College Lake Wildlife Visitors 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	450114
Project lead and author	Oxford Brookes University for Berks, Bucks and Oxon Wildlife Trust
Report date	2015
InnovateUK Evaluator	Ian Orme (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Visitors centre	Tring	Design and build	2010

Floor area (GIA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
362 m^2	Single	B / N/A	N/A

Purpose of evaluation

The study includes a review of building handover, measurement of building fabric performance, assessment of annual energy use and energy demand profiles, performance of low-carbon technologies, environmental monitoring, occupant satisfaction survey and interviews with occupants and management team, a review of heating, ventilation and lighting systems amd a review of the usability and operation of controls.

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

Estimated electricity use for power, heating and hot water: 93.7 kWh/m^2 per annum (including 8% PV contribution). The energy supplied (and carbon emissions) in the College Lake Visitor Centre is from grid electricity and PV generation. Eenergy usage per square metre and carbon dioxide emissions during the monitoring period were compared with *ECON 19* Good practice, typical benchmark, BRUKL, and CIBSE *TM46* benchmarks. Overall the College Lake Visitor Centre uses grid supplied energy that equates to half of the carbon dioxide emissions of the *TM46* benchmark. However, it is 3% higher than the benchmark specified in BRUKL documents.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	13	100%

Overall comfort was rated positively, with the building scoring better than the benchmark. The 'overall' summer and winter temperatures were perceived to be comfortable. The temperature in summer and the variation of temperature in both summer and winter are no different from the BUS benchmark, however the temperature in winter was considered 'too hot'. Air in summer was felt to be overall 'dry' with the rating below BUS benchmark and scale midpoint. Air in winter was considered 'stuffy and still'. This was thought likely to be due to limited window opening during the heating season.

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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.

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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.

This report describes the findings from the two-year in-use (Phase 2) building performance evaluation (BPE) study of College Lake Visitor Centre building. The study includes:

- Review of building handover
- Measurement of building fabric performance
- Assessment of annual energy use
- Analysis of energy demand profiles
- Performance of low carbon technologies
- Environmental monitoring data (Temperature, Relative Humidity, CO_2 levels)
- Occupant satisfaction survey
- Interviews with occupants and management team
- Review of heating, ventilation and lighting systems
- Review of the usability and operation of controls

The overall aim of the study is to improve and optimise energy performance by reducing the gap between the designed and actual performance, using feedback from assessment of energy consumption, demand profiles, in-use monitoring of the thermal environment and occupant satisfaction. To meet this aim, the key objectives of the study are to:

- Increase understanding of the relationship between intended and actual performance in-use.
- Identify the role of occupants in minimising energy use, from full time staff to visitors.
- Evaluate the performance of the building in terms of overheating in summer and the effect of earth-retaining structure, thermal mass and natural ventilation strategies.

1.1 The building and energy systems

College Lake Wildlife Visitors centre (Figure 1) in Tring, forms the main visitors centre at the College Lake nature reserve, run and managed by the Berks, Bucks and Oxon Wildlife Trust and gives vital teaching and office spaces for the Trust to communicate its message to the public.

Figure 1 Left: North facing view of College Lake Wildlife Visitors Centre. Middle: Internal view of interpretation area with rammed chalk walls. Right: South facing view of the visitors centre.

- The centre consists of a gross internal area of 362m².
- It was handed over to the Berks, Bucks and Oxon Wildlife Trust on 31st March 2010.
- It is formed of two gently curving, extruded elements with a split roof linked with high level clerestory glazing.
- The first curve is a single storey grass roofed, earth retaining structure that gives the building a subterranean feeling at the main entrance and contains all the ancillary type rooms of the building;
- The second curve is the main timber framed double height space that the visitor interpretation space, office and cafe are located in.
- The principle elevations have a North/ South orientation.
- The building was designed to be naturally ventilated with manually operated windows. The high level windows are mechanically operated by a manual switch and precipitation sensor.
- Underfloor heating and hot water is powered by 2 Air Source Heat Pumps (ASHPs) (12 kW×2).
- The main energy source of this building is electricity and 3.43kWhp PV panels are integrated on a separate timber structure.
- Upon completion the building achieved:
  - EPC rating of B
  - BER: 23.3 $kgCO_2/m^2$ .annum
  - TER: 40.7 $kgCO_2/m^2$ .annum
- The air permeability rate is 3.41 $m^3/(h.m^2)$ at 50 Pascal (measured on 13 April 2010).

1.2 Occupant survey

An occupant satisfaction survey was carried out using BUS (Building Users Satisfaction) questionnaires. The questionnaires were distributed to regular users of the building on 18th December 2013 and were collected on the same day. A total of 13 questionnaires were obtained (response rate: 100%). In a typical day College Lake Wildlife Visitors Centre receives between 30 and 120 people, 5-15 of which are regular users. The regular building users are mature professionals from the Wildlife Trust with a particular interest in natural and wildlife reserves. The BUS survey respondents varied in terms of the work that they carry out in College Lake Visitor Centre and can be separated in the following general categories:

- Senior management staff
- Reserves team staff
- Catering staff

- Education staff
- Meet and greet staff
- Admin staff
- Volunteer

It was found that overall comfort was rated positively, with the building scoring significantly better than the benchmark. The 'overall' summer and winter temperatures are perceived to be 'comfortable' and better than the benchmark. The temperature in summer and the variation of temperature in both summer and winter are no different from the BUS benchmark, however the temperature in winter is considered 'too hot'.

Air in summer is felt to be overall 'dry' and the rating is worse than both the BUS benchmark and scale mid-point. Air in winter is considered 'stuffy and still'; the ratings are also worse than both the BUS benchmark and scale mid-point. This is likely to be due to the limited window opening during the heating season. However, the monitoring data suggests that air quality is within acceptable levels, with CO_2 levels exceeding 1400ppm for 8% and 10% of occupied hours in the office and seminar room respectively, when the rooms are occupied by a large number of people.

1.3 Aftercare operation, management and maintenance

The handover documentation was reviewed and interviews with management were carried out in order to identify the arrangements that were made for the seasonal commissioning, aftercare and maintenance of the building. Handover documentation including Health and Safety file and O&M manuals became available to the College Lake project team during handover. However, building users and the Facility Manager have rarely used the handover documentation as it is reported that these are difficult to read, confusing and generally badly organised documents. Handover training was provided, however the information was not passed to the new building manager during the internal handover process due to a delay in the appointment of a new manager. A maintenance contract exists for the ASHP but not for other building operations and systems. In cases of breakdown, manufacturers are contacted directly by the building manager. The response rate was reported to be good. During the BPE study, the Facility manager (FM) and volunteers of the Trust have made considerable efforts to understand the building systems and controls with the assistance from the BPE team resulting in a better standard of operation for the building.

1.4 Energy usage

Analysis of monitoring data on energy use has shown that the building is performing well. The annual CO_2 emissions (October 2013 – September 2014) figure of 38.2 $kgCO_2$ /m^2 /annum is 44% better (lower) than the raw CIBSE TM46 benchmark of 67.8 $kgCO_2/m^2$/annum. The annual fossil fuel equivalent energy consumption in the Centre is 85.8 kWh/m^2/annum and is 65% lower than the raw TM46 benchmark of 242.5 kWh/m^2/annum. The total annual electricity consumption during the monitoring period is 33,934 kWh of which 2,878 kWh (8%) was generated by the PVs and used on-site. The total PV generation from October 2013 to September 2014 is 3,030 kWh. The visitor centre performs 3% worse than the building energy consumption defined in the BRUKL document (including equipment). Space heating and hot water account for 26% of the total electricity use, the café space accounts for 29% of the total and the office spaces use 22% of the total.

1.5 Technical issues

Electricity consumption peaks during winter months, which is expected since the Air Source Heat Pumps (ASHPs) are also at their peak performance. There is a very strong correlation between weekly ASHPs' energy usage and heating degree days indicating that the ASHPs and the building are performing well. The overall coefficient of performance for both heat pump units was calculated at 1.9. It should be noted that the CoP specification of the heat pumps in the as-built BRUKL document is 2.63. This CoP variation contributes to the actual energy use being higher than the design estimate. The overall efficiency of the solar PV system is 14.5% which is slightly lower than the manufacturer specified efficiency of 14.8%. PV generation reaches peak at noon in summer.

1.6 Feedback from building owner on the BPE study

Building management

'This study helped to identify excessive electrical usage for heating domestic hot water. Control settings have since been changed (now permanently on winter setting) to use ASHP more for water heating rather than immersion heater. This will save electricity and money as a result.'

'The study also helped highlight over-heating issue in the weeks following an annual service of the ASHPs. This resulted in a change in setting of the timing of when the ASHPs are on, which should also save electricity.'

Engagement of staff and volunteers

'The study has helped us learn more about how the building actually works. This has contributed towards the development of a user guide which was not available at handover.'

'This study helped staff and volunteers better understand how to manage their own comfort, e.g. by disregarding use of the thermostat controls. The controls work on a very long time lag which resulted in a daily see-saw swing of room temperatures as occupiers tried to set the thermostats to a comfortable level.'

'Occupiers also learnt of the need to open lower level windows in conjunction with the upper window to create effective air flow in the office.'

Wider context

'Handover was incomplete and relied heavily on the expertise of a Trust staff member who left the Trust soon after the building was completed. '

‘By bringing members of the original design team together, the study helped bridge some gaps in understanding which probably would have remained if the study hadn’t taken place. We now have direct links with these contacts which will provide on-going benefit to the Trust.’

‘The study has also helped underpin the Trust’s commitment to sustainable building and maintenance issues.’

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 Location, layout and occupancy schedules

The building is located in Bulbourne, Tring, Hertfordshire, HP23 5QG (Figure 2). It is next to the College Lake natural reserves and is accessible on foot and by car. However, there is only one bus route connecting the Visitor Centre with the surrounding areas. The site has designated walk ways which connect to a wider network of routes. Car parking is adjacent to the Visitor Centre on site. The Visitor Centre is surrounded by green and natural reserves (Figure 2).

Figure 2 Location of the building

The gross external area of the centre is 362 m^2. It is a single storey building that is constructed of a combination of masonry and super insulated timber frame supported on a concrete raft foundation, with green roofs (Figure 3) and rammed chalk internal walls. The timber frame is wrapped in wood fibre insulation to minimise cold bridging. The building consists of an office, a seminar room, foyer and café area (Figure 4 and Figure 5).

Figure 3 External view of College Lake Visitor Centre

Figure 4 Foyer area (left), office (top-right and café area (bottom-right)

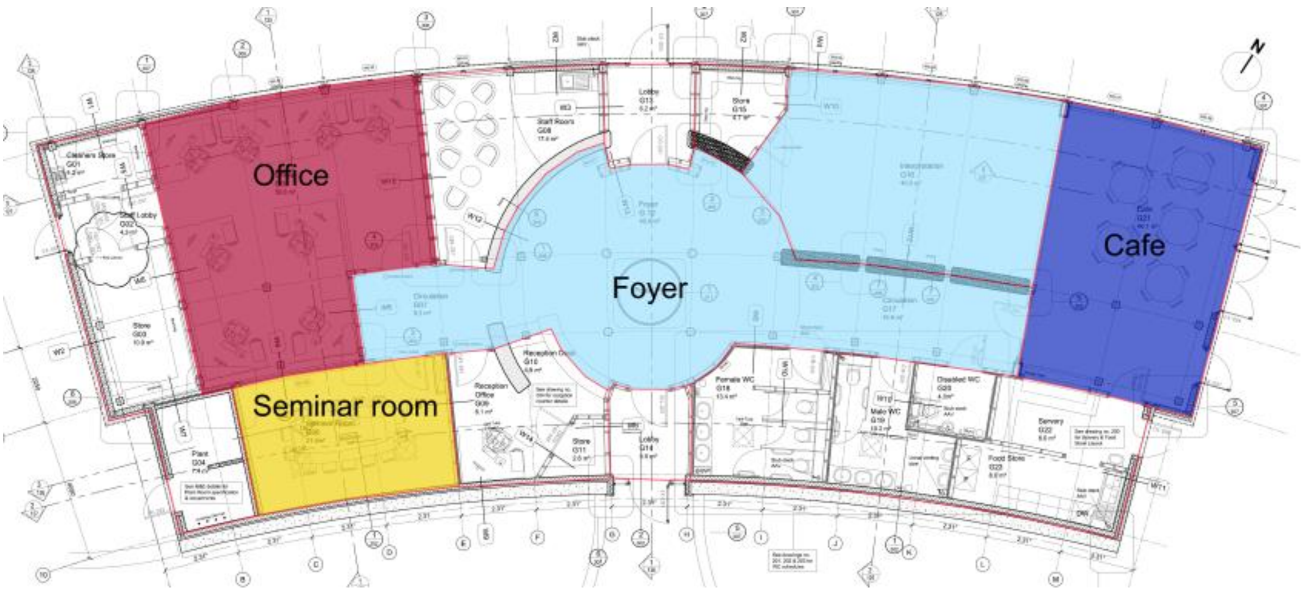


Figure 5 Floor plan

The building is occupied from Monday to Sunday from 8am to 6pm (closed during Christmas). The opening hours for visitors are: 9:30-17:00 (Mar-Oct) and 9:30-16:00 (Nov-Feb). The total number of staff working in the office is 13. Occupancy varies depending on the nature of work. Some staff may work outside the building. The number of visitors varies from 66 per day on weekday to 94 per day at weekend on average. The maximum number of visitors is 817 people per week.

2.2 Design details summary

College Lake Wildlife Visitors centre in Tring gives vital teaching and office spaces for the BBOW Trust to communicate its message to the public. The detailed design information is summarised in Table 1.

Table 1 College Lake Wildlife Visitors Centre general characteristics and mechanical services

Case study design characteristics	
Location	Tring, Hertfordshire
Building type	Office and visitor centre
Floor Area	362 m^2 (GIA)
Main construction elements	*Walls:* Earth retaining concrete frame walls on the south side of the building. The rest of the structure is formed of timber framed walls. *Internal Walls:* Rammed chalk walls on stand up concrete plinth. *Roof:* Grass roof split in two parts that are linked with high level clerestory glazing. *Windows:* Velfac 200 Windows *Doors:* Velfac 500 Door Assembly *Floors:* Fibre reinforced sand cement screed incorporating underfloor heating system.
Ventilation	General Ventilation strategy: Natural Ventilation with manually operated windows. South facing high level windows are operated through switches connected to a natural ventilation control system (Monodraught iNVENT). Toilets: Individual PIR activated low energy extract fans in toilets. Manually control wall extract fan in kitchen.
Space Heating & Hot Water	*Heating Installation* · ASHP (12kW x2 outdoor units) · Underfloor heating with 22 circuits *Hot water* · Hot water storage cylinder integrated into one of the ASHP · Immersion heater connected to Hot water tank
Lighting	*Natural Lighting* · Sun pipes in windowless rooms, i.e. seminar room, toilets *Artificial Internal Lighting* · Fluorescent Luminaires and lamps · Display lighting (LED type luminaires) in reception and retail areas *Controls* · With the exception of the lighting in the Entrance Lobbies and Retail the lighting in all areas is controlled by presence detectors · Daylight sensors in rooms with windows or with sun pipes to dim down the output from artificial lighting when sufficient daylight is available.
Renewables	3.43 kWp PV panels integrated on separate timber structure External Air Source Heat Pump Units (12kW x2)
Air tightness	3.41 $m^3/(h.m^2)$ at 50 Pascal (13.04.2010)

Sustainability rating	EPC rating B BER: 23.3 kg CO_2/m2 .annum
Transportation	Public transport: a bus service every 60-110 minutes links the site to Luton and Aylesbury. For convenience however, most visitors and regular occupants drive to the site. Car park is available on site.

Overall: The overview of the Building User Survey (BUS) responses reveals that users are especially satisfied by the design and appearance of the building and the suitability of facilities in satisfying their needs. The BUS survey results also revealed that the open plan design is likely to cause noise (from visitors and colleagues), thereby reducing the perceived productivity.

2.3 Handover and construction

The design intent of the College Lake building was communicated through official project meetings after practical completion and informal meetings and demonstrations provided by the project contractors and sub-contractors to College Lake team when required.

College Lake Visitor Centre was handed over to the occupants during the practical completion meeting on 31st March 2010. A follow-up meeting was arranged 1 year after practical completion on 15th March 2011 in order to review any outstanding defects. Both meeting notes include a detailed list of snagging items regarding construction and decoration defects; there is no written evidence of:

- Discussion on building M&E services and controls.
- Discussion or demonstration of ASHP systems and controls for users and Facilities Managers in order to ensure energy efficient operation of the building.
- Discussion on the client’s intention for the building to serve as a showcase for the community and as an exemplar low-energy building.
- Demonstration of sustainable features to owner, managers and building users.

During the practical completion meeting, handover documentation was provided to key stakeholders. Table 2 lists the type of documentation available to project team members.

Table 2 Practical completion documentation provided to key stakeholders during handover.

Key Stakeholder	Handover Documentation
Edgar Taylor (contractors)	Checklist of contents of the Health and Safety File Health and Safety File
Client (BBOWT)	Health and Safety File Project / Building fabric certificate O&M manuals for mechanical services

Client (BBOWT) & Project Managers (A+G Architects)	O&M manuals for Electrical services Cleaning and maintenance guide O&M manuals Record Drawings Client Tuition Inspection of the M&E installations at the 12 month Defects Liability Period

A number of challenges and defects have been identified since completion of the project.

- Lighting/Daylighting
  - A number of internal lighting controls had to be adjusted because the “Daylight Linking” would not switch the lights off completely when the available daylight was adequate for normal working.
  - A special device/control is still required to adjust the setting which is still not provided.
- Heating response
  - The building heats up slowly.
  - Although staff have been advised to allow time for the temperatures to adjust and not interfere with thermostats, issues have been identified with individuals changing the thermostat settings to compensate heating.
- Snagging
  - Various snags, i.e. automatic doors, rain chains etc. have been addressed either by contractors who remain the main connection link between College Lake and the sub-contractors or have been adjusted by BBOWT employees and the FM team.
- Thermal bridging
  - Thermal bridging was identified at the junction of lower south facing roof with external wall of plant room on the right (Figure 6). This is a combination of thermal bridging and missing insulation. The small piece of insulation between the top of the wall and the underside of the roof is unlikely to have been installed.

Most of issues were determined through communication with the contractor (Edgar Taylor).

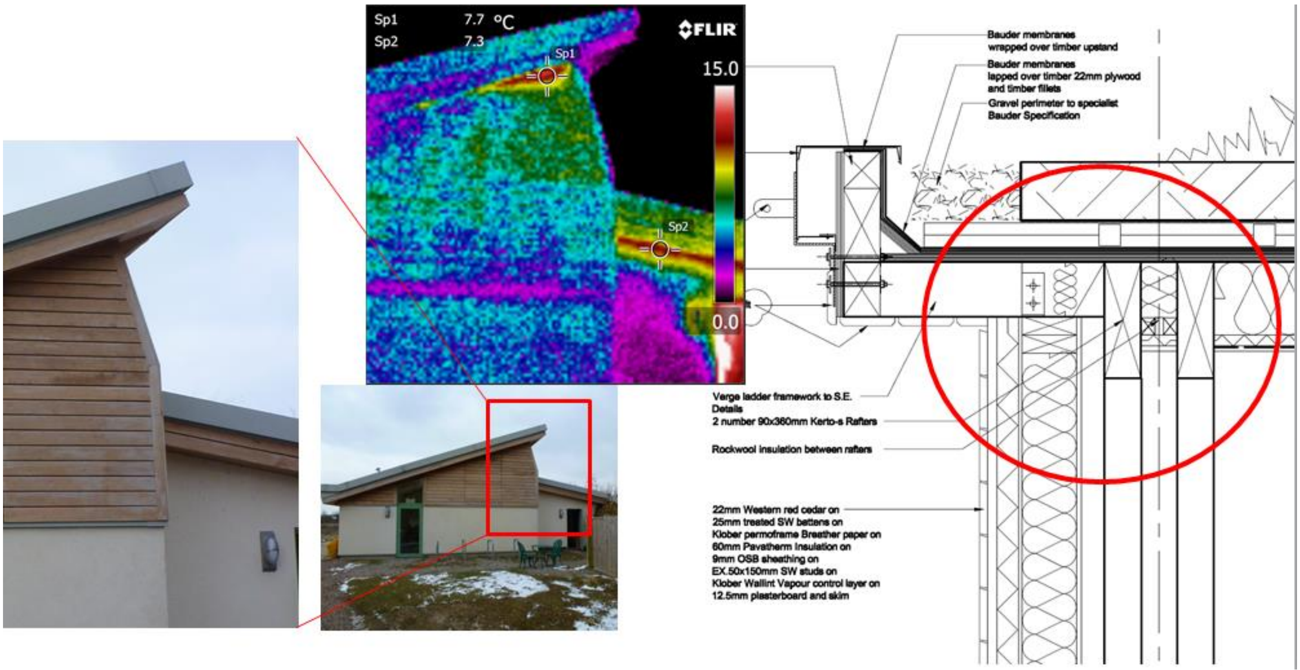


Figure 6 Thermal bridging at the junction of roof with external wall

2.4 Conclusions and key findings

- The building is occupied from Monday to Sunday from 8am to 6pm (closed during Christmas).
- Earth retaining concrete frame walls on the south side of the building. The rest of the structure is formed of timber framed walls.
- Two 12kW ASHPs unit provide heating and hot water for the building.
- 3.43 kWp PV panels integrated on separate timber structure.
- Overall occupants are satisfied with the design of the building and suitability of facilities.
- Although several problems have been identified during building handover, users are generally satisfied with building's performance and available facilities.
- The current FM wasn’t employed when the building was handed over and has since made considerable efforts to understand the building systems and controls with the help of the assistant FM. The first FM, who had received the training, moved on shortly afterwards and the client did not arrange a new handover for the new FM.
- Findings extracted from FMs investigation of building systems and services and after communication with the contractors have started being documented and organised with the handover documentation available on site.
- The FM has established good communication with sub-contractors who are responsible for maintenance of the building.
- Due to lack of handover information and complicated format of existing one, the FM and assistant FM have familiarised themselves with the operation and maintenance requirements of building systems by making their own investigations.

- The BPE study has made considerable impact in fine-tuning the building performance by getting the BMS system re-commissioned, identifying and replacing electricity sub-meters that were not working, and reducing energy wastage from the residual electricity use.

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 Building services and energy related systems summary

Grid electricity and PV are the energy source for College Lake building as the building is not on the gas network. The energy profile is illustrated in Figure 7.

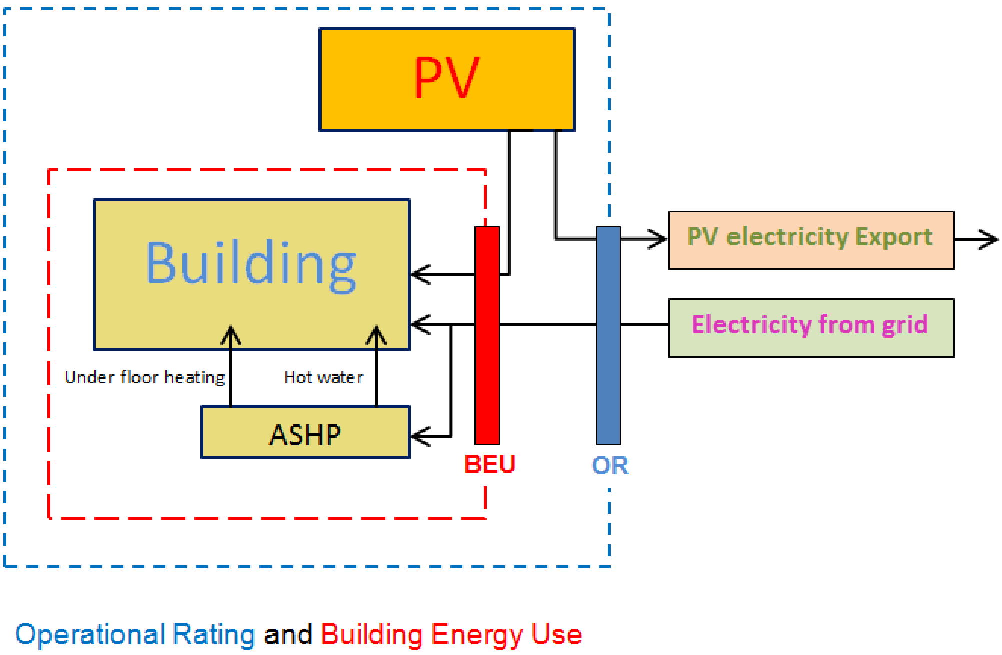


Figure 7 Energy profile of College Lake Visitor Centre (BEU= Building Energy Use, OR= Operational Rating)

The detailed information about building services and energy related system are summarised as below:

Table 3 Building services and energy related systems

Space heating and hot water system	*Heating Installation* · ASHP (12kW x2 outdoor units) · Underfloor heating with 22 circuits *Hot water* · Hot water storage cylinder integrated into one of the ASHP

	· Immersion heater connected to Hot water tank **Heating control problems:** • The building is equipped with Trend IQ3 Web enabled controller and Trend IQView4 display. The FM was not familiar with the building control panel and its functions at the beginning of this project. • At the same time the O&M manuals were found to be too confusing and containing too much information which was not organised in a comprehensive manner.
Ventilation strategy	There is no cooling system in the building. Mechanical ventilation is provided for the seminar room and toilet rooms. Natural ventilation is assisted by high level windows with mechanical opening in the atrium.
Renewables	Solar PV panels (14m x1.5m, 3.43kWp in total) on south east face of roof of separate timber structure building. ASHP (12kW x2 outdoor units)
Water	Local water supply
Lighting	*Natural Lighting* · Sun pipes in windowless rooms, i.e. seminar room, toilets *Artificial Internal Lighting* · Fluorescent Luminaires and lamps · Display lighting (LED type luminaires) in reception and retail areas *Controls* · With the exception of the lighting in the Entrance Lobbies and Retail space the lighting in all areas is controlled by presence detectors · Daylight sensors in rooms with windows or with sun pipes to dim down the output from artificial lighting when sufficient daylight is available.

3.2 Review of installed meters and sub-metering arrangements

Monitoring equipment was installed in March 2013 to collect data on energy usage and environmental conditions occurring in College Lake Wildlife Visitors Centre. The detailed information of monitoring equipment was reported in Quarter 3 (450114 Q3 Evidence 1 Analysis of weekly energy, energy demand profiles and monitoring.pdf). In brief, the equipment is monitoring the following items regarding energy:

Main electricity

- Electricity import from the grid (kWh)

Sub-metering (via BMS)

- Distribution board 2, 3, 4 and 5 (kWh)
- ASHP outdoor units (kWh)

Renewables: PV

- PV total generation (kWh)
- PV export (kWh)

Low carbon system: Air Source Heat pump

- Heat generated by ASHP 1 (heat, kWh)
- Heat generated by ASHP 2 (heat, kWh)
- Space heating (heat, kWh)
- ASHP outdoor units (electricity, kWh)
- Water pumps (electricity, kWh)

The electricity supply system was designed based on room spatial distribution. Five switchboards are responsible for four zones of the building (one is main switchboard). Therefore it is impossible to monitor the electricity usage by usage type (e.g. lighting and small power). Each distribution board is responsible for delivery of electricity to nearby area, as illustrated in Figure 8. For example, DB2 is responsible for electricity supply for lighting and office equipment in the seminar room and reception area; DB3 is responsible for electricity supply in the office, staff kitchen and storage room; DB4 is responsible for electricity supply in the café; DB5 is responsible for electricity supply in the kitchen and toilet. A detailed electricity end use and distribution chart is shown in Figure 9.

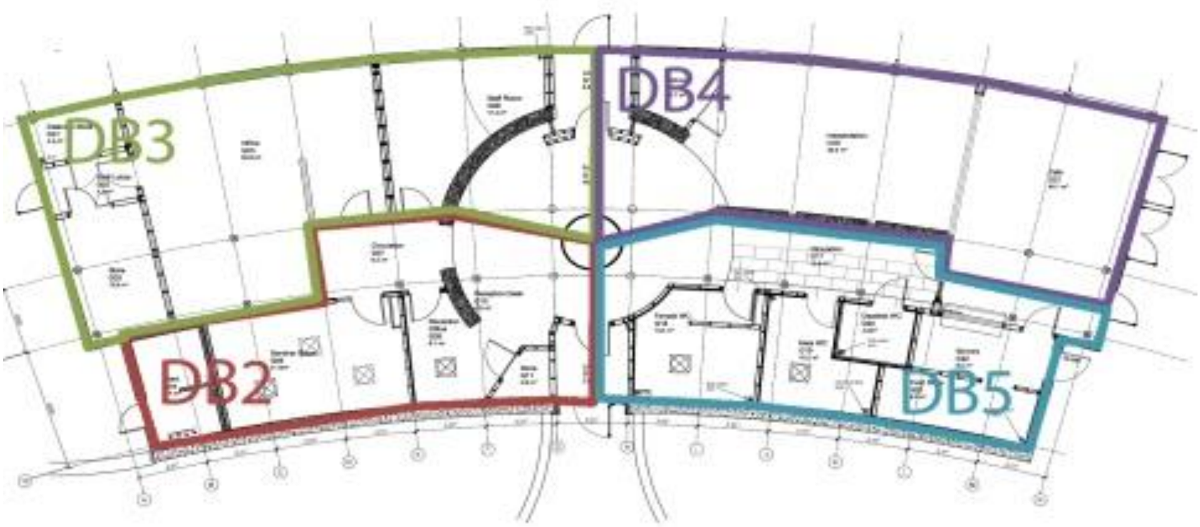


Figure 8 Location of distribution broad

In terms of existing meters, there is a main electricity meter, PV generation meter and a number of sub-meters; however the sub-meters are not connected to BMS in the plant room. The problem of sub-metering was identified by this BPE study and was fixed on 29th October 2013. A diagram of the electricity sub-metering is shown in Figure 9.

The energy monitoring equipment and the first date of its data collection are listed in Table 4. In additional to the variables collected since March 2013, more variables (highlighted in red in Table 4) have been monitored since August and October 2013. They are retrieved from the reconfigured BMS.

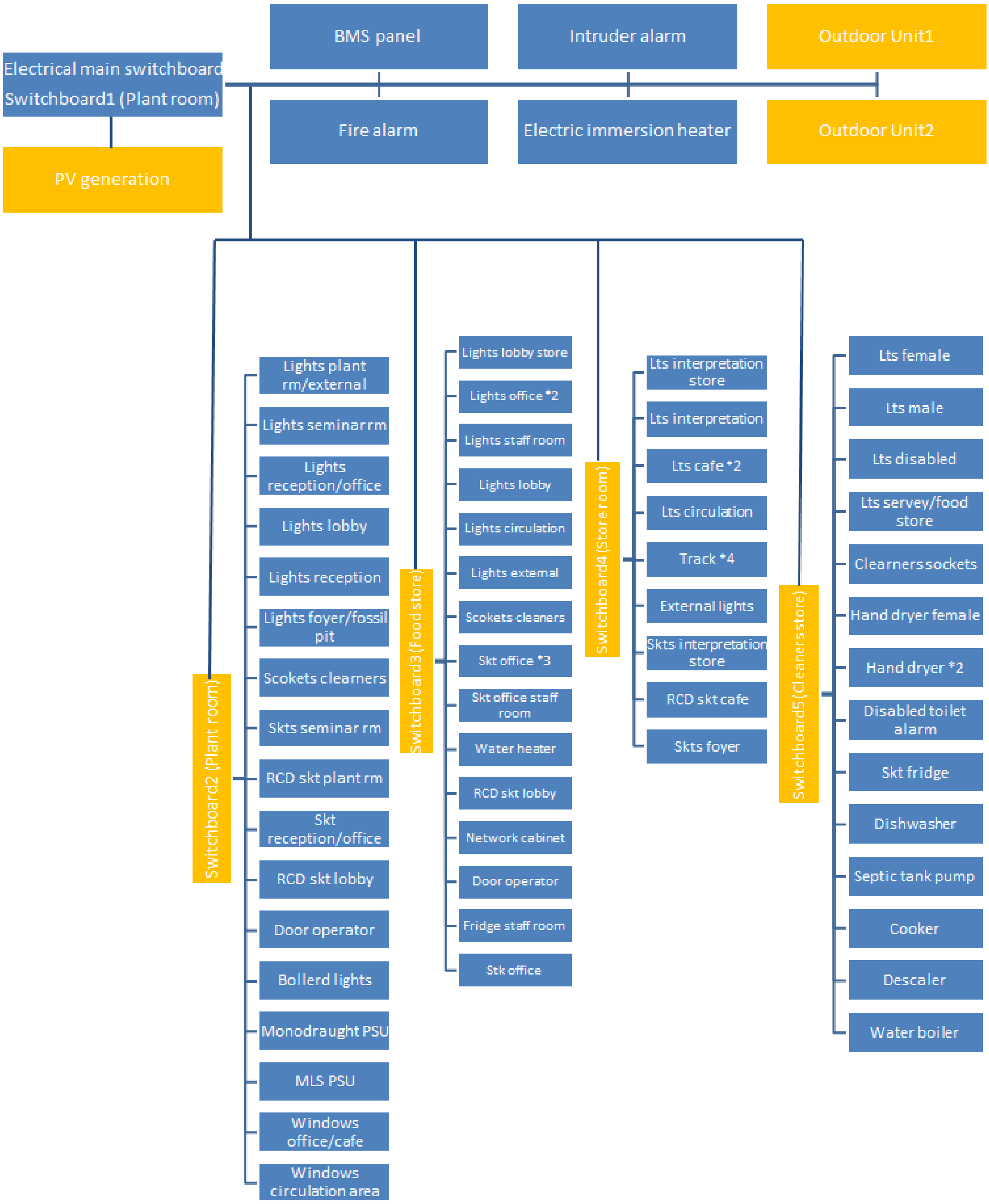


Figure 9 Electricity sub-metering diagram

Table 4 Energy monitoring equipment list

Meter name	Monitoring	Data since	via
BLD import	Electricity, imported from grid	25/03/2013	OBU*
HTG Pump 1	Electricity, used by water pump 1 for heating	31/10/2013	OBU
HTG Pump 2	Electricity, used by water pump 2 for heating	31/10/2013	OBU
HW Pump	Electricity, used by water pump for domestic hot water	25/03/2013	OBU
Heating 1 H Flux 76	Heat, generated by ASHP 1	08/04/2013	OBU
Heating 2 H Flux 59	Heat, generated by ASHP 2	08/04/2013	OBU
HW H Flux	Heat, used for domestic hot water	08/04/2013	OBU
Dis Board 2	Electricity, used in plant room, reception and seminar room	29/10/2013	BMS*
Dis Board 3	Electricity, used in kitchen and cafe	26/08/2013	BMS
Dis Board 4	Electricity, used in café	26/08/2013	BMS
Dis Board 5	Electricity, used in office, staff room	26/08/2013	BMS
Outdoor Unit 1	Electricity, used by ASHP outdoor unit 1	29/10/2013	BMS
Outdoor Unit 2	Electricity, used by ASHP outdoor unit 1	26/08/2013	BMS
PV export	Electricity, PV export to grid	25/03/2013	OBU
PV total	Electricity, total PV generation	25/03/2013	OBU

*OBU: 5-min data were transmitted to the Oxford Brookes University web-portal http://obu.global-net.eu via a wireless data hub and mobile phone network.

*BMS: 5-min data were saved on a dedicated computer by Building Management System (BMS) and automatically shared to BPE team via Dropbox.

All monitoring activities are on-going until February 2015, and the data collected via OBU and BMS do not have significant interruption.

During the monitoring period, the following problems have been noticed and fixed:

- The meter measuring electricity import from the gird was not configured properly. The CT ratio was incorrect and it has been reset to the correct value on 8th November 2013. Previous recorded data has been converted to the correct value.
- Two existing sub-meters did not give correct readings for the electricity consumption through Distribution Board 2 and Outdoor Unit 1. They have been replaced and connected to BMS on 29th October 2013.
- Existing BMS did not have the ability to store monitoring data. The system has been reconfigured to export sub-metered data to a dedicated computer.
- OBU web portal shows the PV generation value twice of the real value. This has been considered in the data analysis in this report.

4 Key findings from occupant survey and environmental analysis

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.

The occupant satisfaction survey was carried out in College Lake Nature Reserve Visitor Centre in Tring, using BUS (Building Users Satisfaction) questionnaires. The questionnaires were distributed to regular users of the building on 18th December 2013 and were collected on the same day. A total of 13 questionnaires were obtained (response rate: 100%).

In a typical day College Lake Wildlife Visitors Centre receives between 30 and 120 people, 5-15 of which are regular users. The regular building users are mature professionals from the Wildlife Trust with a particular interest in natural and wildlife reserves. According to the demographic data, the majority of people who responded to the questionnaires are above thirty years old; most of respondents are females. 66% of them have been working in this building for more than one year.

The BUS survey respondents varied in terms of the work that they carry out in College Lake Visitor Centre and can be separated in the following general categories:

- Senior management staff
- Reserves team staff
- Catering staff
- Education staff
- Meet and greet staff
- Admin staff
- Volunteer

The temperature, RH, CO_2 and windows/door opening have been monitored from 26th March 2013 for the areas illustrated in Figure 10 (foyer, café, office and seminar room).

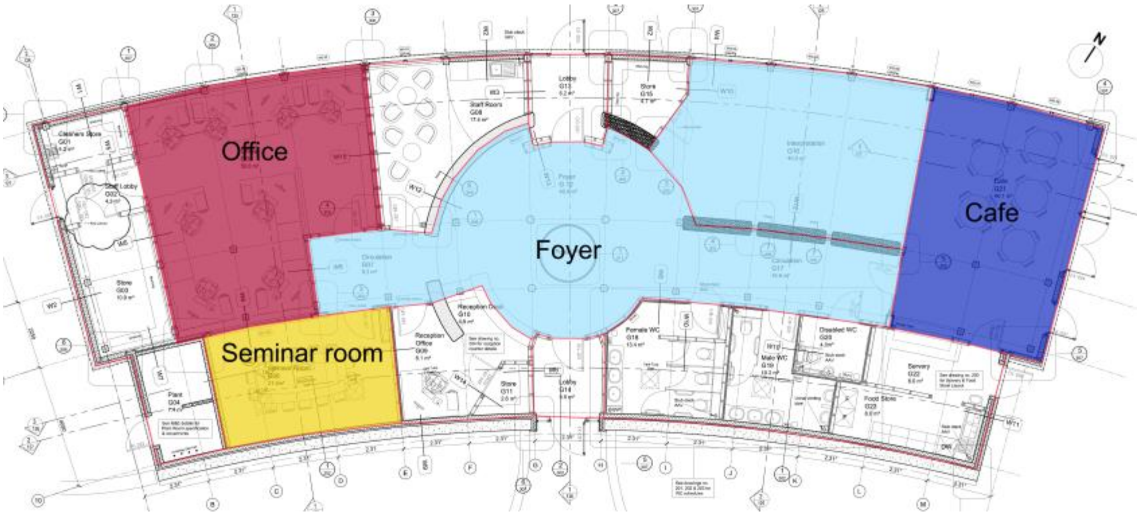


Figure 10 Environmental monitoring areas

The following sub-sections triangulate the findings from the questionnaires, interviews and environmental analysis to determine the root causes for specific findings and where, if possible, energy usage is impacted and what could be done to improve energy usage.

