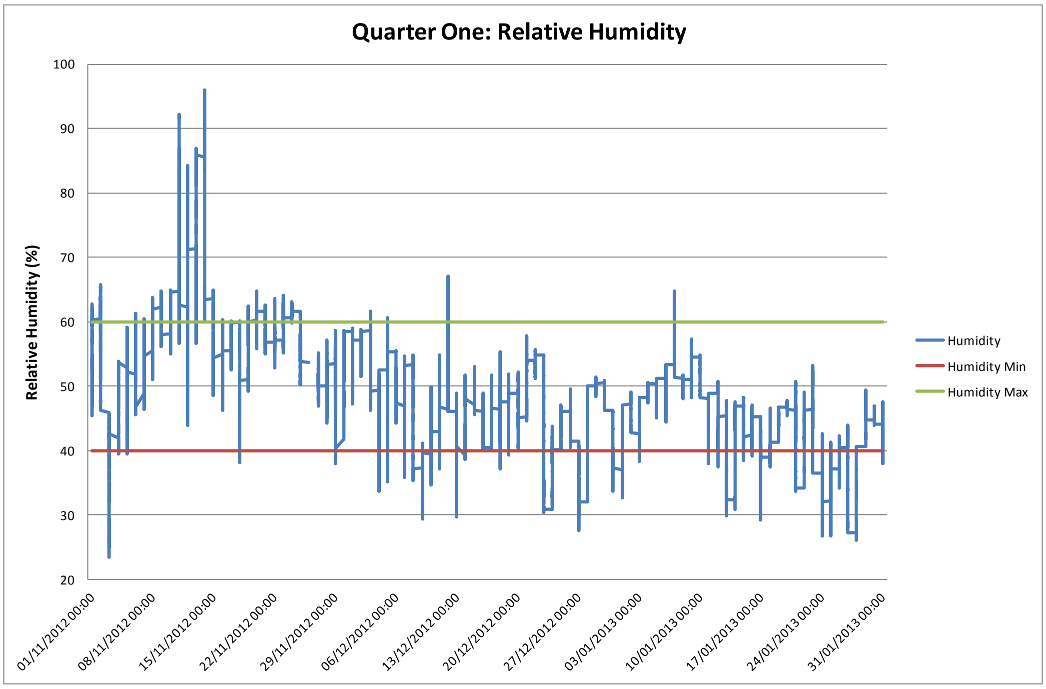


Figure 110: Quarter One Humidity

Relative Humidity in quarter one, was for the most part between the suggested minimum and maximum limits of 40% and 60%. A peak of high humidity levels were recorded between 6th November and 17th November, a smaller peak between 19th and 25th November and two other notable dates when the humidity was high; 12th December 2012 and 7th January 2013.

There were periods of generally low humidity in late December, early January 2013, and also during mid- to late January. The maximum recorded reading for relative humidity in quarter one was 95.97% on 14th November at 2.25pm (which is likely due to a fault with the sensor) and the minimum relative humidity reading for the first quarter was 23.36% on the 3rd November at 2.35pm. Average relative humidity in quarter one was 49.39%.

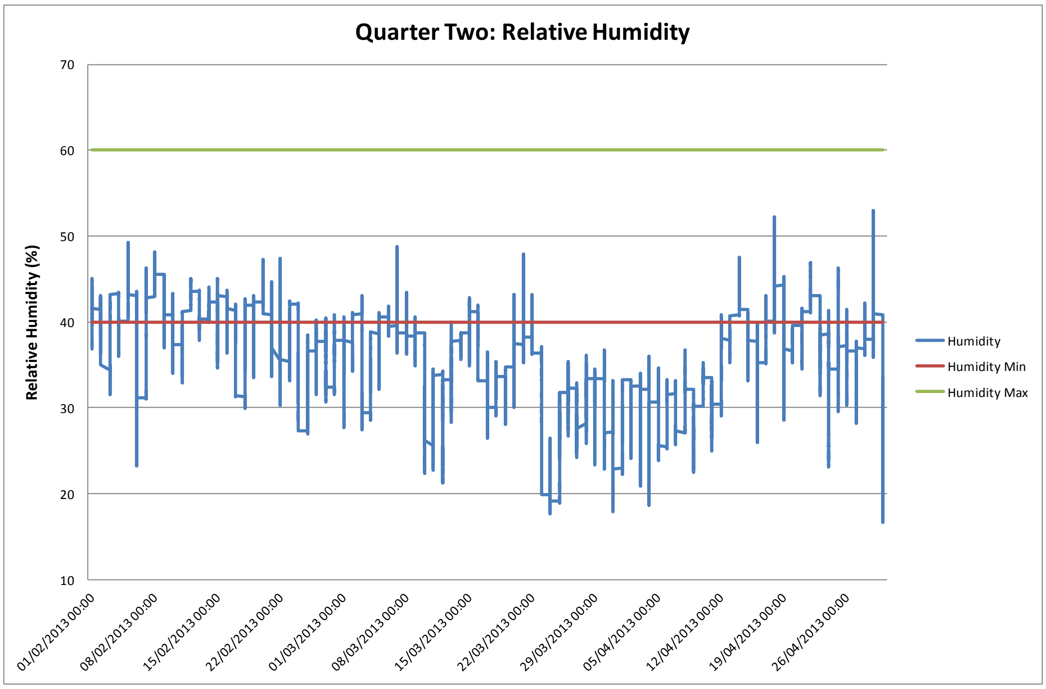


Figure 111: Quarter Two Humidity

Overall, the relative humidity for quarter two showed that conditions were drier than recommended; 70% of the readings (taken every five minutes) showed a relative humidity of below 40%. The lowest recorded relative humidity reading was 16.7% on the 30th April at 4.10pm. The highest relative humidity reading for quarter two was 52.99%, on the 29th April (1.45pm) and the average over the three months was 36.22%.

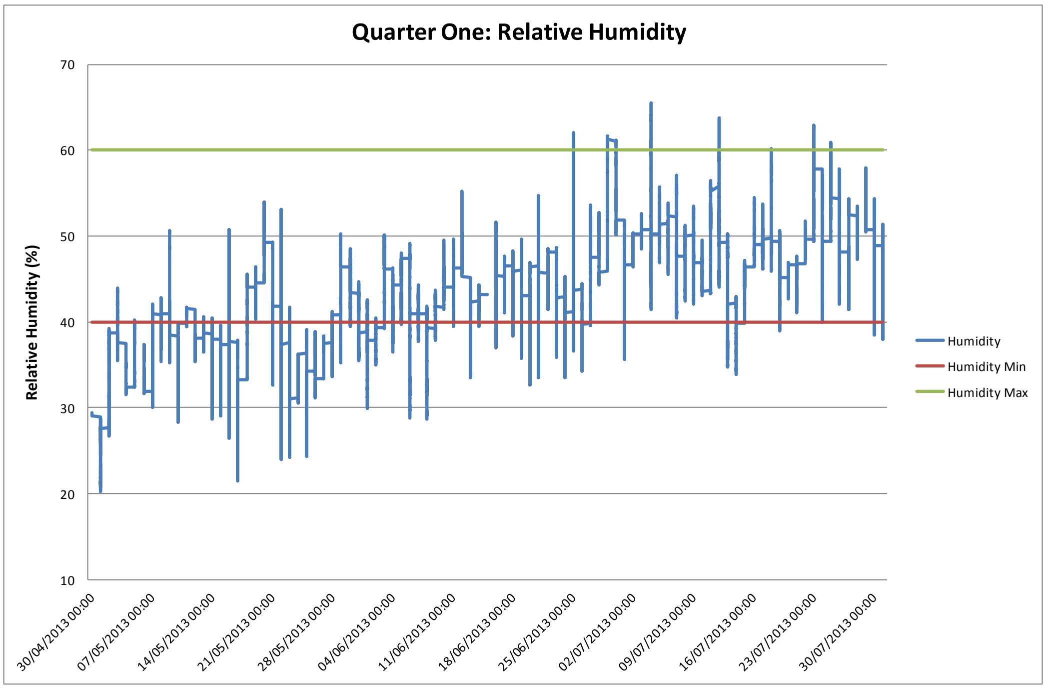


Figure 112: Quarter Three Humidity

In quarter three, the relative humidity reading started quite low, but the general trend was that they increased towards the end of July. In June and July the majority of readings were between the recommended minimum and maximum values. Overall, 32.14% of readings were below 40%. The average relative humidity was 43.32%.

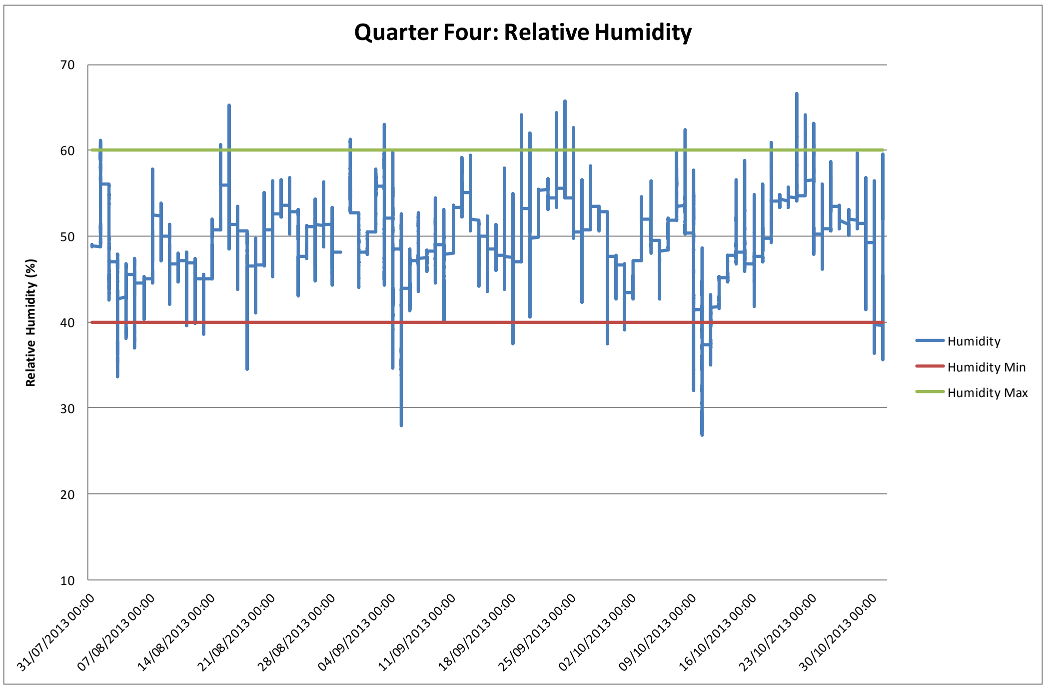


Figure 113: Quarter Four Relative Humidity

For the majority of the time during quarter four, the relative humidity readings were between the recommended minimum of 40% and the recommended maximum of 60%. Only 0.85% of readings were above 60% and only 3.37% of readings were below 40%.

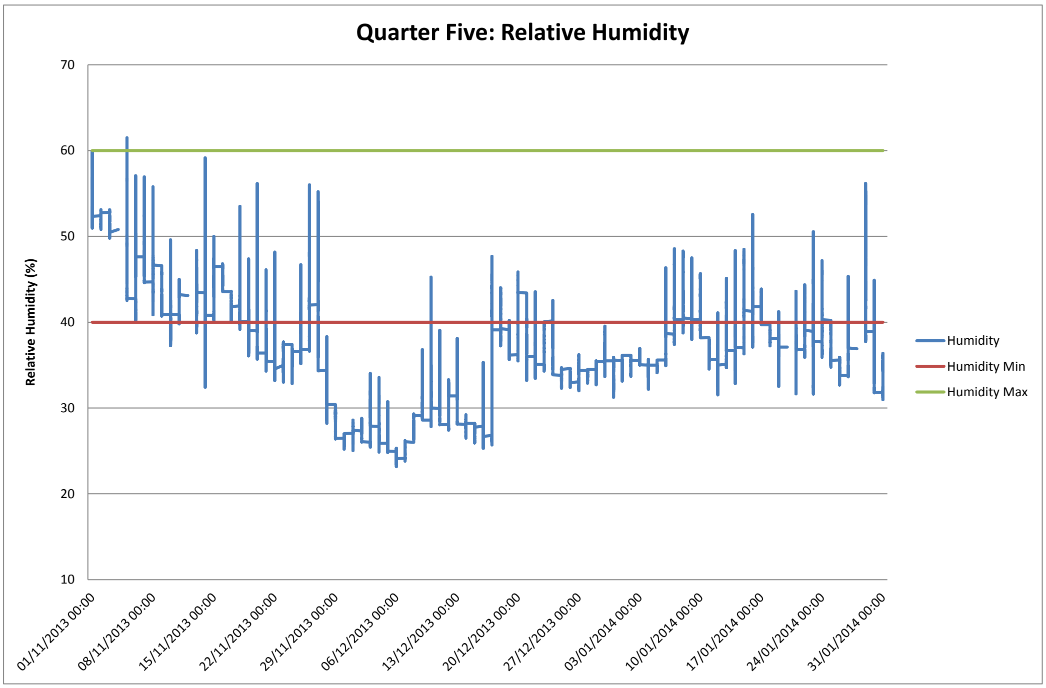


Figure 114: Quarter Five Relative Humidity

As in Quarter Two, relative humidity within the Visitor Centre in quarter five was quite low, with 70.58% of readings below the recommended minimum of 40%. The majority of these lower readings are from the beginning of December to mid-January. Anecdotal evidence from building occupants is that they generally find the Visitor Centre to be 'very dry'.