4.1 Overall comfort

Among the 13 respondents to the BUS, it was found that overall comfort was rated positively, with the building scoring significantly better than the benchmark (Figure 11). Only one respondent had negative responses and all others rated the building above neutral.

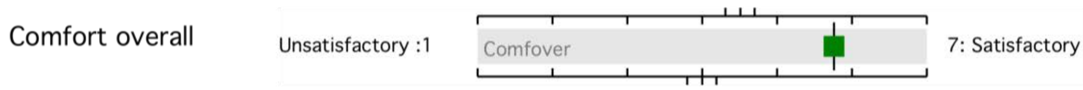


Figure 11 Overall comfort rating

The following table lists the temperature and air quality conditions in the building during the survey (11am-3pm 18th December 2013). It is expected that the environmental conditions present during the survey would impact the response. The relatively high CO_2 level during this time period is likely to be due to the large number of occupants present in the building for the Christmas gathering.

Table 5 Temperature and air quality measurements during survey (11am-3pm 18 Dec 2013)

	External		Cafe		Foyer			Office			Seminar		
	RH (%)	Temp (°C)	RH (%)	Temp (°C)	CO_2 (ppm)	RH (%)	Temp (°C)	CO_2 (ppm)	RH (%)	Temp (°C)	CO_2 (ppm)	RH (%)	Temp (°C)
Max	91	9.5	59	21.4	1348	56	21.2	1753	53	23.3	1270	49	22.1
Mean	90	9.2	55	20.9	1206	54	21.0	1526	52	22.8	867	47	21.5
Min	89	8.7	54	19.7	922	52	20.3	1277	51	21.8	533	45	20.4

4.2 Seasonal thermal comfort

The 'overall' summer and winter temperatures are perceived to be 'comfortable' and better than the benchmark. However when investigated deeper with directed questions toward too hot, too cold, etc., the responses are less desirable (section 4.2.1).

The temperature in summer and the variation of temperature in both summer and winter are no different from BUS benchmark, however the temperature in winter is felt to be 'hot' (worse than both the BUS benchmark and scale mid-point). Figure 12 illustrates the findings from the BUS questionnaire regarding seasonal temperature.

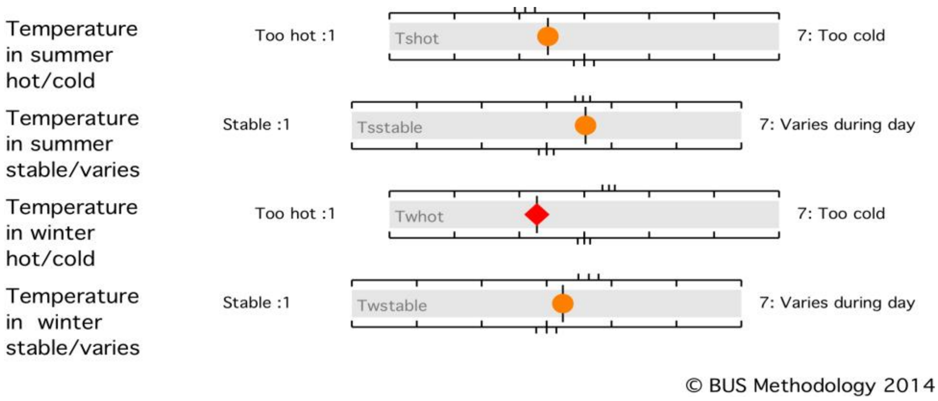


Figure 12 BUS responses: temperature in winter and summer

4.2.1 Temperature stability

According to the BUS, temperatures in summer and winter are perceived to slightly vary (no significant difference from the benchmark). To investigate temperature stability, Figure 13 illustrates the maximum, minimum and average temperatures during occupied hours (8am-6pm) for each day and Figure 14 illustrates the degrees of variation from the minimum temperature. The temperature is calculated from recorded 5-minute data for a period of 1 year from 29th Sept 2013. Notably between the two graphs, summer temperatures are less stable than winter temperatures, which is in agreement with BUS results. The maximum temperature variation during working hours is 5 ^{o}C in July. The temperature data are from the office room where most of occupants are based.

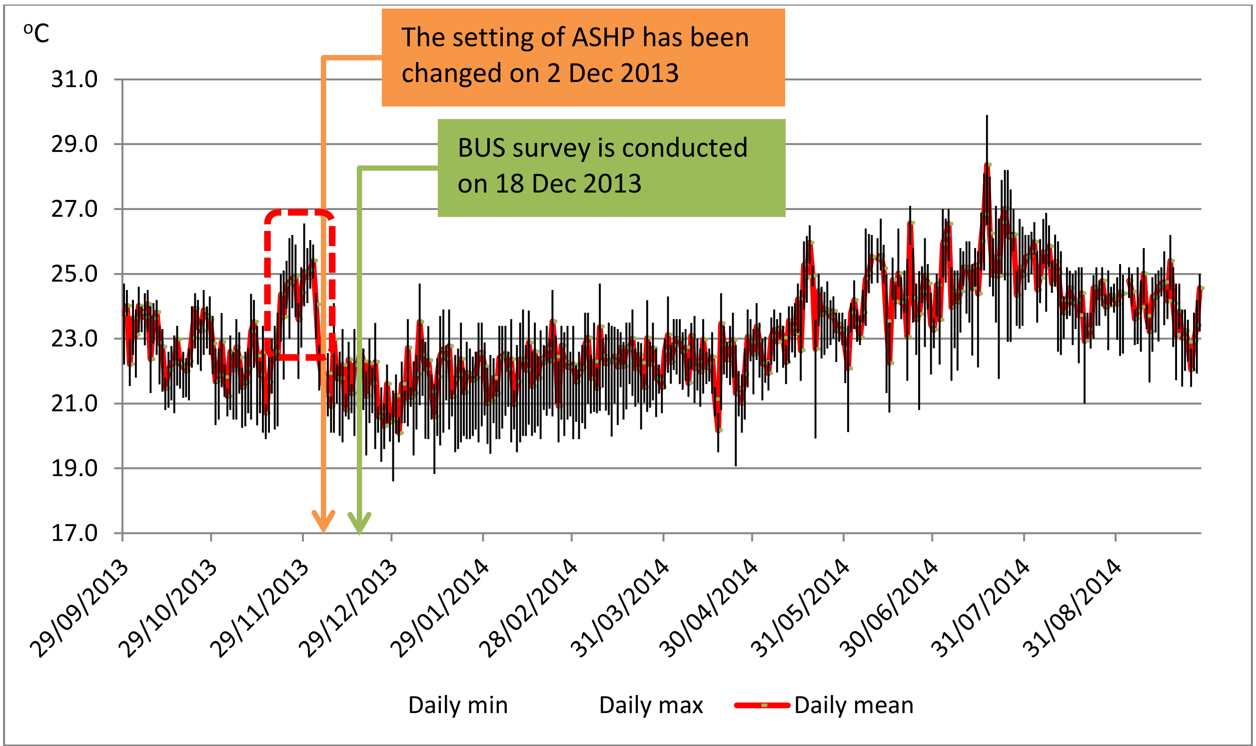


Figure 13 Maximum, minimum and average temperature of occupied hours (8am-6pm) for a period of 1 year from 29th Sept 2013 (office space)

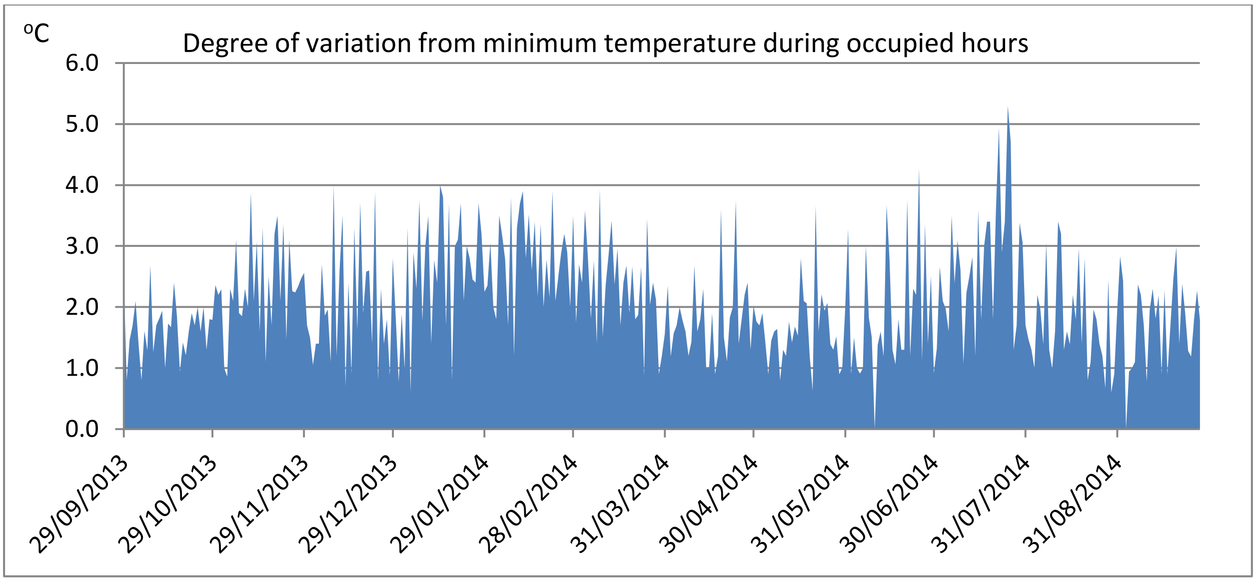


Figure 14 Degree of variation from minimum temperature during occupied hours (8am-6pm) for a period of 1 year from 1st April 2013 (office space)

4.2.2 Seasonal thermal comfort

The BUS questionnaire results (Figure 12) also shows that the occupants feel hot in winter which is significantly worse than the BUS benchmark and scale mid-point. Further investigation shows that 45% (5 out

11) respondents (Figure 15) feel warm or hot in winter. This may be due to the temporary settings of the heating system in the maintenance period (20th November – 2nd December 2013, the red box in Figure 13). The record shows that the heat exchangers and pumps were serviced by an engineer on 20th November 2013 and heating was turned on 24/7 during this period. On the other hand the building is highly insulated; therefore it is likely to overheat in winter due to internal heat gain, such as office equipment and people. The BUS survey was conducted on 18th December 2013 which is half a month after the hot period; and the occupants are very likely to fill the questionnaire based on their recent experiences.

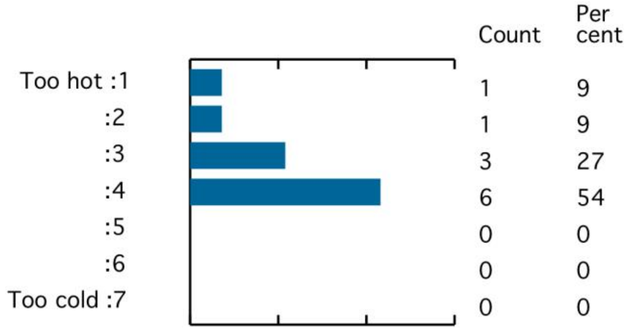


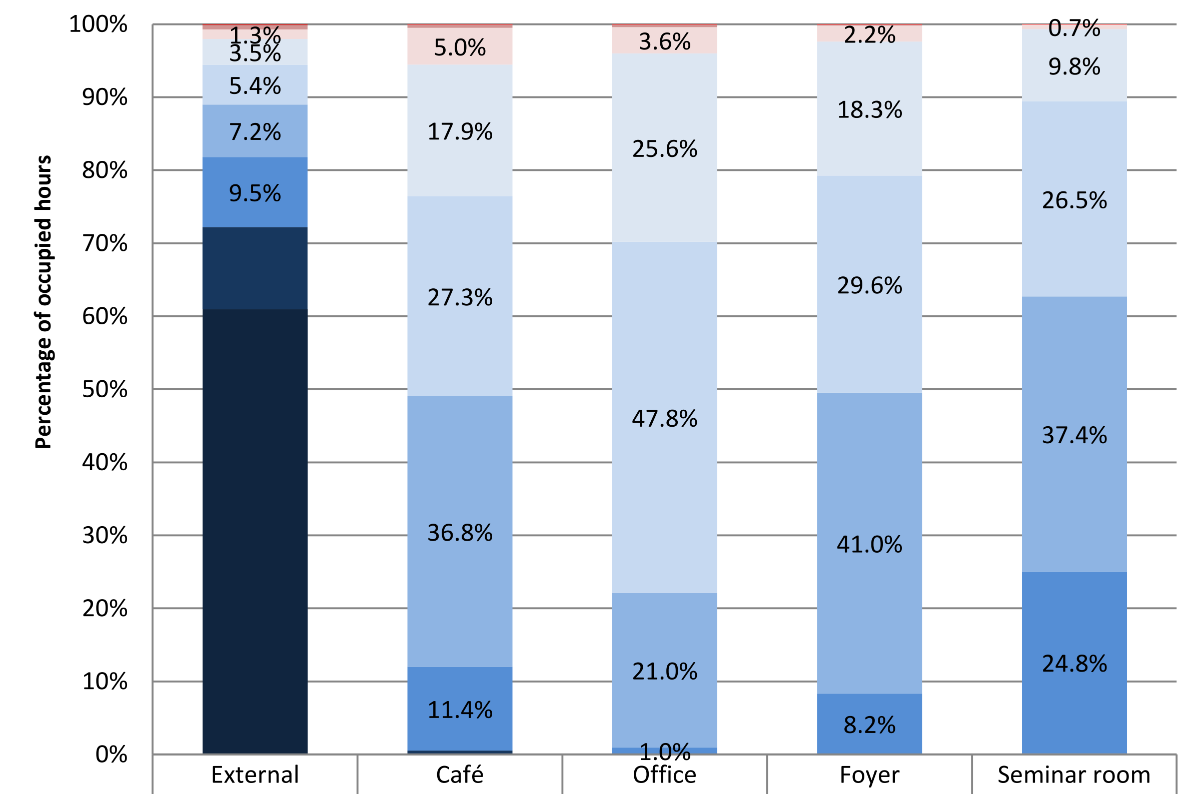
Figure 15 Temperature in winter

According to the monitored data, the temperature in office space reached 30.4°C in July and August 2013. This is in line with comments from occupants. Further investigation shows that for 1.5% of the occupied hours (during April 2013 – March 2014), temperatures were above 28 °C in office which exceeds the CIBSE Guide A overheating criteria (1%). The café has a higher overheating risk (1.9%) compared to all the other spaces.

- *'If too hot, stuffy I have to go outside or open windows'*
- *'Prefer to be outside and the air quality is often stuffy in the building'*
- *'Can be too hot or too cold!!'*
- *'Have had issues with heating - too hot/ too cold'*

---Comments from occupants

The overheating percentage in office drops to 0.4% during October 2013 and September 2014(Figure 16). It does not exceed CIBSE overheating criteria (1%) and BS EN 15251 adaptive thermal comfort criteria (Figure 17). Note that the limit of adaptive thermal comfort band stays constant in winter and the limit in summer changes according to external temperature.



	External	Café	Office	Foyer	Seminar room
>32	0.0%	0.0%	0.0%	0.0%	0.0%
30-32	0.1%	0.0%	0.0%	0.0%	0.0%
28-30	0.6%	0.5%	0.4%	0.2%	0.0%
26-28	1.3%	5.0%	3.6%	2.2%	0.7%
24-26	3.5%	17.9%	25.6%	18.3%	9.8%
22-24	5.4%	27.3%	47.8%	29.6%	26.5%
20-22	7.2%	36.8%	21.0%	41.0%	37.4%
18-20	9.5%	11.4%	1.0%	8.2%	24.8%
16-18	11.2%	0.5%	0.0%	0.1%	0.1%
<16	60.6%	0.0%	0.0%	0.0%	0.0%

Figure 16 Percent of occupied hours at a given temperature for a period of a year from 29th Sept 2013

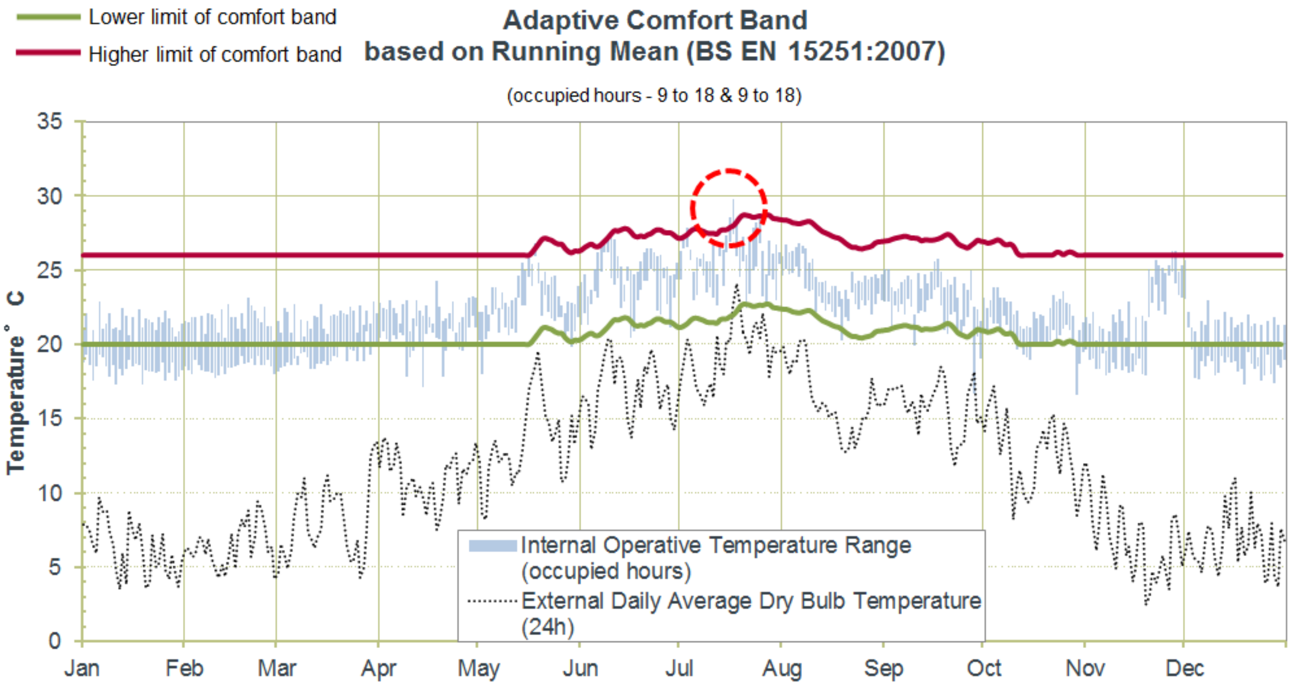


Figure 17 Adaptive comfort band and indoor temperature in office for a period of a year from 29th Sept 2013 (0.4% of occupied hours exceeded adaptive comfort upper limit)

The thermal comfort survey conducted in July 2014 shows that the comfort votes (Figure 18) correspond to indoor temperature. The higher the office temperature is; the higher the vote (towards warm) is. Note that due to time limit of comfort survey, the data is only available for 5 working days.

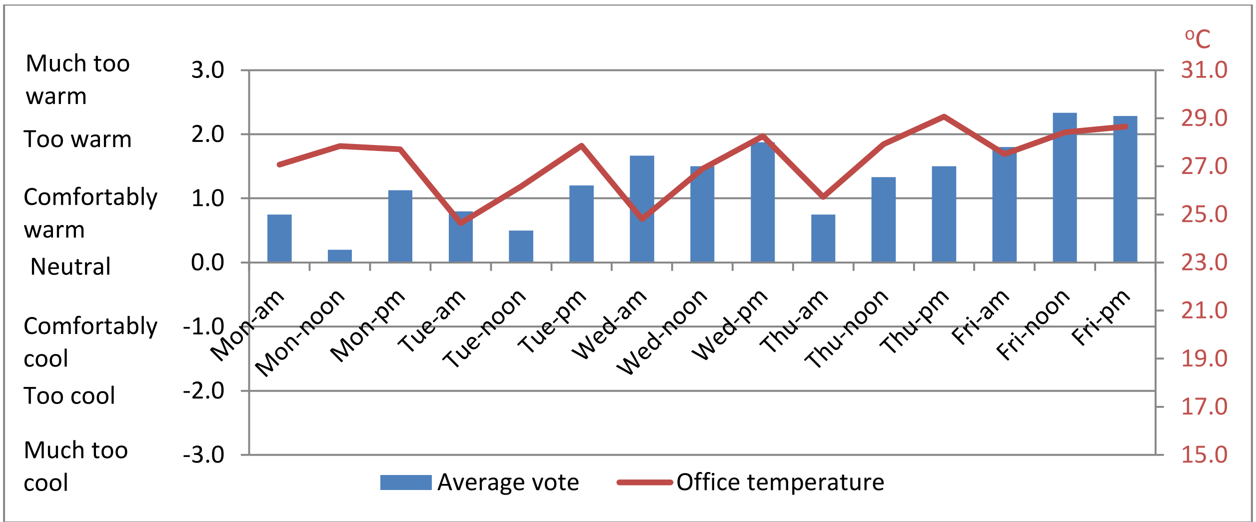


Figure 18 Thermal comfort survey

Figure 19 shows the temperature distribution during occupied hours in summer (June, July and August 2013), Figure 20 shows the temperature distribution during occupied hours in winter (November, December 2013 and January 2014). Note: 'occupied hours' are 8am – 6pm everyday (including weekends due to the building's opening). It shows that office is the hottest office tends to have higher temperature than other spaces. Seminar room is the coldest space in the building comparing with other three spaces, because it has no external windows and is partly submerged. Due to opening of doors, the temperature in cafe and foyer are far more impacted by the 'comings and goings' of the visitors to the Centre.

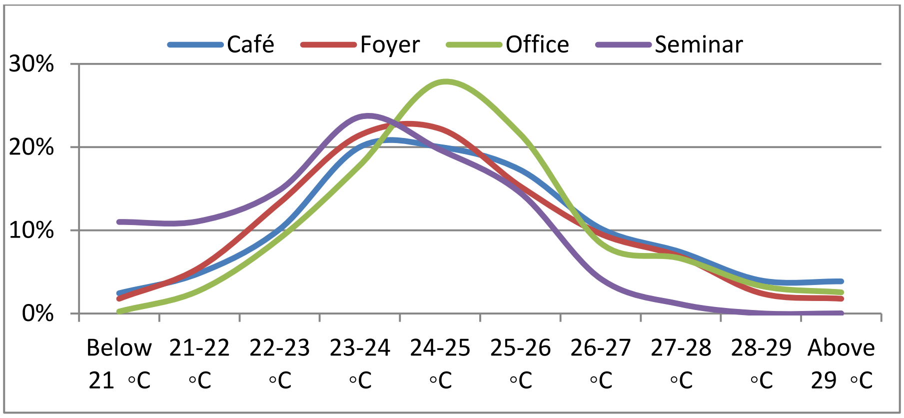


Figure 19 Temperature distribution in summer (June, July and August 2013)

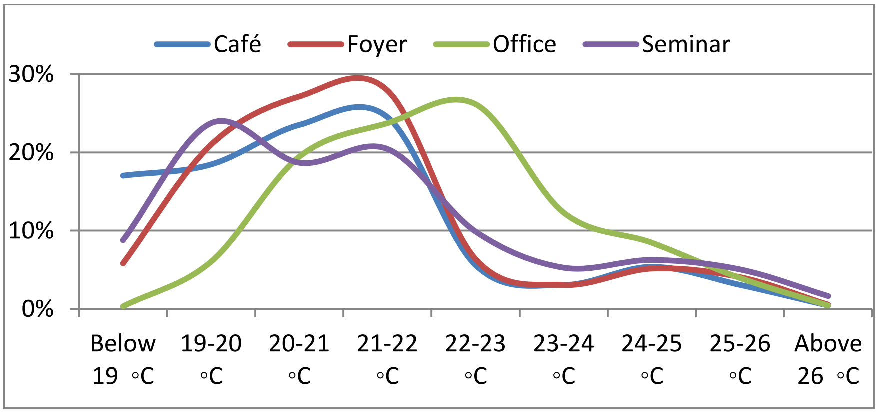


Figure 20 Temperature distribution in winter (November, December 2013 and January 2014)

Table 6 summarises the percentage of occupied hours for which specific spaces are within or outside of CIBSE operative temperature ranges. It shows that:

- More than half of occupied hours in café, foyer and seminar room are within CIBSE Guide A recommendations.
- About 20% of occupied hours in café, foyer and office are above CIBSE Guide A recommendation.
- The café, foyer and office haven't exceeded the overheating CIBSE criteria (1%) and adaptive thermal comfort criteria (BS EN 15251)

Table 6 Occupied hours at the recommended dry bulb temperatures for the café, foyer, office, and seminar room

	External	Café	Office	Foyer	Seminar room
Overheating (1% annual occ. hrs. over operative temp. of 28°C)	**0.7%**	**0.5%**	**0.4%**	**0.2%**	**0.0%**
Percentage of hours **above** CIBSE Guide A recommendation	4.8%	22.9%	29.2%	20.4%	10.5%
Percentage of hours **within** CIBSE Guide A recommendation	8.7%	49.6%	63.8%	53.8%	47.3%
Percentage of hours **below** CIBSE Guide A recommendation	85.2%	27.0%	7.1%	25.8%	42.2%

The monthly minimum, maximum and average temperature for difference spaces, typical winter week and typical summer week, winter day average temperature and summer day average temperature were plotted in Appendix. Same set of figures for relative humidity was also shown Appendix.

4.3 Air quality

As shown in Figure 21 below, air in summer is felt to be 'dry' and the rating is worse than both the BUS benchmark and scale mid-point.

Air in winter is felt to be 'stuffy and still'; the ratings are also worse than both the BUS benchmark and scale mid-point. This is likely to be due to the lack of ventilation and windows opening in heating season. This was investigated further by analysing indoor (monitored) CO_2 levels in different areas of the building.

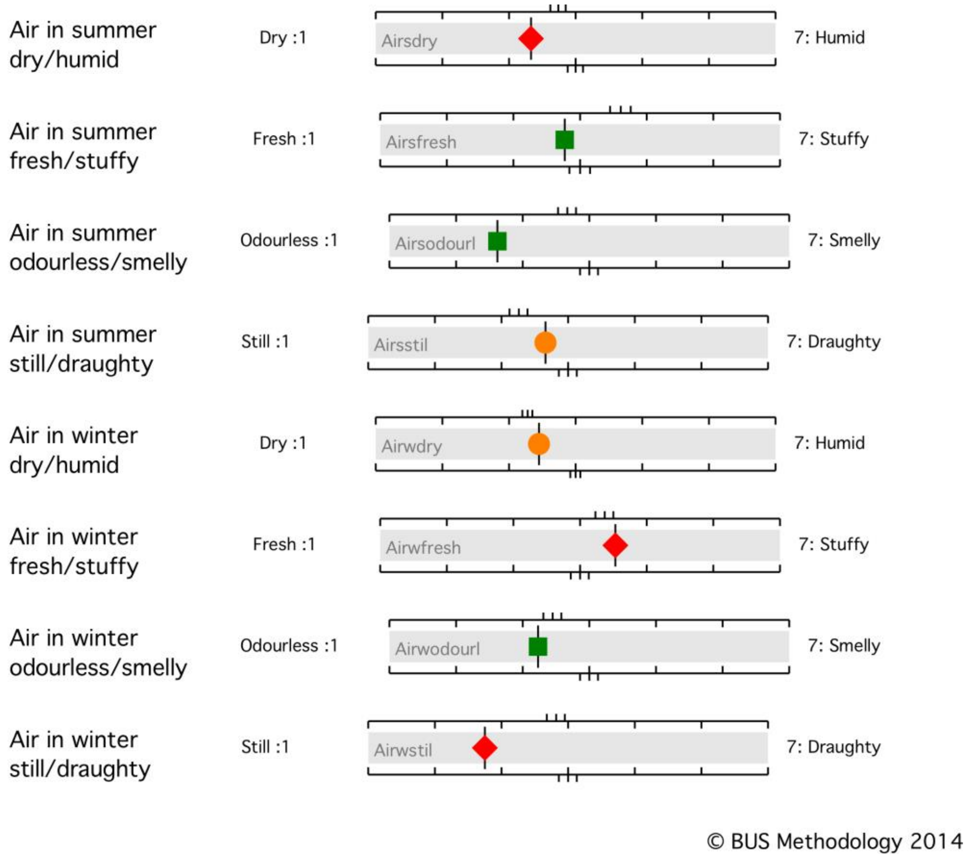


Figure 21 Air quality detail variables in winter/summer

4.3.1 CO_2 concentration

According to the BUS (Figure 21), air in winter is stuffy and still (scoring significantly worse than the BUS benchmark). Figure 22 illustrates the CO_2 concentration for occupied hours in the foyer, office and seminar room over the winter and summer months. The graphs indicate that CO_2 levels are kept reasonably low in summer corresponding with the ‘fresh’ and ‘odourless’ air votes in the BUS, demonstrating that the natural ventilation strategy is effective at providing fresh air in summer. However, for 8% of occupied hours in office and 10% of occupied hours in seminar room, the CO_2 levels exceeded 1400 ppm in winter. This also corresponds with the user perception of air being ‘stuffy’ and ‘still’, implying that natural ventilation strategy on its own is not effective in providing fresh air in winter.

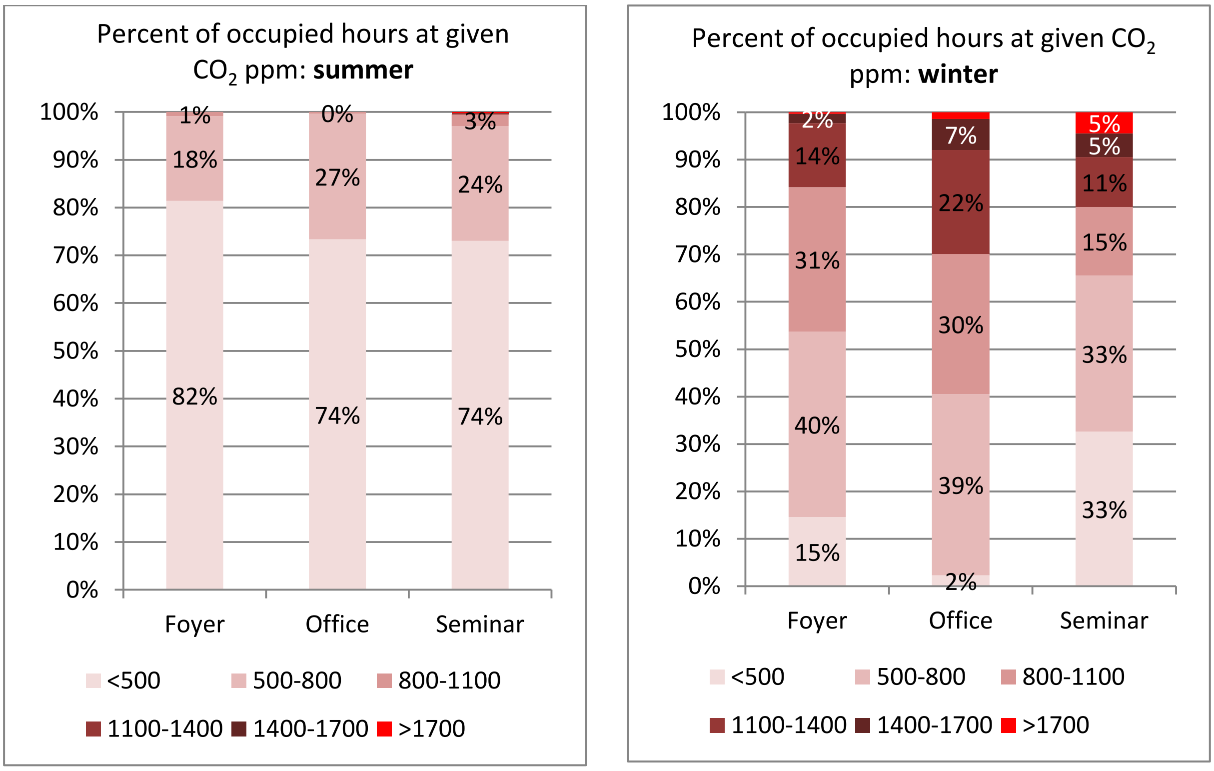


Figure 22 percent of occupied hours at a given CO_2 concentration range in summer (left) and winter (right)

As both BUS survey and monitoring statistic data show that there are very high levels of CO_2 in winter, the average hourly CO_2 concentration is calculated to investigate when and where the high CO_2 level occur. Figure 23 shows that CO_2 levels in all spaces increase in the early morning when staff and visitors arrive the building and they reach peak levels in the late afternoon when people leave the building. The CO_2 levels during weekdays are higher than the CO_2 levels at weekends. The weekday/weekend difference is small for the foyer because it is occupied by more transient visitors. The weekday/weekend differences are significant for the office and seminar room because less staff work at weekends. In general, the office has the highest CO_2 level and it often exceeds the highest acceptable limit of CO_2 (1000ppm) from noon to 7pm.

Air quality can be improved by opening windows. However, windows cannot be fully opened (for security purposes) and they will be closed automatically if it is raining outside, which is likely to be the reason why CO_2 levels are high in winter. Another reason could be that a greater number of people in the office during the winter because they spend less time outside in the winter months.

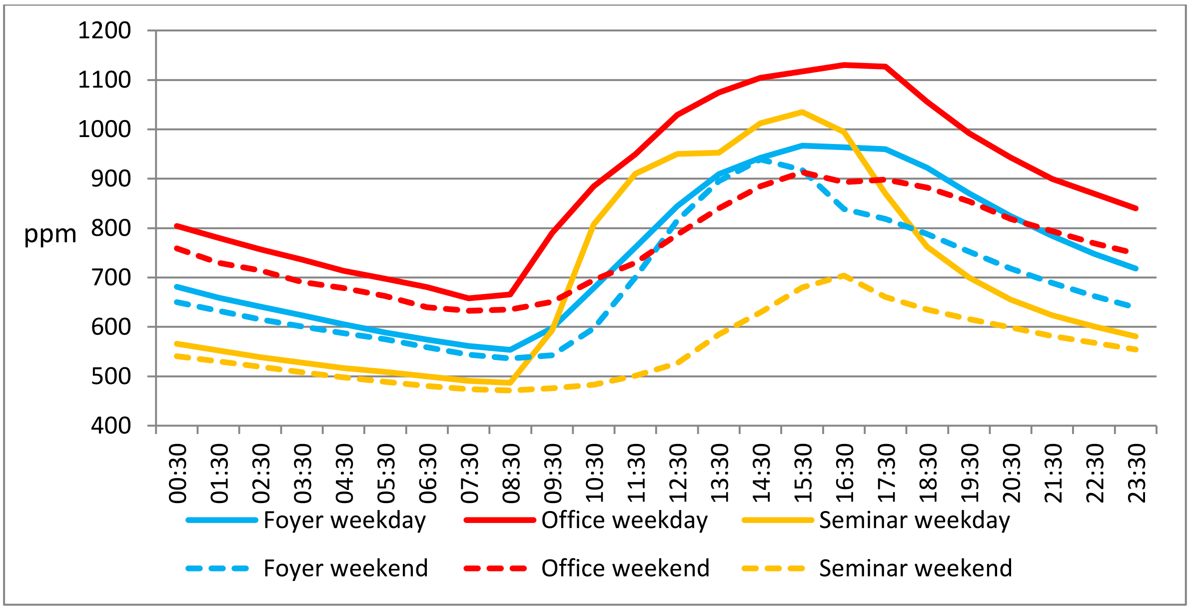


Figure 23 Average CO2 concentration (ppm) during weekdays and weekends in winter

4.3.2 Relative humidity in summer

According to the BUS (Figure 21), air in summer is dry (scoring significantly worse than the BUS benchmark). Figure 24 illustrates the relative humidity for occupied hours in the café, office foyer and seminar room over the winter and summer. The graphs indicate:

- The BUS respondents said the building was dry in summer. The monitoring data also shows that the summer RH is slightly lower (drier) than winter. For 12%-19% of occupied hours in summer the % RH is lower (drier) then the recommended range 40-70%, whereas for 1%-9% of occupied hours in winter it is lower (drier) then the recommended range.
- The summer RH, for the majority of occupied hours (over 80%), is within the recommended range 40-70%. In winter, over 90% of occupied hours are within the recommended range.

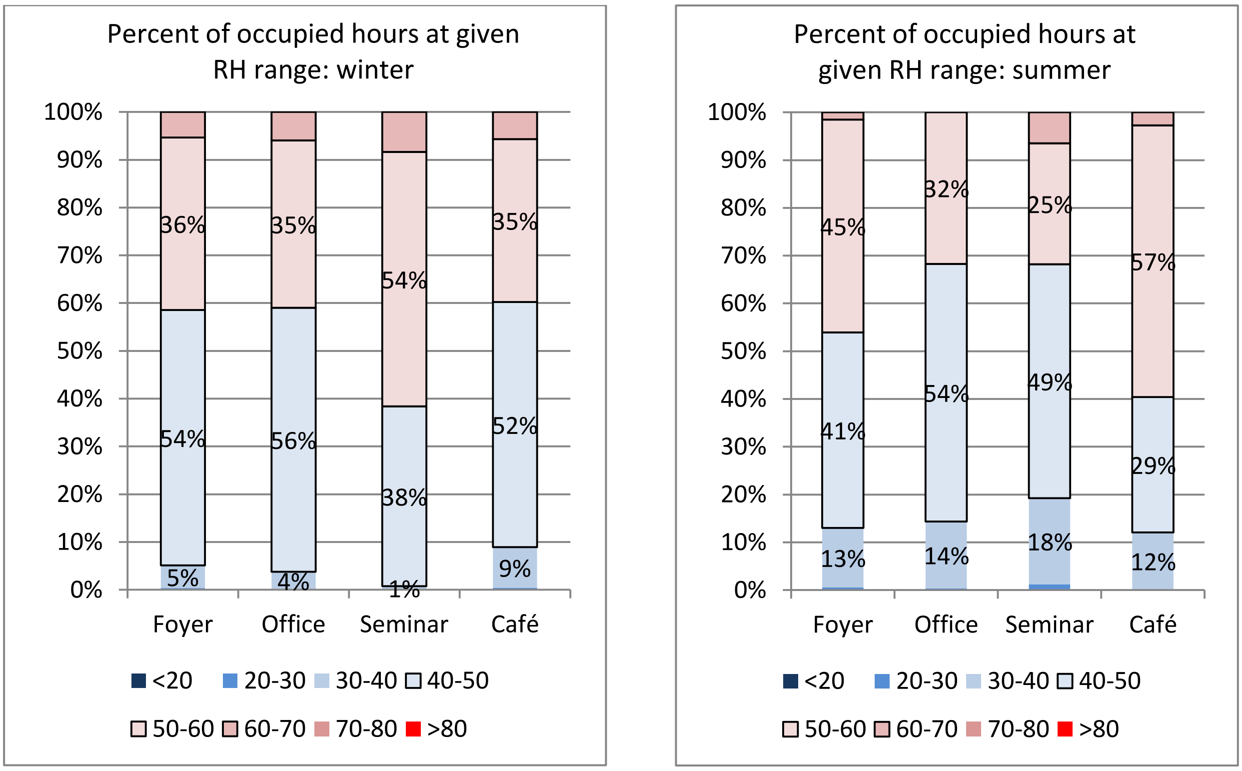


Figure 24 Percent of occupied hours at a given relative humidity range in winter (left) and summer (right). Note: black borders indicate recommended operative RH percentages.

4.3.3 Relative humidity and the number of visitors

The relative humidity during the week of 26th Aug – 1st Sept 2013 was plotted in Figure 25. The week was chosen due to its highest number of visitors during the whole monitoring period. The number of visitors is shown in red numbers. The measured RH patterns appear more influenced by external conditions than internal moisture generation rates (from visitors).

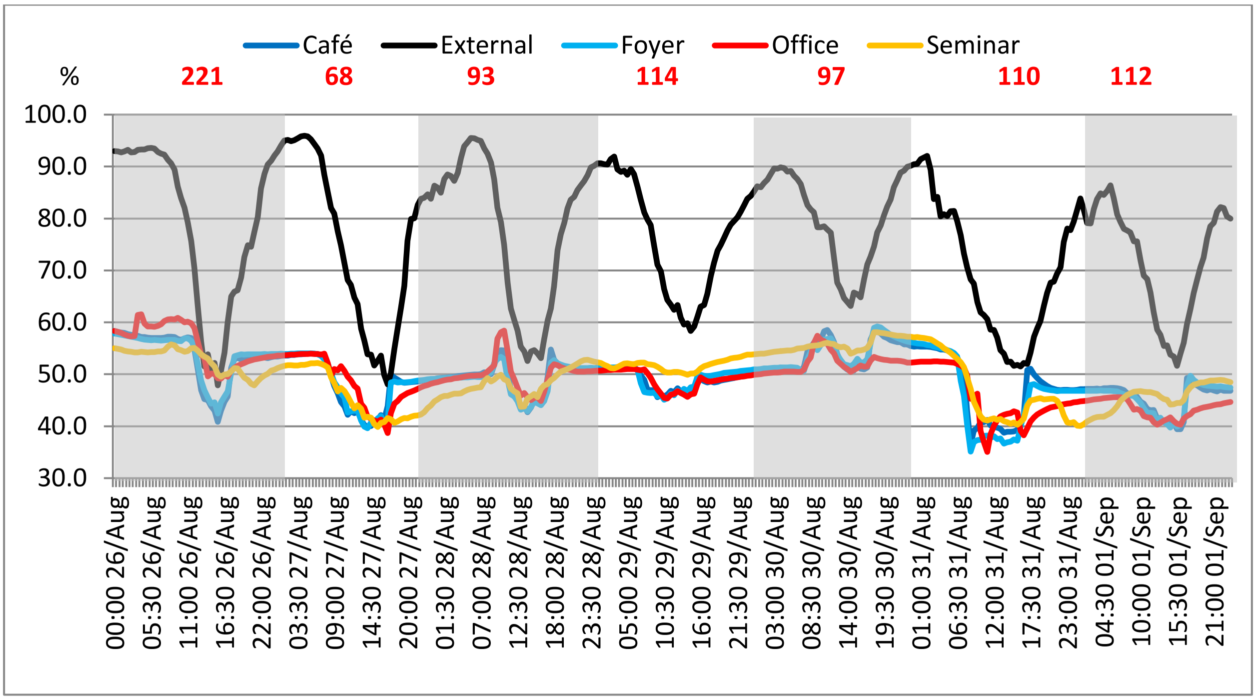


Figure 25 Relative Humidity during 26th Aug – 1st Sept 2013

4.4 Lighting

Overall lighting is perceived to be satisfactory and better than the BUS benchmark (Figure 26). Although occupants don't perceive glare from sun and sky, natural light levels are considered to be more than required and worse than the BUS benchmark (Figure 27). This is similar to the finding from the spot-checks of daylight factor (Figure 28). It shows that the measurements taken in the cafe and interpretation area indicate quite high illuminance levels (1440lux and 1516 lux respectively). This may be associated with the 'white' finish to the chalk walls.

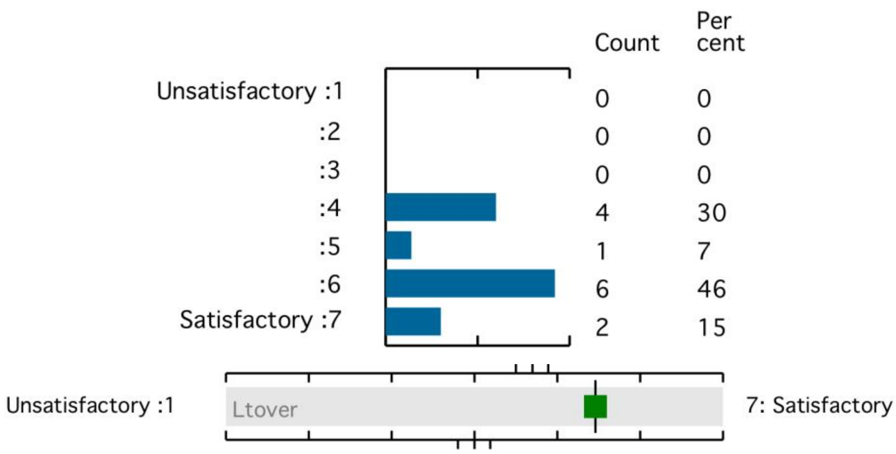


Figure 26 Lighting overall

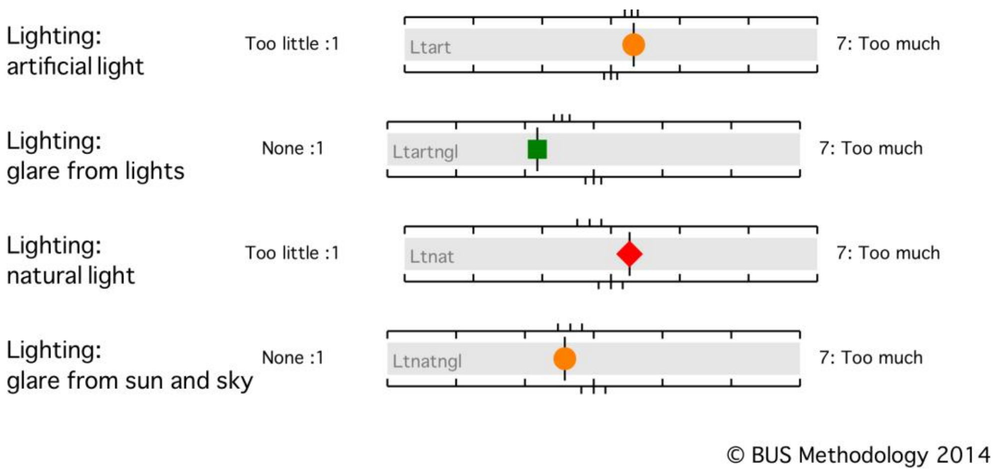


Figure 27 Lighting detail

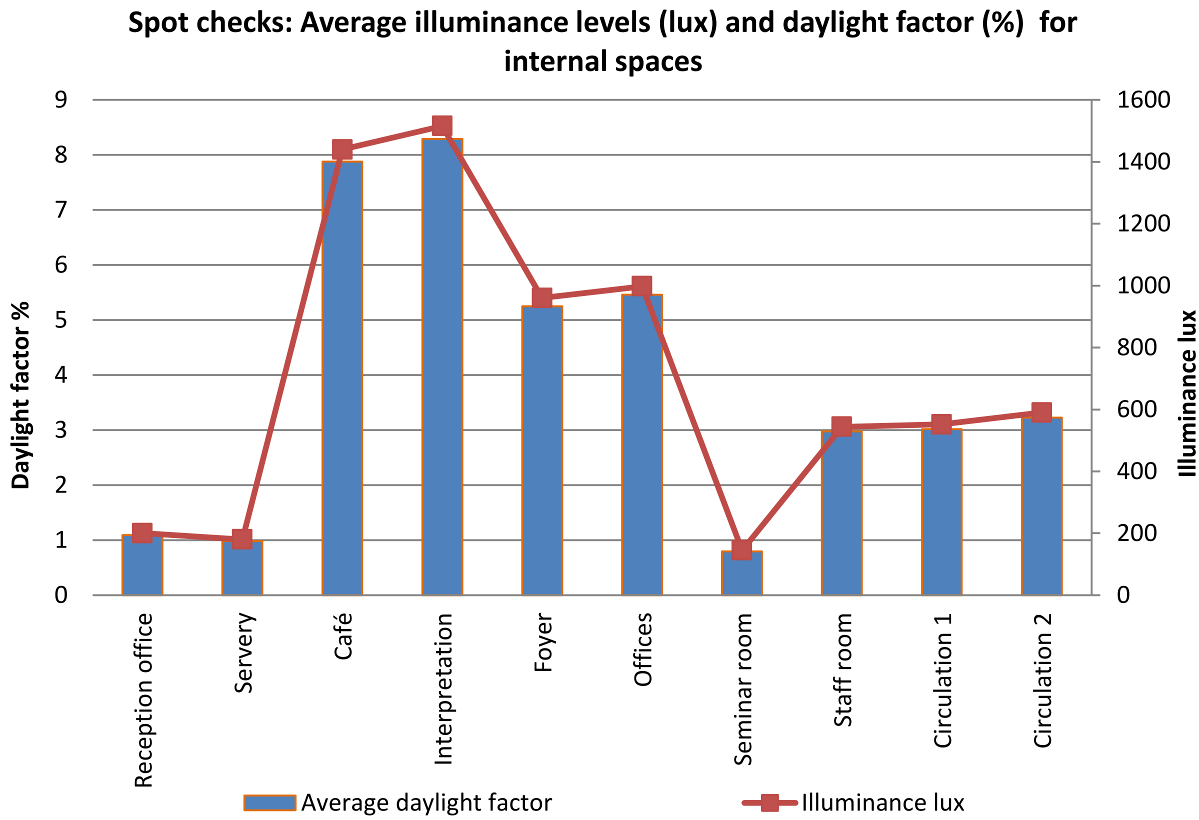


Figure 28 Average daylight factors at College Lake Visitor Centre

4.5 Perception of control

4.5.1 Control over ventilation and heating

Because heating was turned on 24/7 during 20th November – 2nd December 2013, the room temperatures are constantly high at night (red line in Figure 29). Occupants open windows (green bar in Figure 29) to reduce the indoor temperature during working hours when outdoor temperature is in the range of 0-10 °C.

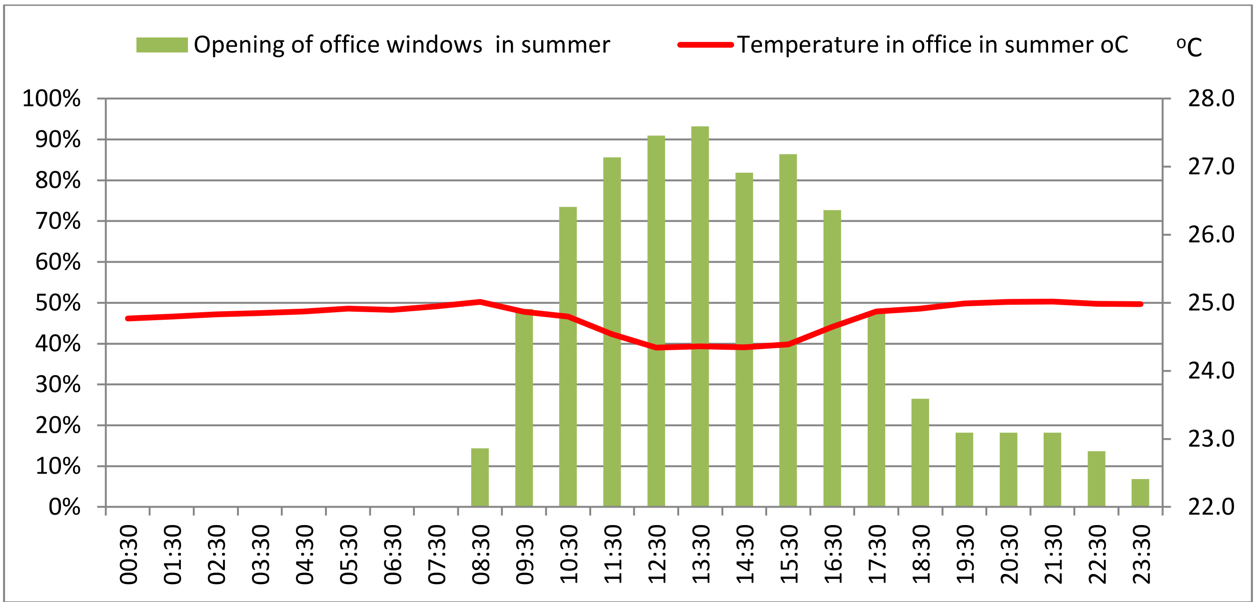


Figure 29 Percentage of time office window opened during the period of 21st Nov – 1st Dec 2013

The BUS survey also indicates that air is stuffy and still in winter (Figure 21); fresh and odourless in summer; this is likely due to the lack of ventilation and window opening in the heating season. The relationships between CO_2 level and the percentage of the time windows opened in summer and winter are plotted in Figure 30. The window opening during working hours in summer ensure that the indoor CO_2 levels stay constantly at a low level. The less often opening of windows in winter results in high CO_2 level in winter. To add to this, Figure 31 and Figure 32 give the details of the natural ventilation override. As the review of natural ventilation control suggests the degree of fine control is poor for providing natural ventilation.

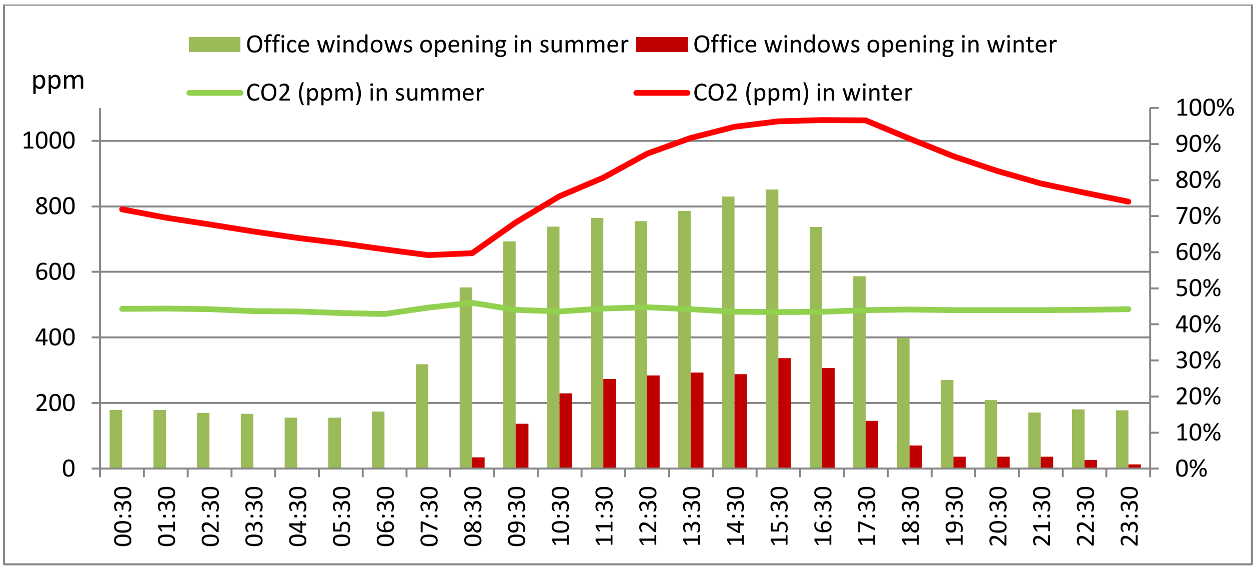


Figure 30 Office windows opening and CO_2 level in both summer (JJA) and winter (NDJ)

Criteria	Poor	Excellent
Clarity of purpose		
Intuitive switching		
Usefulness of labelling & annotation		
Ease of use		
Indication of system response		
Degree of fine control		
Accessibility		

Comments

Intuitive to open by pressing the button. Immediate response of windows opening can be observed from where the control located. Not fully openable. Good for security purposes. Windows will be closed automatically if raining outside.

Figure 31 Control review for natural ventilation override

Figure 32 Control of windows

4.6 Relationship between temperature, humidity and CO_2 level

As illustrated in Figure 33, RH and temperature in winter are in range of 20-24°C and 40%-55%; RH and temperature in summer are in the range of 22-30°C and 30%-70% as expected for a naturally-ventilated building. Most of points are distributed within CIBSE comfort criteria (the dot line).

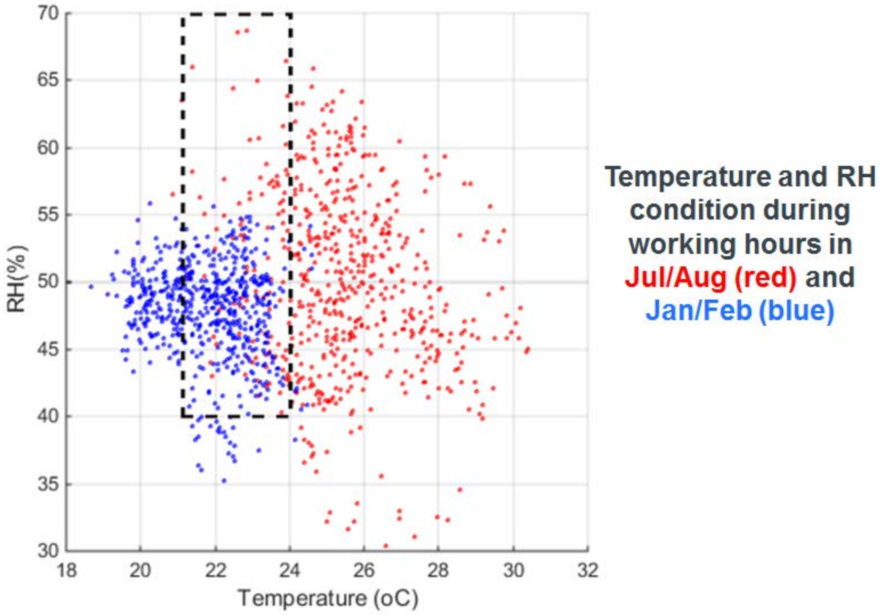


Figure 33 Relative humidity and temperature in office

The distributions of temperature and CO_2 plots have distinct pattern (Figure 34) in summer and winter. Higher CO_2 levels and lower temperatures occur in winter indicate poor levels of natural ventilation. Higher temperature and lower CO_2 level occur in summer as windows are opened in summer enabling fresh air and heat to flow into the building.

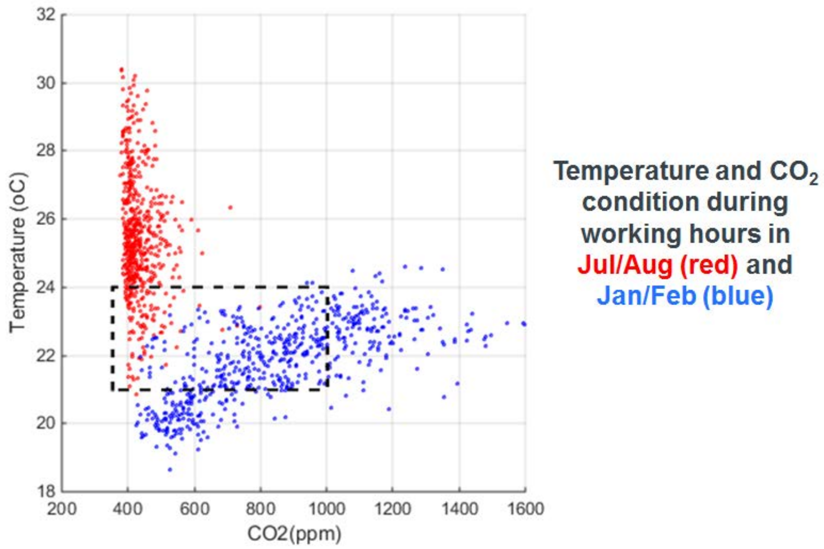


Figure 34 CO_2 level and temperature in office

Winter RH level is in range of 40%-55%, and it varies from 30% - 65% in summer. The CO_2 levels in winter are significantly higher than the levels in summer due to poor levels of ventilation, as shown in Figure 35.

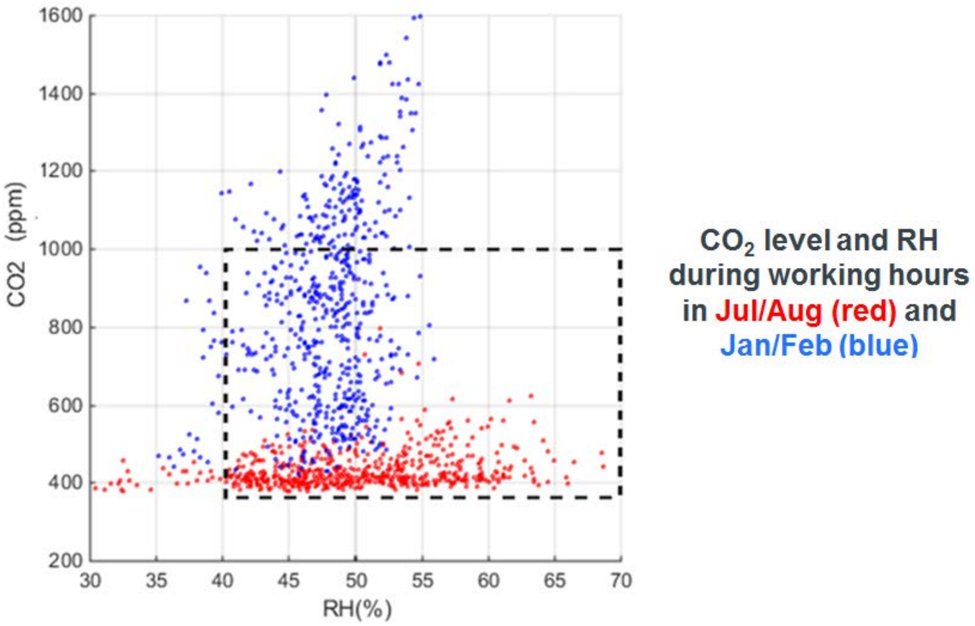


Figure 35 CO_2 levels and RH in the office space

In winter, there is a positive correlation (blue line in Figure 36) between the CO_2 variation and absolute humidity variation. This indicates that both CO_2 and absolute humidity are affected by people (typically generating 40–60 grams per hour per person absolute humidity, based on CIBSE Guide A) and they are contained within the building. In summer, no positive correlation exists, because more fresh air is introduced by opening of windows.

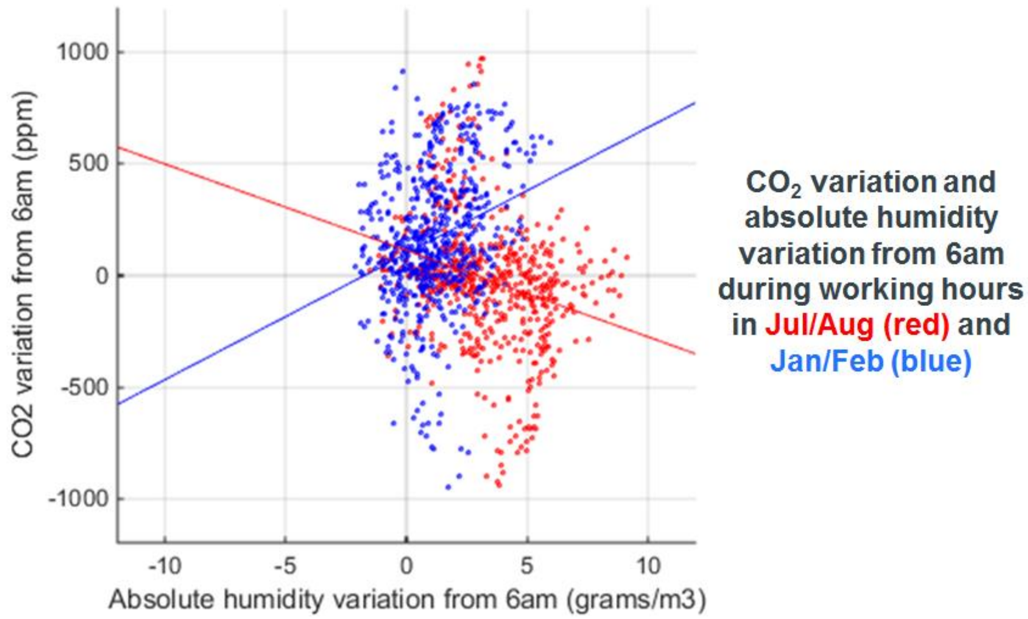


Figure 36 CO_2 variation and absolute humidity variation from 6am in office

4.7 Other areas of concern

4.7.1 Noise level and productivity

'In open plan setting quite likely to get distracted / involved in others conversation and with visitor enquiries'

---Comments from occupants

Although the overall noise levels are perceived to be no different from BUS benchmark, more detailed questions on sources of noise indicate some concerns (Figure 37). Noise from the inside of the building is perceived to be problematic and is rated as 'too much' which is worse than the BUS benchmark. The noise is mainly from colleagues and visitors (mainly screaming children during school holidays). It is noted that this has a negative impact on occupants' productivity.

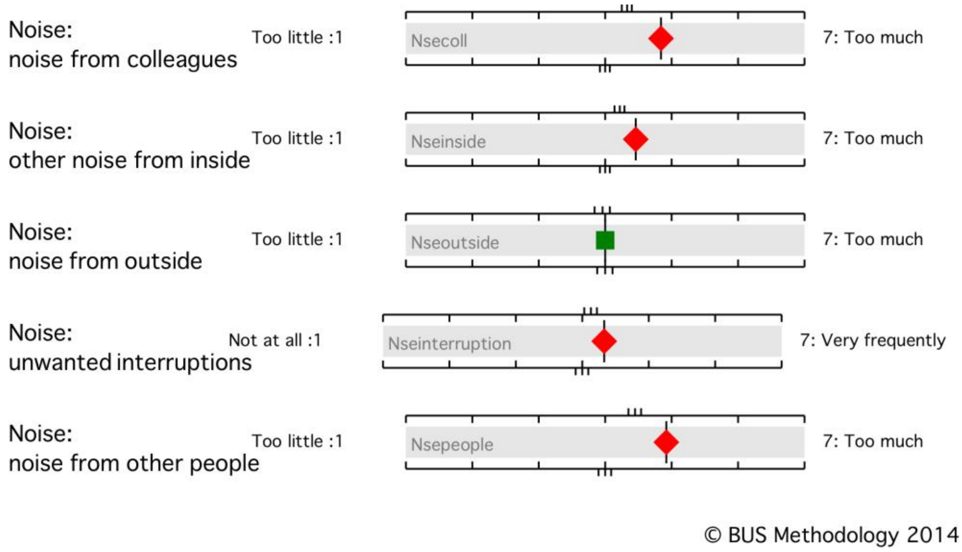


Figure 37 Noise detail variables

4.8 Conclusions and key findings

- Relative humidity (RH) in summer, for majority of occupied hours (over 80%), is within the recommended range 40-70%. In winter, over 90% of occupied hours are within the recommended range and they do trend toward the drier side of the acceptable range.
- About 1.0%, 1.5% and 1.9% of occupied period in Foyer, office and Café respectively are overheated in 2013 (over 1% of occupied hours over the 28^{o}C threshold, CIBSE Guide A criteria). This is not a major overheating problem as they just slightly over the limit.
- The measured RH patterns appear more influenced by external conditions than internal moisture generation rates (from visitors).

- In general, winter indoor temperatures range between 19°C-23°C, however it is noticeable that indoor temperature is reasonably high during the period from 20th November 13 to 2nd December 2013 because the space heating was on almost all the time. This is due to the faulty settings of the heating system during the maintenance period.
- High levels of CO_2 are observed in all spaces during working hours in winter. It often exceeds the highest acceptable limit of CO_2 (1000ppm) in the afternoon.

Following actions are recommended to improve comfort conditions in the building:

- Open windows manually for a short time during lunch time and ensure a good supply of fresh air in winter. However, windows cannot be fully opened (for security purposes) and they will be closed automatically if it is raining outside. This might be the reason why CO_2 levels are high in winter. This shows the need to have a holistic control strategy at the design stage.
- Close the office door if necessary to stop the noise transmission from the visitor area.
- Encourage an office culture wherein the discussion and communication between colleagues can be conducted in staff kitchen or seminar room. This would reduce internal background noise levels and increase productivity.
- Review the heating setpoint settings in BMS and reduce the heating setpoint slightly if necessary to avoid occupants feeling hot in winter.

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 Review of arrangements for seasonal commissioning, aftercare and maintenance

According to available handover documentation which has been reviewed by the BPE team, maintenance procedures and schedules are recommended in O&M manuals. However the College Lake team has not been using the information included in the manuals when this study was conducted.

- An O&M manual for Mechanical services (issued by Darnells Ltd) provides guidance on maintenance procedures. Maintenance instructions are provided according to the type of mechanical services equipment to be inspected and maintained on an after installation, 3 monthly, 6 monthly and 12 monthly frequency basis.
- Maintenance Log Book format is proposed in mechanical services O&M manual, but does not form a complete and proper document that could be used as logbook.
- An official building logbook does not exist on-site.
- The current FM has developed a spread sheet where maintenance activities details (system, description, controls, type of maintenance activity, frequency, appointed sub-contractors and cost) are recorded.
- Emergency Lighting monthly check is included in the O&M manual for Electrical services (issued by CT Walters Electrical Ltd).
- Electrical services commissioning certificates are contained within Electrical services O&M manual, including schedule of record drawings, schedules of materials, luminaires schedule, manufacturers' details, intruder alarm completion and commissioning certificates.
- The Health and Safety File provides general user guidance on Cleaning and Maintenance procedures and scheduling.

According to the responses of key stakeholders to the handover questionnaire survey, EDP consulting limited (M&E engineers) were responsible for re-inspecting the M&E installations during the 12 month Defects Liability Period (Evidence of inspection of the M&E installations was provided to the client after handover).

- All seasonal commissioning check was included in the Contract Works at 6 months after Practical Completion.
- The contractor has re-balanced the heating system after the first seasonal change (winter 2010) since the building commenced being occupied.

- The designers who are also the project managers were not involved in any arrangements for seasonal commissioning, aftercare or maintenance.
- College Lake's FM has arranged maintenance contracts for all services.
- The main challenge faced by FM was identifying what was needed, due to the FM not being provided with specific guidance/training when he commenced his collaboration with College Lake centre in January 2012.

5.2 Evaluation of handover data: log book, O&M manuals, user guides for occupants

Handover documentation including Health and Safety file and O&M manuals (Figure 38) became available to the College Lake project team during handover. However, building users and FMs have rarely used the handover documentation as they report that these are difficult to read, confusing and generally badly organised documents.

The full list of handover documentation available to the College Lake team is presented in Table 7.

Table 7 Handover documentation checklist

Handover documentation checklist	Available on site (✓)
Legal contract, Project description, consultants & construction details	✓
Health and Safety file	✓
Architectural, Civil & Structural, electrical and mechanical drawings	✓
Building Fabric specifications, Structural information, Risk assessments & Method statements	✓
Mechanical and Electrical services O&M manuals	✓
System Specifications	✓
Commissioning records	✓
Building Logbook	x
Strategy for energy and metering	x
Building User guide	x
Energy assessment documents	x

According to the review of handover documentation by the BPE team combined with the outcomes of the handover review workshop:

- O&M manual provides mainly guidance on installation and operation of the electrical and mechanical services.
- Documents in O&M manuals and Health and Safety File have been placed in hard cover folders, but documents within different sections are not clearly divided. As a result the required content is difficult to be found and read.
- No user guide has been produced on how to operate the building services on an on-going basis as well as in breakdown.
- Since a building logbook was not issued during handover there is a lack of information about maintenance procedures having been undertaken in College Lake since commencement of occupation.
- FMs do not usually refer to O&M manuals for guidance when there is a building defect, but prefer direct communication with contractors.
- No clear guidance on energy metering and sub-metering strategy of the building was provided through handover data.
- Although hard copies and CDs of the building O&M manuals and Health and Safety File were issued and provided to the client and BBOWT FMs at the time of handover, the latter has been missed by the current operators and cannot be located anymore.

Figure 38 Handover documentation available on-site

According to the results of the handover review questionnaire survey obtained by the BPE team, overall the building meets its users' expectations at a good level and provides suitable facilities/environment in relation to its primary purpose/function, while key stakeholders have perceived the handover process generally well (Figure 39). However a few problems were identified through questionnaires:

- The collaboration of contractors and owner with the FMs working with BBOWT at the time of handover was quite unsatisfactory.

- Internal handover could have been far more refined. Changes in staff in BBOWT during building handover had negative impacts on the internal handover.
- Current FMs could have been provided with more detailed training and information on existing handover documentation on-site by previous FMs.
- Delays in the delivery of the project did occur due to a fire incident on site. However this had only a minor impact on the handover process.
- More user-friendly and better organised handover documentation could have been provided.
- Better communication between design and construction team with end users and FMs could have improved the delivery of project's initial design intent.
- Better training on the M&E building services could have been provided to FMs and users, e.g. presentation sessions and walkthroughs with the design team and contractors.
- Familiarisation with available handover documentation and training of FMs on how to use the provided O&M manuals could improve the building maintenance and management process.

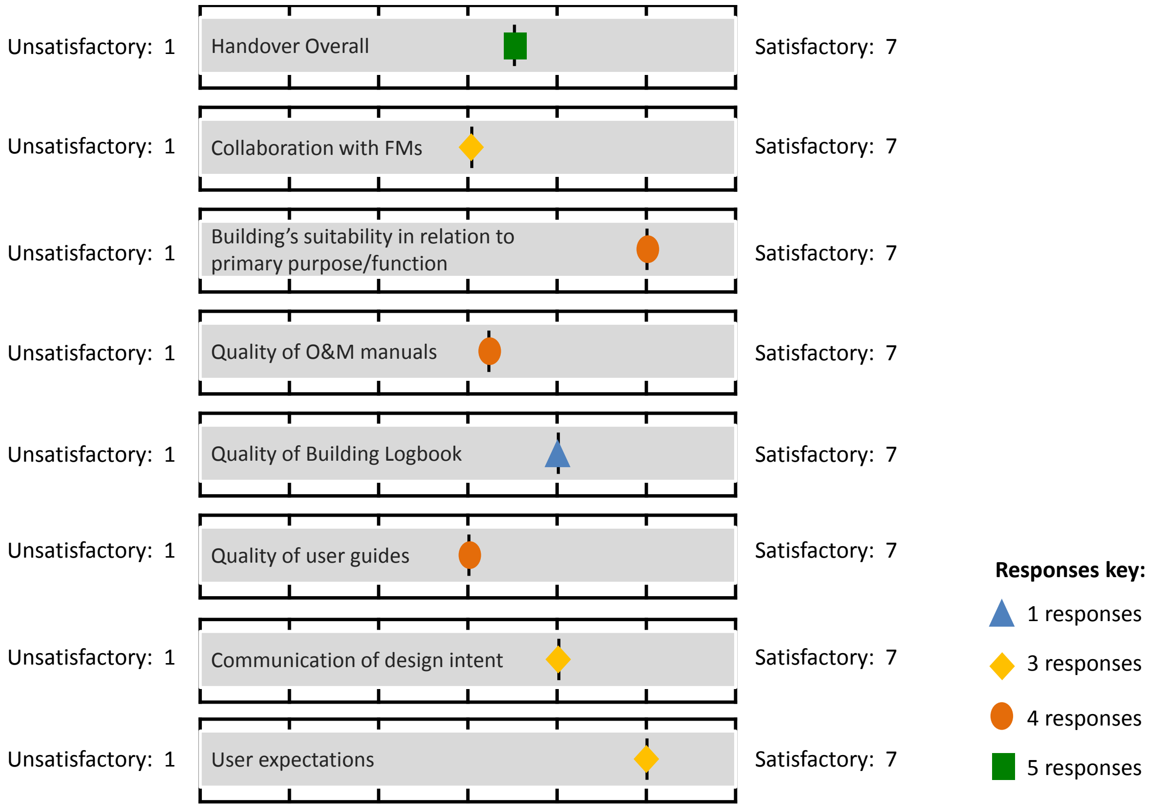


Figure 39 Average ratings of handover process aspects

5.3 Feedback/recommendations to College Lake project team

The review of the handover process for College Lake building through desktop research, a handover questionnaire survey and handover review workshop revealed several issues faced after the practical completion of the project that have been identified in the previous sections. All issues were discussed among key stakeholders during the handover review workshop. Valuable conclusions have been drawn that also form recommendations for future similar developments.

a. Design intent

- End-users requirements should be carefully considered during design stage.
  - The building should be fit for purpose and thus satisfy the end users criteria.
  - Users should be able to comment on the actual building performance and express their needs according to the type of activities they undertake in the building.
- Effective communication is a very important element
  - Make sure strong links between contractors and sub-contractors have been established not only before, but also after the end of defects period.
  - Good communication should also be ascertained between building FMs and contractors in order to tackle any building defects quickly and effectively and receive further information on building services when required.
  - End users should also be able to communicate their perception of the building ranging from its physical layout through to the suitability of systems (e.g. heating, ventilation etc.) and controls. Feedback should be provided to FMs by users in order to improve the sustainable performance of the building.

b. Seasonal commissioning and aftercare

- Seasonal commissioning of building services would improve building performance and identify any under-performing controls.
- Low energy buildings have become main stream but not always familiar to FMs.
  - Dedicated handover on how to maintain low energy buildings will have to happen.

c. Training and familiarisation of occupants

- Demonstrations of building systems and controls should be scheduled to take place more than once when new operators join the building's FM team.
  - Further emphasis should be given on BMS training which is essential to bring all issues regarding building operation together.
- Organising demonstrations and training in videos would be an excellent way of informing future employees and would strengthen the internal handover process.
  - Most key stakeholders agreed that video demonstrations and repeated live training is a preferred option over the O&M manuals only.
  - Videos and training handover could have acted as internal transition of information.
- Complete knowledge is an essential feature of building handover.
  - A person - specialist should exist among the building team that has knowledge of all systems and controls.
  - More than one person should be responsible in receiving a holistic training and demonstration of building services.
  - All information received though training and demonstrations should be properly documented for future reference.

- FM is key to running the building efficiently, therefore it would be desirable for FMs to be able to demonstrate a certain level of experience in maintaining/operating similar buildings.

d. Handover documentation

- O&M manuals
  - Handover documentation should be carefully organised in order to provide the required information which should also be easy-to-find within the O&M manuals.
  - O&M manuals do not have to be too large. It was suggested that approx. 80% of the information could be shrunk into a smaller manual and 20% of useful guidance can be in a separate section of O&M manual to be used as reference.
  - A short overview of building systems (e.g. formed in a 2-3 paragraph statement for each system that would summarise how the system works, who designed it and who to contact in case of a problem) would simplify the interaction of users with O&M manuals.
- User guide is very important part of handover documentation
  - User guide should be available on site to inform end users about building systems and controls. Otherwise users may not be satisfied by building performance due to lack of knowledge of how to operate it.
  - User guide should be produced in a convenient layout that would provide comprehensive and easy-to-read and find information.
  - User guide is proposed to organise information for each building feature under the titles: Intent - Strategy - Residual Risks – Guidance.