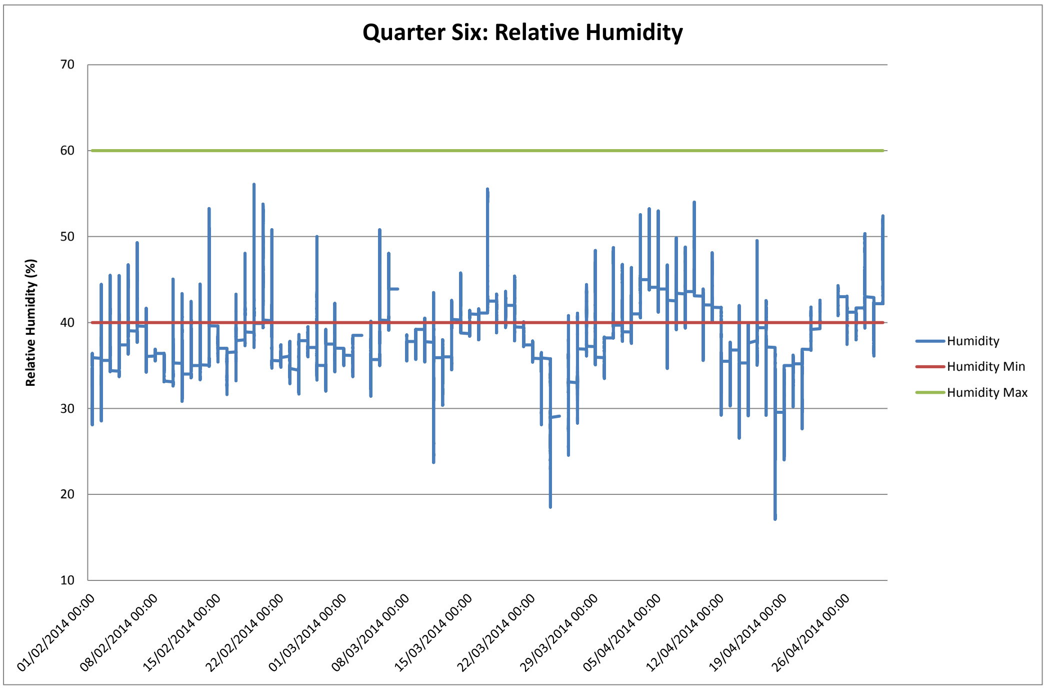


Figure 115: Quarter Six Relative Humidity

Again in quarter six, the relative humidity readings were generally lower than recommended; 65.88% of readings were below 40% RH. The percentage of low readings in quarter five and six are similar to quarter 2.

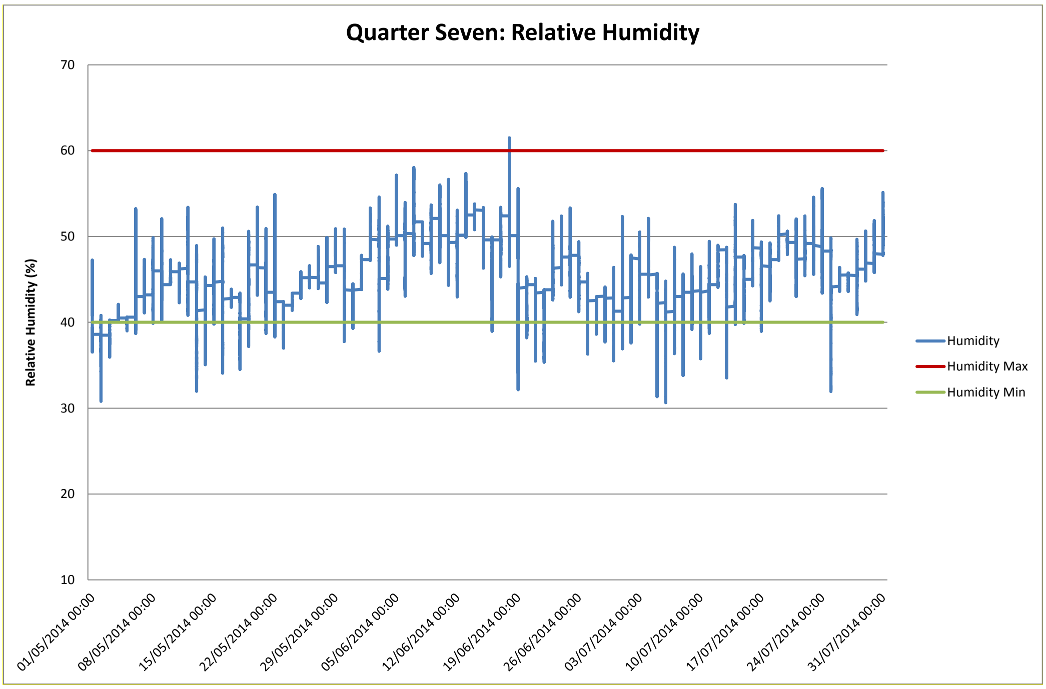


Figure 116: Quarter Seven Relative Humidity

In general, the relative humidity readings for quarter seven were between the recommended levels of 40% and 60%. For only 11.35% of the time were the readings out with these limits – and only on one occasion was the relative humidity higher than 60%.

A summary of the key figures from the temperature measurements are outlined in Figure 117. The high and low readings are presented as a percentage of the total number of readings. As the weather station was installed on site in January 2014, external relative humidity readings are available for quarter 6. The maximum reading (100%), minimum (22.33%) and average (84.29%) readings show that the external and internal humidity levels are very different, being dry in the Visitor Centre compared to the external factors.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7
AVERAGE	49.39	36.22	43.32	49.60	36.96	38.54	45.05
MAX	95.97	52.99	65.44	66.59	61.48	56.07	61.48
MIN	23.36	16.70	20.27	26.78	23.16	17.12	30.46
High Readings (%)	11.11%	0.00%	0.60%	0.85%	0.01%	0.00%	0.04%
Low Readings (%)	12.98%	70.68%	32.14%	3.37%	70.58%	65.88%	11.31%

Figure 117: Key Figures (Relative Humidity)

10.8.3 Air Quality

Air quality is a measurement of the level of CO_2[8] within the internal environment, and is measured in parts per million (ppm). Typically, 'Good' practice levels should be below 1000 ppm and ideally less than 600 ppm as when CO_2 levels are in excess of 1000 ppm, drowsiness and lethargy are common side effects, with a

[8] CO_2 – Carbon dioxide

noticeable drop in productivity and concentration. Levels of between 1,000 and 2,700 ppm have been shown have an adverse effect on building occupants wellbeing and up to a 14% reduction in cognitive function.

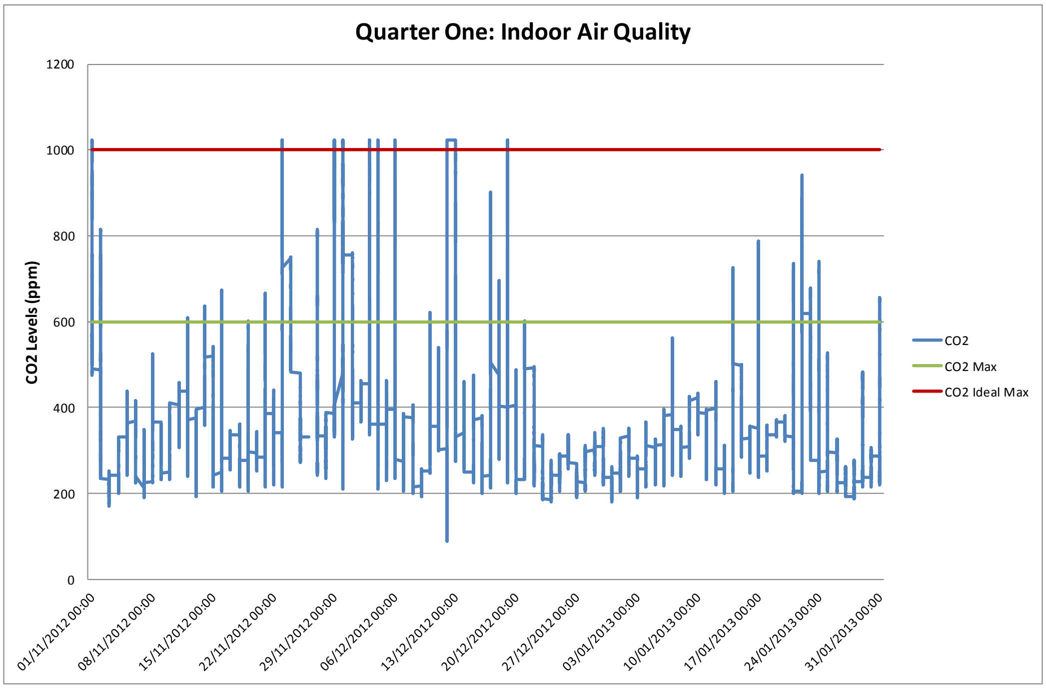


Figure 118: Quarter One Air Quality

Generally during quarter one, the CO_2 levels were below the ideal maximum of 600ppm, with an average reading of 362.74ppm. On occasion the CO_2 levels have increased but for the majority of time, they are still below the recommended maximum CO_2 level of 1000ppm. On nine occasions shown on the graph, the CO_2 levels increased above this maximum. Most of these occasions occurred in the winter months, when perhaps the windows were not open to ventilate the building due to cold external temperatures.

These also fall during a busy time for events within the Visitor Centre. Each of the spikes in CO_2 levels above 1000ppm are investigated below in Figure 119 with increased occupancy generally the reason for increased CO_2 levels. It must also be noted that the ventilation system was not operational during this quarter.

The CO_2 sensor installed within the Visitor Centre is only able to produce readings up to 1023ppm as this is the limitation of the sensor recommended by our supplier for measuring CO_2 levels within an office environment.

Date	Activity
1st November 2012	On the 1st November the Visitor Centre hosted an event in the morning that would have been attended by up to 40 people. There were a further two meeting held during the day, such that the Visitor Centre was above its normal occupancy levels throughout the day.
23rd November 2012	On the 23rd November, a meeting was held in the Visitor Centre over most of the day. Around 15-20 guests were in attendance.
29th November 2012	A site meeting was held in the Visitor Centre on the 29th November; around 10-15 people attended.
30th November 2012	A staff meeting (five or six attendees) was held in the afternoon.
3rd December 2012	A number of meetings were held in the Visitor Centre on the morning of the 3rd December.
4th December 2012	An event, with around 30-40 delegates was held in the afternoon of the 4th December.
6th December 2012	A workshop was held on the 6th December with around 15-20 guest attending all day.
12th December 2012	An event, with 40+ delegates was held in the afternoon on the 12th December.
19th December 2012	A staff meeting, with 20+ staff in attendance was held over lunchtime on the 19th December.

Figure 119: Activities within Quarter One

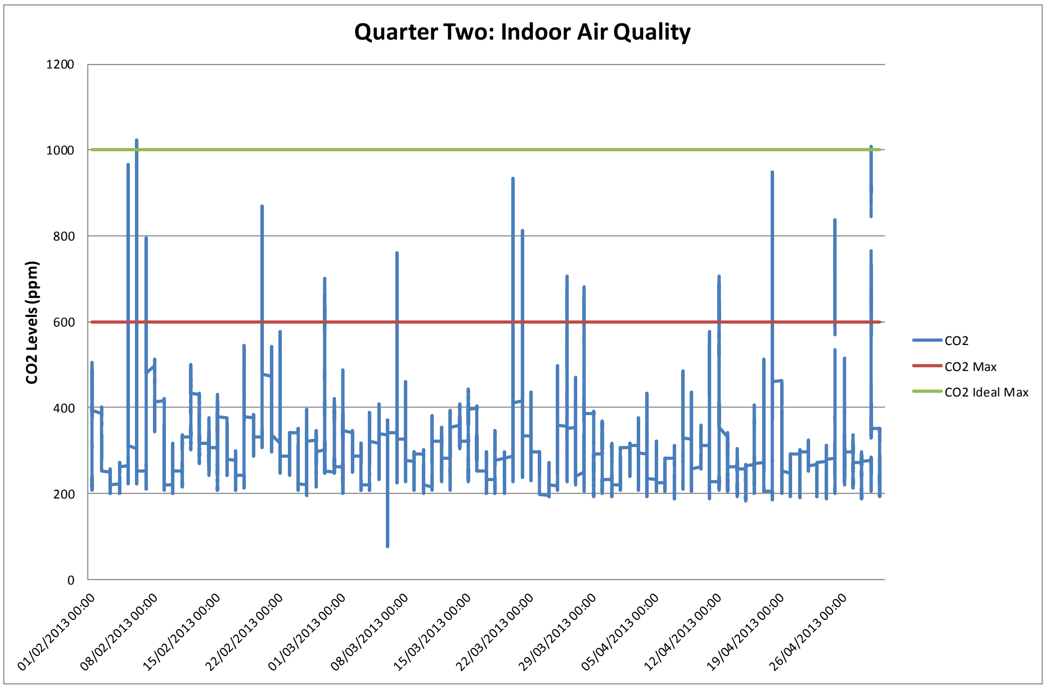


Figure 120: Quarter Two Air Quality

For the majority of the second quarter, the CO_2 levels within the Visitor Centre were between 200ppm and 400ppm, with an average level of 306.98ppm. On around 14 occasions, the CO_2 levels increased above the recommended ideal maximum of 600ppm. On two occasions, the 6th February and 29th April 2013, the CO_2 levels increased above the maximum recommended level of 1000ppm. On the 6th February, an event was held in the afternoon with around 40 delegates attending; on the 29th April, a meeting was held all day in the Visitor Centre. The ventilation system was still not operational during this quarter but as the weather grew warmer outside, the Visitor Centre staff will have had windows open more frequently.