In addition, during the handover review workshop the BPE team made substantial reference to BSRIA's Soft Landings framework as an exemplar procedure that would ensure improved operational readiness and performance in use (UBT, 2009). The Soft Landings recommend the review of the buildings' handover process as a unique opportunity to achieve a greater involvement of the whole project team - designers, constructors, operators and end users.

Therefore, a building handover should involve:

- Support in the first weeks of occupation from the building design and contractors team.
- Demonstration of operation and maintenance of controls and technologies for the building users (windows, taps, heat controls, check meters, etc.).
- Technical guidance to the FM and building manager in a clear, simple manner.
- Provision of handover documentation (Logbook, O&M manuals, User guides for Occupants and management).
- Arrangements for aftercare, operation management and maintenance.

Finally, following the evaluation of the available handover information, documentation and handover review workshop at College Lake Visitors centre, there are a number of recommendations for future projects to ensure a successful transition from design of buildings to in-use:

- Include building or FM manager in the pre-construction design meetings.
- Tailor a bespoke move-in support plan with the user and owner from the project start – including a programme of induction sessions.
- Consider techniques such as: Soft Landings, walkthroughs, photographic surveys survey, discussions with occupants and site manager, hindsight review, energy logging and energy workshops.
- Make sure that facility managers and building end users attend handover sessions.
- Involve caretakers and facilities teams in the planning process to clarify roles and responsibilities.
- Develop a Welcome Letter to aid staff in understanding the building systems and seasonal operation strategies as well as explain normal teething issues before inductions begin.
- Consider carrying out a Building Performance Evaluation study.

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.

Energy monitoring results obtained through manual meter readings, the OBU web-portal and BMS are presented in this section. Manual meter readings were taken on 9th October 2013 and 6th October 2014 (363 days) for simple energy assessment. Five-minute sub-meter data were recorded (between 29th October 2013 and 6th October 2014) for detailed energy analysis. It reveals information about the energy usage in College Lake Wildlife Visitors Centre.

6.1 Simple assessment (TM22 benchmarking and analysis)

The following simple assessment from TM22 benchmarking and analysis covers the period 9th October 2013 and 6th October 2014 (363 days).

The energy supplied (and carbon emissions) in the College Lake Visitor Centre is from grid electricity and PV generation. Grid electricity consumption for a year to 6th October 2014 was 31,056 kWh which equates to carbon dioxide emissions of 13,835 $kgCO_2$ per annum (at the carbon factor for electricity of 0.4455, Figure 40 and Table 8). This equates to 85.8 kWh/m^2/annum and 38.2 kg CO_2/m^2 /annum.

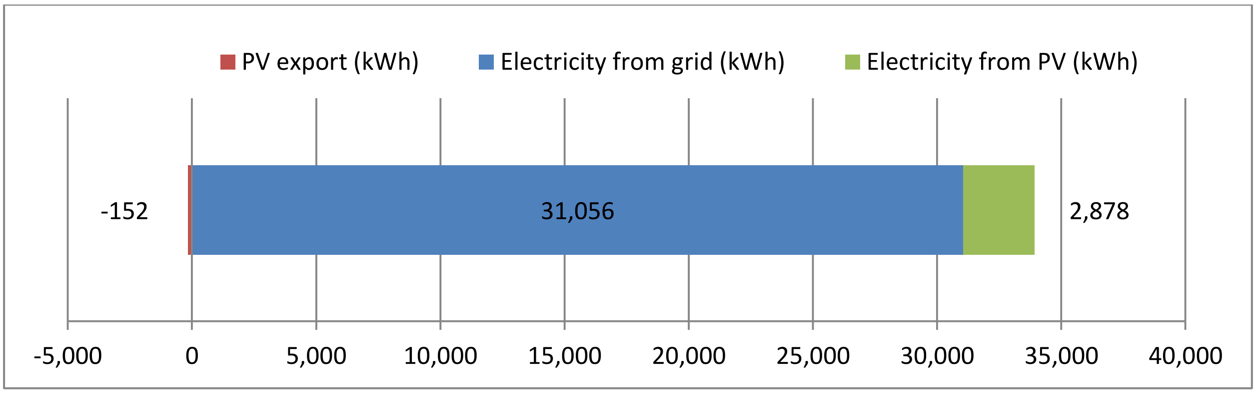


Figure 40 Total electricity used in College Lake Visitor Centre (7th Oct 2013- 6th Oct 2014)

The photovoltaic electricity generated on site has been metered at 3,030 kWh per annum for the 12 months to 6th October 2014, of which 2,878 kWh (95%, Figure 42) was used on site, and 152 kWh (5%) was exported to the grid. Renewable (PV) contributes 8% of total energy usage; the rest is imported from the grid (Figure 41).

The annual total electricity usage (from both the grid and PV) of the Visitor Centre for a year to 6th October 2014 is 33,934 kWh (93.7kWh/m^2 per year, or 93.0 kWh/day on average).

Table 8 Actual figures of total electricity used, generated and imported in College Lake Wildlife Visitors Centre during the monitoring period (7th Oct 2013- 6th Oct 2014)

	Actual values kWh	Normalised values kWh/m^2
Electricity mains	31,056	85.8
PV electricity generation	3,030	8.4
PV electricity export	152	0.4
PV electricity used	2,878	8.0
Total electricity consumption (including PV)	33,934	93.8

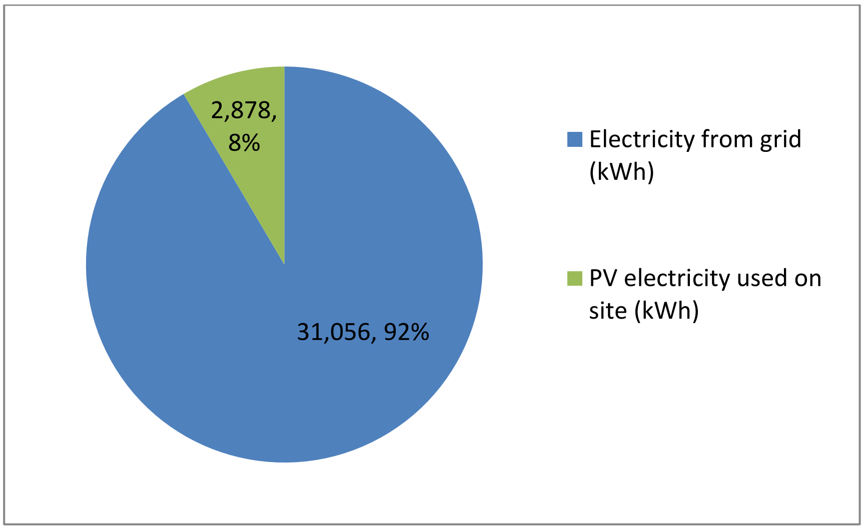


Figure 41 Total electricity usage makeup in College Lake Visitor Centre (7th Oct 2013- 6th Oct 2014)

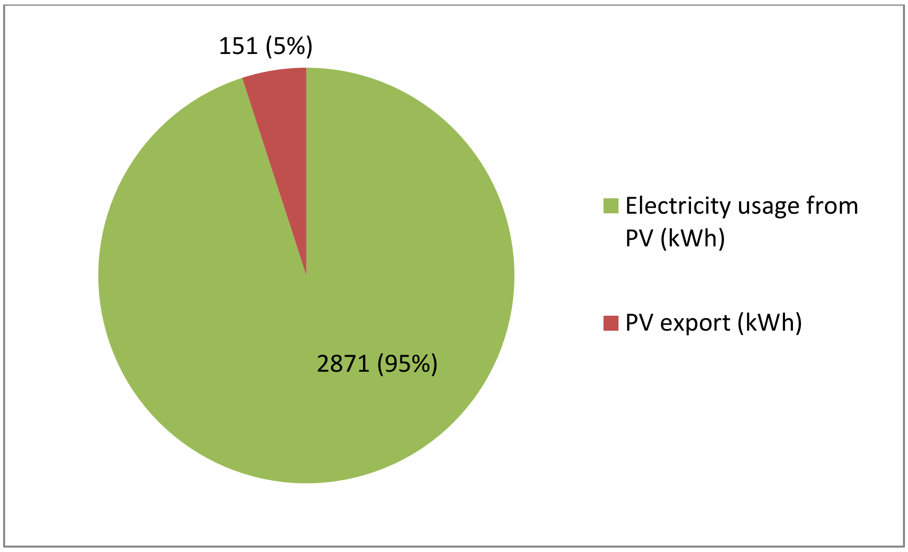
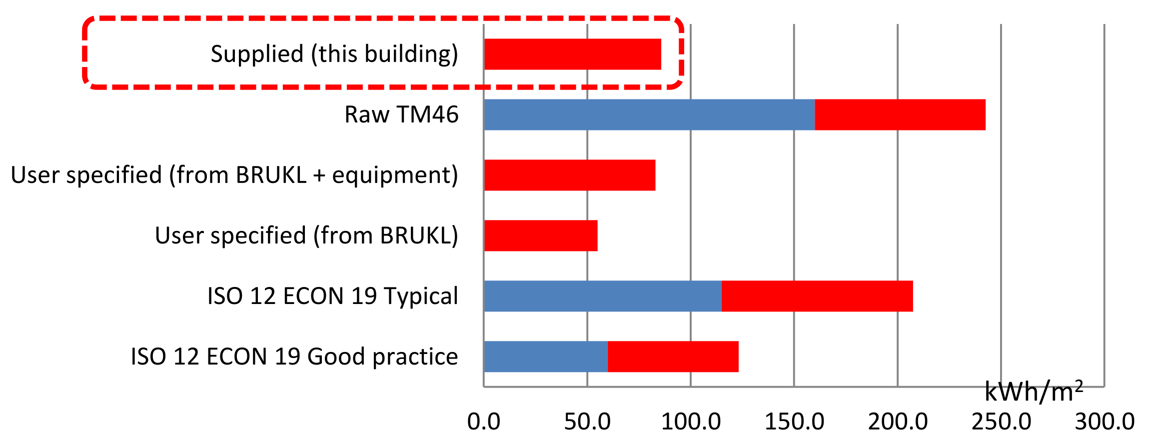


Figure 42 Electricity usage from PV vs. PV export (7th Oct 2013- 6th Oct 2014)

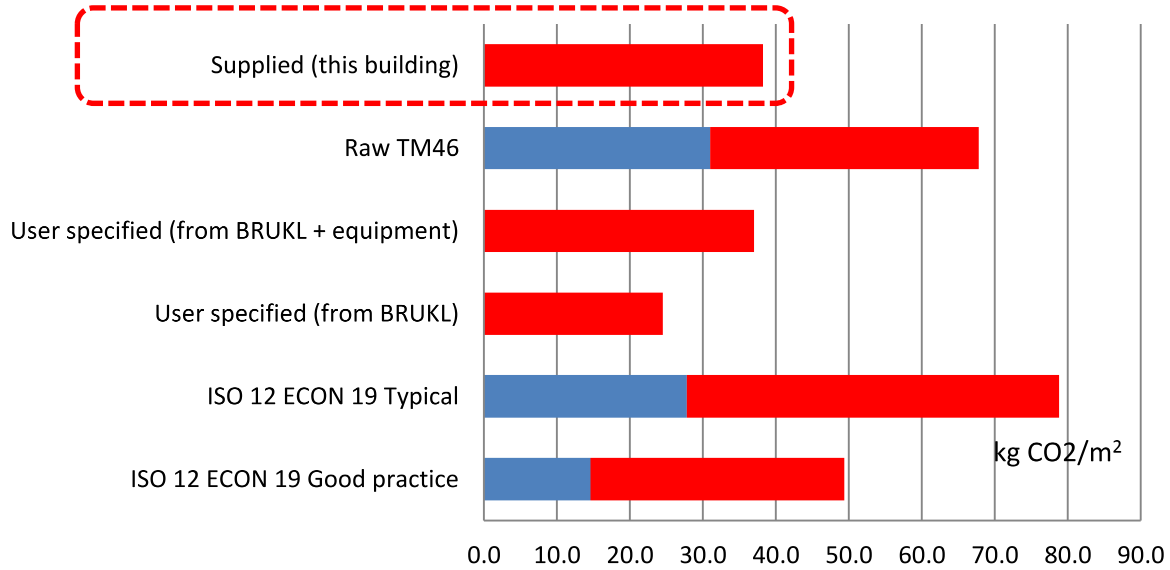
College Lake Visitor Centre's annual (supplied) energy usage per square metre and carbon dioxide emissions during the monitoring period (a year to 6th October 2014) are compared with ISO 12 ECON 19 Good practice, typical benchmark, BRUKL and TM46 in Figure 43 and Figure 44. Supplied energy use and resultant CO_2 emissions are significantly lower than the TM46 benchmark and ISO 12 ECON 19 benchmark (both good practise and typical benchmark).

Overall the College Lake Visitor Centre uses grid supplied energy that equates to half of the CO_2 emissions of the TM46 benchmark. However, it is 3% higher than the benchmark specified in BRUKL documents (83 kWh/m^2 including 37 kg CO_2/m^2 from equipment, Figure 43).



	ISO 12 ECON 19 Good practice	ISO 12 ECON 19 Typical	User specified (from BRUKL)	User specified (from BRUKL + equipment)	Raw TM46	Supplied (this building)
Fuel/thermal	60.0	114.8			160.0	
Electricity	63.2	92.7	55.0	83.0	82.5	85.8

Figure 43 Energy supplies excluding renewables (7th Oct 2013- 6th Oct 2014, 93.7 kWh/m²/year including PV)



	ISO 12 ECON 19 Good practice	ISO 12 ECON 19 Typical	User specified (from BRUKL)	User specified (from BRUKL + equipment)	Raw TM46	Supplied (this building)
Fuel/thermal	14.6	27.8			31.0	
Electricity	34.8	51.0	24.5	37.0	36.8	38.2

Figure 44 Carbon emissions (7th Oct 2013- 6th Oct 2014)

6.2 Comparison with other buildings

Comparison is also made with peers; College Lake Visitor Centre uses less energy than most other buildings of similar uses for which data was accessible. The annual energy use of the other buildings ranges from 42 kWh/m^2/annum (Mayville Community Centre) to 442 kWh/m^2/annum (Donnington Community Centre, Figure 45). Data for Angmering Community Centre, Mayville/Mildmay Community Centre and College Lake Visitor Centre were collected between 2012 and 2014, whereas the other community centres were studied between 2006-2007. With the exceptions of Angmering Community Centre, Mayville/Mildmay Community Centre and College Lake Visitor Centre, nearly all of the other buildings do not perform well even when compared to typical benchmarks. These are largely community centre buildings which are found to have a poor fabric performance in terms of heat loss, lack of insulation in the walls, and leaky fabric.

Angmering Community Centre performs better than the CIBSE Guide F-Good practice benchmark as a result of the good performance of the ground source heat pump (GSHPs, COP of 3.68), relatively low thermostat settings and careful management of energy use.

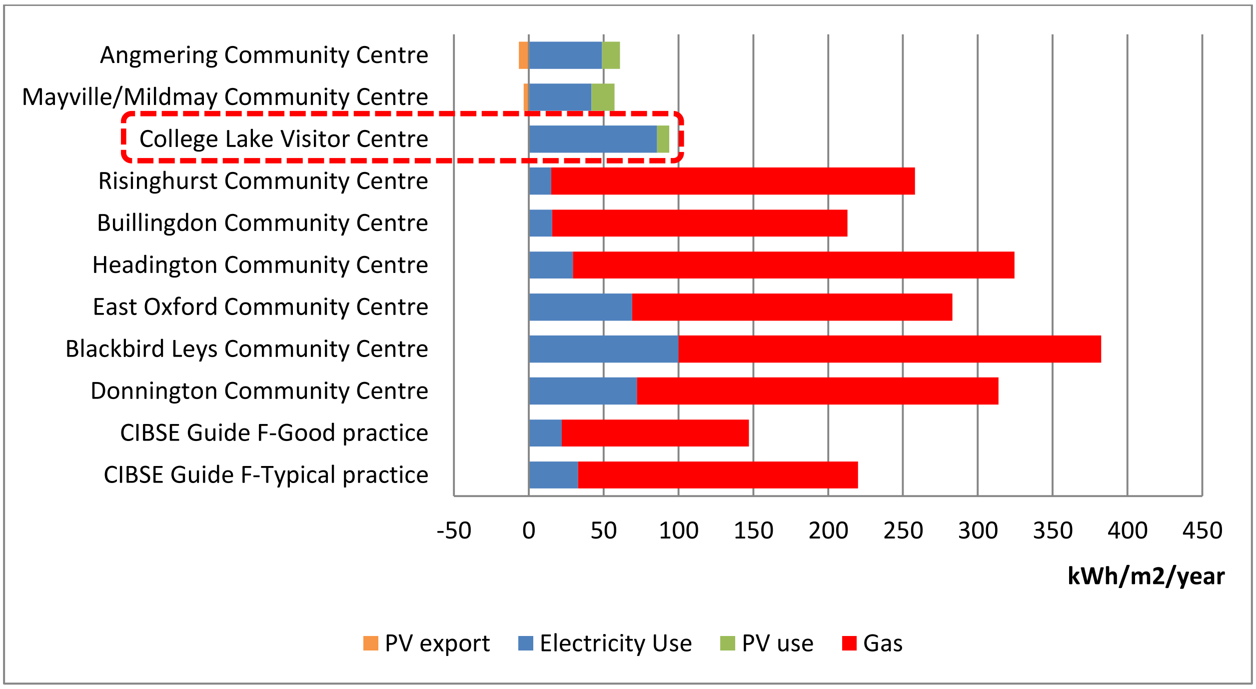


Figure 45 Comparison with other similar use buildings

6.3 Sub-metered electricity usage

Sub-metering data of four distribution boards and two outdoor units are available from 29th October 2013 to 6th October 2014. Each distribution board is responsible for delivering electricity to a nearby area, as illustrated in Figure 8. For example, DB2 is responsible for electricity supply for lighting and office equipment in the seminar room and reception area; DB3 is responsible for electricity supply in the office, staff kitchen and storage room; DB4 is responsible for electricity supply in the café; DB5 is responsible for electricity supply in the kitchen and toilet. A detailed electricity end use and distribution chart is shown in Figure 9.

The sub-metered electricity usages by space are shown in Figure 46. The two ASHP units use 25.8% of total electricity. The café area and adjacent space (DB5 - 29%) and office spaces (DB3 - 22%) have higher electricity consumption than other spaces. This is mainly due to office equipment in the office and cafe machinery and fridges in café area.

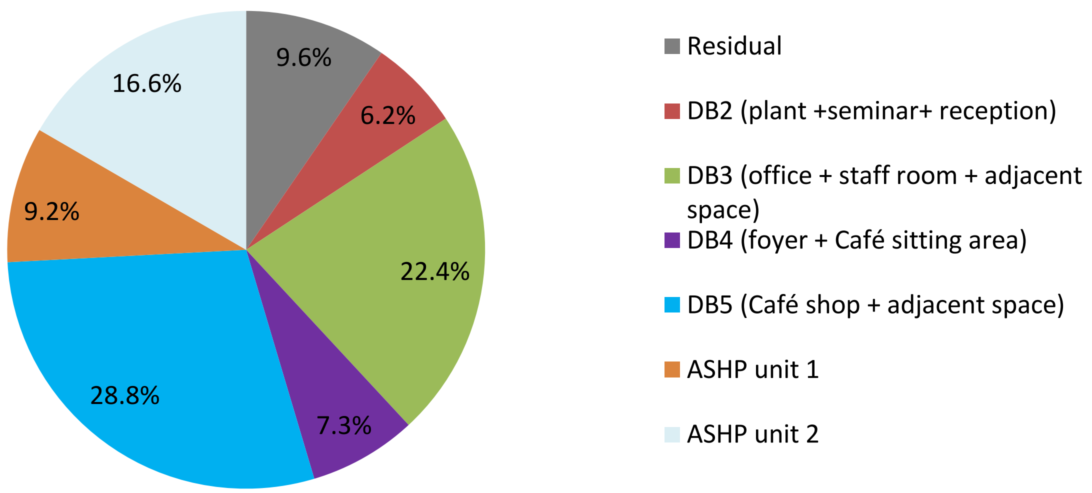


Figure 46 Sub-metered electricity use (by space and ASHPs)

Figure 47 Sub-meter arrangement by space

6.4 Comparison with BRUKL estimation

As the sub-metering arrangement is not designed according to end uses (by space in this case study building), the end use energy data of auxiliary, lighting and equipment were calculated by TM22 analysis (bottom-up approach), heating and hot water data were gathered through sub-metering of ASHPs and 2 heat meters. The comparison between actual energy end usage and BRUKL estimation are made in Figure 48 and Figure 49.

Figure 48 shows that actual energy for heating is 61% more than BRUKL estimation and the actual energy for equipment is 64% more than BRUKL estimation. The actual energy for lighting is 37% less than the BRUKL estimation. The actual energy for hot water and auxiliary are slightly less than the BRUKL estimations. A bigger proportion of energy was consumed by equipment (Figure 49) compared to BRUKL estimate.

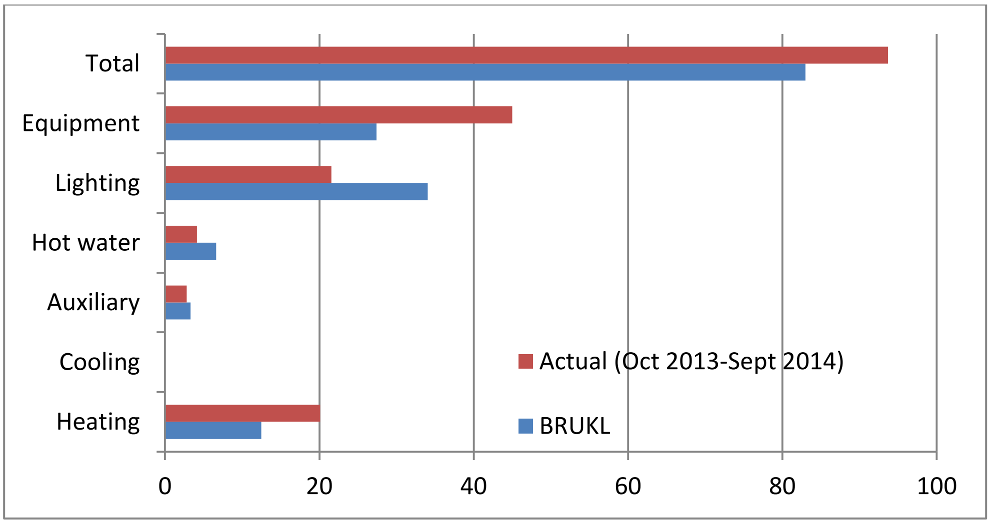


Figure 48 Actual energy end usage is compared with BRUKL estimation (absolute value)

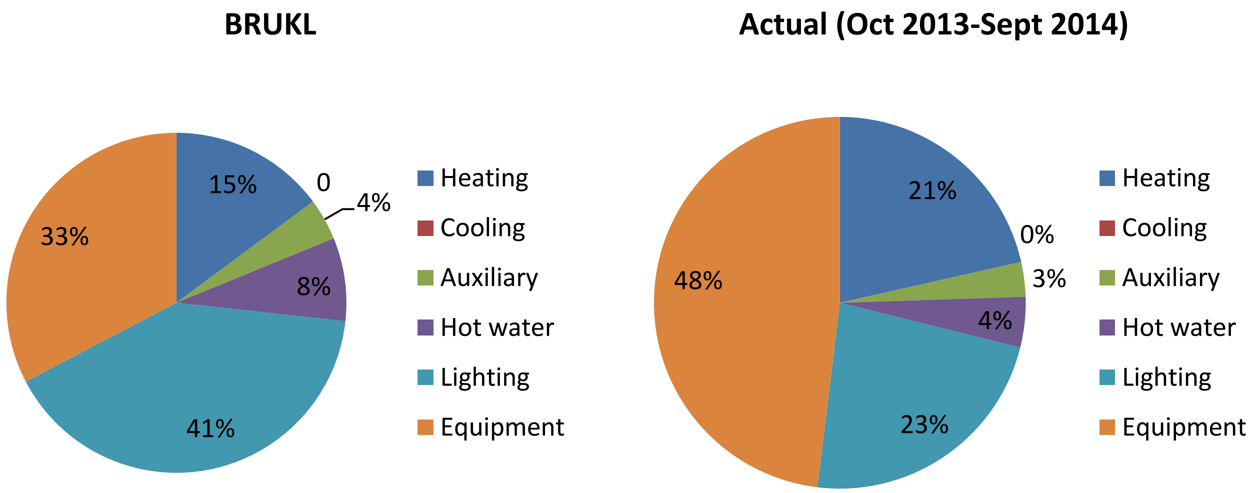


Figure 49 Actual energy end usage is compared with BRUKL estimation (by percentage)

6.5 Electricity usage profile

The 5-min readings of the main electricity meter and PV generation/export are available from 26th March 2013 to 6th October 2014; 5-min readings of sub-metering data of four distribution boards and two outdoor units are available from 29th October 2013 to 6th October 2014. These data enabled the authors to plot monthly, weekly, daily and hourly electricity usage profiles.

6.5.1 Monthly electricity consumption and external temperature

Figure 50 shows that the energy consumption changes significantly according to external temperature as well as high electricity usage from the grid in winter, and low electricity usage from the grid in summer, as expected. The very high electricity usage in November 2013 is due to the heating was turned on 24/7 during 20th November – 2nd December 2013 (discussed in Figure 12, section 4.2.1).

The PV generation contributes to a higher percentage of the electricity consumption in summer; PV export is minimal throughout the year.

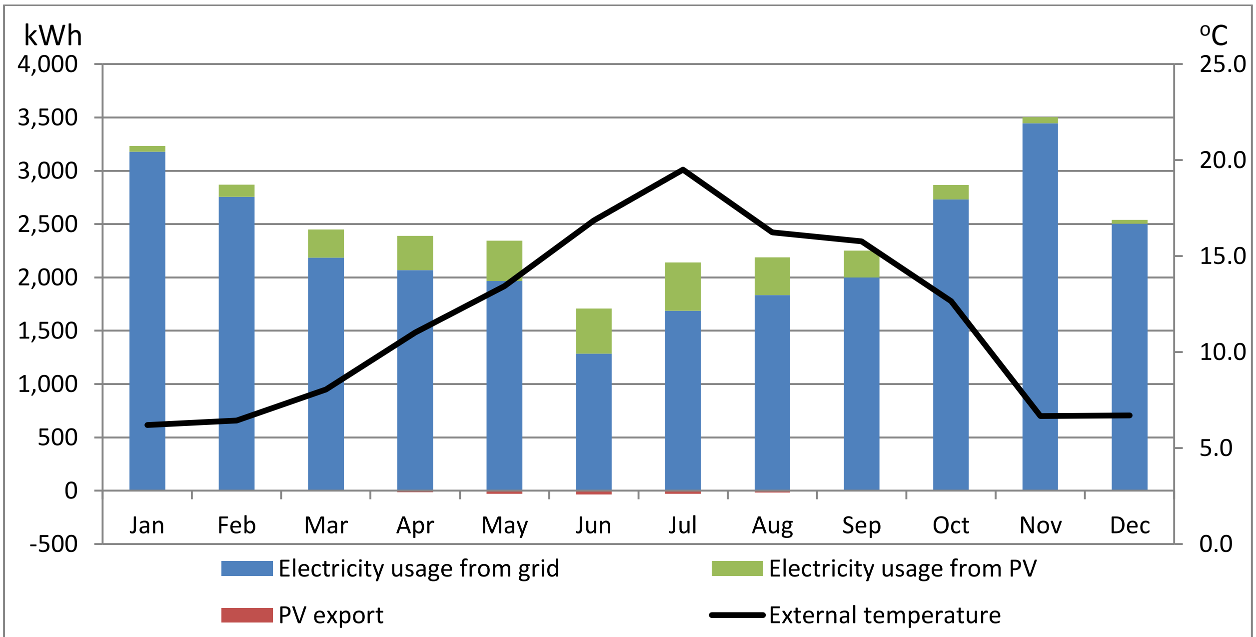


Figure 50 Monthly electricity usage from grid and PV (Oct 2013- Sept 2014)

6.5.2 Weekly electricity consumption, fuel cost and carbon emission

The metered weekly electricity consumptions and weekly average external temperature from 30th September 2013 and 28th September 2014 (364 days, 52 weeks) are illustrated in figure below. It shows that the weekly energy usages are in the range of 500 kWh to 1,116 kWh (Figure 51). The base load of electricity usage is about 530 kWh per week throughout the year. The consumption increases significantly when external temperature drops. The energy consumption changed significantly when the heating settings were changed in November 2013.

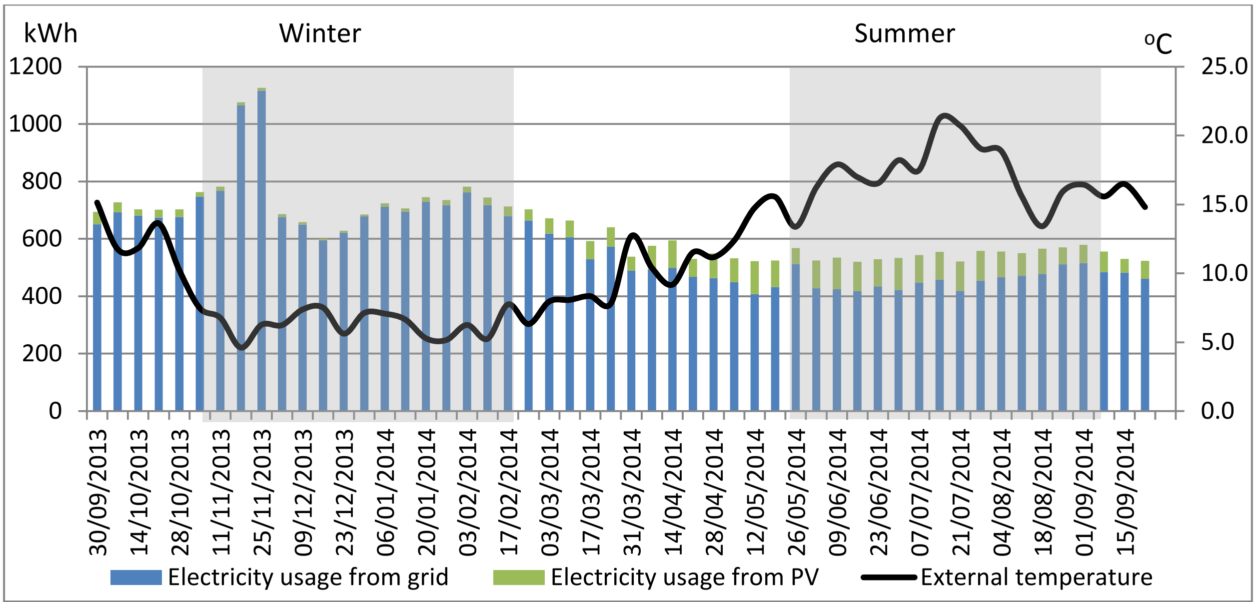


Figure 51 Weekly electricity consumption for a period of 52 weeks between 30th September 2013 and 28th September 2014

Figure 52 shows that weekly fuel costs range from £60.00p to £162.80p per week over a one year period from 30th September 2013. (Tariff rate: 14.4p/kWh plus 17.98p standing charge per day). The predicted annual electricity bill is £4,425.

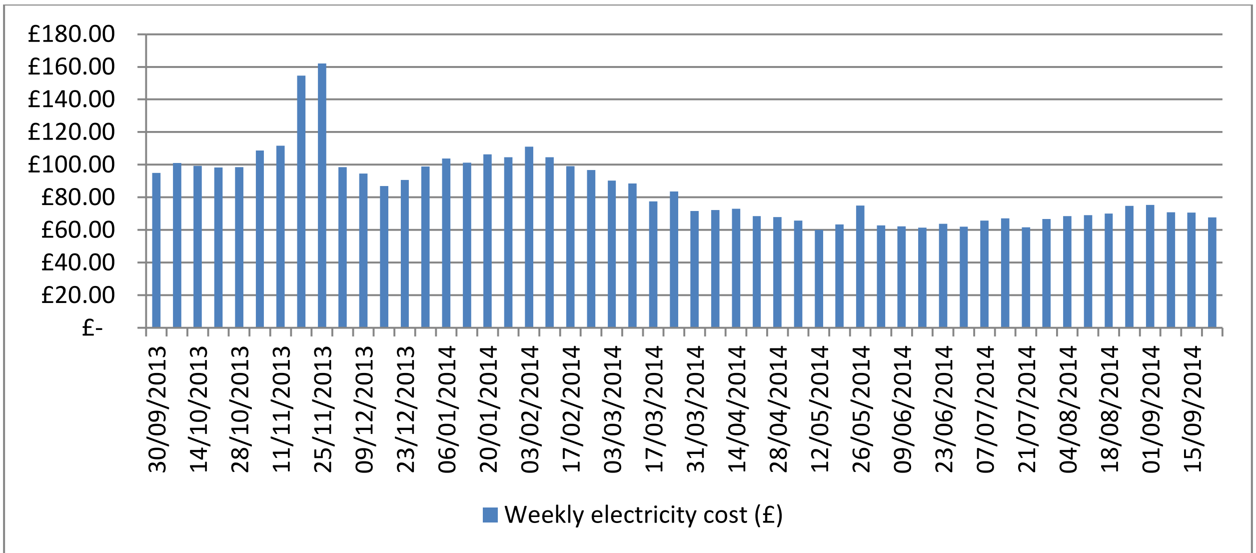


Figure 52 Weekly electricity costs for a period of 52 weeks between 30th September 2013 and 28th September 2014

Figure 53 shows that weekly CO_2 emissions range from 182 to 497 kgCO_2 per week over a one year period from 30th September 2013 (carbon factor 0.4455). The annual CO_2 emission is 14 tons (38.2 kg CO_2/m^2/year).

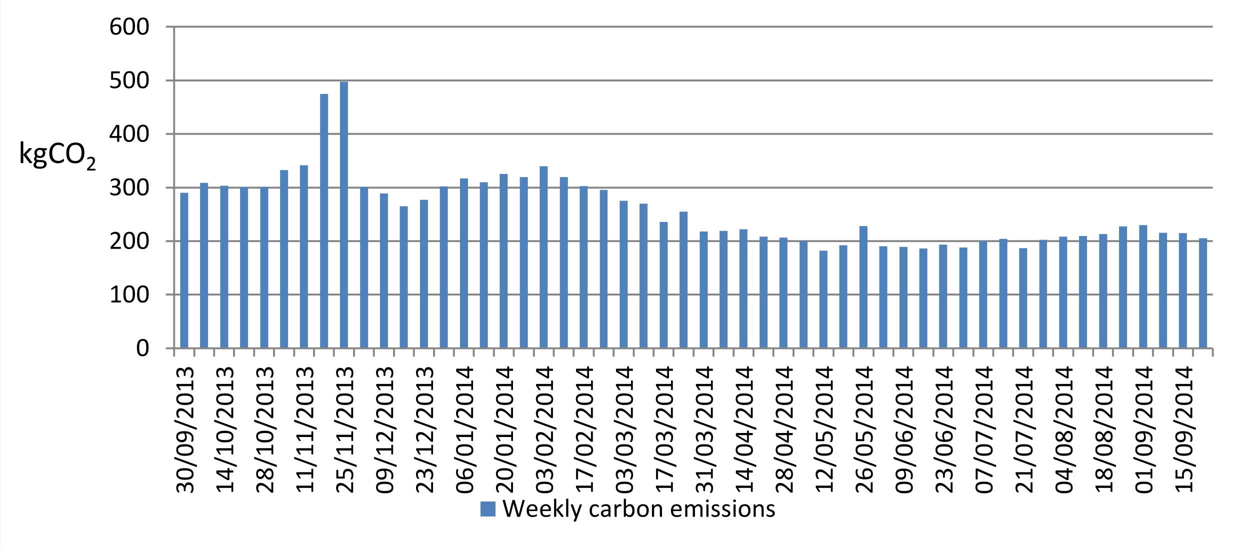


Figure 53 Weekly CO2 emission for a period of 52 weeks between 30th September 2013 and 28th September 2014

The weekly PV generation, use on site and export is plotted in Figure 54. It shows that the PV generation is significantly less during winter. 94.9% of PV electricity generation is used on site; the rest is exported back to the grid. A total of 3030 kWh electricity was generated by the PV panels (3.43 kWp, 883 kWh/kWp) last year and the equivalent saving is £439 (9% of total bill).

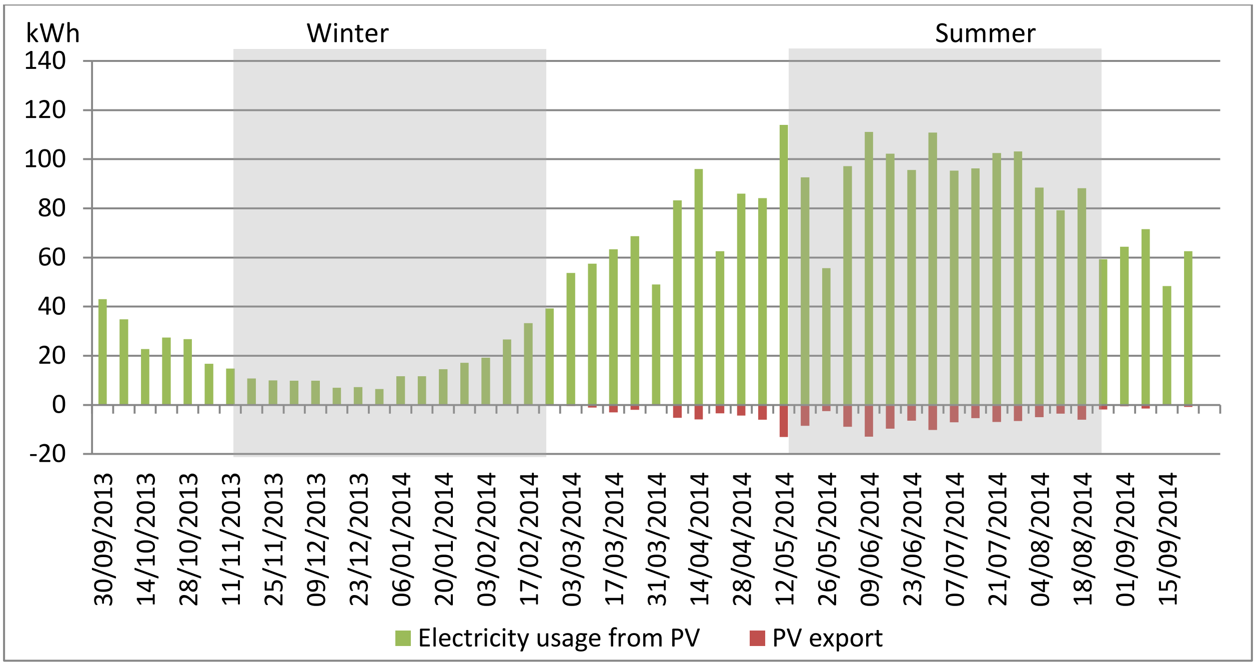


Figure 54 PV usage on site and PV export for a period of 52 weeks between 30th September 2013 and 28th September 2014

6.5.3 Degree day analysis

The weekly energy consumptions are compared with the local Weekly Heating Degree Days data (HDD15.5, HDD14 to HDD6). The Degree Days data were calculated from weather data gathered through external weather stations placed outside the building. The results show that HDD10 has a better correlation with energy consumption as compared to others. The correlation between building total electricity usage and weekly HDD is reasonable strong (R^2 = 0.614, Figure 55 and Figure 56).

Using the HDD10 results (Figure 56; strongest correlation), the building has a 528 kWh base load and the energy consumption increases 8.5kWh with every HDD10 rise. Note that due to the missing data in July and August 2014, four weeks were excluded in the Degree Day analysis.

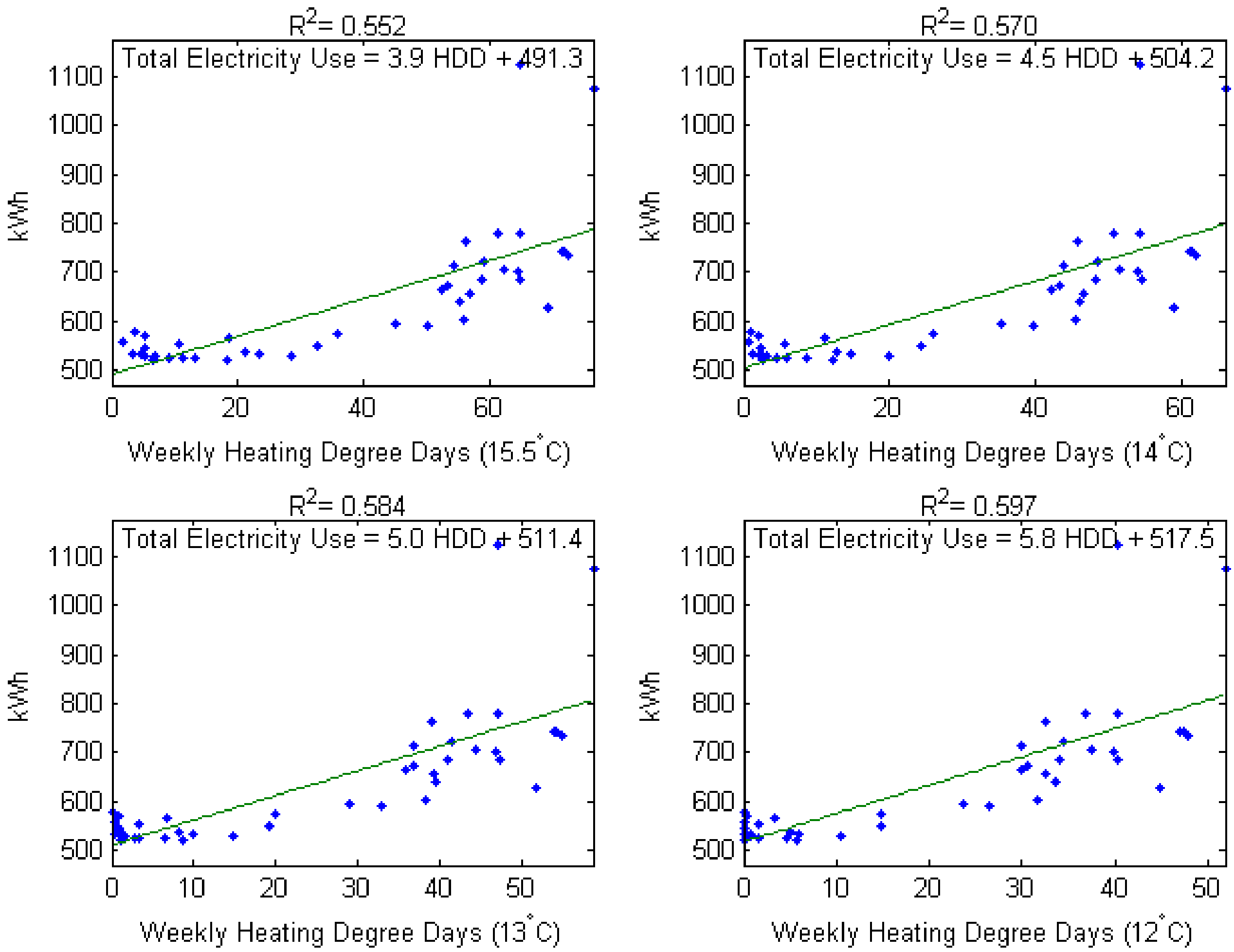


Figure 55 Weekly HDD15.5 - HDD12 vs Weekly energy consumption for 42 weeks until 29th September 2014

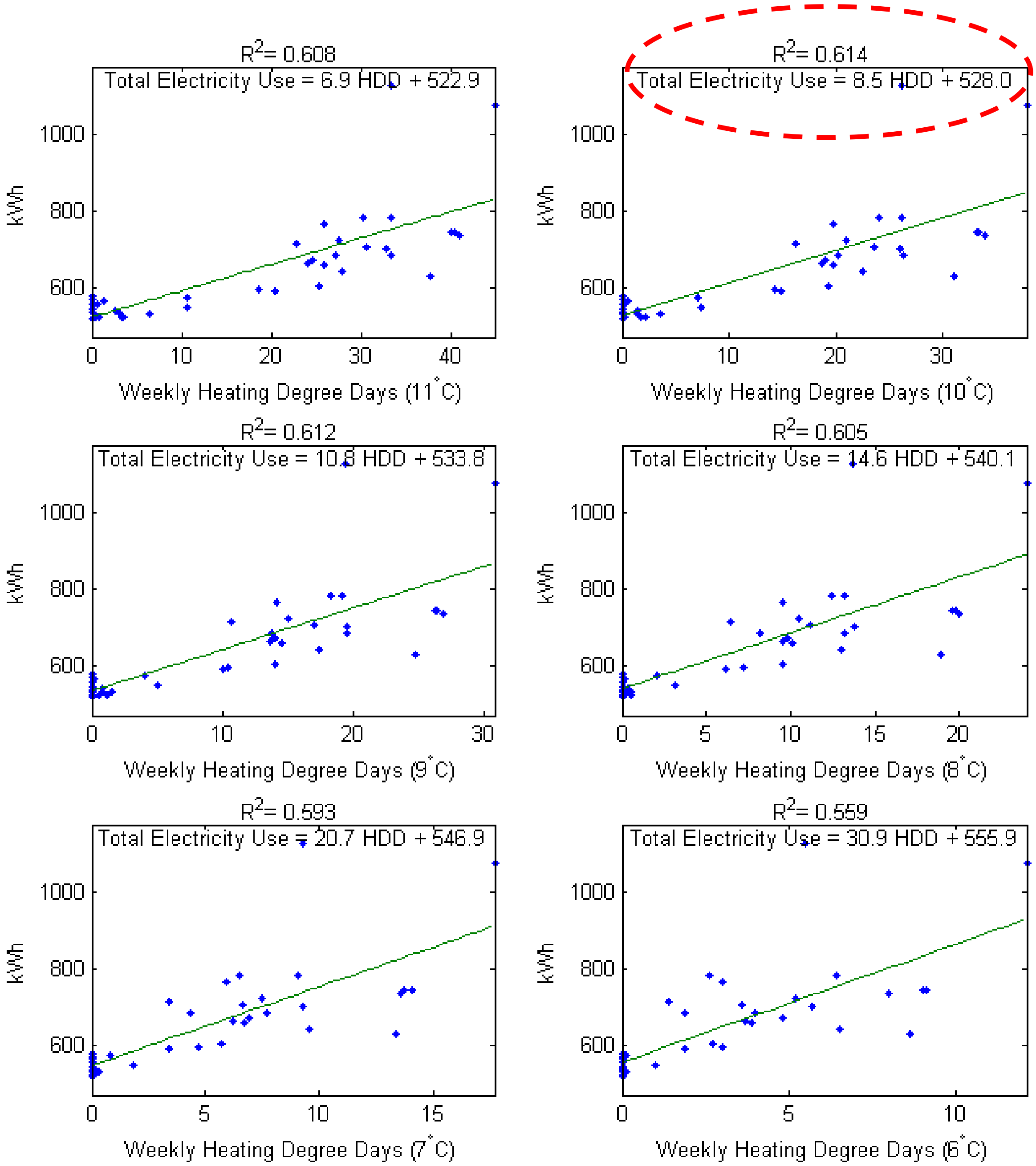


Figure 56 Weekly HDD11 - HDD6 vs Weekly energy consumption for 42 weeks until 29th September 2014

Further investigation shows that there is a strong relationship (R^2=0.7) between the ASHPs electricity usage and external temperature (Heating Degree Days), as evidenced in Figure 57. The Weekly Heating Degree Days 10°C has the best correlation with weekly ASHPs electricity usage and the base load for ASHPs is 61.9 kWh.

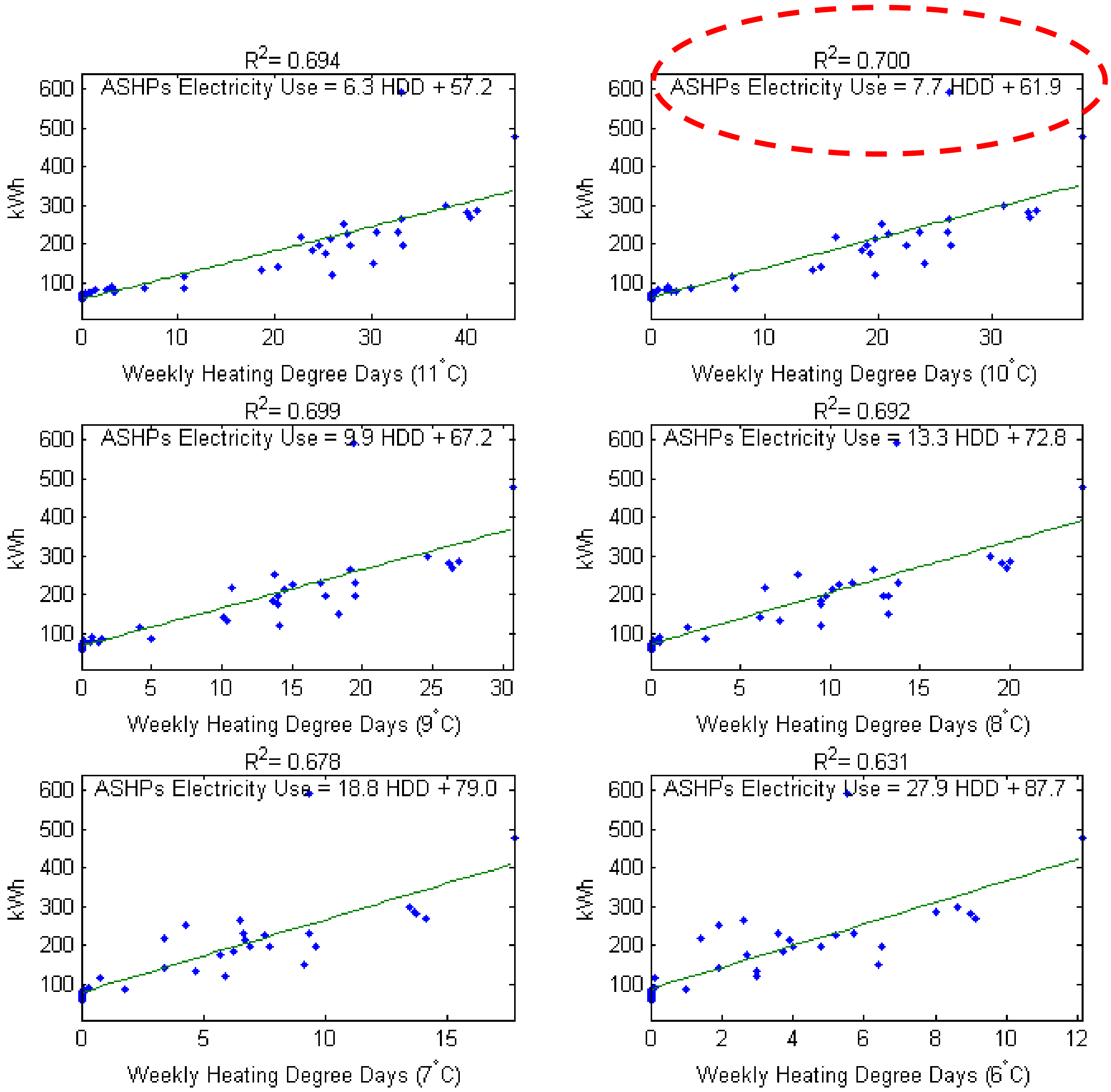


Figure 57 Weekly HDD11- HDD6 vs Weekly ASHPs electricity consumption for 42 weeks until 29th September 2014

6.5.4 Weekly sub-metered electricity usage

The overall sub-metered electricity use breakdown was shown in Figure 46. The sub-metered weekly electricity usage between 11th November 2013 and 30th March 2014 is plotted in Figure 58. It shows that ASHP units, office spaces (DB5) and café area (DB3) have bigger energy usages than other spaces. The consumptions from distribution boards are relatively stable over the time period, whereas the consumption from ASHPs outdoor units varies significantly depending on the external temperature.

Due to the Christmas break, the energy consumption from the distribution boards (which are mainly for lighting and small power) shows a significant drop from the week starting from 23rd December 2013.

For the first three weeks in Figure 58, it is noticeable that there is high energy usage from ASHPs and high residual electricity usage (not metered electricity usage); an investigation into the residual electricity usage is shown in the detailed analysis in section 7.2. In addition to this, the electric immersion heater (not-metered) has kicked in due to the fault of exchanger in this period; the problem was fixed on 20th November 2013.

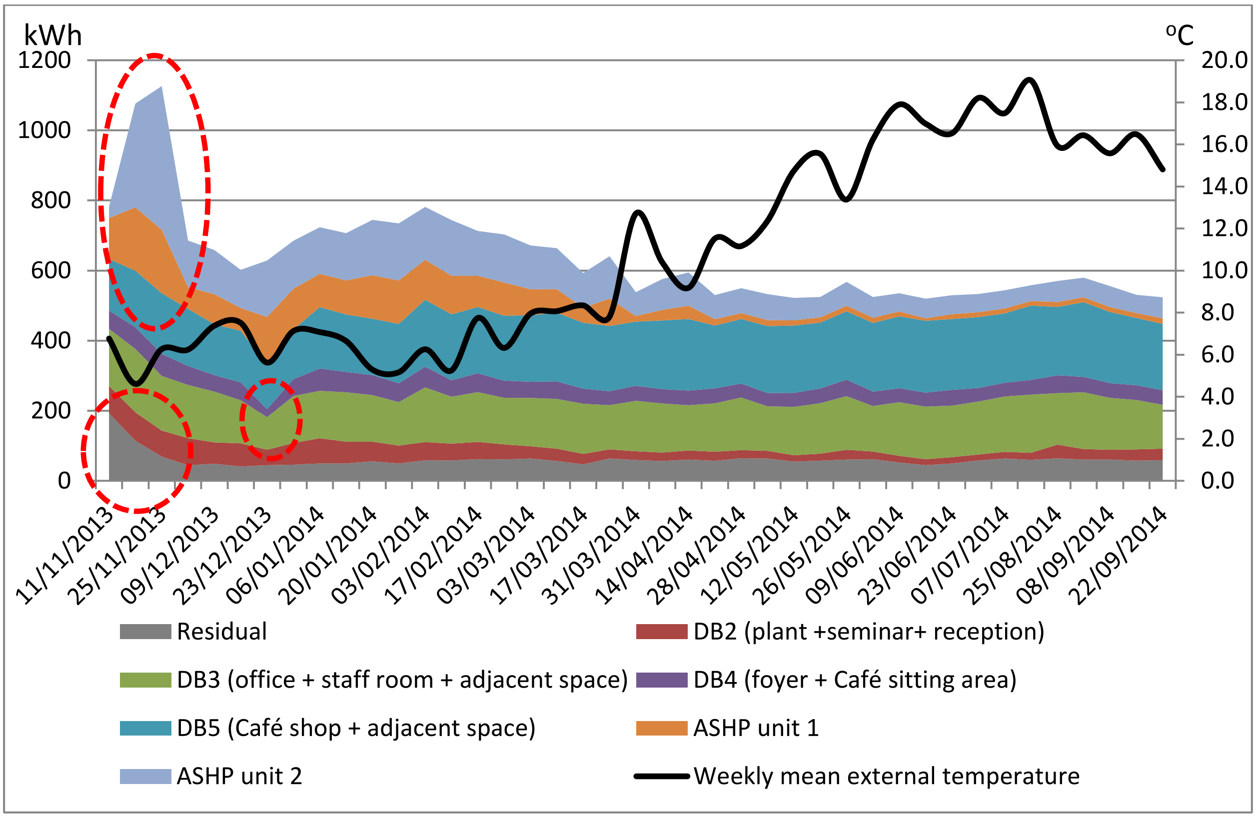


Figure 58 Weekly sub-metering of electricity use (11th Nov 2013 – 15th Jun 2014)

The heating was left on for 24/7 between 20th November and 2nd December 2013; which not only led to high energy usage in November 2013, but is also likely to have led to the high indoor room temperatures (25°C, Figure 59) that were observed during that period.

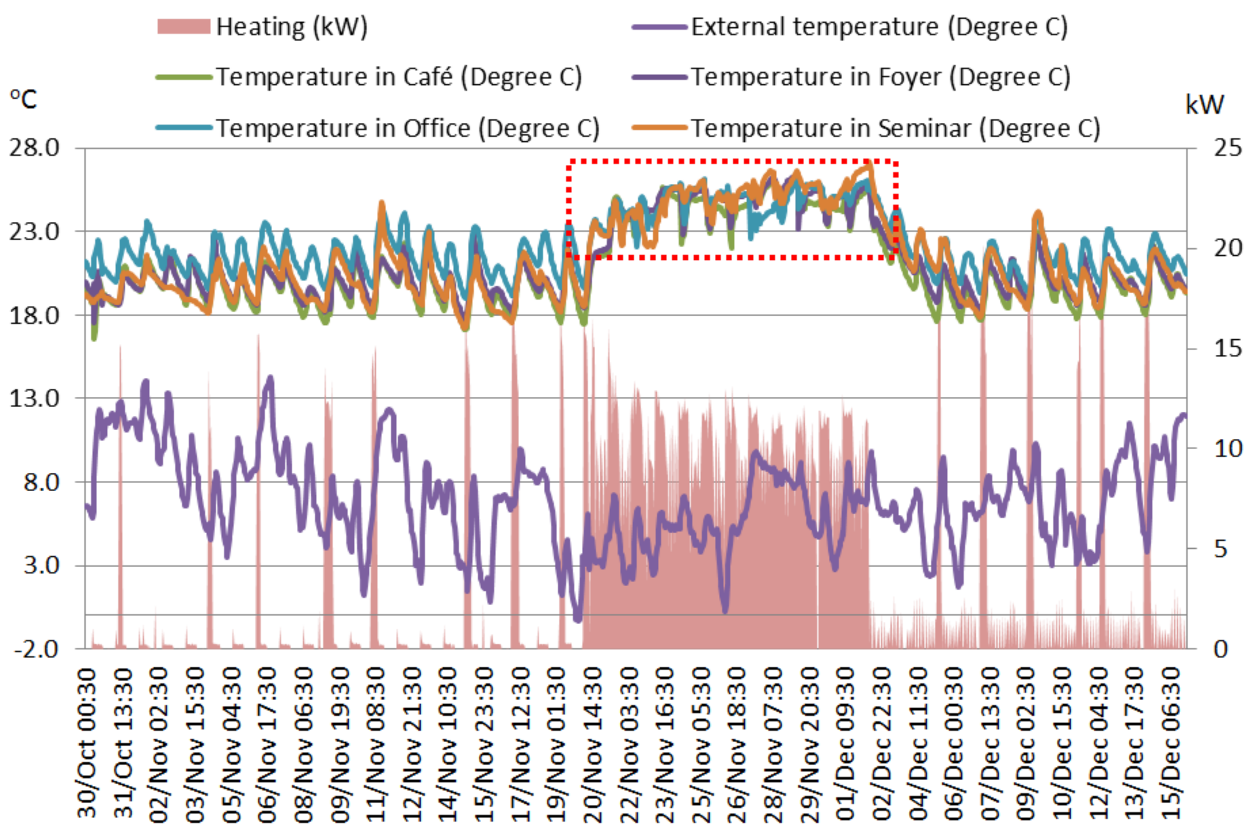


Figure 59 High indoor temperature in Nov 2013

The percentage of electricity used for ASHPs and weekly external temperature is shown in Figure 60. It indicates that 52% of the total electricity use was used for heating and hot water in late November 2013, but this drops to 12% in June 2014. The rest is used for lighting, office equipment and others. Further analysis (Figure 61) shows that the percentage of electricity used by the ASHPs closely follows external temperature and can be predicted using the equation shown in Figure 61.

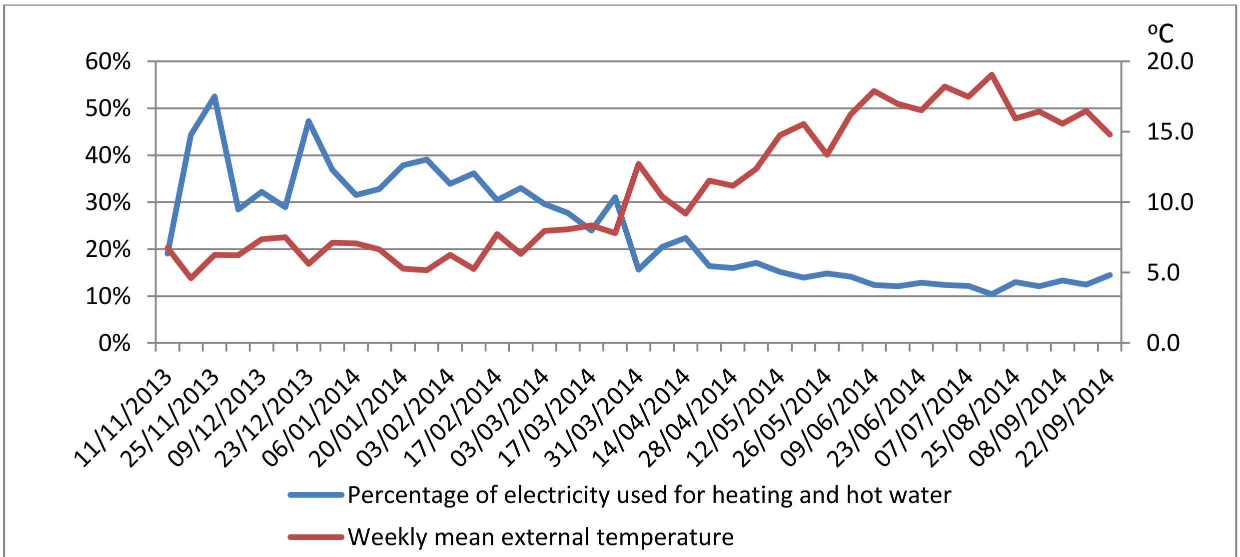


Figure 60 Percentage of electricity used for ASHPs and external temperature

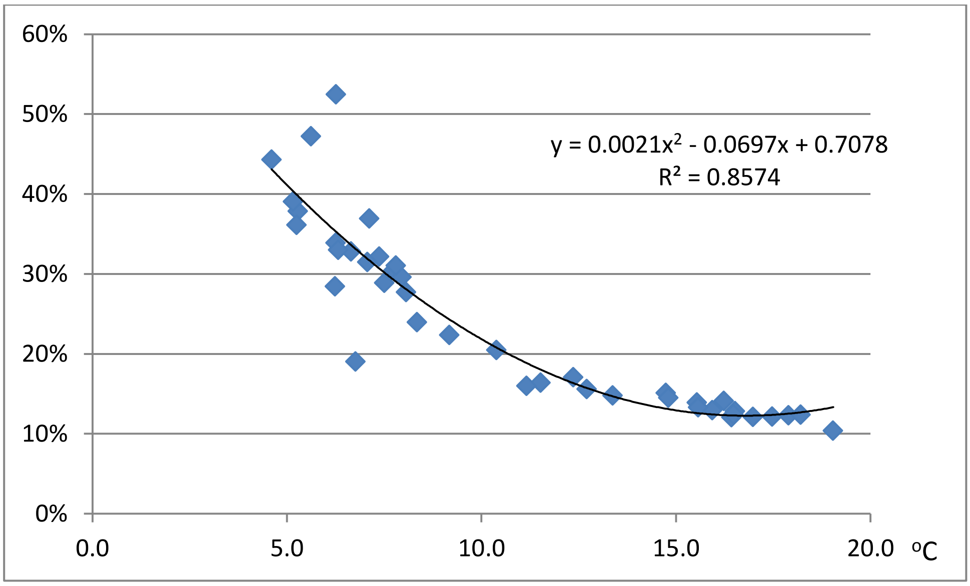


Figure 61 Percentage of electricity used for ASHPs and its relationship to external temperature

The analysis of sub-metering data also shows an increasing trend (red line in Figure 62) of weekly electricity usage in the café shop, toilet and food storage area (BD5) from winter to summer.

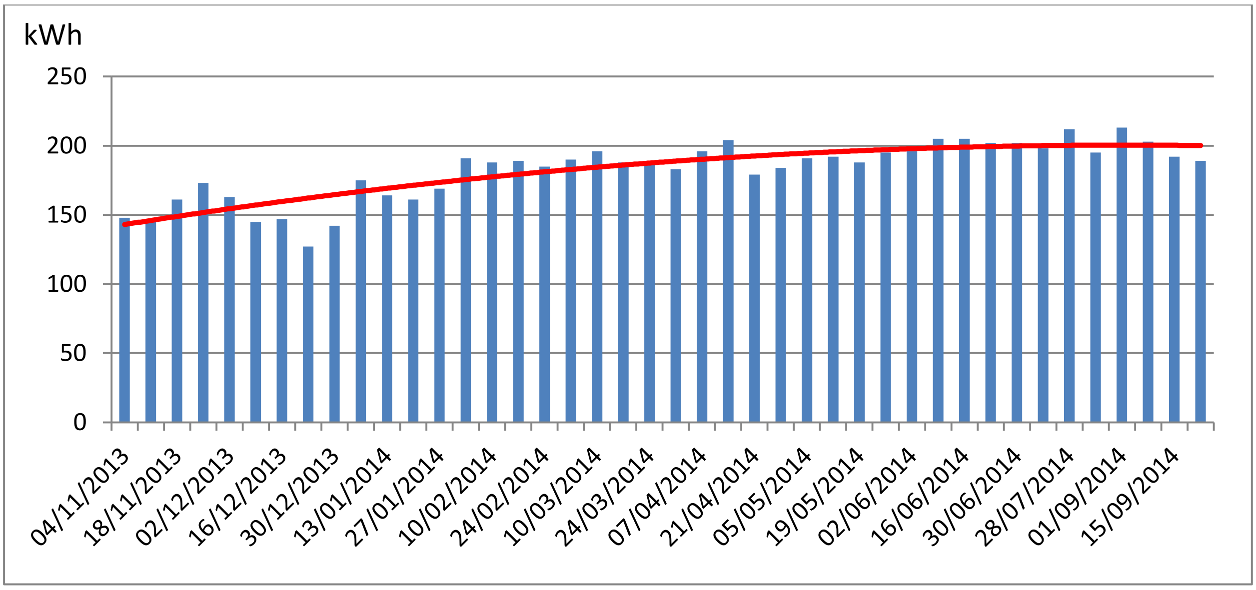


Figure 62 Weekly sub-metering of café shop (DB5)

6.5.5 Hourly total electricity load profile and PV generation profile

The average hourly total electricity loads during weekdays and weekends are plotted in Figure 63. There is little difference between the weekday and weekend load profiles, most likely due to the visitor centre being occupied seven days a week. The base load is around 2.0 kW at night and the average load increases up to 6 kW during working hours. The increase is mainly due to the use of space heating and office equipment during working hours.

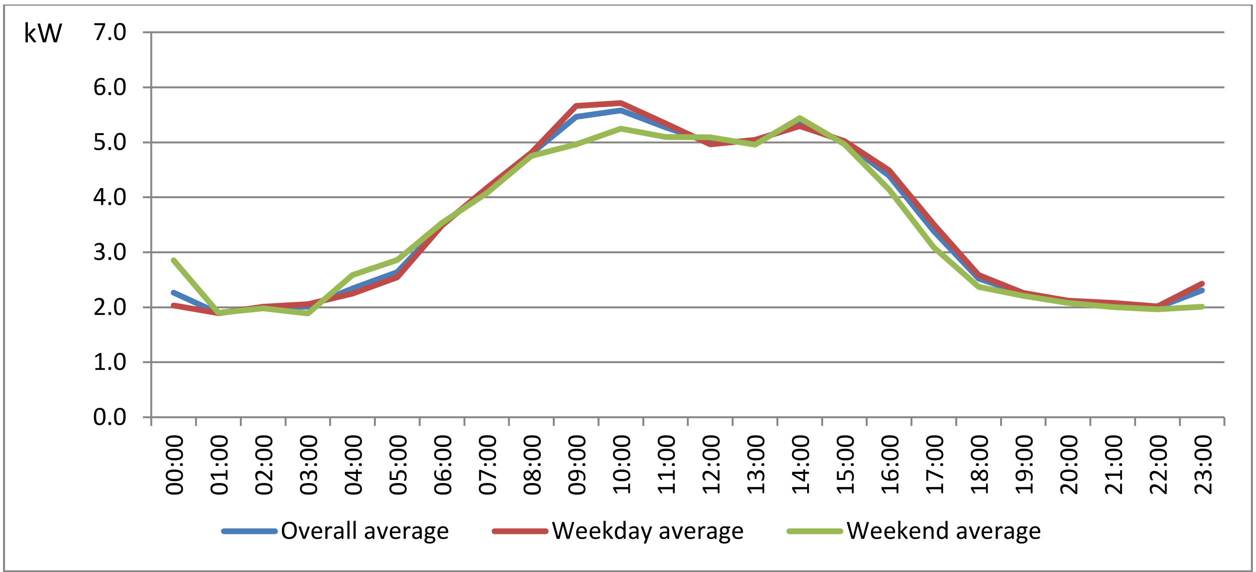


Figure 63 Hourly total electricity load profile (including PV generated electricity use)

The hourly electricity load of the building during the whole monitoring period is plotted in Figure 64. It shows that the peak load was up to 14kW in April 2013 and Feb 2014. This is mainly due to the use of space heating during that period. The typical load during working hours is around 6kW (green) and the typical load out of working hours is around 2 kW (blue), which are in line with the findings from average load figures. It is also noticeable that the load is relatively high at night in late November 2013 (light blue line). This is due to the 24/7 heating setting in November 2013.

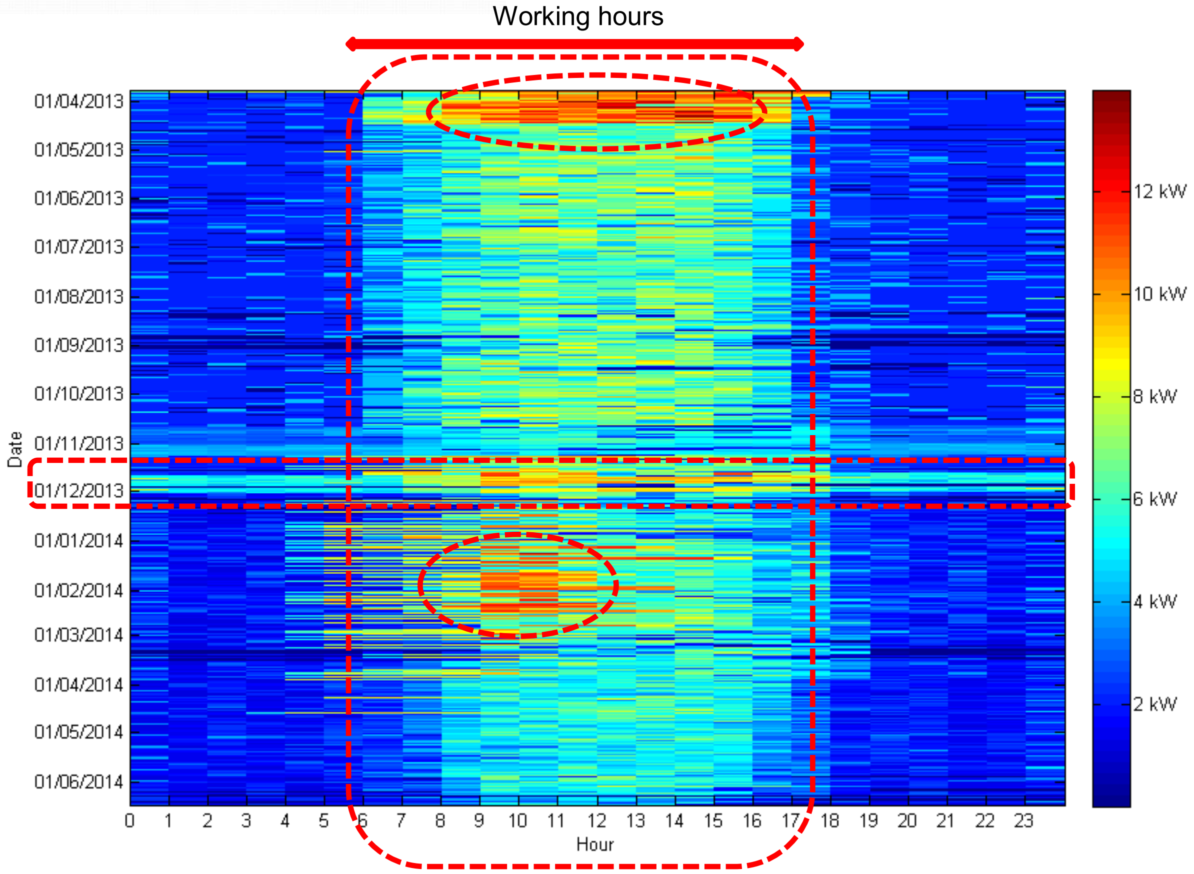


Figure 64 Hourly electricity load during 26th Mar 2013 – 15th Jun 2014 (including the use from PV generation)

The hourly profile of PV generation during the period 26th March – 1st December 2013 is plotted in Figure 65. Average PV generation rate increases to 1.0 kW at noon. The maximum PV generation rate could be up to 3kW at noon, whilst the minimum PV generation rate at noon is less than 0.5 kW during cloudy (and winter) days.

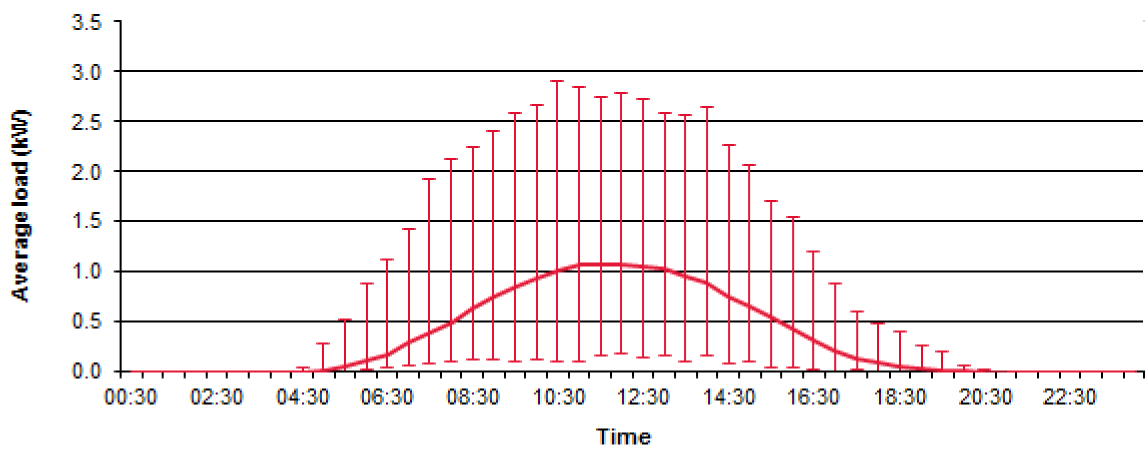


Figure 65 PV generation profile during 29th Sept 2013 – 28th Sept 2014

The hourly profile of PV export during the same period is plotted in Figure 66. The average PV export rate is minimal in general; however the exporting rate reaches up to 1 kW in some instances.

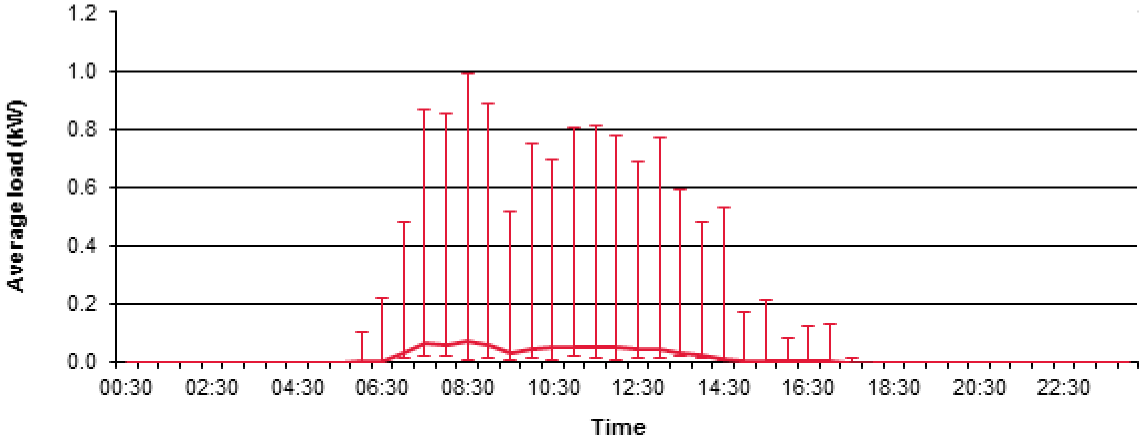


Figure 66 PV export profile during 29th Sept 2013 – 28th Sept 2014

The hourly PV electricity generation during the monitoring period is plotted in Figure 67. It shows that the PV panels produce more electricity in summer and the generation happens between 7:00 -17:00. In December the PV generation is minimal.