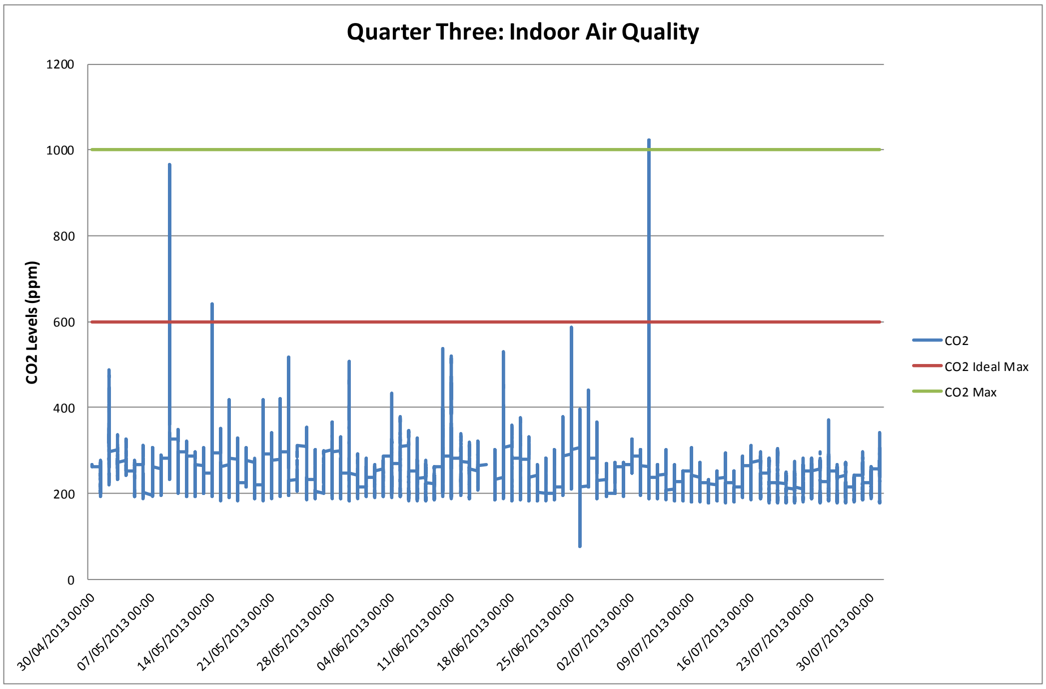


Figure 121: Quarter Three Air Quality

In the third quarter, which covers the months of May, June and July, the CO_2 levels were in the majority below the ideal maximum of 600ppm. Most of the readings fall between around 200ppm and 350ppm with an average reading recorded of 246.57ppm. On two occasions the CO_2 levels were above the ideal maximum of 600ppm and on one occasion, 4th July 2013, the CO_2 levels reached above the 1000ppm recommended maximum. There were no meetings or events held on the 4th July, and there was not a greater volume of people within the Visitor Centre than normal so it is difficult to understand why this spike in readings occurred.

The ventilation system was correctly operating by June 2013, which may be the cause of the fewer fluctuations in the graph (excluding the 4th July) from the end of June onwards. However, the Visitor Centre staff also generally had windows and doors open for much of the working day as the building warmed due to solar gain and external temperatures.

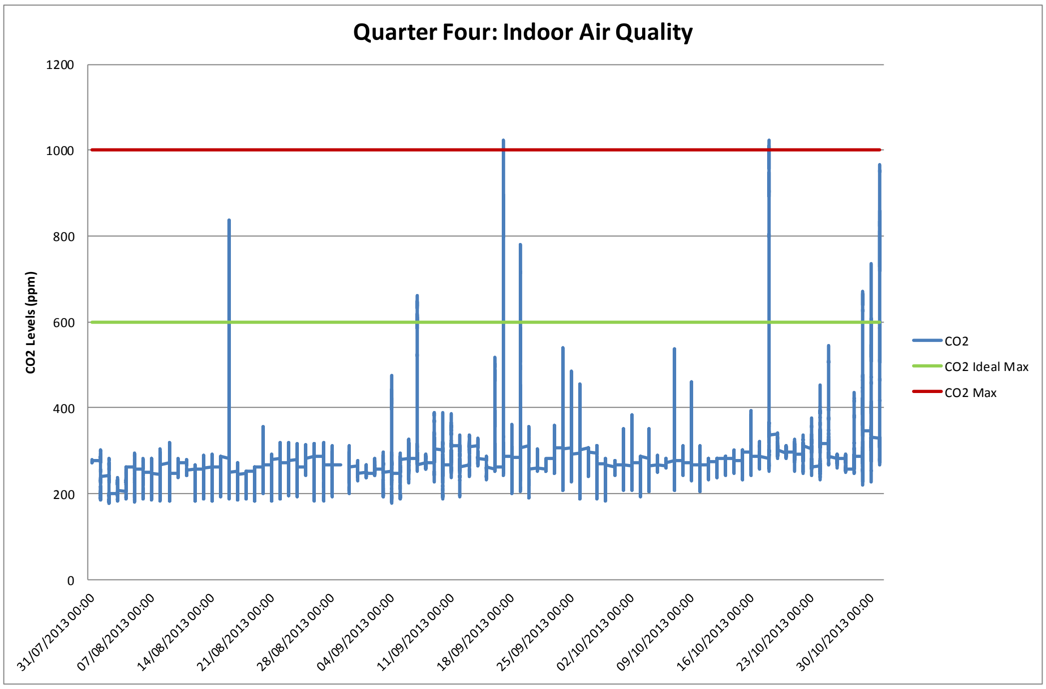


Figure 122: Quarter Four Indoor Air Quality

The CO_2 levels within the Visitor Centre during quarter four (August, September and October) were generally steady between approximately 200ppm and 300ppm. The average reading for this quarter was 276.13ppm.

On 17th September and 18th October, the CO_2 levels rose above 1000ppm; a large meeting (around 15 delegates) was held and a large event was being set up on these respective dates. On six further dates, the CO_2 levels were above the ideal maximum of 600ppm but were still below 1000ppm.

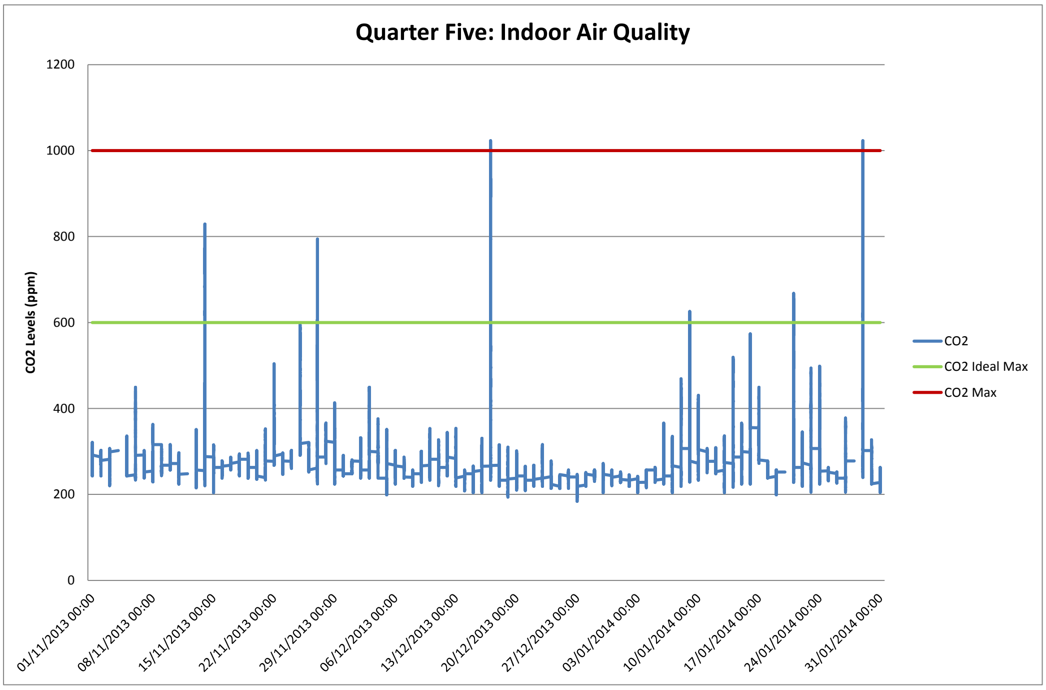


Figure 123: Quarter Five Indoor Air Quality

Indoor air quality in quarter five was generally well within the recommended maximum level of 600 ppm. On only two occasions did the CO_2 levels increase beyond the absolute maximum of 1000 ppm; between 12.05pm and 12.40pm on 17th December and from 10am to 14.50pm on 29th January 2014. Following each of these peaks, the CO_2 levels returned back to normal acceptable levels.

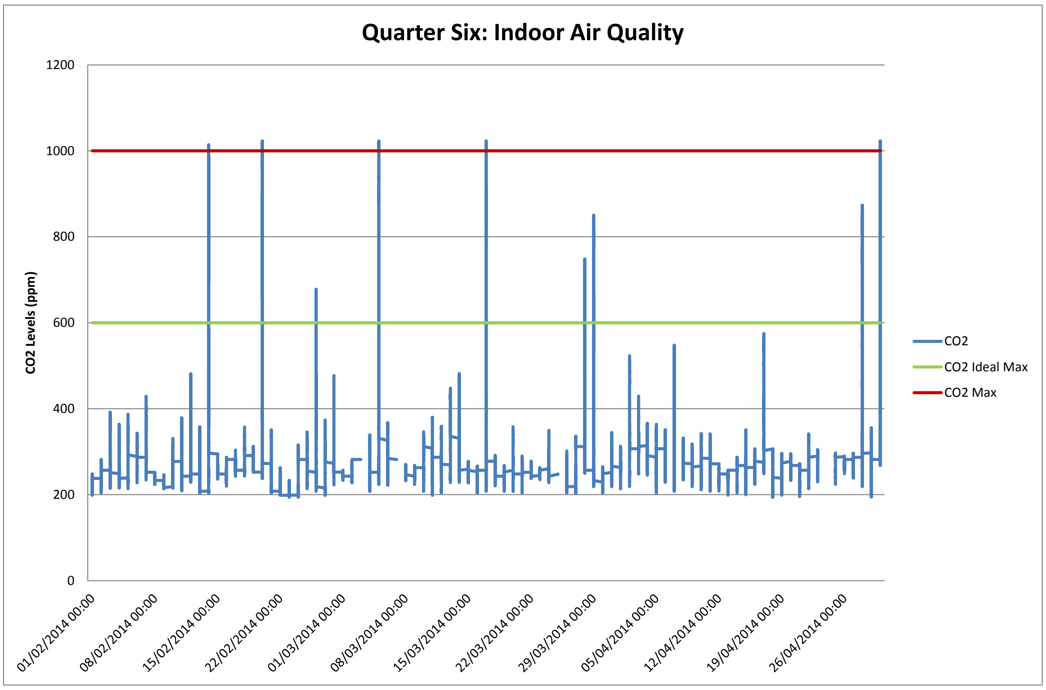


Figure 124: Quarter Six Indoor Air Quality

Again, in quarter six the CO_2 levels were generally between 200 and 400 ppm. On five separate dates, the CO_2 levels increased briefly above 1000 ppm but the levels then returned back to acceptable levels.

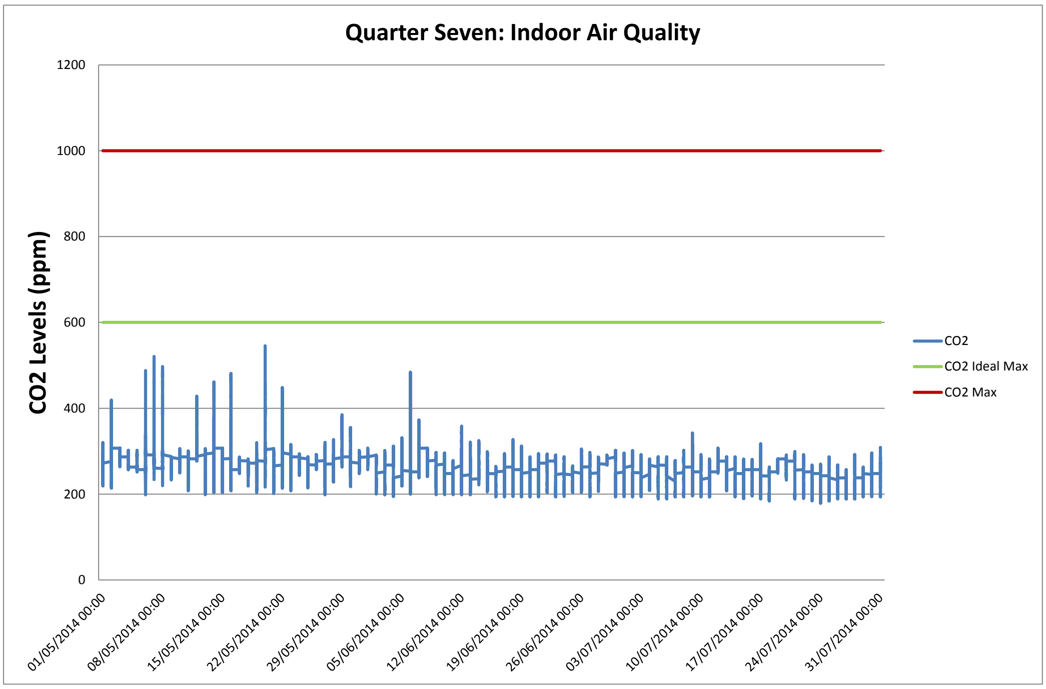


Figure 125: Quarter Seven Indoor Air Quality

In quarter seven, the average CO_2 levels were 255.01ppm, and on no occasions did the readings exceed the recommended ideal maximum of 600ppm. As this quarter covers the summer months, May, June and July, it is likely that staff working in the Visitor Centre will have had windows and doors open to cool the building, and as such there would be no expected issues with indoor air quality.

	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 5**	**Quarter 6**	**Quarter 7**
AVERAGE (ppm)	362.74	306.98	246.57	276.13	278.13	280.18	255.01
MAX (ppm)	1023	1023	1023	1023	1023	1023	545.52
MIN (ppm)	88.33	75.52	77.34	177.09	184	194	179
Above 600ppm (%)	6.99%	2.58%	0.21%	0.94%	0.84%	1.61%	0.00%
Above 1000ppm (%)	1.67%	0.02%	0.08%	0.10%	0.26%	0.34%	0.00%

Figure 126: Key Figures (Air Quality)

A summary of the key figures from the temperature measurements are outlined in Figure 126. The above 600ppm and above 1000ppm readings are presented as a percentage of the total number of readings. As can be seen in Figure 126, the maximum CO_2 reading for each quarter (except quarter seven) was 1023ppm – this is the maximum reading that the CO_2 sensor installed in the Visitor Centre can provide.