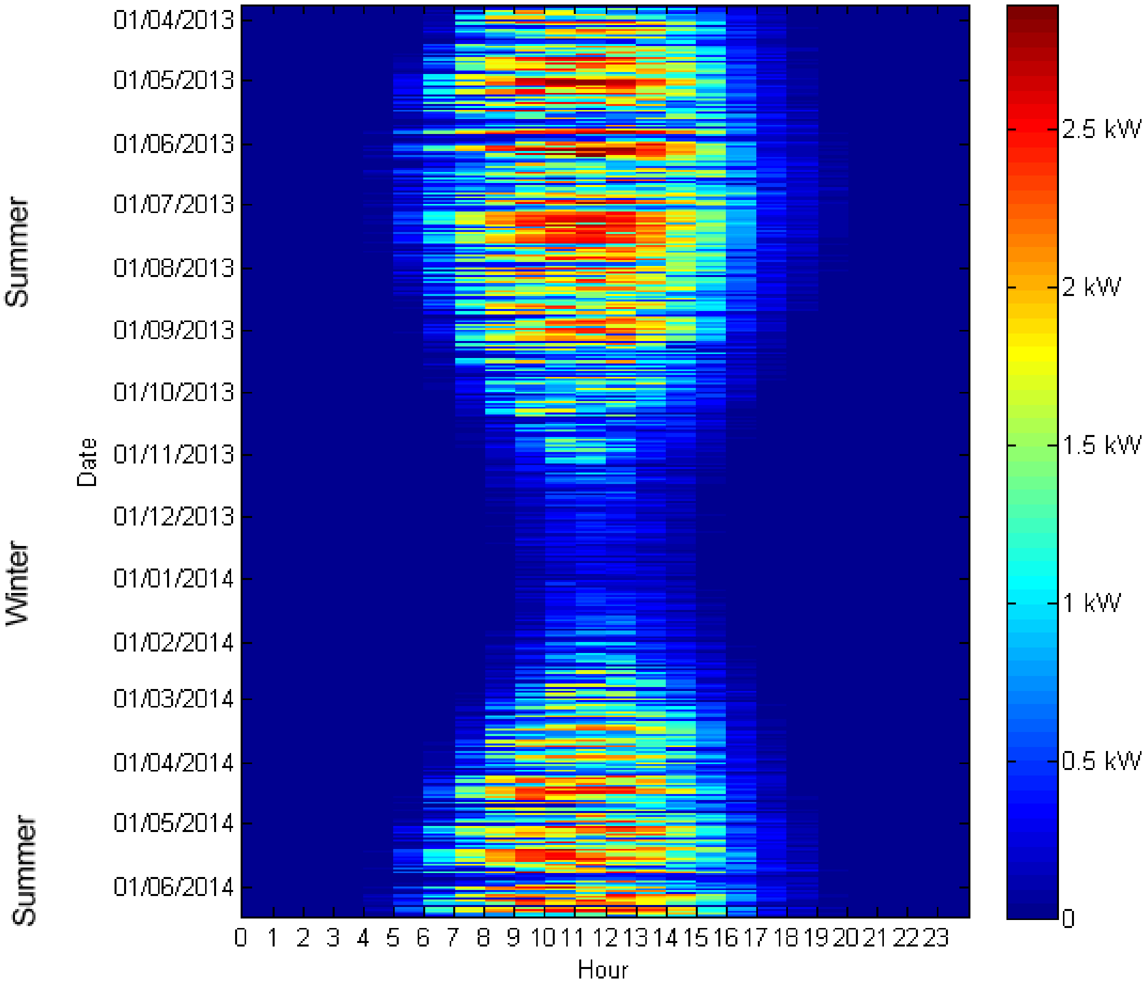


Figure 67 Hourly PV electricity generation during 26th Mar 2013 – 15th Jun 2014

6.5.6 Hourly sub-metered electricity load profile

The sub-metered hourly energy usage of the four buildng spaces and two ASHP units are plotted in Figure 68. Each block represents the hourly energy usage from 4th November 2013 to 15th June 2014 (top to bottom) and from midnight to late evening (left to right). The colour indicates hourly energy usage: the brighter the colour, the higher the energy consumption.

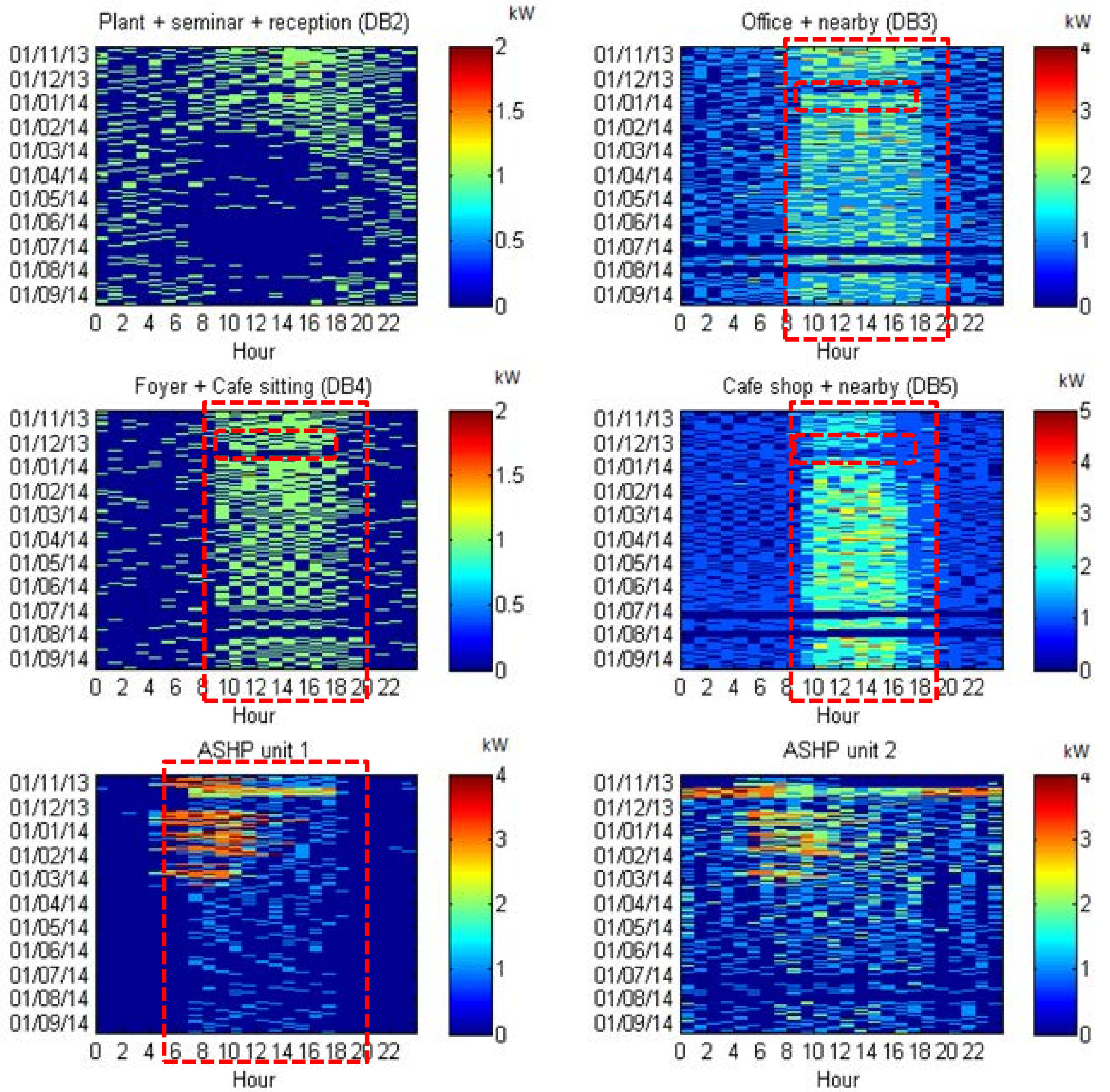


Figure 68 Sub-metered hourly energy usage during 4th Nov 2013 – 30th Sept 2014

The electricity consumption in the office (top-right of Figure 68), café shop (middle-right of Figure 68) and foyer (middle-left of Figure 68) spaces have a clear pattern indicating that electricity consumption mainly happens during working hours (9:00-18:00) all year around, apart from the Christmas break. This is also evidenced in the hourly profile figures (top-right, middle-right and middle-left of Figure 69).

The middle-right of Figure 68 also indicates that there is a slightly increasing trend of energy usage in the café shop and adjacent space (more red and yellow in the bottom part of the figure). This is in line with the findings from Figure 62. This increasing trend of electricity usage in the café shop is mostly likely due to the increased number of visitors in the summer season and a newly installed dishwasher.

The bottom 2 plots in Figure 68 shows that the ASHP units used more electricity in cold months than other spaces. ASHP unit 1 generally starts operating from 4-7am and completely switches off at 6pm. ASHP unit 2 operates all day suggesting it is used to maintain the hot water temperature in the water tank.

The distribution board 2 (top-left of Figure 68) combines energy usage from the plant room, seminar room and reception area. It used more electricity in the winter period during working hours (mainly afternoon) than in the summer months. This is partly due to the electricity usage of the water pumps in the heating system in winter, and partly due to more lighting energy usage in the seminar room and reception area during the winter. The longer daylight hours and brighter sky in summer helped reduce light energy in the seminar room and reception area.

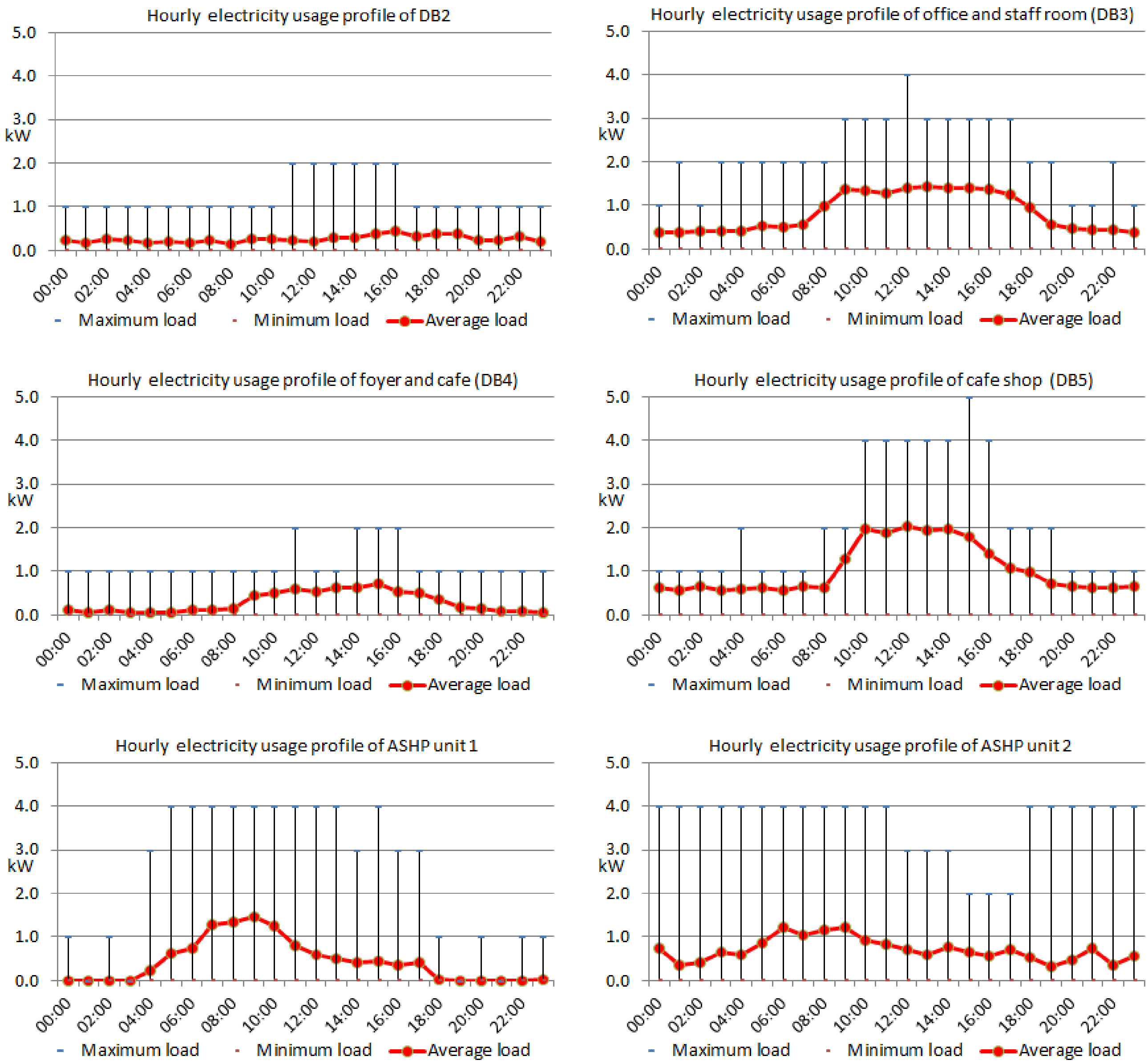


Figure 69 Hourly profiles of sub-metered electricity usages during 4th Nov 2013 – 30th Sept 2014

6.6 Efficiency of PV panels and heat pumps

6.6.1 Efficiency of PV

The hourly efficiency of the PV system during the whole monitoring period is plotted in Figure 70. The average efficiency during daytime is around 14.5% which is slightly lower than the manufacturer specified efficiency 14.8%. Given the parameters being measured, this is remarkably close to the manufacturer specified efficiency. The PV generation reaches peak at noon, the average efficiency reduces in the morning and late afternoon due to sun angles.

The relationship between weekly PV generation and the solar energy reaching the PV panels is plotted in Figure 70. There is a strong relationship between PV generation and solar energy (R^2 0.9825).

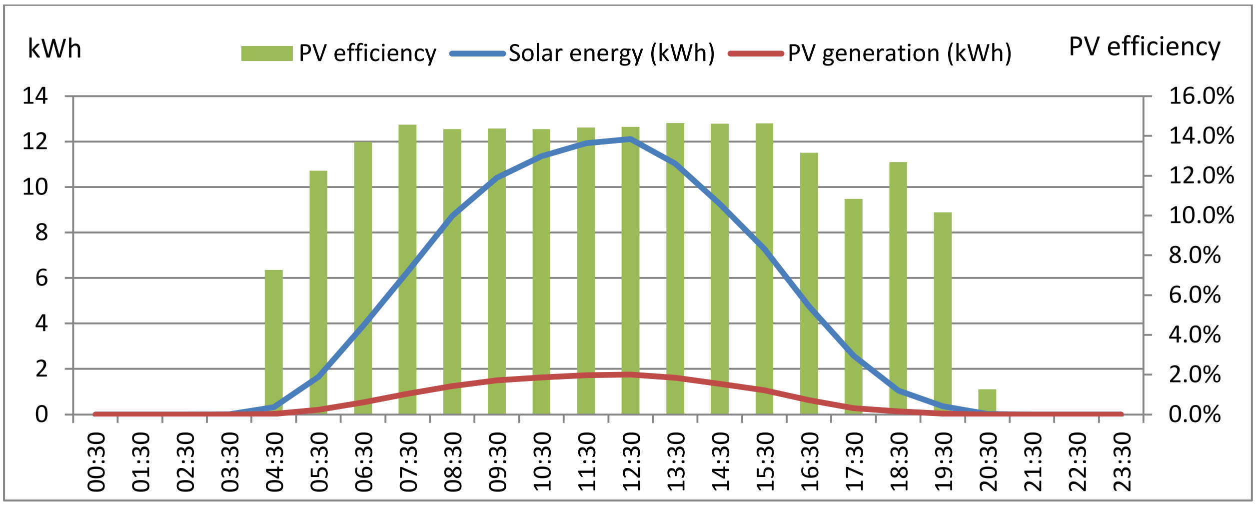


Figure 70 Overall hourly efficiency of PV panel

As discussed previously, PV generation gradually reduces from August to December (Figure 54). Overall only 5% of PV generation is exported back to grid and 95% of it is used on site, as illustrated in Figure 42. In total, 3030 kWh electricity was generated by the PV panels (3.43 kWp, 883 kWh/kWp) last year and the equivalent financial saving is £439 (9% of total bill).

6.6.2 Performance of ASHPs and its heat output

During the monitoring period (4th Nov 2013 - 28th Sept 2014), 83% of heat produced through the heat pumps was used for space heating and 17% of it was used for hot water (Figure 71). The ASHP heat output for hot water stays constant during the monitoring period, while the heat output for space heating varies according to the external temperature (Figure 72). Note that the hot water in Figure 71 and Figure 72 is produced by ASHPs and it does not include the hot water produced by local electric hot water heaters.

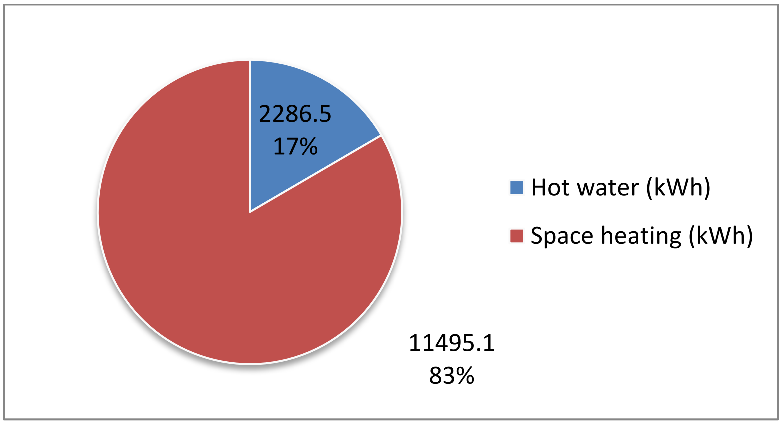


Figure 71 Percentage of heat used for space heating vs. heat for hot water from 4th Nov 2013 to 28th Sept 2014

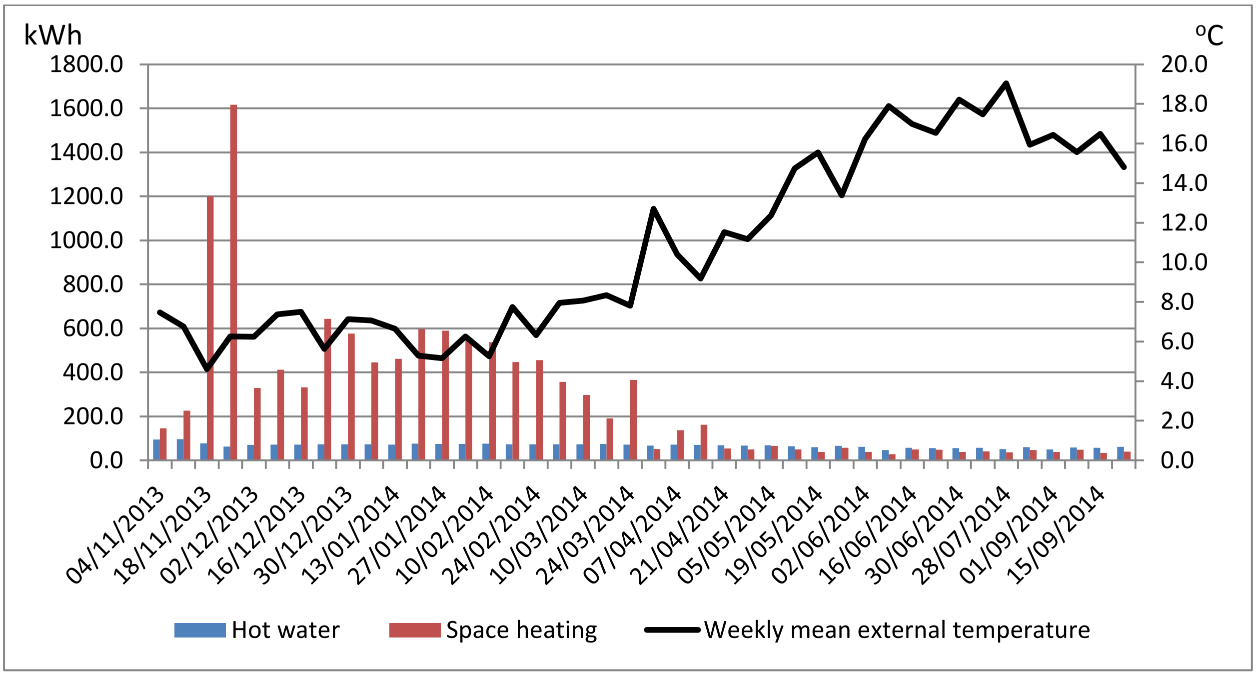


Figure 72 Weekly heat demand for space heating and hot water (ASHP only) (4th Nov 2013 – 28th Sep 2014)

The average Coefficient of Performance (COP) over the monitoring period is 1.9 (within range of 1.2 to 2.9, Figure 73), which is 24% lower that the COP value (2.63) as defined in the as-built BRUKL document. The weekly COP of ASHPs decreases from winter to summer, as the demand is less.

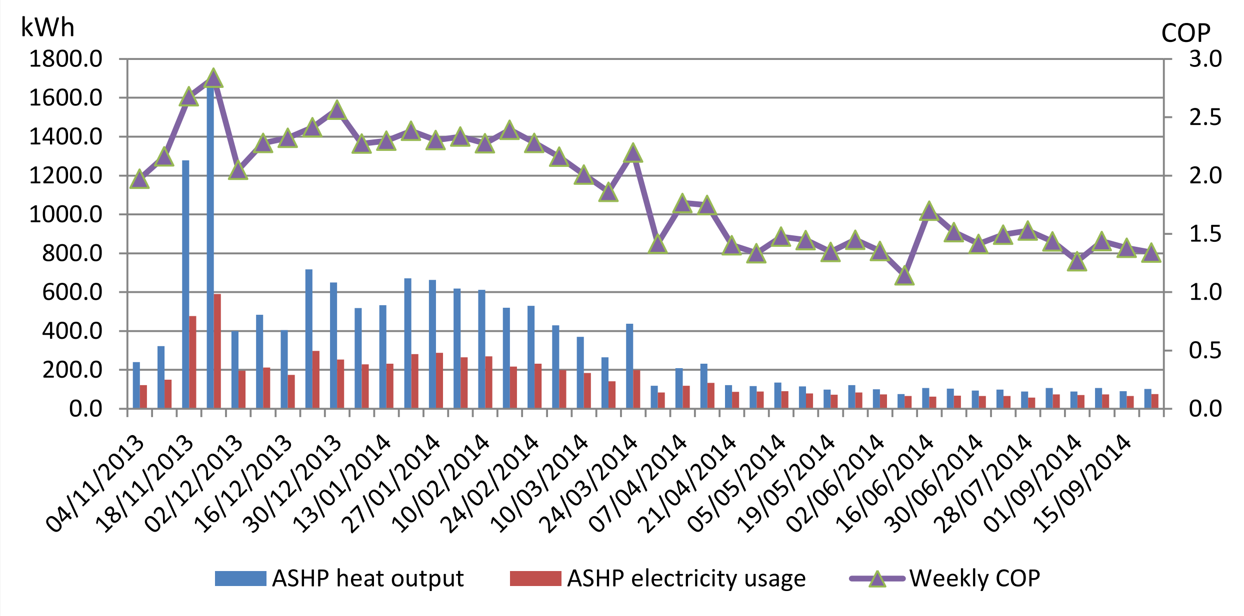


Figure 73 Weekly heat output from ASHPs and its energy usage

A detailed study (Figure 74) shows that the weekly COP drops as external temperature rises. Note that external temperature has an impact on the heating demand therefore underuse of the ASHPs in summer can also reduce the COP; Figure 73 shows that COP was around 2.6 - 2.8 in winter weeks and reduced to 1.2 in summer weeks.

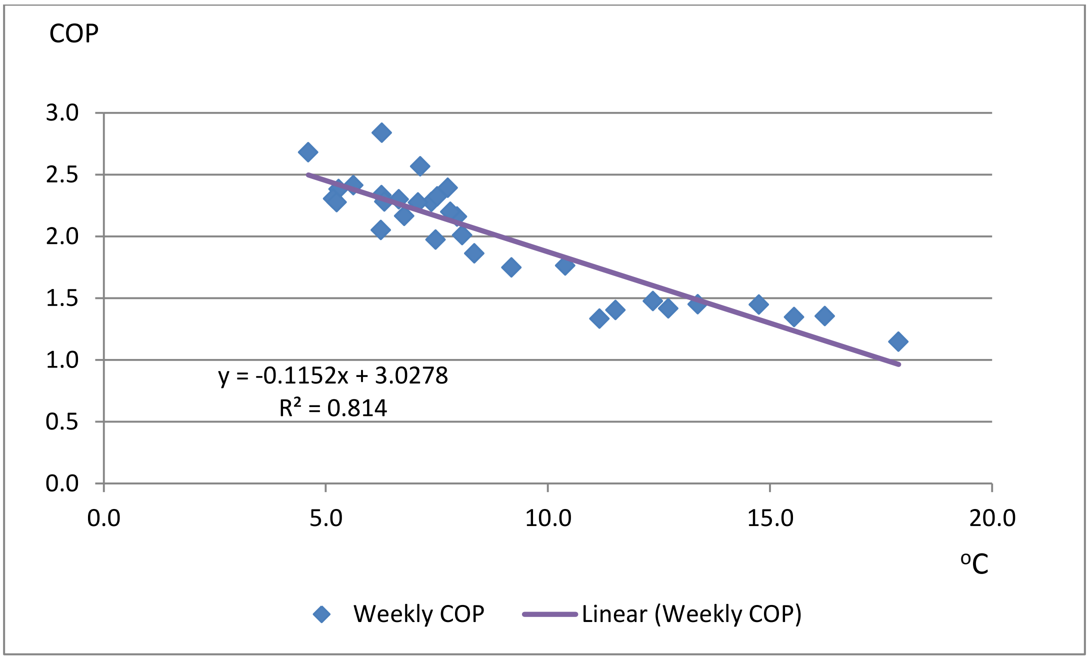


Figure 74 Relationship between external temperature and weekly COP

As a lower COP occurs in summer, it is interesting to review the design strategy for using the ASHPs for meeting the summer Domestic Hot Water demand. The electricity consumption of ASHPs in summer months (May–Sep 2014) and their heat output are illustrated in Figure 75 and Table 9. It shows that the heat for DHW is less than the ASHPs electricity consumption. If the ASHPs are used for DHW only, the efficiency is in range of 78%-86% which is less than the efficiency of an electrical heater; therefore for the summer months without any heating demand, the immersion heater could be used instead in principle. Considering the maintenance of ASHPs, the system could be running regularly to make sure that the pump and diverter valve circulates the fluid round the underfloor heating pipes and the hot water cistern can become seized up.

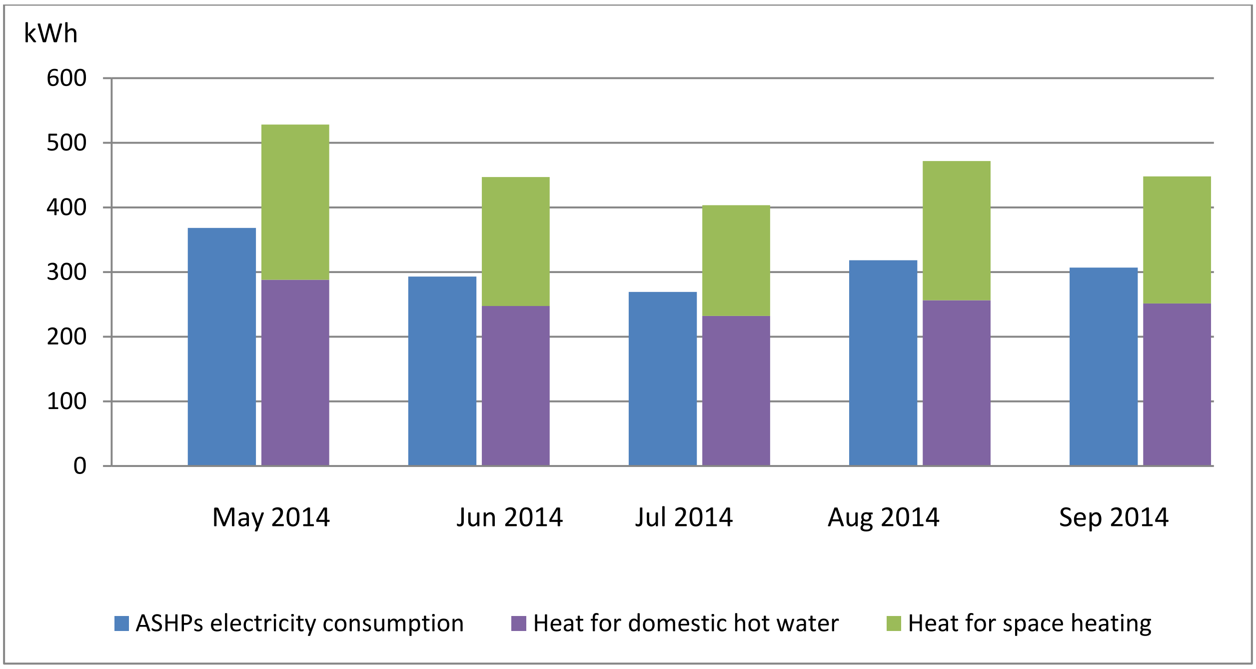


Figure 75 ASHPs electricity consumption and output in summer months

Table 9 ASHPs electricity consumption and output in summer months

	ASHPs electricity consumption (kWh)	Heat for domestic hot water (kWh)	Heat for space heating (kWh)	Heat for DHW / ASHPs electricity
May-14	368.0	288.2	240.0	78%
Jun-14	293.0	247.3	199.6	84%
Jul-14	269.0	231.9	171.3	86%
Aug-14	318.0	256.3	215.2	81%
Sep-14	307.0	251.3	196.4	82%

6.6.3 Heating and hot water heat usage profile

The ASHPs supply hot water to the WC sinks and local electrical water boilers which provide hot water for drinks in the café and staff room. The sub-metered hourly heat usages for space heating and hot water (for WC sinks only) from 4th November 2013 to 28h September 2014 are plotted in Figure 76. Both the hourly data

(Figure 76 left) and the averaged daily profile (Figure 77 left) indicate that the hot water usage reaches its peak in the morning and drops off when staff leave the building. Note that the change of starting peak hours on 30th March is due to the daylight saving time changing. The horizontal dark blue line in the bottom of Figure 76 (left) is due to missing data on 10th June 2014.

Similar to the findings from the electricity usage of ASHPs, the heating system (Figure 76 right and Figure 77 right) operates in the early morning in cold months (November to March). The horizontal light blue bar in late November 2013 is due to 24/7 setting of heating operating profile (discussed previously).

The weekly heat usage for space heating and hot water during the monitoring period is shown in Figure 72. It indicates that space heating varies according to the external temperature and electricity consumption drops as the external temperature increases. The hot water usage generally remains constant during the monitoring period.

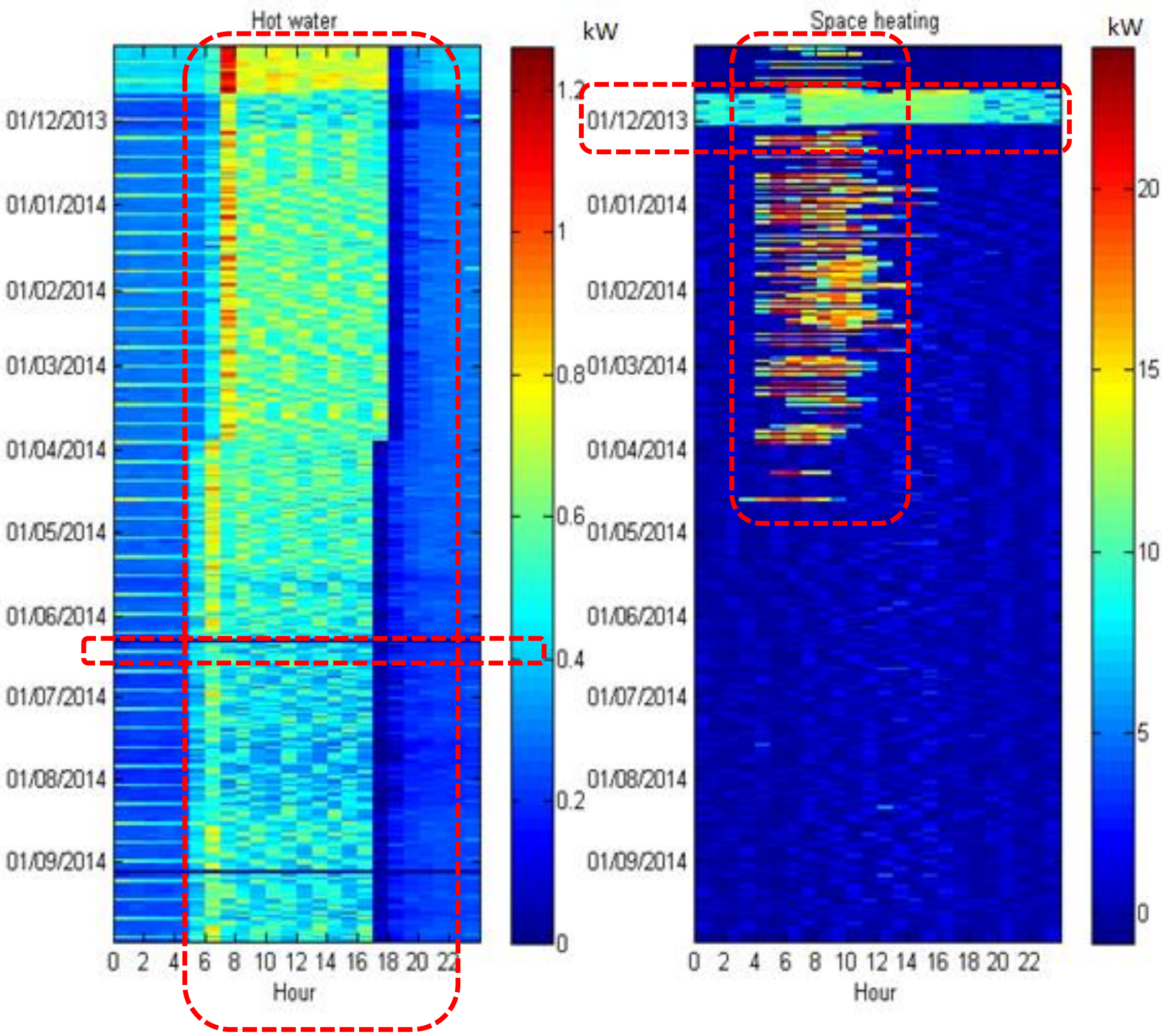


Figure 76 Hourly heat usage for space heating and hot water during 4th Nov 2013 – 28th Sep 2014

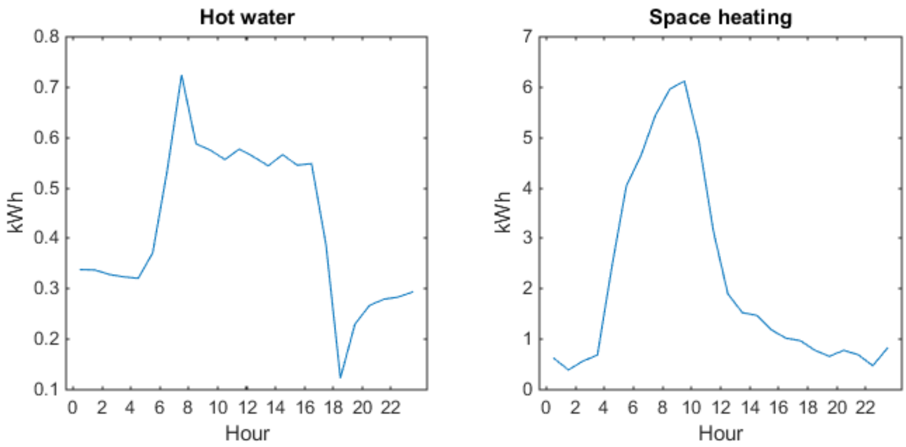


Figure 77 Daily profile of heat usage for space heating and hot water (average over 4th Nov – 15th Jun 2014)

6.7 Conclusions and key findings

- The annual total electricity usage (from both the grid and PV) of the Visitor Centre during one year monitoring period to 6th October 2014 is 33,934 kWh (93.7 kWh/m^2 per year, 85.8 kWh/m^2 per year), which is 3% higher than the benchmark specified in the BRUKL documents (with equipment energy use).
- The PV system has generated 3,030 kWh in total (3.43 kWp, 883 kWh/kWp), from which 95% has been used on-site and 5% has been exported back to the grid. The equivalent annual energy cost saving is about £439 (9% of total bill).
- The average efficiency of the PV panels during daytime is around 14.5% which is slightly lower than the manufacturer specified efficiency 14.8%.
- Renewables (PV) contribute to 8% of the total energy usage; the rest is imported from the grid.
- As expected, PV generation is significantly reduced in winter; PV export is reduced to almost zero from early October.
- Overall the actual CO_2 emissions (38.2 kg CO_2/m^2) of College Lake Visitor Centre are 65% better than the CO_2 emissions of the TM46 benchmark. Furthermore, actual emissions are only 3% higher than the benchmark specified in the BRUKL documents (37 kg CO_2/m^2 including equipment). These findings suggest that the building performance is very similar to that specified during the design stage.
- There is little difference between weekday and weekend load profiles, because the visitor centre is used seven days a week. The base load is around 2.0kW at night and the average load increases up to 6kW during working hours.
- During the period from 20th November 2013 to 2nd December 2013, the space heating was almost constantly on due to the temporary faulty settings of the heating system made during maintenance.
- Even for a passive low energy building, space heating demand is much higher than the demand for hot water- almost 83% of the energy produced by the heat pumps was used for space heating and 17% was used for hot water. However demand for hot water presents a fairly constant load fluctuating

around 0.5 kW, whereas the load for space heating fluctuates between 0 and 24 kW. These findings highlight the fact that hot water demand in buildings of this type is much lower, and much more controllable, than the space heating demand.

- The average Coefficient of Performance (COP) of the heat pumps over the monitoring period is 1.9 (ranging from 1.2 to 2.9), which is 24% lower that the COP value (2.63) defined in the as-built BRUKL document (which follows the manufacturer’s specifications). The COP stabilised at 2.6 - 2.8 in winter weeks and reduced to 1.2 in summer weeks.
- The electricity consumption of ASHPs peaks in the early morning, whereas the electricity consumption for appliances and lights peaks around midday and early afternoon. During the monitoring period, 25.8% of the total building electricity consumption is used by the ASHPs.

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 Controls

Highlights of the review of the in-use performance and usability of controls are summarised in this section. For detailed photographic and graphic survey of each control refer to Quarter 4 Evidence 2 Forensic survey for assessing performance and usability of controls report.

Heating and hot water controls

- The usability of heating and hot water control of the ASHP is not intuitive and needs instructions to use it properly. The heating and hot water controls are located the plant room which is accessible from outside the building only. The building manager and a volunteer engineer are responsible for operating the heating and hot water system. The building manager understands the basic operation of the system, such as switching the heating on, and setting up the weekly running profile. The BMS and Heat Pump system manual are available but it was found to be very technical. It would be recommended that the other member of staff also receive training on how to operate the heating and hot water system. A clear and easy-to-read manual could also help.
- The degree of fine control offered by the controls of the ASHP is good. However, it is not clear how the building is zoned. It is very likely that only one temperature setting applies for all spaces. Many thermostats were found in the building space. The temperature range of the thermostat controls is not clear and indication of system response is unknown due to the slow response of underfloor heating system. The building manager advises users not to use the thermostat and leave it on a neutral setting. It would be recommended that the building is further zoned and the thermostat is kept at lower temperatures in office are during weekend.
- Tighter control of required internal temperatures for different activities and spaces would help in increasing comfort levels and reducing energy usage.
- The response of the underfloor heating system is known to be slow. All occupants might be not familiar with this sort of system and could reduce perceived thermal comfort.