10.9 TM22 Reporting

The TM22 Tool, which contains all the energy consumption data for year one and associated analysis is included as a separate file.

The TM22 Tool initially conducts a 'simple assessment', see Figure 127, based on the energy consumption within the specified building. In the case of the Visitor Centre, there is only an electricity supply. As can be seen from the graphs the amount of energy used, and associated CO_2 emissions are greater than had been specified at design stage, but significantly lower than the TM46 benchmarks.

BUILDING ENERGY SUMMARY

Energy, carbon and cost summary	Units	Electricity	Fuels	Thermal
Non renewable fuel or electricity supplied to site	kWh/annum	7,954	0	0
Separable energy uses	kWh/annum	0	0	0
Renewable energy used on site	kWh/annum	0	0	0
Renewable energy exported	kWh/annum	0	0	0
Output from CHP used in building	kWh/annum	0		0
Exported CHP	kWh/annum	0		0

Unit values	Energy supplied (kWh/m² GIA)	
	Fuel/thermal	Electricity
Supplied	0.0	72.3
Exported CHP	0.0	
Raw TM46	120.0	95.0
User Specified	0.0	14.0
Benchmark from DEC	0.0	14.0

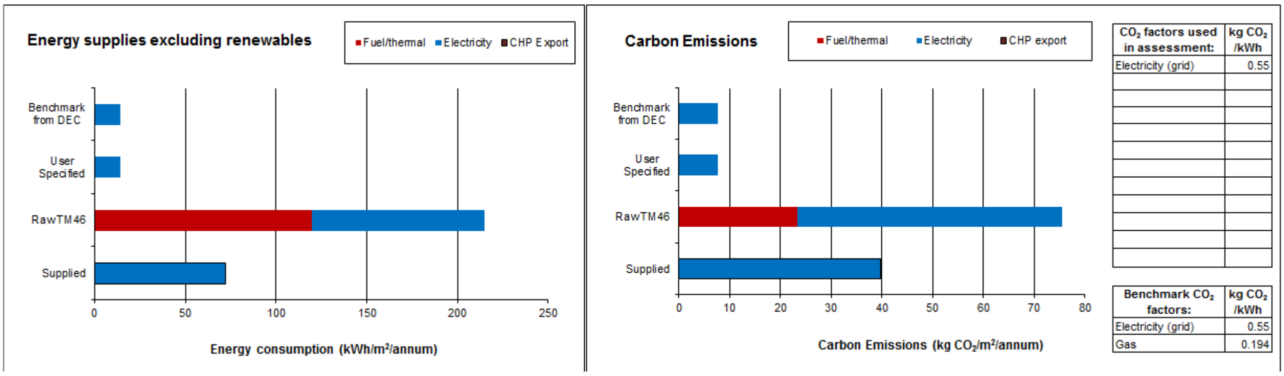


Figure 127: Simple Assessment

As there is only electrical energy use within the Visitor Centre, the next assessment the TM22 tool conducts is an electrical energy end use breakdown. A comparison is made between the energy used in the Visitor Centre and the comparable energy use as determined in the ECON19 guide (see Figure 128). The electricity used in the Visitor Centre is greater than the good practice and typical ECON19 values, as well as the TM46 benchmark. However, space heating and hot water end uses are included in the electricity consumption in the Visitor Centre but not in the benchmarks. In the heat demand graph, the amount of energy used for space heating and hot water provision is greater in all three benchmarks, than that used by the Visitor Centre, shown in red on the electricity graph (approximately 41kWh/m^2/year).

A more specific breakdown of end use energy consumption is shown in Figure 129 and a table containing all the relevant sub-system details is included in Figure 130. Again, this table shows that for most end uses, the electricity consumption in the Visitor Centre is less than in the benchmarks. The exceptions are space heating, domestic hot water and air movement. These differences are due to the use of electricity only in the Visitor Centre, and also the use of a MVHR system, instead of air conditioning.

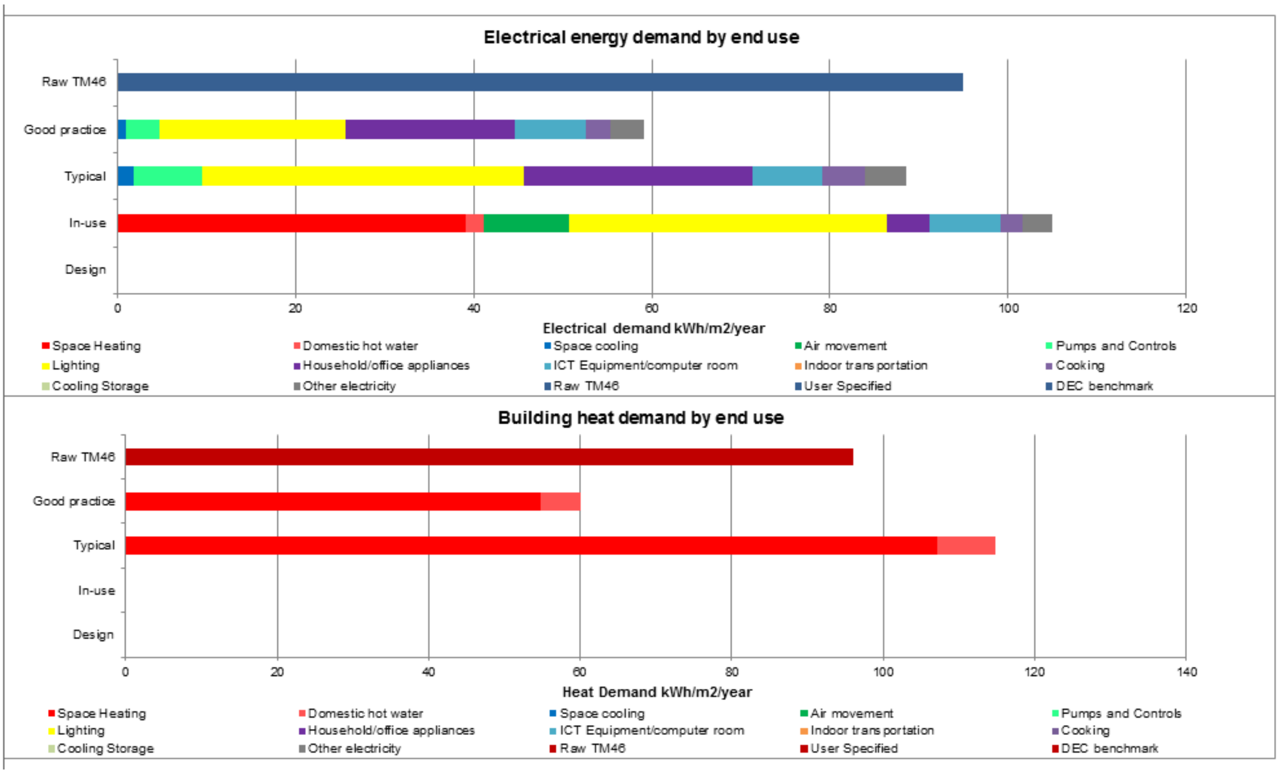


Figure 128: ECON19 Comparison Graphs

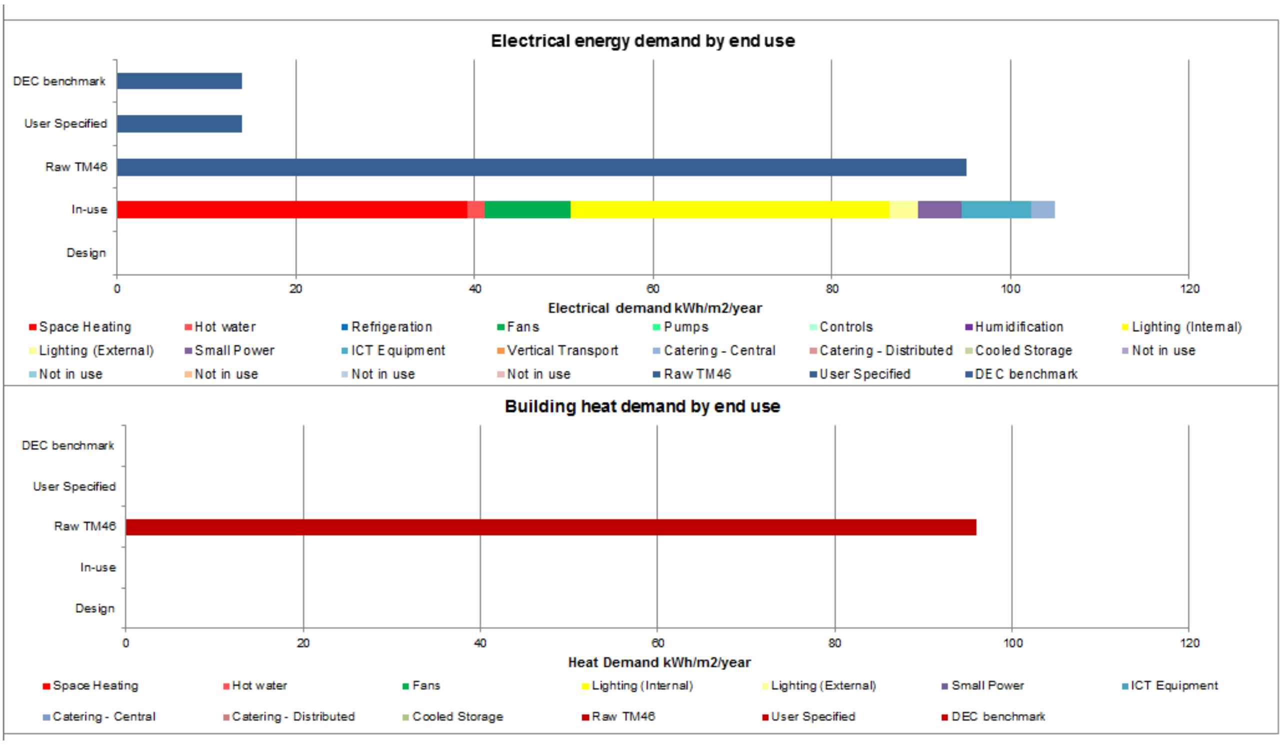


Figure 129: Sub-System Analysis

	Electricity demand (kWh/m2/year)		
System	**In-use electricity (kWh/m²/year)**	**Typical benchmark (kWh/m2/year)**	**Good practice benchmark (kWh/m2/year)**
Space Heating	39.2		
Domestic hot water	2.0		
Space cooling	0.0	1.9	1.0
Air movement	9.6	0.0	0.0
Pumps and Controls	0.0	7.6	3.8
Lighting	35.7	36.1	20.9
Household/office appliances	4.8	25.7	19.0
ICT Equipment/computer room	7.9	7.9	7.9
Indoor transportation	0.0		
Cooking	2.5	4.8	2.9
Cooling Storage	0.0		
Other electricity	3.2	4.8	3.8
Total	**104.9**	**88.6**	**59.2**
Metered building energy use	**72.3**		
Variance TM22 versus metered total	**32.6**		
Variance TM22 versus metered total	45%		

Figure 130: Electricity Demand

Figure 131 allows a comparison to be made against specific end uses as outlined in ECON19. The Visitor Centre has been compared with a ‘Type 2’ office (open plan and naturally ventilated) – as there is no air conditioning. The Visitor Centre sits between a Type 2 and a Type 3 office, but the energy consumption benchmarks are more stringent for a Type 2 office so these benchmarks have been used. Additionally, the Visitor Centre is much smaller than the recommended comparable office size (1,500m² or more).

The specific benchmarks for lighting and equipment use in Type 2 offices are shown in Figure 132. Electricity use for lighting is slightly higher than the typical ECON 19 benchmark (39 kWh/m²/year compared to 38kWh/m²/year). Electricity use for equipment is much lower in the Visitor Centre, than the benchmarks (8kWh/m²/year compared to a typical benchmark of 27kWh/m²/year and a good practice benchmark of 20kWh/m²/year). This is despite the ICT equipment in the Visitor Centre being used for more than twice the recommended hours/year. This is likely due to the small number of staff who work in the Visitor Centre at any one time.