Electrical equipment controls

- The electrical control panel are intuitive to use and have good labelling and annotation.

- Light switches are intuitive to use. But there is no indication of which switch controls which row of lights therefore users need to experiment.
- The lights in some spaces offer a good level of fine control. E.g. Automatic dimming light control is available in the seminar room. Presence detectors are functional in the office space.
- The control of the PV system is accessible from outside the building, located in the separate timber structure. The switching for the device is not intuitive and more clarity of purpose is needed. Clear indications of on/off and response are displayed on the control panel.
- The control of fans is intuitive and easy to use. The response of control is clearly visible, and there is very good labelling indicating its purpose and how to operate. There are three options of fan speed on the control panel.
- Assistance on the use of the audio system in the seminar room is needed. It is recommended that training on how to operate this system is given to regular users and an easy understandable user guide is also needed.

Water services controls

- Kitchen taps are well labelled and easy to use. Mixing tap allows for a good degree of fine control. Intuitive and easy to use. Good water flow is available.

Door, windows and blinds

- Windows and doors purpose and operation are clear. Windows are intuitive to open and offer security.
- Top windows are difficult to reach and operate manually. Motors were added to the top windows of the visitor area and office which allow users to open them by pressing a switch. Electrical windows control interface is intuitive to use and well labelled.
- The ventilation strategy relies on stack and cross ventilation. It is recommended that further explanation on how the ventilation strategy works is given to users. Additionally it is important that management takes care in ensuring each space is ventilated before and after the use of spaces, as well as when the spaces are in use.
- Continuous window opening in the heating season may increase the energy usage of the building. This indicates the fact that occupants may not be particularly concerned about energy usage in the building, and comfortable environmental conditions are not achieved without occupant adaptation.
- Blinds offer a good degree of fine control. They are easy to use. In some cases the blinds are kept closed by the users and artificial lighting is used which may be leading to energy wastage.

Others

- The number of people passing the check point is displayed on screen. It is an important factor for the visitor centre. The number on the screen is clear and easy-to-read for everyone.

7.2 Residual of sub-metering data and the usage of electric immersion heater

The sub-metered weekly electricity usage during 10th November – 14th December 2013 is plotted in Figure 78. It shows that the ASHP outdoor units, office spaces (DB5) and kitchen (DB3) have bigger energy usages than other spaces. The consumptions from the distribution boards are relatively stable over the time period, whereas the consumption from ASHPs outdoor units varies significantly depending on the external temperature.

The BPE study has noticed a significant amount of residual (not sub-metered energy, red bar in Figure 78 in this building. It could be attributed to the consumption of the electric immersion heater. Further study shows that the electric immersion heater was continuously on due to the fault of the exchanger responsible for the water; the problem was fixed on 20th November 2013. Following this, the residual reduced significantly from 25% to 5% as illustrated in Figure 79.

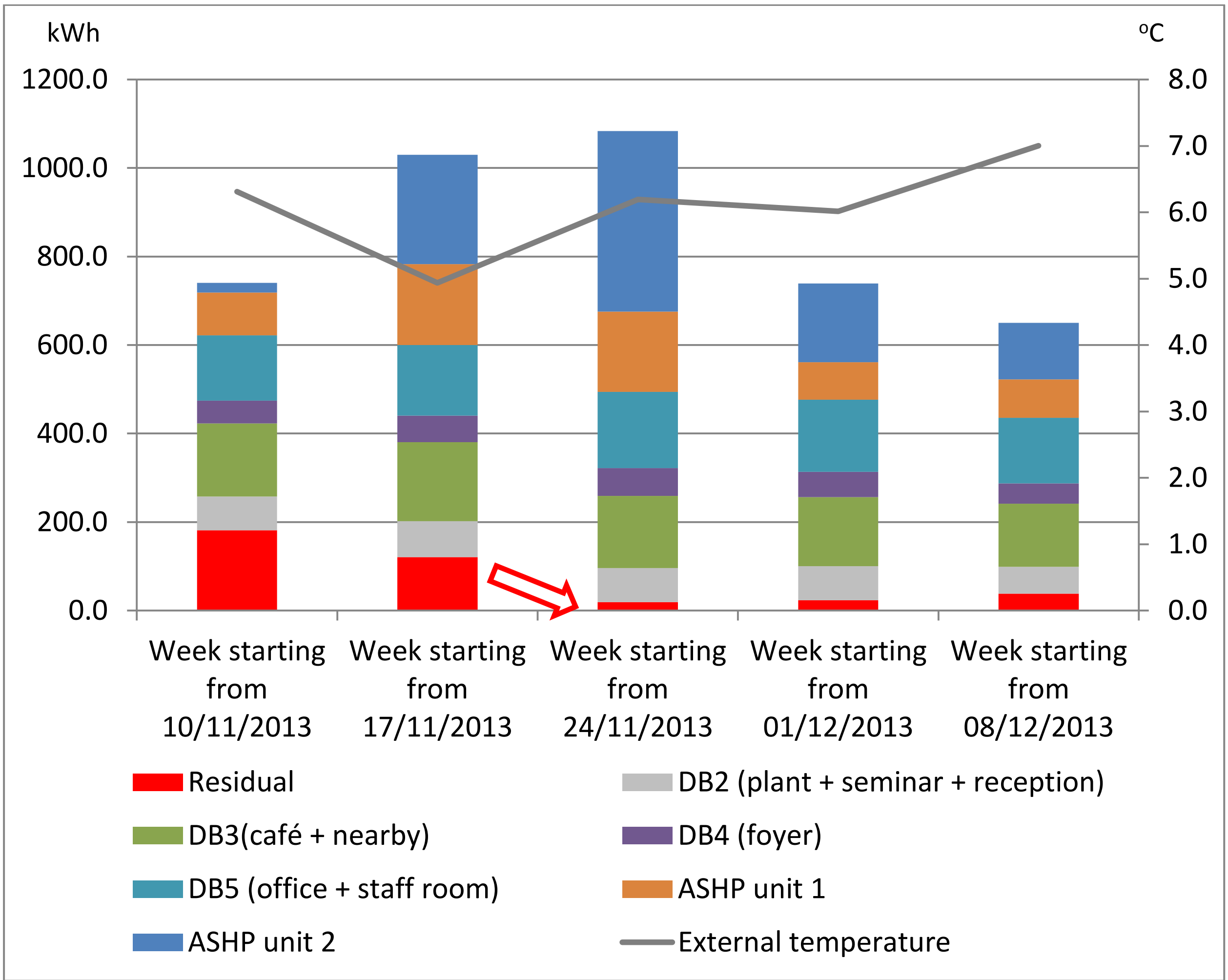


Figure 78 Sub-metered weekly electricity usage 10th Nov – 14th Dec 13

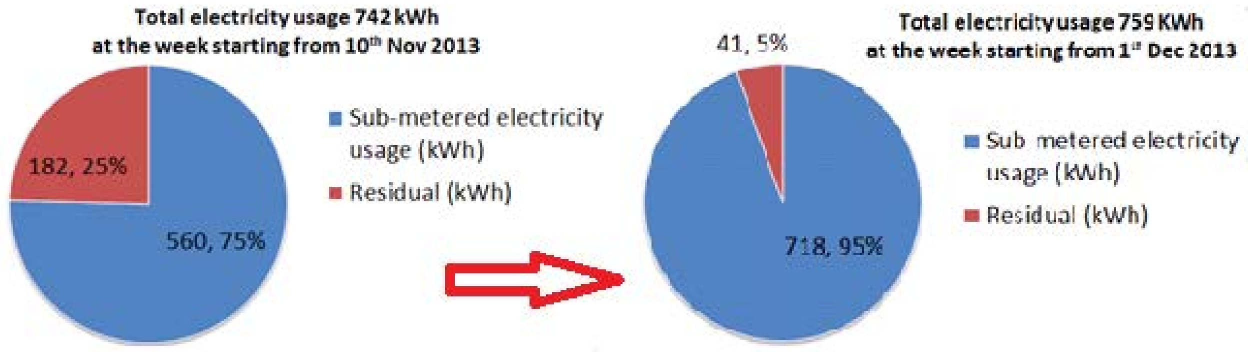


Figure 79 Residual reduction by fixing the fault in the workings of the electric immersion heater

7.3 Operating hours of heating system

The room temperatures and heating load during the winter period are plotted in Figure 80. It shows indoor temperatures range between 18°C-23°C in general, however it is noticeable that indoor temperatures are reasonably high (over 25°C) during the period from 20th November 2013 to 2nd December 2013 because the space heating was on almost all the time. This is likely to be due to the settings of the heating system in that period being incorrect. The problem was fixed on 2nd December 2013.

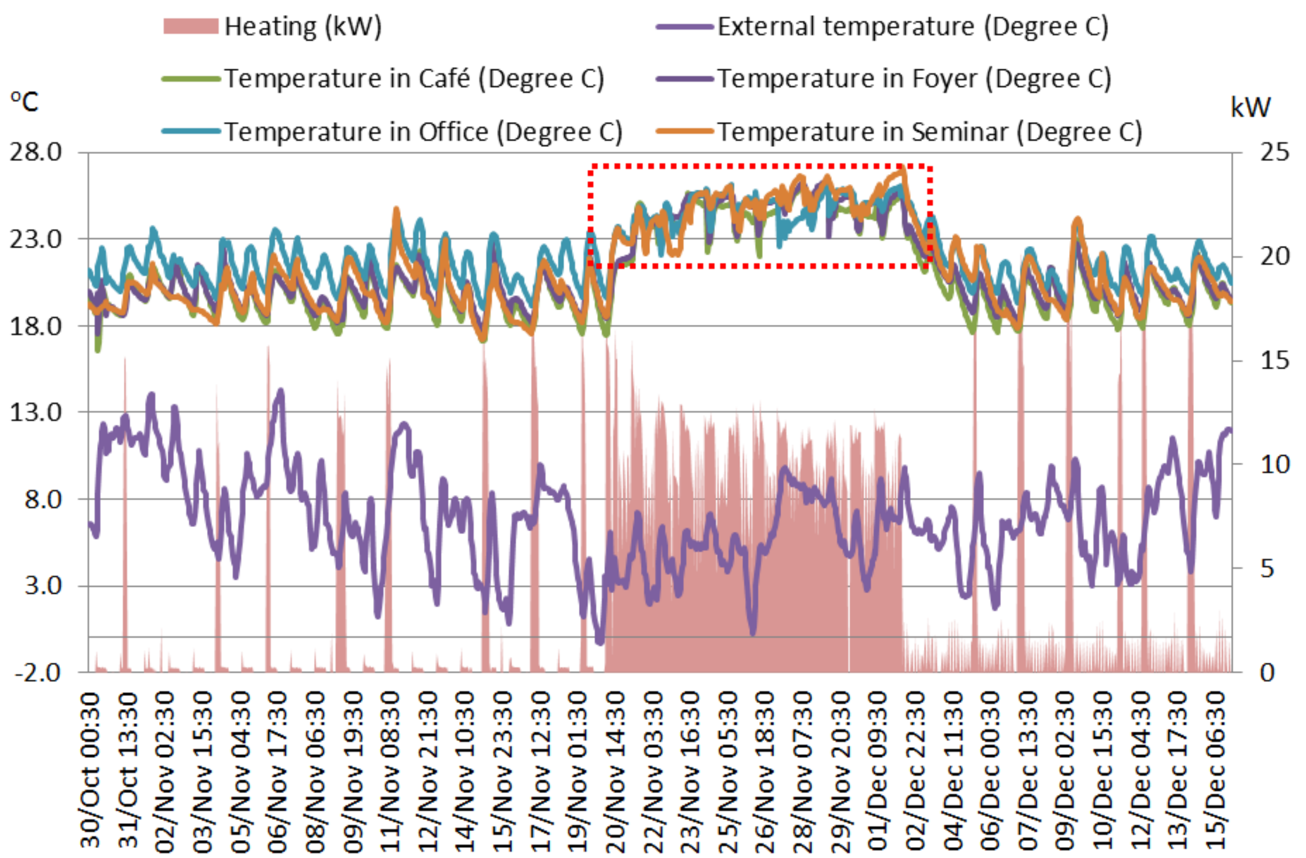


Figure 80 Indoor/outdoor temperature and heating demand in winter

Further analysis has been carried out for November and December 2013 in order to evaluate the energy demand during winter months. A 10-week winter period (3rd November 2013 - 11th January 2014) was selected to analyse the relationship between the ASHPs' heat output and its electricity demand for this particular period. The hourly ASHPs' electricity demand is closely related to the fluctuations of the ASHPs' heat output, as illustrated in Figure 81. It is noticeable that there is a different operating pattern (high energy consumption and output) during 21st November -2nd December 2013 .

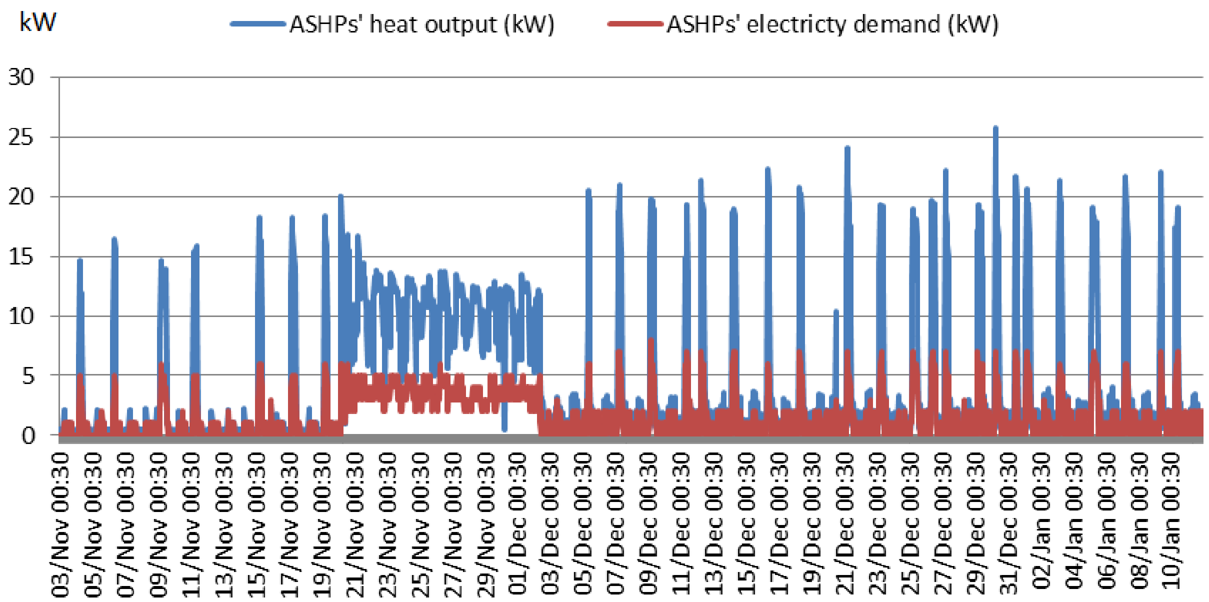


Figure 81 Heat output from ASHPs and its energy demand in typical winter weeks

7.4 Technical review of equipment

A site survey was undertaken to identify any areas of potential energy wastage. The occupants have a strong awareness of their energy use and take great care in ensuring lights and electrical appliances are switched off at the socket when no one is in the room. However, a few areas of energy wastage were identified.

The key equipment energy consumption was established through a walkthrough inside the visitor centre in order to spot and measure the energy consumption of the different equipment and devices. The data analysis was undertaken using one of the aspects of CIBSE TM22 v2.17 (Figure 82).

A list was compiled with on-site observations noted during the walkthrough. The power rating of running appliances was measured using a portable true power meter (Figure 83). The operation schedule of each device was defined and the data were entered in the CIBSE TM22 v2.17 tool. However, it was not possible to measure the true power rate of some appliances due to its usage, such as the Internet server (Figure 84), and fly catcher light. The measured appliances include: touch screen TV, desktop PCs, laptops, torch charger, phone charger, Walkie-talkie charger, microwave, coffee machine, laminator, cash register, Chip and PIN card reader, exhibition light, fridges, and freezer.

The calculation of equivalent full load hours is calculated for each season as follows: Equivalent full load hours = Seasonal hours available (from profile) x Usage Factor x Load Factor x Seasonal usage factor. The equivalent full load hours for each of the three seasons are then added together to determine the annual total.

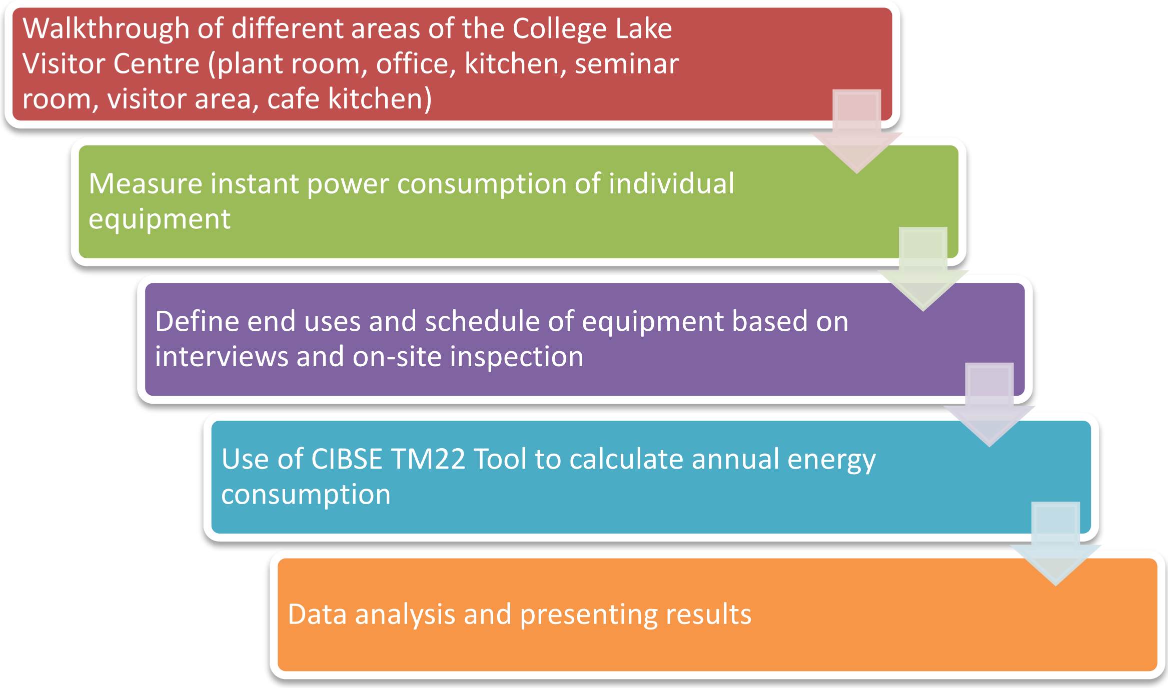


Figure 82 Calculation of key equipment energy consumption schematic

Figure 83 True power meter- energy monitoring socket

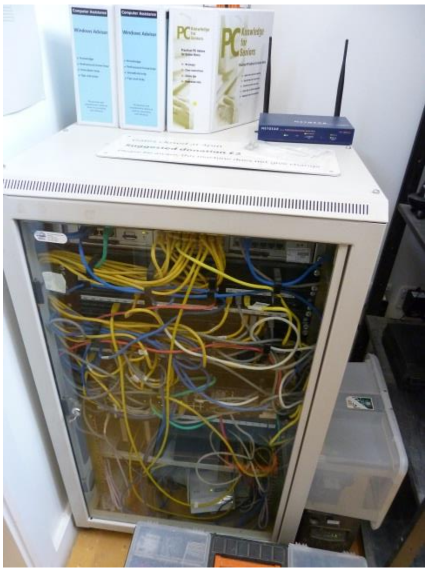


Figure 84 Internet server & UPS

The annual energy consumption breakdown of the appliances showed that the Internet/telephone server, touch screen TV, fridge and desktop computers consume the largest amounts of electricity. The Internet/telephone server consumes 1,226kWh/annum whereas the touch screen TV consumes 703kWh/annum. It is to be noted that due to lack of measured data it is assumed that the server has a power rate of 0.7kW with a 1.0 load factor. Other kitchen and office appliances such as the electricity hot water heater, microwave, fly catcher light and printer were found to consume reasonable amounts of energy in range of 300- 500kWh/annum. The wireless router, cash register machine, chargers and bank card reader consume less than 30kWh of electricity annually.

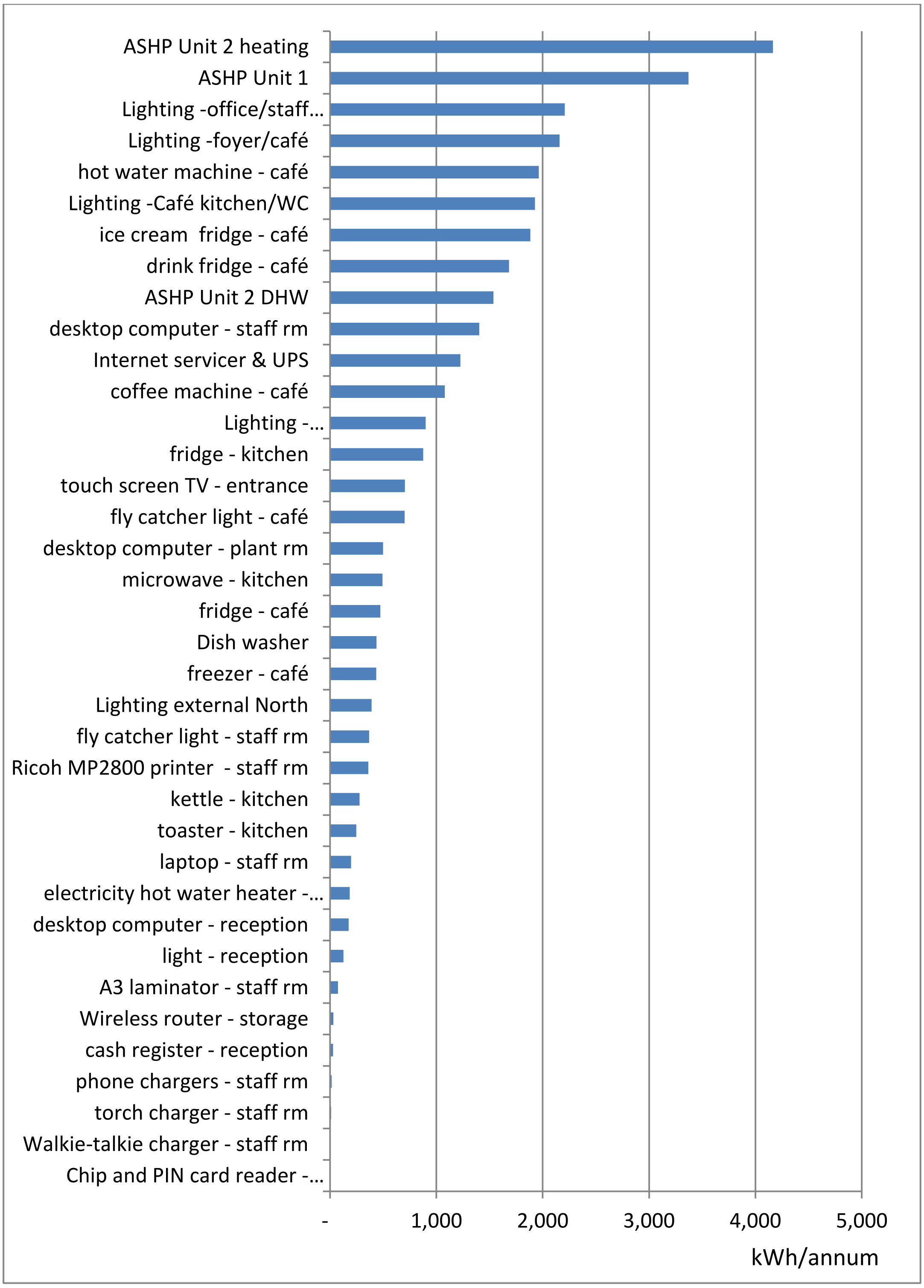


Figure 85 Appliances annual energy consumption breakdown (kWh/annum)

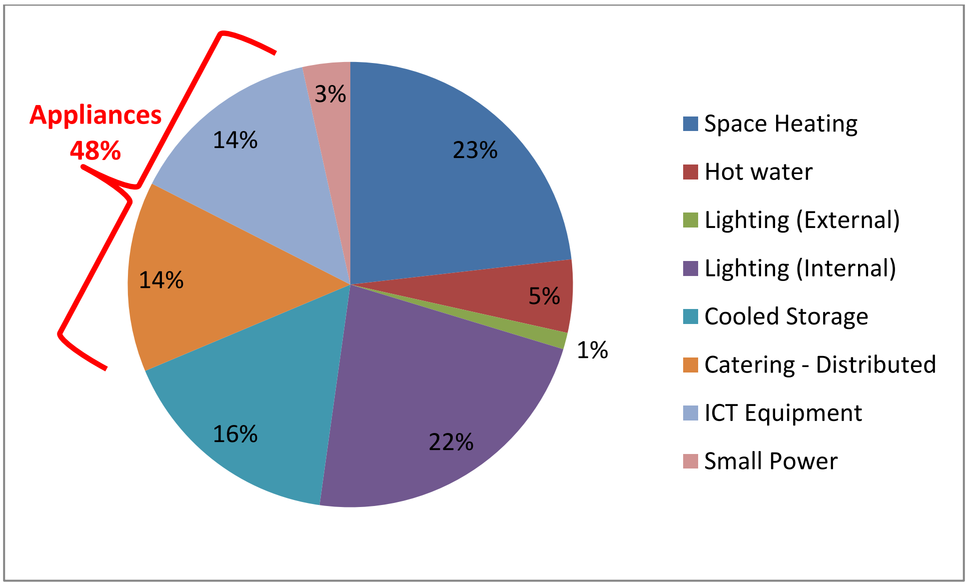


Figure 86 Annual electricity consumption distribution by end use category

The heating and hot water consumes 28% of total electricity used by the building. The lighting (both internal and external) consumes 23% of total electricity. Appliances consume 48% of total electricity, including 16% for cooled storage (fridge and freezer), 14% for catering and 14% for ICT equipment respectively (Figure 86).

7.5 Conclusions and key findings

Key findings from the survey of performance of controls are:

- The operation of ASHPs should be carefully monitored by facility manager. Any faulty event should be quickly identified and fixed.
- The average COP of ASHPs over the monitoring period is 1.9 (within range of 2.6 - 2.8 in the winter, but reduce to 1.2 in the summer).
- Heating and hot water controls are not intuitive and need instructions for using them properly.
- The degree of fine control offered by the BMS is good. However, it is not clear how the building is zoned. It is very likely that only one temperature setting applies for different thermal zones.
- The electrical control panel is intuitive to use and has good labelling and annotation.
- The control of fans is intuitive and easy to use. The response of control is clearly visible. Very good labelling indicates its purpose and how to operate.
- Kitchen taps are well-labelled and easy to use. Mixing tap allows for good degree of fine control. Intuitive and easy to use. Good water flow is available.
- Windows and doors purpose is clear. Windows are intuitive to open and offer security.

- Top windows are difficult to reach and operate manually. Motors were added to the top windows which allow users to open them by pressing a switch. Electrical windows control interface is intuitive to use and well labelled.
- Window opening for a short period in winter could improve the air quality; however continuous window opening for a longer period during the heating season may lead to increased heat loss and result in higher energy use for heating.
- The Internet/telephone server, touch screen TV, fridge and café machine were found to consume the largest amount of electricity followed by the desktop computers. This shows how ICT equipment is becoming a key end use of energy in sustainable buildings intended to have a low heating demand.
- Annual electricity consumption of key equipment contributes to 52% of the total building electricity consumption when compared to the annual electricity consumption data of the previous year.

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 findings across BPE study elements

Table 10 below presents a summary of the key findings associated with the BPE study elements.

Table 10 Key findings across BPE study elements

BPE Study Elements	Findings
Review of handover and commissioning	• Although several problems were identified during handover, users are generally satisfied with building's performance and available facilities. • The first FM received a handover but following staff change and a delay in the appointment of a new FM, the current FM did not receive an internal handover. Despite this, he has made considerable efforts to understand the building systems and controls with the help of the assistant FM. • FM has established good communication with sub-contractors who are responsible for maintenance of the building. • Energy sub-meters were not connected to the BMS, as required by the system specifications, raising questions about the commissioning of the system.
Occupant satisfaction survey using BUS questionnaires	• The overall picture of the survey revealed a positive opinion towards the Visitor Centre. • An overview of the BUS survey responses reveals that users are especially satisfied with the building's image to visitors, design of the building and overall air quality and indoor temperature. Furthermore, the building is meeting their needs. • All but three of the building's 'overall categories' of the BUS survey are rated as significantly better than the BUS benchmark. • Overall noise, health and perceived productivity are rated as similar to the BUS benchmark. Health and productivity might be affected by the feeling of 'stuffiness' experienced by occupants at times and especially when windows are closed for long periods. • Open plan design is likely to cause noise (from visitors and colleagues), thereby reducing the perceived productivity.
Operation, maintenance and	• An official building logbook does not exist and maintenance and breakdowns are not being recorded as required by building regulations.

management	• No user guide has been produced on how to operate the building services on an on-going basis as well as in breakdown. • FMs do not usually refer to O&M manuals for guidance when there is a building defect, but prefer direct communication with contractors. This, combined with the lack of a logbook and proper documentation, may lead to information being forgotten as time passes or not being passed on to new staff members following staff changes. • No clear guidance on energy metering and sub-metering strategy of the building was provided through handover data. • The designers who are also the project managers were not involved in any arrangements for seasonal commissioning, aftercare or maintenance. • Since a building logbook was not issued during handover there is a lack of information about maintenance procedures having been undertaken in College Lake since commencement of occupation.
Analysis of actual performance	• CO_2 levels may exceed the recommended limit of 1000ppm during the afternoon and during times of high occupancy. However, CO_2 levels recorded are not considered problematic. The annual total electricity usage (from both the grid and PV) of the Visitor Centre during one year monitoring period to 6th October 2014) is 33,934 kWh (93.7kWh/m^2 per year including PV, 85.8 kWh/m^2 per year excluding PV), which is 3% higher than the benchmark specified in BRUKL documents (with equipment energy use). • The PV system has generated 3,030 kWh in total (3.43 kWp, 883 kWh/kWp), from which 95% has been used on-site and 5% has been exported back to the grid. The equivalent saving is £439 (9% of total bill). • The average efficiency during daytime is around 14.5% which is slightly lower than the manufacturer specified efficiency 14.8%. • Renewable (PV) contributes to 8% of total energy usage; the rest is imported from the grid. • As expected, PV generation is significantly reduced in winter. PV export is reduced to zero from early October. • Overall the CO_2 emission (38.2 kg CO_2/m^2) of College Lake Visitor Centre is 44% better than the CO_2 emissions of the TM46 benchmark. However it is 3% higher than the benchmark specified in BRUKL documents (37 kg CO_2/m^2 including equipment). • 83% of the energy produced by the heat pumps was used for space heating and 17% was used for hot water. • Average Coefficient of Performance (COP) over the monitoring period is 1.9 (within range of 1.2 to 2.9), which is 24% lower that the COP value (2.63) defined in as-built BRUKL document. COP stabilised at 2.6 - 2.8 in winter weeks and reduced to 1.2 in summer weeks.
Review of performance and usability of controls	• The controls are simple to use and effective. Occupants and management are satisfied with them. • Original controls for velux windows and kitchen hatch had to be changed by the management as they were unnecessarily complicated.
Energy wastage	• Management is very conscious of reducing equipment electricity consumption by switching off all appliances that are not being used.
Thermal imaging	• Thermal bridging at the junction of roof with external wall

8.2 Suggestions for improvement- categorised as no, low, medium & high cost measures

Table 11 below presents a summary of the key findings associated with the BPE study elements.

Table 11 No, low, medium & high cost measures for improving the case study building

Cost	Improvement	Disruption to occupants
No cost	**Lighting** • Clean and replace bulbs when necessary • Switch lights off when spaces are not in use **Heating and hot water** • Reduce the heating setpoint by 1-2°C if necessary • Change the heating setpoint to 15°C during Christmas holidays **Ventilation** • Open both high and low windows in office during lunch time in winter to improve CO_2 level. This could be included in the Duty manager's job list. • Use trickle vents to improve CO_2 level (Figure 87) in winter • Use ventilation system in seminar room during meeting • Add label to ventilation control **Appliances** • Switch appliance off if they are not in use	Low Low Low Low Low Low Low Low Low
Low cost (<£1k)	**Lighting** • Replace lamps with more efficient ones **Heating and hot water** • Commission the system annually **Ventilation** • Add vent diffuser to the ventilation outlet in seminar room • Install CO_2 watchdog in seminar room and office to raise the awareness of air quality **Appliances** • Use energy efficient appliances	Low Low Medium Low Low
Medium (£1k to £5k)	**Heating and hot water** • Use solar thermal for hot water in summer (cost around £3,000 to £5,000) **Ventilation** • Replace the ventilation system in seminar room with Mechanical Ventilation Heat Recovery System	Medium Medium

	• Install CO_2 sensor in seminar room to control the ventilation • Install automatic windows opening controller based on both CO_2 level and temperature in office	Medium Medium

Figure 87 Use trickle vent for improving CO_2 level in office

8.3 Recommendations and key messages

Key messages for the client, owner and occupiers are as follows:

- The BPE study has made considerable impact in fine-tuning the building performance by getting the BMS system re-commissioned, identifying and replacing electricity sub-meters that were not working, and reducing energy wastage from the residual electricity use.
- As a charitable organization, they may not have dedicated full time building manager. Increasing the energy awareness of the building occupants can ensure that the building operates efficiently.
- Include building or facility manager in the pre-construction design meetings if possible. However for a small organisation like BBOWT, permanent facility manager may not be possible.

- Commissioning of BMS should be followed through and deployed for active energy management of the building. Dedicated computer for BMS helps to record data for longer periods.
- Tailor a bespoke move-in support plan with the user and owner from the project start – including a programme of induction sessions.
- Ensure that there is internal communication of handover and training within the organisation in case personnel leave.
- Create an office culture that the discussion and communication between colleagues can be conducted in staff kitchen or seminar room. This could reduce internal background noise level and increase the working productivity.
- Make sure that facility managers and building users attend handover sessions.
- Open windows manually for a *short* time during lunch time to ensure a good supply of fresh air in winter. Windows also can be opened so that background ventilation can take place.

Key messages for the industry are as follows:

- Graduated handover is necessary for smooth running of the building – including a programme of induction sessions. More user-friendly and better-organised documentation on performance of services, systems and controls should be provided.
- Develop a visual and easy to understand user guide for occupants and FM. Architects should take the lead on this.
- Better training on the M&E building services should be provided to FMs and users, e.g. presentation sessions and walkthroughs with the design team and contractors.
- Overheating in naturally-ventilated buildings should be tackled through adaptive comfort opportunities. Ventilation in winter is essential for maintaining good levels of air quality without increasing energy use (e.g. use of trickle vents in windows).
- Self-consumption of PV electricity should be encouraged to avoid paying for grid electricity.
- BPE can be used as a diagnostic tool for identifying services or systems faults. Embed evaluation of building performance as part of building management walkthroughs, photo survey, discussions with occupants and site manager, hindsight review, energy logging and assessment.

Key messages for building operators are as follows:

- Make sure that facility managers and building end users attend handover sessions.
- Natural ventilated buildings provide thermal variation across seasons which are usually perceived to be comfortable by users if the building is managed well.
- Hot water in summer can be heated using electric immersion rather than heat pumps.
- Maintenance contracts for low energy systems (heat pumps) should be put in place for smooth running of these systems.
- FM or building owner to check commissioning of BMS and sub-meters post-handover. Since BMS systems are usually capable of receiving energy data, having a dedicated computer for BMS helps it to record data for longer periods for energy management.
- FM team should use the BMS system for active energy management of the building. Review the heating setpoint settings in BMS and reduce the heating setpoint slightly if necessary to avoid hot feeling in winter.

Reflection on the evaluator feedback

The feedback provided by TSB evaluator has helped to identify the areas of focus of the BPE study as (1) Effectiveness of 'fabric first' passive approach (2) Energy use compared to CIBSE, industry benchmarks using TM22 (3) Comfort criteria in office, meeting spaces with reference to summertime overheating (4) Performance of air-source heat pumps (5) The effect of the specified construction systems on moisture levels (6) The impact of the users on energy management and use.

1. The earth retaining structure and green roof north facing have helped to reduce heat gain in summer. The monitoring data shows that the building does not exceed CIBSE overheating criteria and BS EN 15251 adaptive thermal comfort criteria. The building fabric also helps to maintain comfortable indoor temperatures in winter while at the same time the heating energy use is responsible for 23% of total energy consumption (usually over 50% in conventional non-domestic buildings).
2. Comparisons are made in sections 6.1 and 6.4. Supplied energy use and resultant CO_2 emissions are significantly lower than the TM46 benchmark and ECON 19 benchmark (both good practice and typical benchmarks). Overall the College Lake Visitor Centre uses mains electricity that equates to half the CO_2 emissions of the TM46 benchmark. However, it is 3% higher than the benchmark specified in BRUKL documents.
3. Thermal comfort study has been described in section 4.2. More than half of occupied hours in café, foyer and seminar room are within CIBSE Guide A recommendations. About 20% of occupied hours in café, foyer and office are above CIBSE Guide A recommendation. About 1.0%, 1.5% and 1.9% of occupied period in Foyer, office and Café respectively are overheated in 2013 (over 1% of occupied hours over the 28^{o}C threshold, CIBSE criteria). However the café, foyer and office haven't exceeded the overheating CIBSE criteria (1%) and adaptive thermal comfort criteria (BS EN 15251) in 2014.
4. The performance of air-source heat pumps is reported in section 6.6.2. The average Coefficient of Performance (COP) over the monitoring period is 1.9 (within range of 1.2 to 2.9), which is 24% lower that the COP value (2.63) as defined in the as-built BRUKL document. The weekly COP of ASHPs decreases from winter to summer, as the demand is less.
5. The monitoring data shows that the summer RH, for the majority of occupied hours (over 80%), is within the recommended range 40-70%. In winter, over 90% of occupied hours are within the recommended range. Further study shows that the measured RH patterns appear to be more influenced by external conditions than internal moisture generation rates (from visitors). In winter (when windows are closed), there is a positive correlation between the CO_2 variation and absolute humidity variation. This indicates that both CO_2 and absolute humidity are affected by people (typically generating 40–60 grams per hour per person absolute humidity, based on CIBSE Guide A).
6. Regular project meetings and workshops were held with the building management team and building users. They have become more engaged with controlling their indoor environment and reducing energy use. Occupants have felt that the BPE study has helped them to understand deeper about how the building actually works and also discover faults related to building performance. The study has also helped to highlight the wintertime over-heating issue. This has resulted in a change in setting of the timing when the ASHPs switch on, which has in turn saved electricity. Occupiers have also learnt the need to open lower level windows (slightly) in conjunction with the upper window to create effective air flow in the office.