System	In-use electricity (kWh/m2/year)	In-Use Full load W/m2	System hours/year	Utilisation
Space Heating	39	47.2	830	9.5%
Hot w ater	2	0.2	8,760	100.0%
Fans	10	1.1	8,760	100.0%
Lighting (Internal)	36	9.9	3,603	41.1%
Lighting (External)	3	0.5	5,933	67.7%
Small Pow er	5	6.1	794	9.1%
ICT Equipment	8	1.4	5,708	65.2%
Catering - Central	3	18.3	138	1.6%
Total	**105**	**84.7**		

Figure 131: Overall Average Installed Loads

	Type 2 Office	
Lighting	**Good Practice**	**Typical**
W/m2	12	18
hrs/yr	3000	3000
percentage utilisation	60%	70%
EU1 kWh/m2/year	22	38
Equipment		
W/m2	12	14
hrs/yr	2500	3000
percentage utilisation	65%	65%
EU1 kWh/m2/year	20	27

Figure 132: ECON 19 - Type 2

Office Benchmarks

Energy Demand Profiles

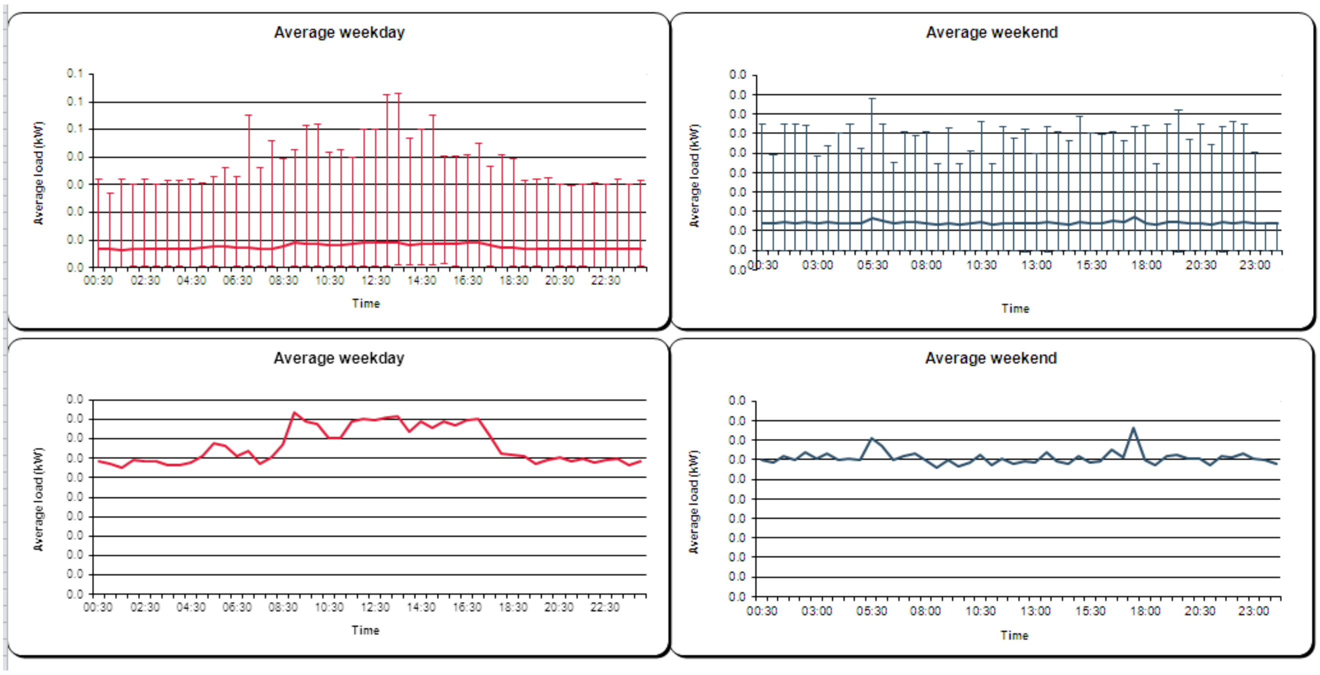


Figure 133: Circuit 1 – Fans (Year 1 – with and without error bars)

The fans circuit was not switched on until May 2013, but since then it has followed a steady consumption rate, peaking during office hours on weekdays.

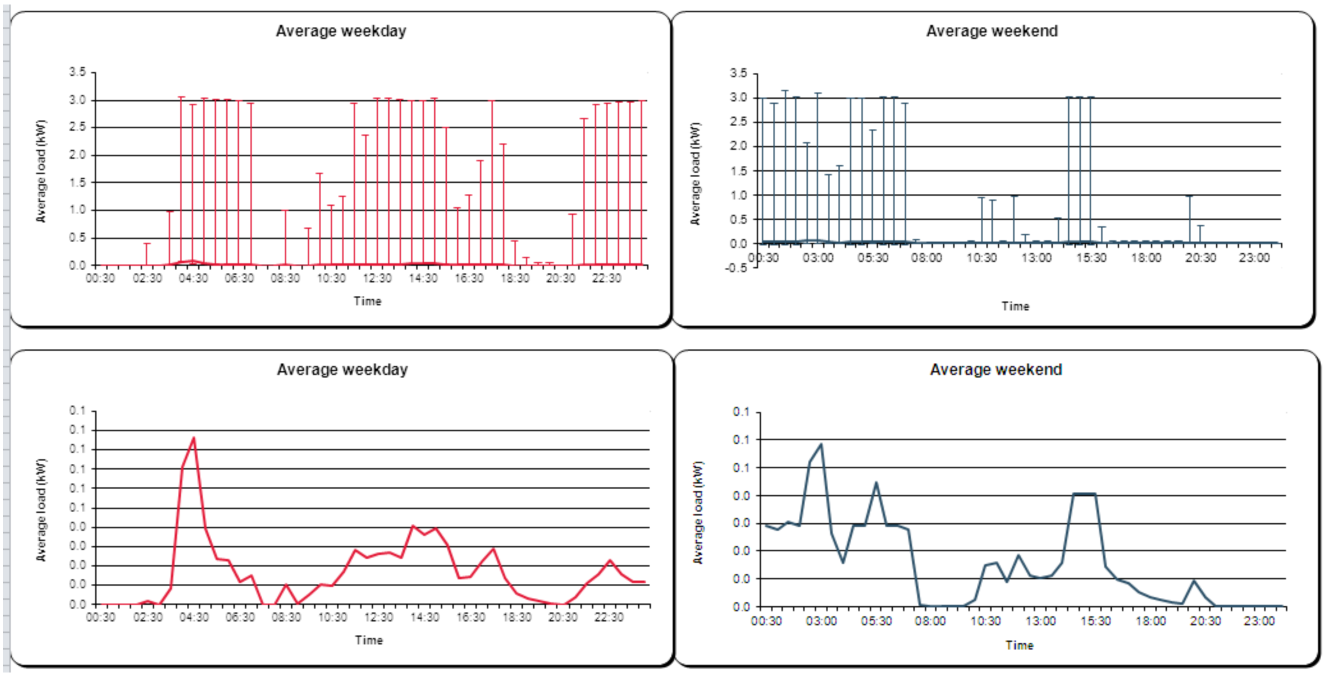


Figure 134: Circuit 2 - Hot Water (Year 1 – with and without error bars)

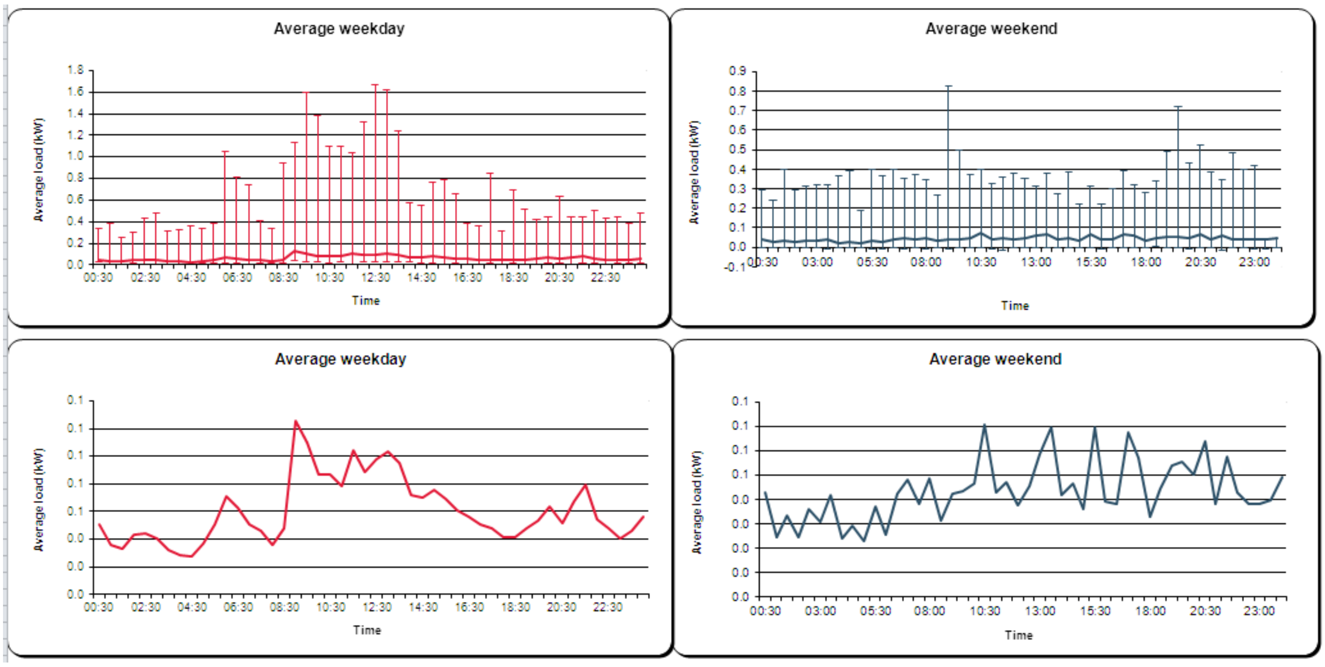


Figure 135: Circuit 3 - Kitchen Power (Year 1 – with and without error bars)

The kitchen power circuit recognises a base level of consumption, with sporadic peaks. These peaks result from use of the kettle, toaster and microwave in the kitchen.

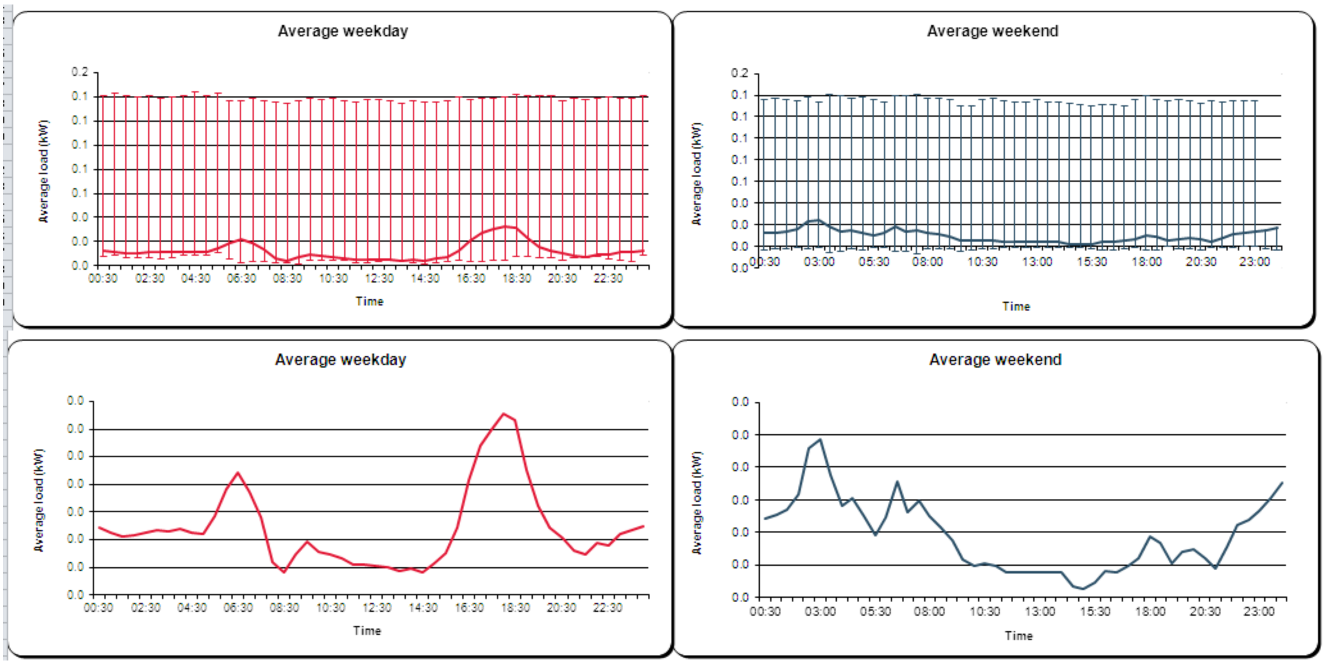


Figure 136: Circuit 4 - Lighting Zone 1 (Year 1 – with and without error bars)

As expected, lighting consumption is limited during the day, however, it is not clear why it would peak in the evening and morning and decrease again overnight, as the Visitor Centre is occupied by security staff from 6pm to 6am.

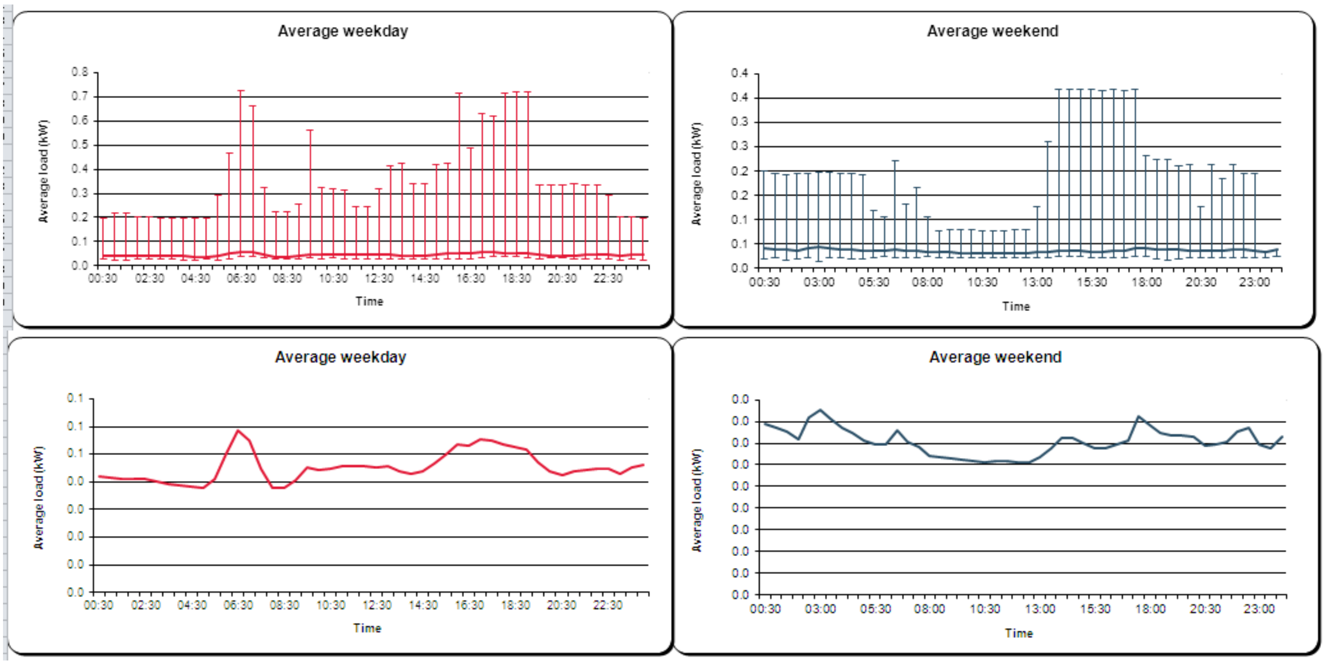


Figure 137: Circuit 5 - Lighting Zone 2 (Year 1 – with and without error bars)

Defined peaks are shown in the lighting zone 2 circuit, particularly in the early morning weekdays.

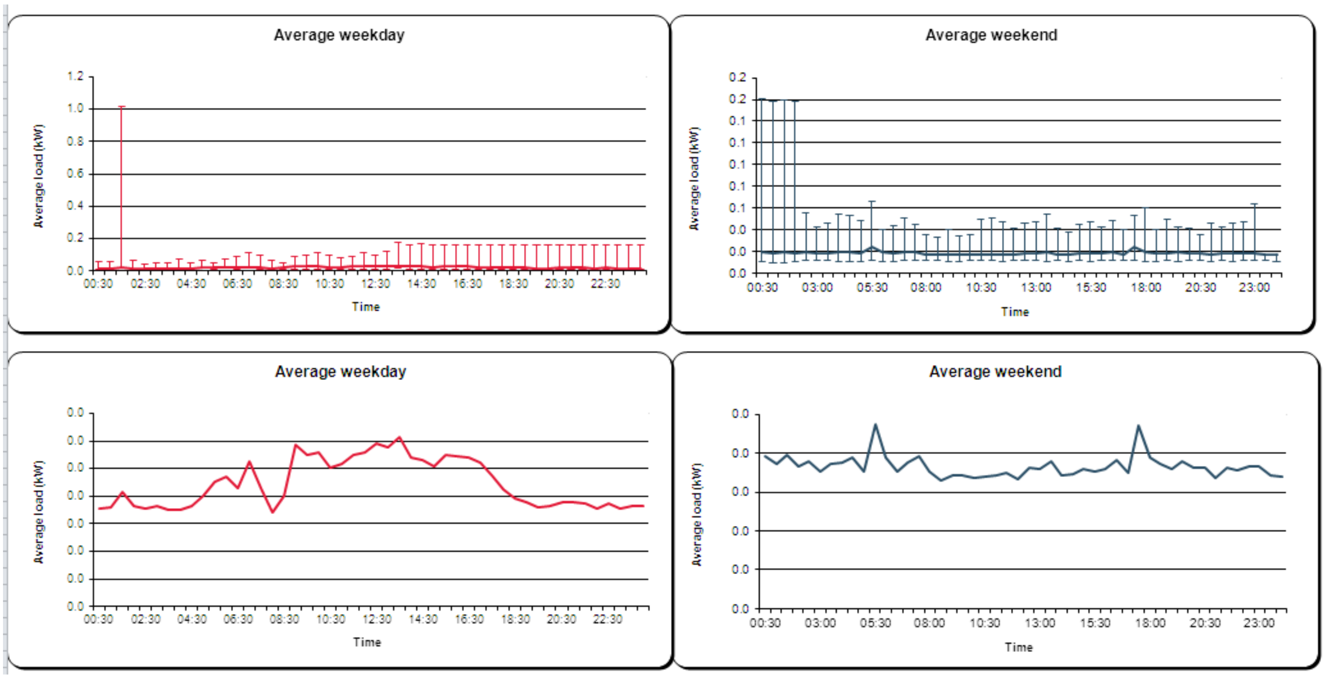


Figure 138: Circuit 6 - Lighting Zone 3 (Year 1 – with and without error bars)

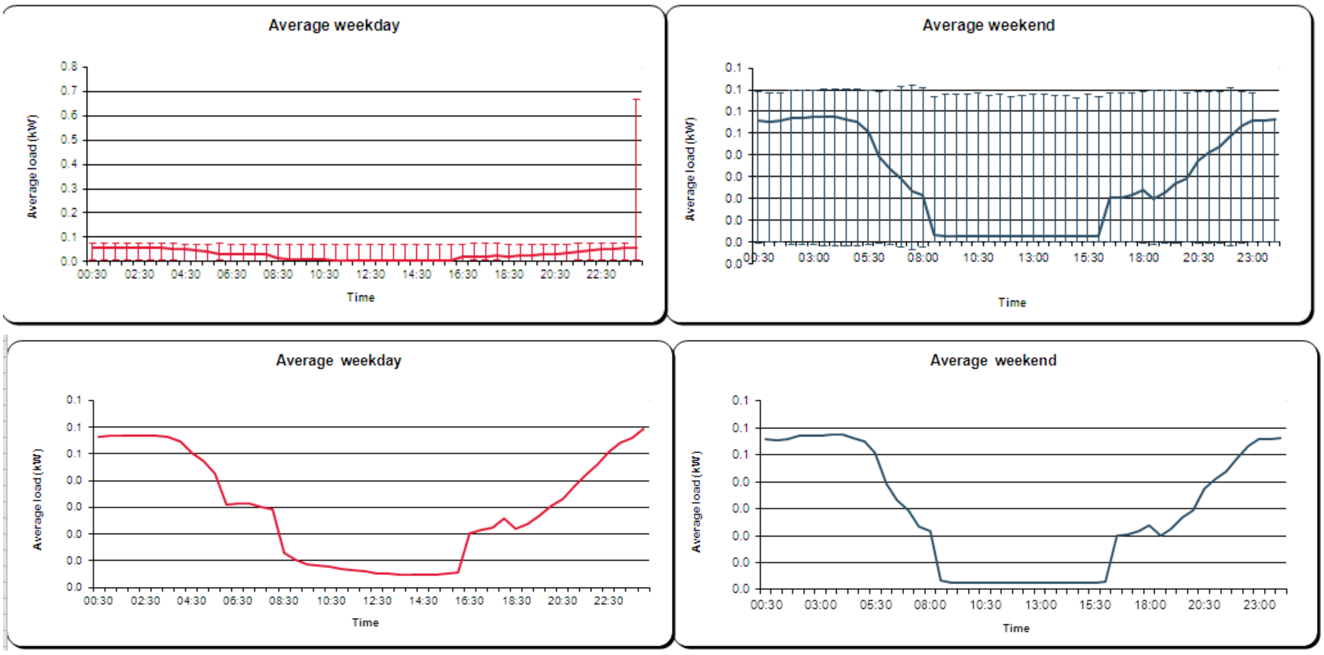


Figure 139: Circuit 7 - External Lighting (Year 1 – with and without error bars)

External lighting is controlled by a timer and as such, the profiles are quite distinct, with little or no electricity consumed during the day. The electricity consumption shown during the day results from a few isolated days when the timer has not correctly switched off the lights.

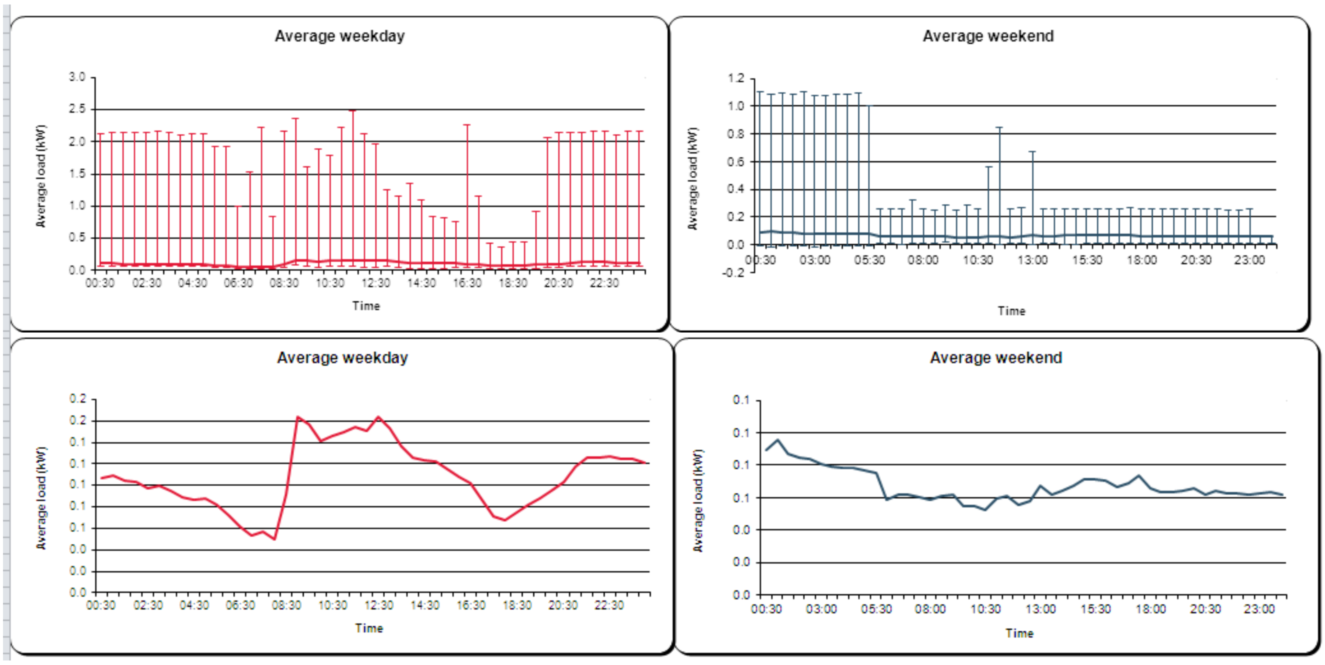


Figure 140: Circuit 8 - Small Power Zone 1 (Year 1 – with and without error bars)

The consumption profiles for year one shows more energy consumed during the day in year one for both small power zones (Figure 140 and Figure 141)

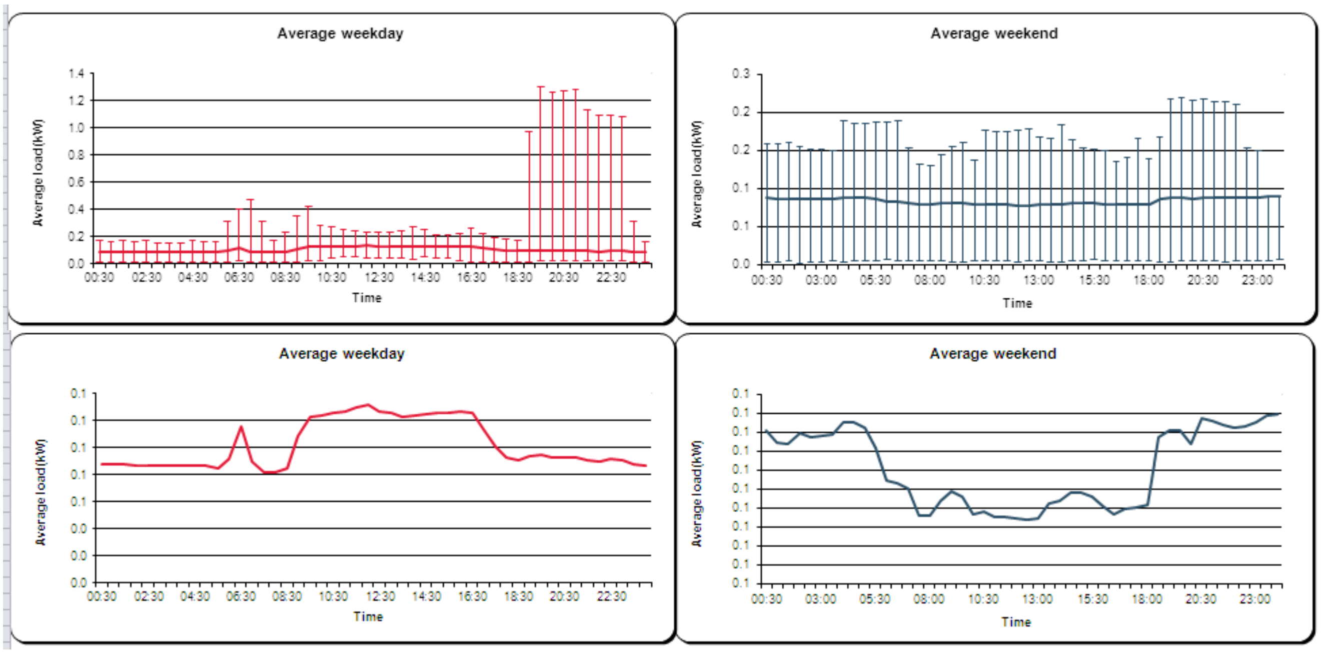


Figure 141: Circuit 9 - Small Power Zone 2 (Year 1 – with and without error bars)