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.

The BPE study of a civic building such as College Lake Visitor Centre has provided important lessons for the industry, clients, developers, building operators and the supply chain. The BPE study has revealed several issues regarding lack of commissioning of BMS systems and connection with sub-meters, design of sub-metering arrangements by space and not by end use of energy, inadequate documentation of building performance through commissioning records, logbooks and user guides, as well conflict with window controls, as well as management and maintenance of the building. The study has also enhanced the capabilities of the building management team, and helped to fine-tune the building performance, which was the initial aim of the BPE study also.

Wider lessons learnt from the study for different stakeholders, are presented in the following sections.

Lessons for industry

- As much as possible, involve the FM team right from the inception and briefing stage of a building project so that expectations can be managed and appropriate services and systems can be designed and specified for a particular building type.
- Consider the usability of all control interfaces; discuss the interface design with manufacturers and provide feedback on controls.
- Trial building user guide design with laypersons to ensure they are not overly technical and are user friendly.
- The installation and commissioning process for services (e.g. ASHP systems) are critical; ensure technicians are knowledgeable about the process and documentation is thorough and complete. Provide on-site training at all levels to ensure appropriate fitting of materials and equipment.
- The commissioning of BMS systems should be checked especially the connection with sensors, energy meters and sub-meters. BMS should be set up to receive and retain data at least for 6 months.
- Ensure there is reconciliation of outputs from meters and sub-meters to ensure they have been set up and commissioned properly.
- Sub-metering arrangements should be designed according to sub-meter end uses to facilitate energy management.

- In-depth knowledge about the site and context is vital. Investigate how nearby road noise, for example, can impact occupant satisfaction resulting in reluctance to open windows (with unintended knock-on effects leading to discomfort and increased energy usage).
- Communication and involvement of all parties involved in the design and construction process (including client and suppliers) through all stages is essential. This includes documentation and agreement for all changes to be shared for successful future development.
- Soft Landings based approach is highly recommended to ensure that design teams remain engaged with the project post-handover and during the in-use stages. The following could be adopted as part of s SL approach:
  - At the design development stage, review design targets, usability and manageability – involving future building manager(s). Confirm roles and responsibilities of all stakeholders.
  - Before handover, include FM staff and contractors in reviews.
  - During the first few weeks of occupation there should be support from the design and construction team by conducting demonstration of operation and maintenance of controls and technologies for the building users, and providing technical guidance to the FM and building manager in a clear, simple manner.
  - Final stage involves 1-3 years of aftercare, monitoring, review, fine-tuning and feedback.

Lessons for clients and developers

- The clients should ensure good engagement and communication between all stakeholders possibly through a Soft Landings framework. Ensure that FM team is involved from early on in the project.
- Ensure that design and construction team has adequate expertise in delivering the design intent of the project.
- Insist on proper documentation of performance of building fabric, services and systems
- In case of a change in FM team, ensure that internal handovers are thorough and induction and training are properly documented through audio and video recordings.

Lessons for building operators

- Provide hands on training (and re-training) of equipment and controls for occupants and staff preferably after commissioning has been satisfactorily completed, and the occupants have had time to settle in and develop personal queries around the operation of the building
- Reach out and provide an atmosphere of openness where occupants can discuss concerns regarding their environment and control. When a building operator is willing to work with clients to find the most comfortable condition for the majority, the use of additional personal heating equipment can be reduced.

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 Monthly and weekly profile of temperatures, CO_2 levels and humidity

10.1.1 Monthly maximum, minimum and mean temperature

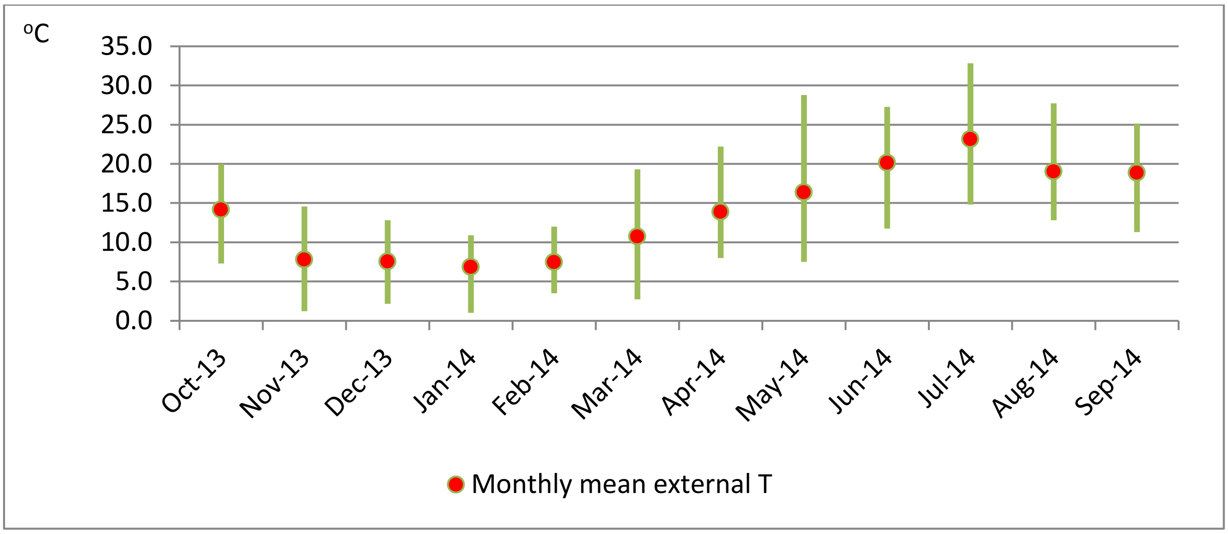


Figure 88 Monthly maximum, minimum and mean external temperature

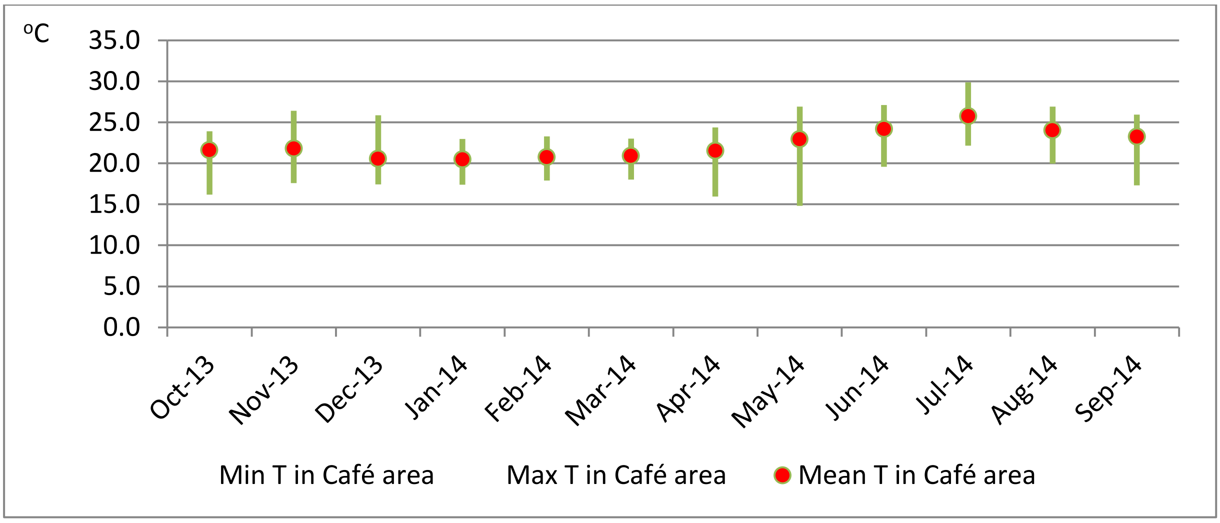


Figure 89 Monthly maximum, minimum and mean temperature in cafe

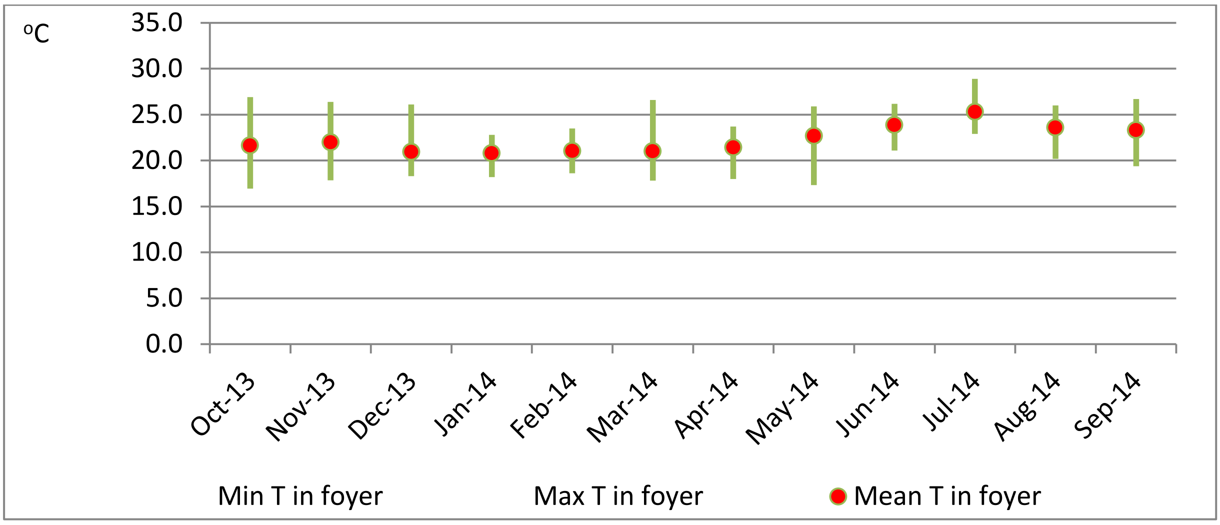


Figure 90 Monthly maximum, minimum and mean temperature in foyer

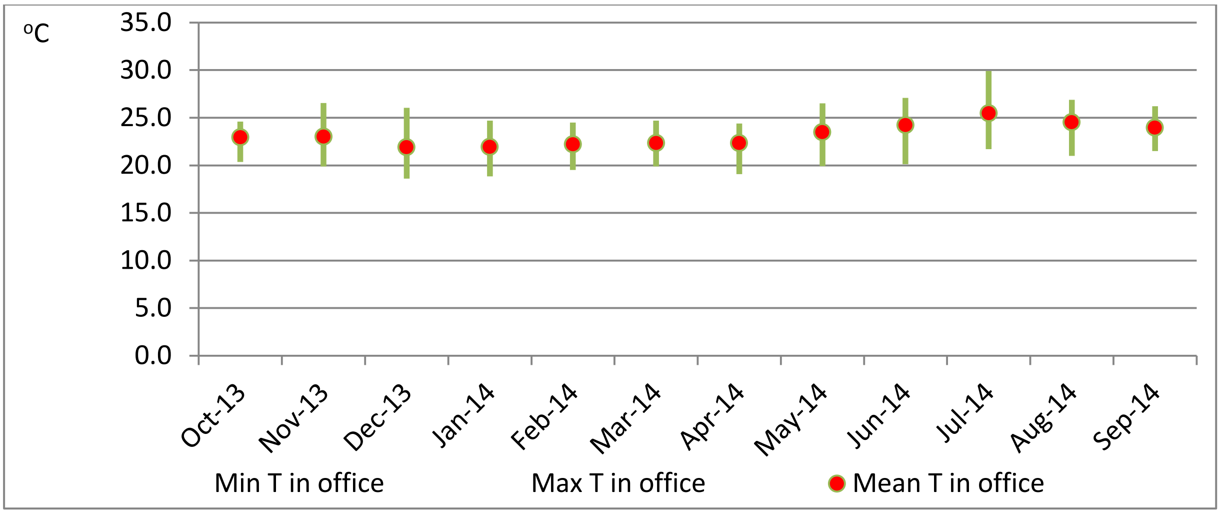


Figure 91 Monthly maximum, minimum and mean temperature in office

10.1.2 Typical winter week and typical summer week

Temperatures range between 20°C-25°C during a typical winter week (27th Jan – 2nd Feb 2014). Café space is 1-2°C cooler than office space in winter

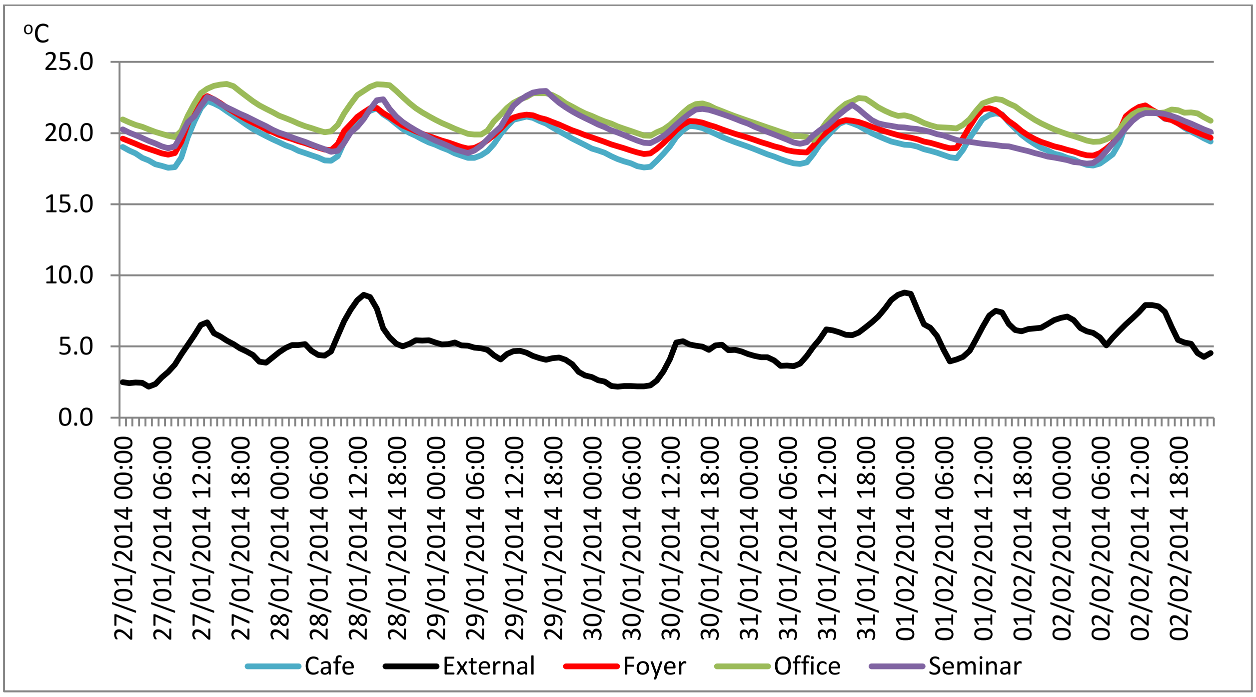


Figure 92 Temperature in typical winter week

Temperatures range between 24°C-30°C during 14th July – 21st July 2014. There is an overheating risk when external temperature is higher than 30°C. Café space is 1-2°C warmer than office space in summer.

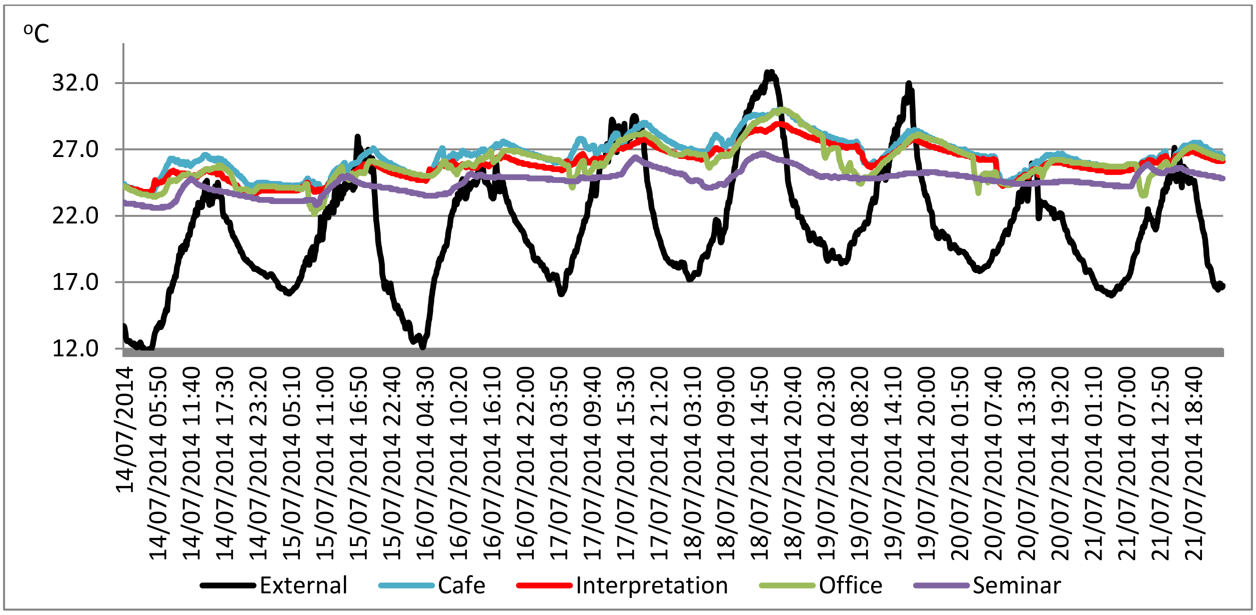


Figure 93 Temperature in typical summer week

10.1.3 Winter daily average and summer daily average

Office temperatures range between 25°C-27°C in summer. Temperatures in seminar room range between 23°C-25°C. The lowest temperature occurs in early morning, and the highest temperature happens around 6pm.

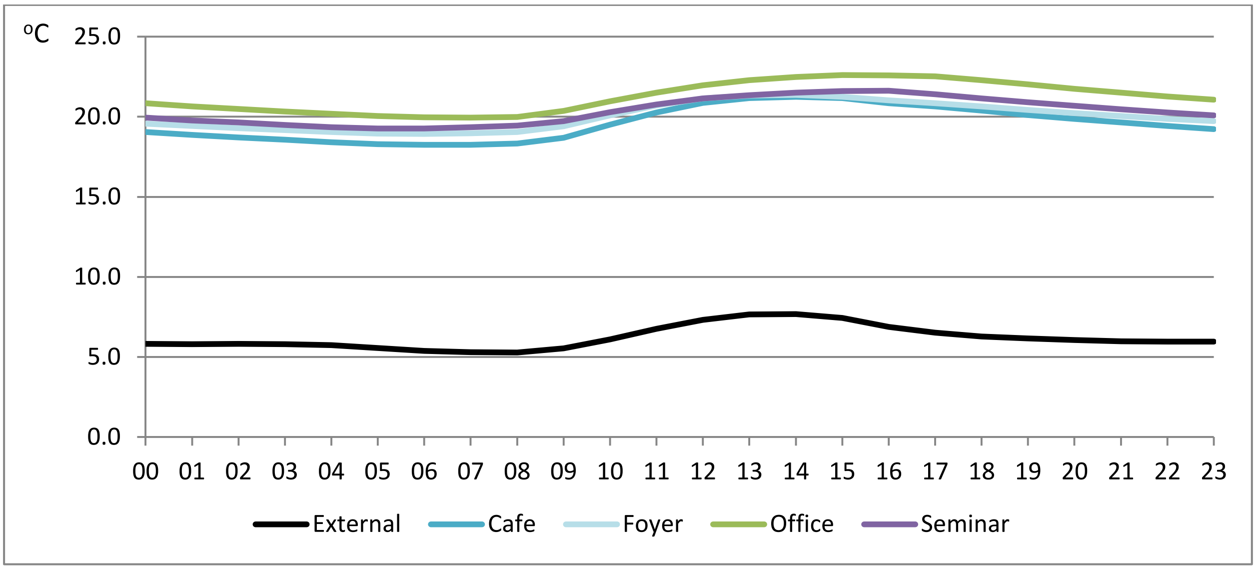


Figure 94 Average hourly temperature in Jan 2014

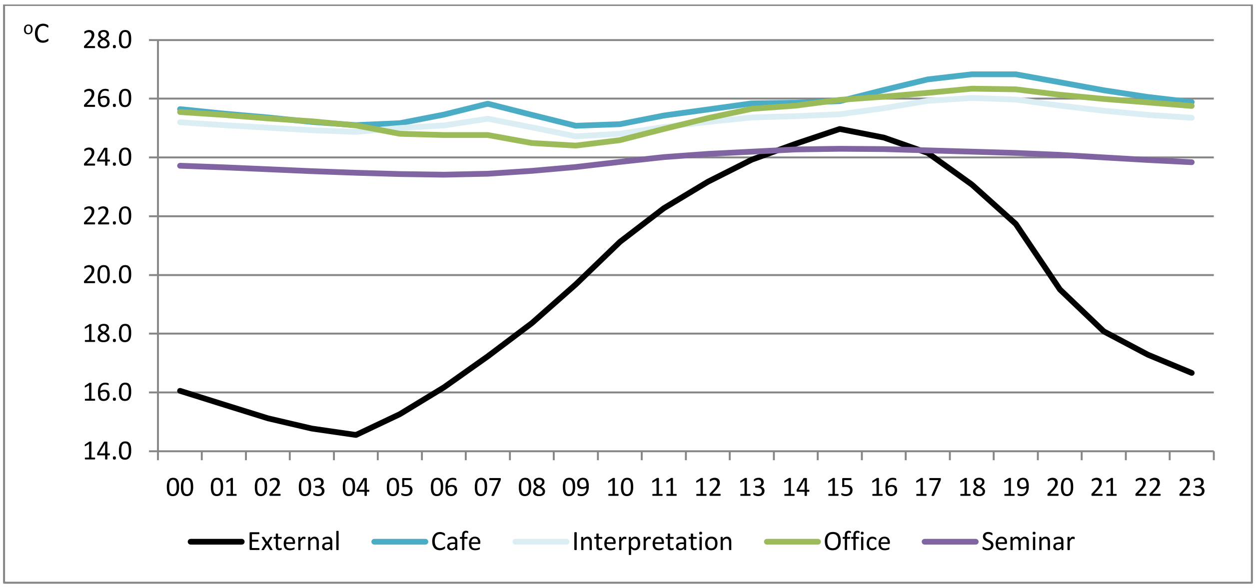


Figure 95 Average hourly temperature in July 2014

10.1.4 Monthly maximum, minimum and mean RH

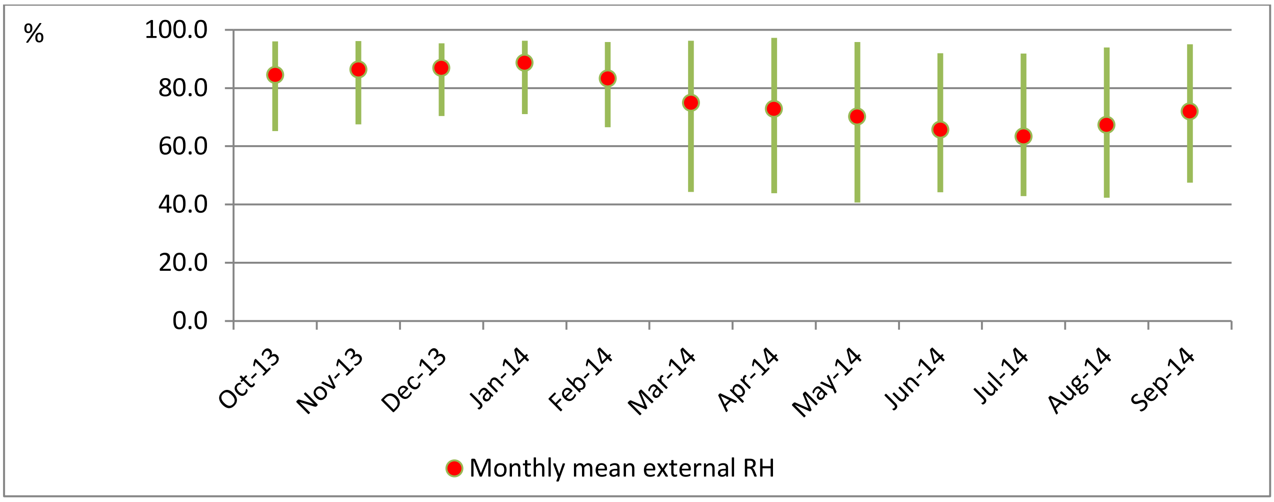


Figure 96 Monthly maximum, minimum and mean external RH

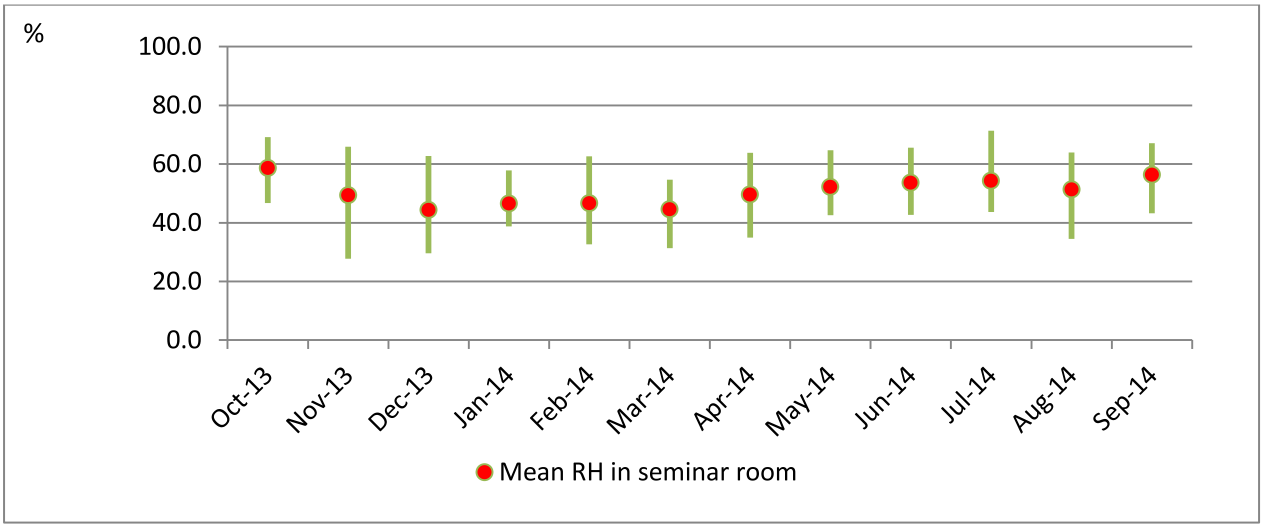


Figure 97 Monthly maximum, minimum and mean RH in seminar room

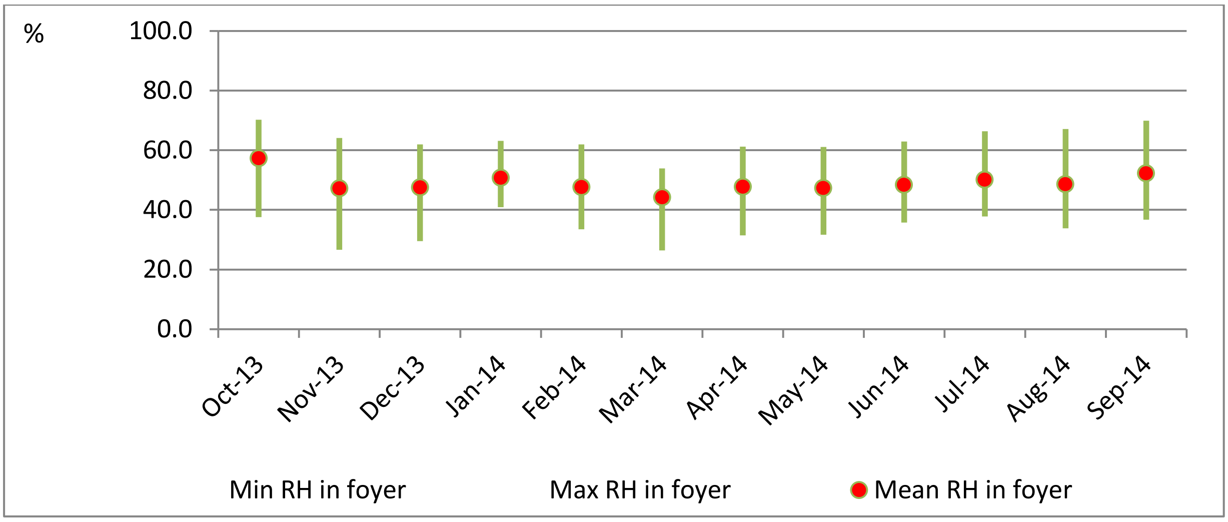


Figure 98 Monthly maximum, minimum and mean RH in foyer

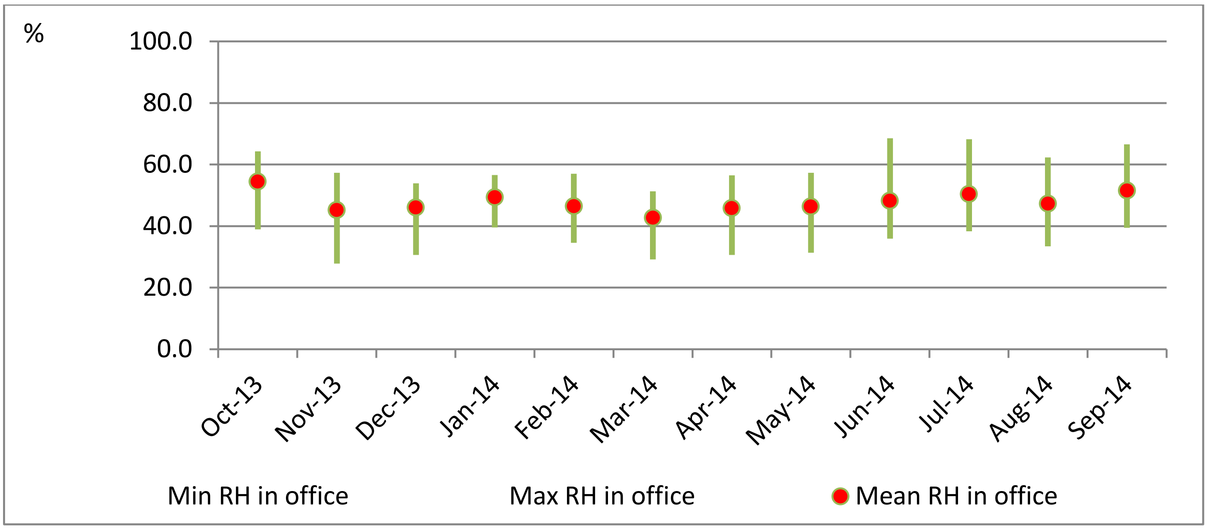


Figure 99 Monthly maximum, minimum and mean RH in office

10.1.5 Monthly maximum, minimum and mean CO_2 level

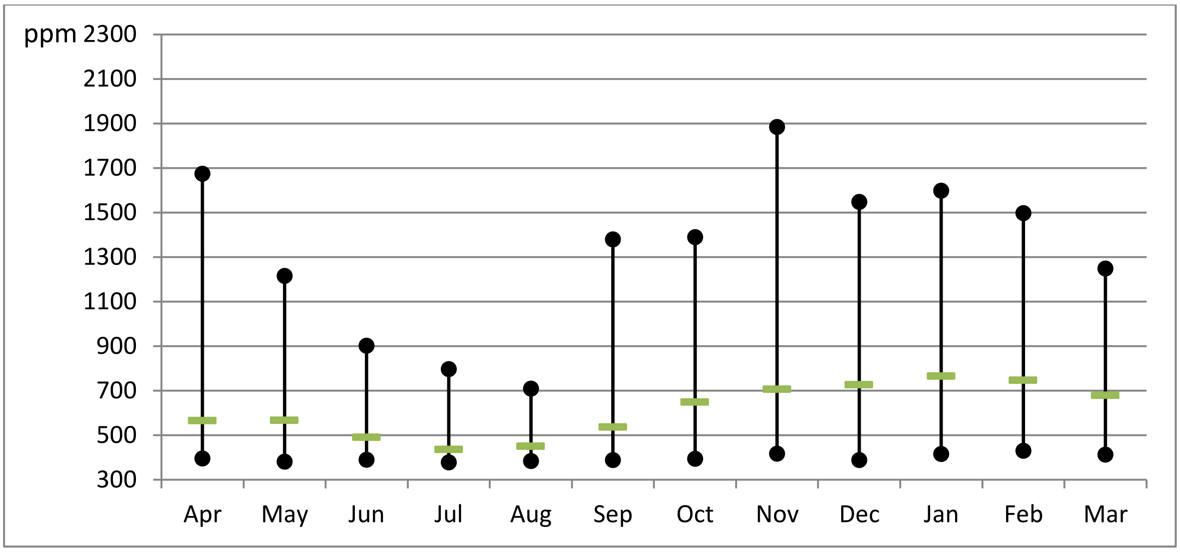


Figure 100 Monthly maximum, minimum and mean CO2 level in Foyer

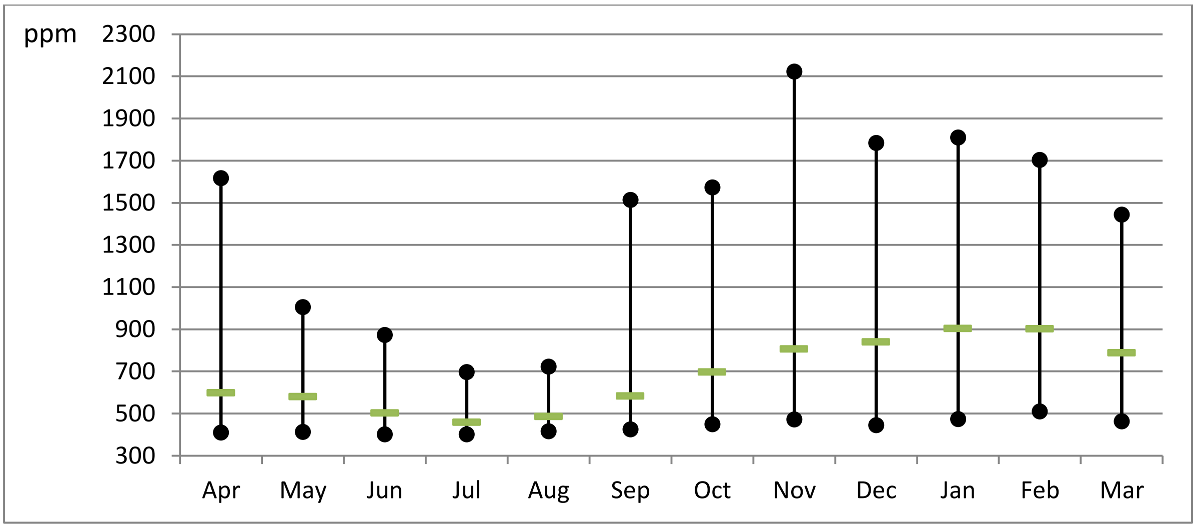


Figure 101 Monthly maximum, minimum and mean CO_2 level in office

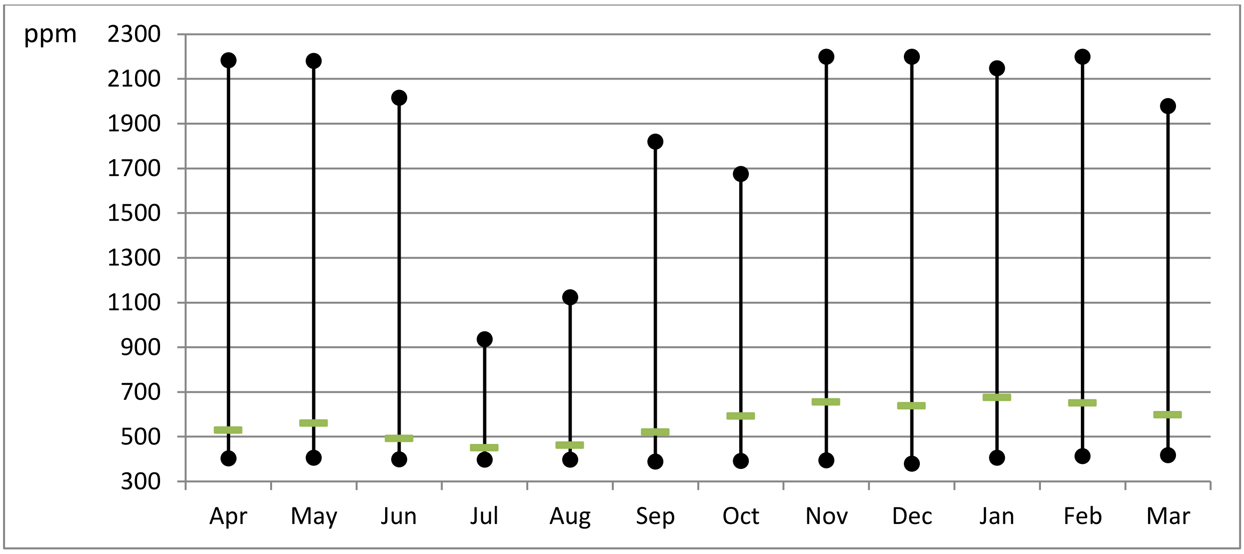


Figure 102 Monthly maximum, minimum and mean CO_2 level in seminar room

10.3 Energy Performance Certificate

Energy Performance Certificate
Non-Domestic Building

HM Government

College Lake Widlife Visitor Centre
Upper Icknield Way
Tring
Hertfordshire
HP23 5QG

Certificate Reference Number:
0090-9020-0030-8000-0003

This certificate shows the energy rating of this building. It indicates the energy efficiency of the building fabric and the heating, ventilation, cooling and lighting systems. The rating is compared to two benchmarks for this type of building: one appropriate for new buildings and one appropriate for existing buildings. There is more advice on how to interpret this information on the Government's website www.communities.gov.uk/epbd.

Energy Performance Asset Rating

More energy efficient

A+

Net zero CO_2 emissions

A 0-25

B 26-50

C 51-75

D 76-100

E 101-125

F 126-150

G Over 150

Less energy efficient

32 This is how energy efficient the building is.

Technical information

Main heating fuel:	Grid Supplied Electricity
Building environment:	Heating and Natural Ventilation
Total useful floor area (m^2):	361
Building complexity (NOS level):	4
Building emission rate ($kgCO_2/m^2$):	23.37

Benchmarks

Buildings similar to this one could have ratings as follows:

28 If newly built

76 If typical of the existing stock

10.4 Air permeability test

Air permeability test values for College Lake Wildlife Visitors centre

Building regulations target for Air permeability in non-domestic buildings	As designed air permeability value	As built air permeability test result (April 2010)
10m³/(h.m²) at 50Pa	5 m³/(h.m²) at 50Pa	3.41 m³/(h.m²) at 50Pa