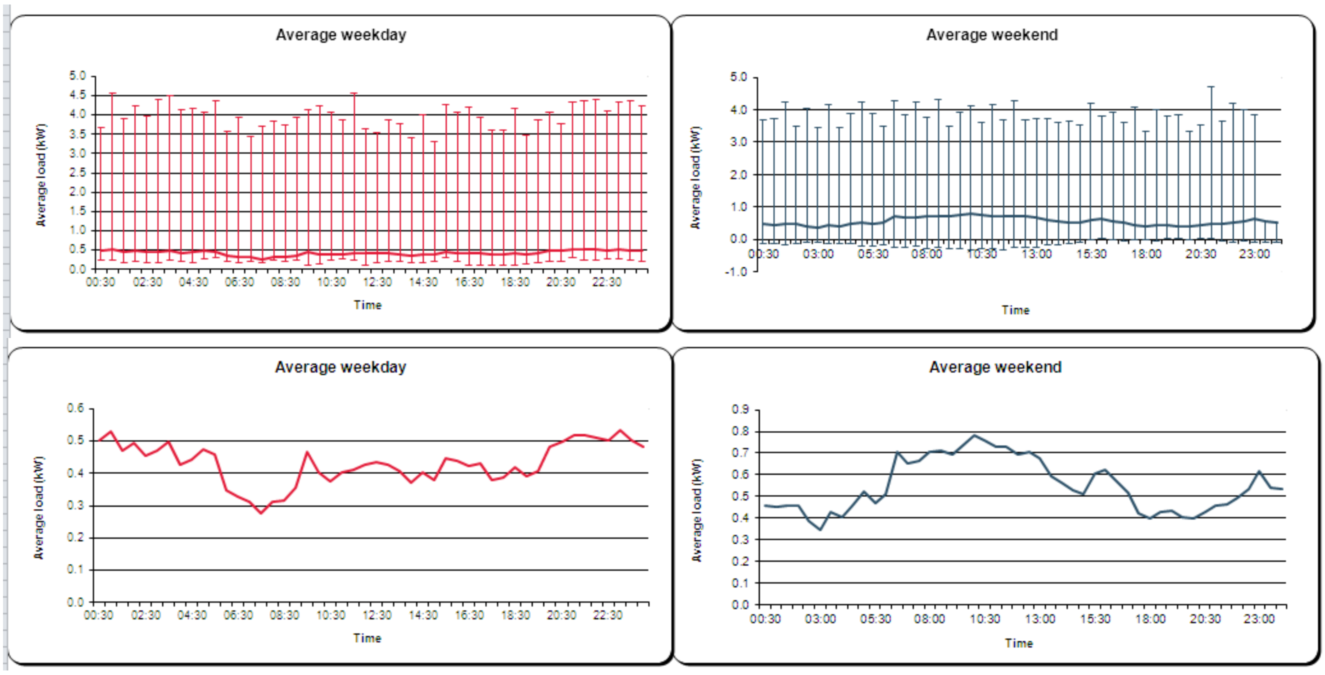


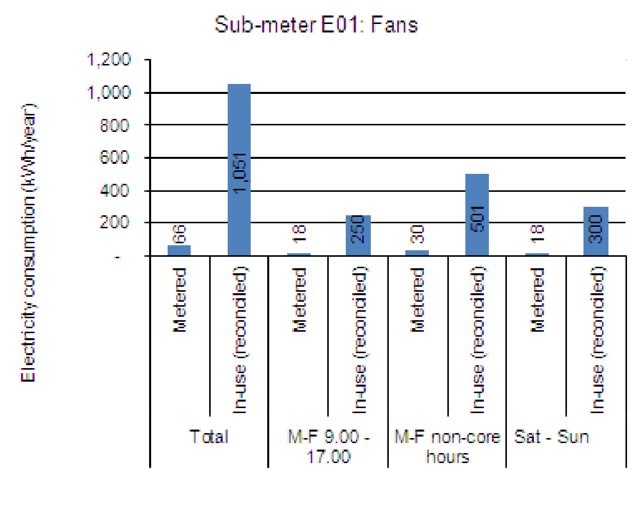
Figure 142: Circuit 10 - Space Heating (Year 1 – with and without error bars)

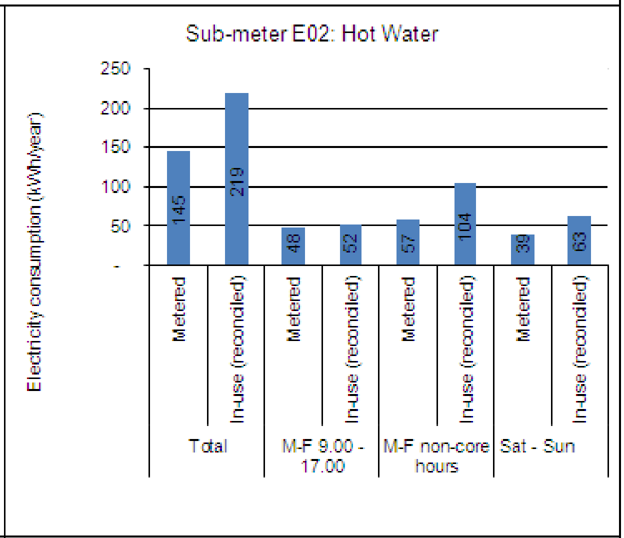
10.10 Energy Consumption

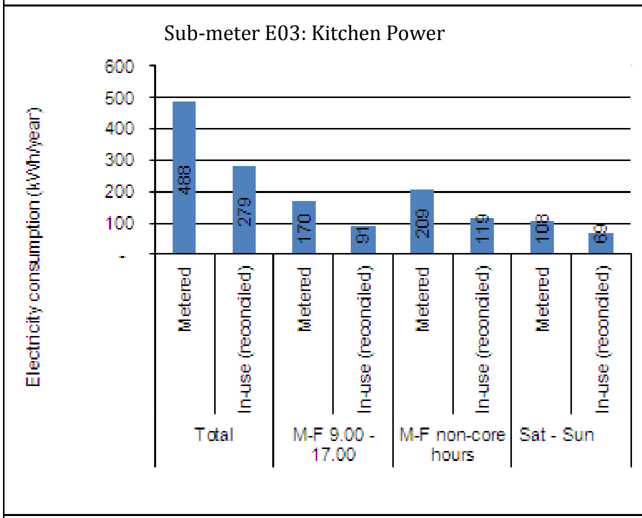
The discrepancies between the 'metered' value and the 'in-use' value as shown in Figure 143, can be explained as follows.

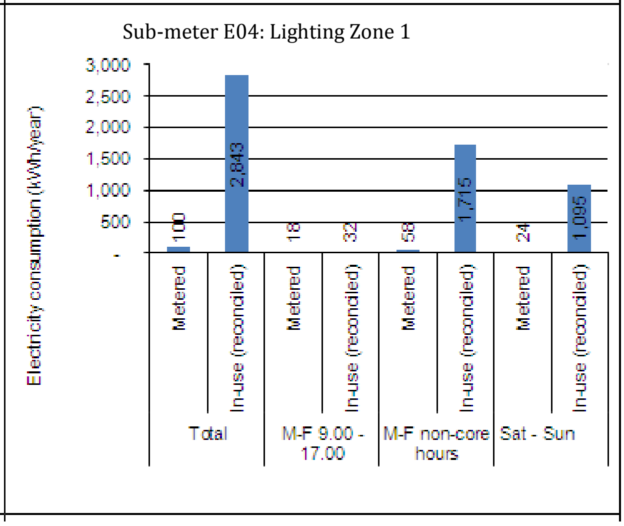
- Sub-meter 1, Fans: this circuit includes the MVHR system. The in-use figures for all time periods are considerably greater than the metered values. This is because the MVHR system was not switched on properly when the building was initially occupied. It was apparent that the circuit was not operating correctly, as very little energy was being consumed, but the unit was not correctly switched on until M&E contractors inspected the building in May 2013.

- Sub-meter 2, Hot water: this circuit measures the energy used to provide additional hot water on top of that provided by the solar thermal panel. The small discrepancy between measured and in-use figures is likely due to the amount of hot water provided by the solar panel.
- Sub-meter 3, Kitchen Power: this circuit has a discrepancy in that the metered figures are greater than the in-use figures. This is most likely due to an increase in use of the kettle when the boiler unit was not working correctly, particularly for washing dishes and cleaning (see section 6) compared to estimations.
- Sub-meter 4, Lighting Zone 1: this circuit covers the lighting in the main event space in the Visitor Centre. The discrepancy between metered and in-use data for this circuit is because of the use of electricity generated by the PV array to power these lights.
- Sub-meter 5, Lighting Zone 2: this circuit covers the lighting in the staff area. The actual metered consumption is much lower than the estimated in use figure. BRE staff members using the Visitor Centre have noted that in general the levels of daylight are sufficient that artificial lighting is not required. In addition, they have commented that even when natural light levels fall, they are reluctant to switch on the lights as they find them to be too bright.


Sub-meter E01: Fans
Electricity consumption (kWh/year)
1,200
1,000
800
600
400
200
-
66
1,051
18
250
30
501
18
300
Metered
In-use (reconciled)
Total
M-F 9.00 - 17.00
M-F non-core hours
Sat - Sun


Sub-meter E02: Hot Water
Electricity consumption (kWh/year)
250
200
150
100
50
-
145
219
48
52
57
104
39
63
Metered
In-use (reconciled)
Total
M-F 9.00 - 17.00
M-F non-core hours
Sat - Sun


Sub-meter E03: Kitchen Power
Electricity consumption (kWh/year)
600
500
400
300
200
100
-
488
279
170
91
209
119
108
69
Metered
In-use (reconciled)
Total
M-F 9.00 - 17.00
M-F non-core hours
Sat - Sun


Sub-meter E04: Lighting Zone 1
Electricity consumption (kWh/year)
3,000
2,500
2,000
1,500
1,000
500
-
100
2,843
18
32
58
1,715
24
1,095
Metered
In-use (reconciled)
Total
M-F 9.00 - 17.00
M-F non-core hours
Sat - Sun

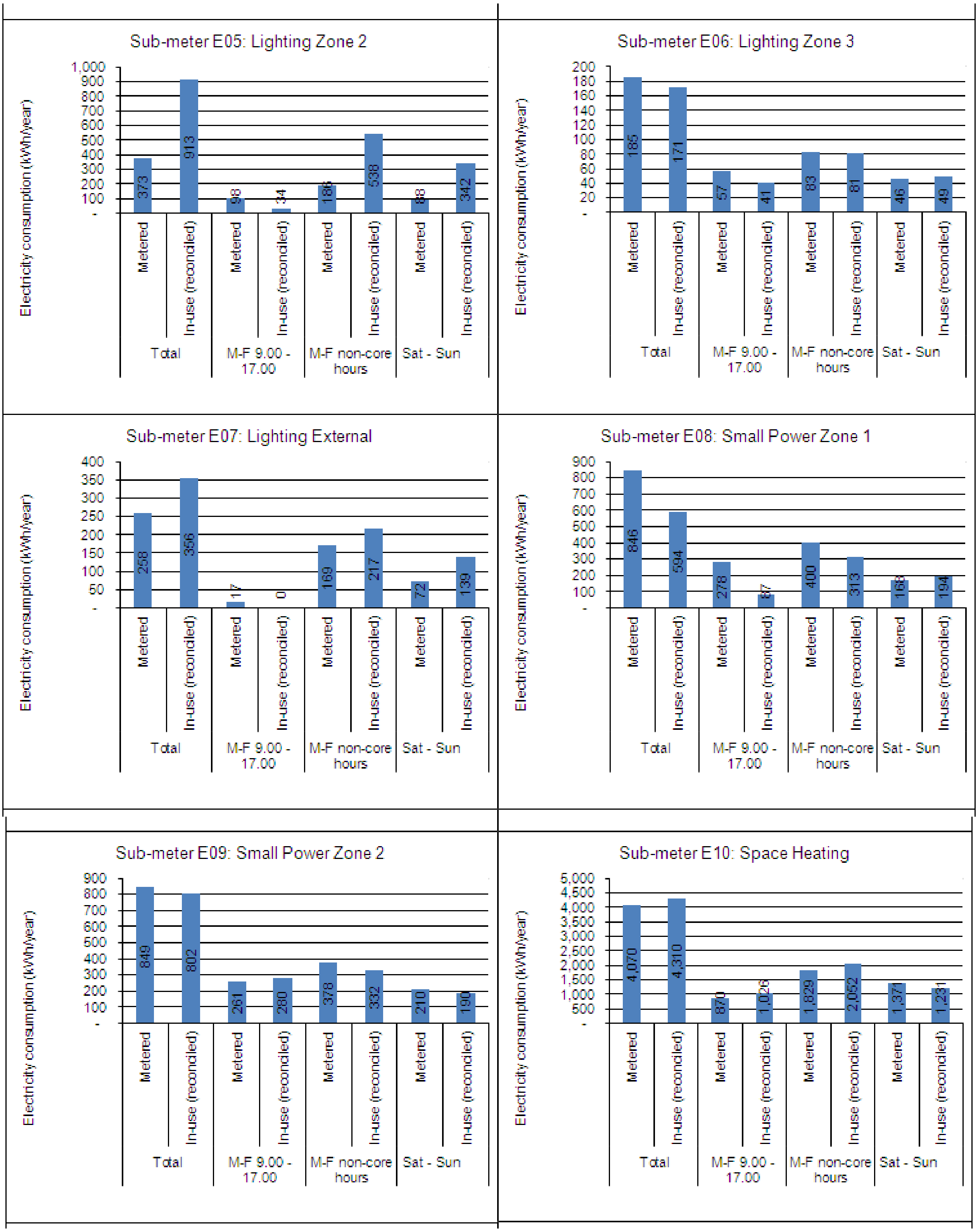


Figure 143: Electricity Consumption (Sub-meters)

Total energy consumption, by end use, is shown in Figure 144. How this consumption varies over the core and 'non-office' hours is shown in Figure 145.

	Fans	Hot Water	Kitchen Power	Lighting 1	Lighting 2	Lighting 3	Ext. Lighting	Small Power 1	Small Power 2	Space Heating
Nov 12	0.94	3.25	46.63	12.20	53.02	15.77	19.15	25.13	30.06	401.31
Dec 12	0.74	6.48	36.97	19.41	52.85	15.40	33.76	79.62	69.30	608.75
Jan 13	0.66	6.76	31.77	13.69	36.82	14.14	33.51	46.95	81.58	592.97
Feb 13	0.62	3.01	38.68	11.84	25.36	12.25	28.45	70.37	72.55	533.09
Mar 13	0.67	12.07	45.34	4.30	25.46	13.92	26.75	60.04	87.07	668.09
Apr 13	0.83	24.33	42.85	5.43	21.22	13.92	15.89	57.29	82.60	357.12
May 13	0.65	13.49	50.41	8.53	27.94	15.93	10.90	77.35	79.81	287.16
Jun 13	2.99	1.59	45.73	1.40	20.49	14.85	13.71	95.33	80.93	65.07
Jul 13	16.49	12.66	37.27	6.06	18.94	17.96	24.68	70.70	58.54	20.41
Aug 13	15.86	28.39	34.00	2.01	27.04	16.14	16.49	147.82	79.37	58.53
Sep 13	16.20	14.44	36.80	7.72	29.74	18.23	22.08	72.65	78.21	104.24
Oct 13	16.56	17.81	39.75	9.77	40.19	17.67	18.60	83.16	71.16	247.15
Nov 13	16.39	4.12	41.59	20.47	59.70	18.74	10.56	661.13	423.89	98.66
Dec 13	16.44	0.58	32.66	55.18	7.49	16.72	20.09	862.05	687.60	14.30
Jan 14	16.72	1.13	44.47	38.53	0	15.93	10.94	788.66	660.28	0
Feb 14	15.11	3.98	38.08	16.50	0	13.67	10.56	919.99	429.76	0
Mar 14	17.00	7.05	33.61	9.00	0	14.86	9.39	604.82	553.48	68.45
Apr 14	15.10	154.54	33.43	11.62	0	16.08	11.33	426.48	197.71	8.12
May 14	16.09	366.06	42.48	7.49	0	20.09	16.42	262.88	65.85	0
Jun 14	15.25	182.80	45.68	7.11	0	17.74	0	57.25	61.04	0
Jul 14	15.40	172.42	66.63	6.13	0	18.47	25.33	42.54	65.25	0

Figure 144: Total Energy Consumption by End Use

	Distribution of energy consumption across week (kWh/annum) Year One				**Distribution of energy consumption across week (kWh/annum) Year Two**			
	HH total kWh	**M-F 9.00 - 17.00**	**M-F non-core hours**	**Sat - Sun**	**HH total kWh**	**M-F 9.00 - 17.00**	**M-F non-core hours**	**Sat - Sun**
Fans	66	18	30	18	151	39	71	41
Hot Water	145	48	57	39	895	229	427	239
Kitchen Power	488	170	209	108	410	121	200	89
Lighting Zone 1	100	18	58	24	179	22	122	35
Lighting Zone 2	373	98	186	88	92	17	49	26
Lighting Zone 3	185	57	83	46	161	45	76	40
Lighting External	258	17	169	72	121	13	83	25
Small Power Zone 1	846	278	400	168	4,680	424	2,434	1,822
Small Power Zone 2	849	261	378	210	3,179	341	1,362	1,477
Space Heating	4,070	870	1,829	1,371	240	58	117	65
Total	**7,380**	**1,835**	**3,399**	**2,144**	**10,110**	**1,309**	**4,941**	**3,860**
% of Total Energy	**100%**	**24.86%**	**46.06%**	**29.05%**	**100%**	**12.95%**	**48.88%**	**38.18%**
% of Total Time	**100%**	**23.81%**	**47.62%**	**28.57%**	**100%**	**23.81%**	**47.62%**	**28.57%**

Figure 145: Breakdown of Energy Consumption

As outlined in section 6.1.1, the Visitor Centre was expected to be occupied during office hours only. As can be seen in Figure 145, the total energy used during office hours only in year one was 1,835kWh/year. This equates to 16.68kWh/m²/year – and 11.78kWh/m²/year not including small power consumption, much more in line with the expected value of 14kWh/m²/year which would include an allowance of non-office hours occupation, for example for early morning cleaning. In year two (November 2013 to July 2014), the total 'office hours' consumption has been 1,309kWh.

During office hours only, in year one the space heating circuit consumed 7.9kWh/m²year, still slightly above the expected value of 5.31kWh/m²year. Assuming that actual small power consumption is constant each month, the amount of electricity used by the bar heaters (which provided space heating from November to April 2014) can be calculated as approximately 6,644kWh or 60.4kWh/m². This is equivalent to having both heaters on full for 1,660 hours, or almost ten full weeks. From May 2014 onwards when the bar heaters were no longer used, the electricity consumption on the small power circuits returned to 'normal' pre heater use figures.

The figures at the bottom of the table in Figure 145 show the percentage of the total energy used in each time period, compared to the percentage of the total time each period contains. For year one, these are very similar, indicating that energy consumption was generally quite regular over the week. In year two however, the proportion of energy used during office hours has reduced, and a greater percentage of energy has been consumed over the weekends. Notable exceptions include external lighting, which is clearly used more often in non-office hours.

Space heating in year one follows a similar pattern (21%, 45%, 34%) to the time percentages. Small power use in year two (which includes the space heating) is vastly different – (circuit one, 9% and circuit two 11%, 52% and 43%, 39% and 46%), indicating that a much greater proportion of energy was used to heat the Visitor Centre during non-core hours than might be expected, even considering potentially cooler external temperatures overnight.

These patterns in energy use can be clearly seen in Figure 146and Figure 147.

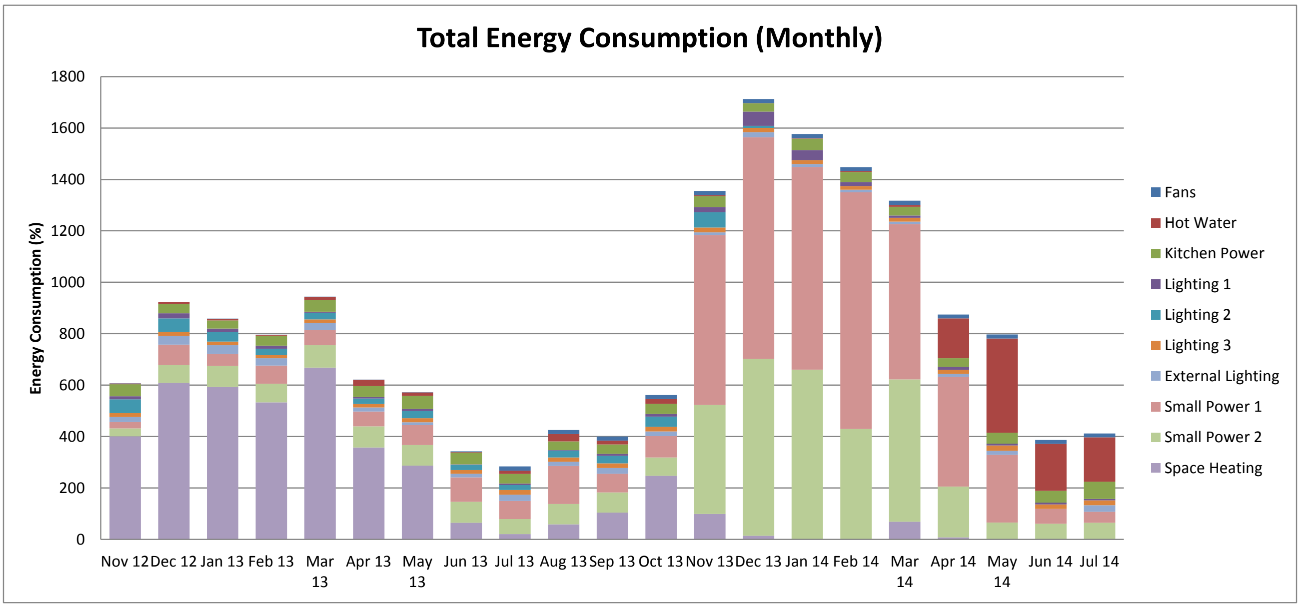


Figure 146: Total Energy Consumption (kWh)

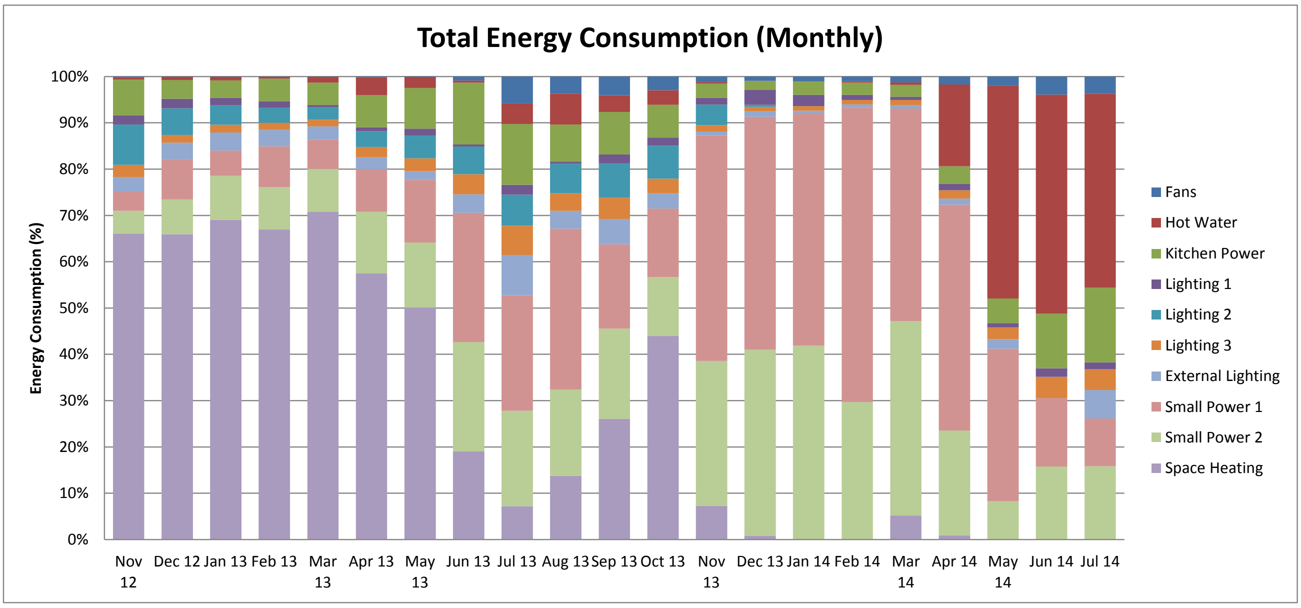


Figure 147: Total Energy Consumption (%)

The graph in Figure 147 clearly shows the change from the use of the ASHP for heating, to the use of electric heaters which are plugged into the small power circuits. Use of the small power 1 circuit increased from an average monthly consumption of 78kWh to an average 710kWh per month and likewise the consumption on the small power 2 circuit increased from 76kWh to 492kWh.

This change in heating provision can also be seen in Figure 148 below. This graph shows the increase in use of the space heating circuit from July/August to September and October, before the electric bar heaters were utilised from November onwards. The heating circuit was switched back on for testing in March, hence the energy used at that point. No heating was used from May 2014 onwards, so the consumption on the small power circuits reverts back to normal small power use.

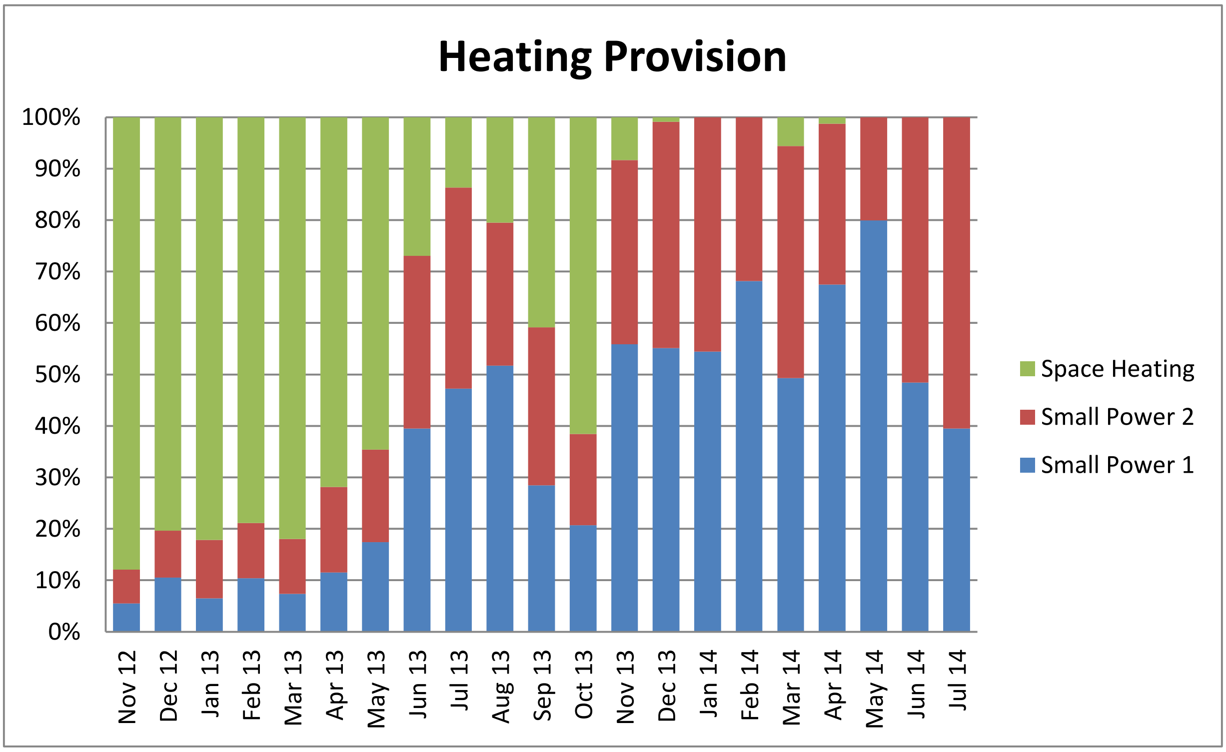


Figure 148: Heating Provision

10.11 Energy Performance Certificate

Included as a separate file.

10.12 'CarbonBuzz Report'

Included as a separate file.