Crawley Library

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Innovate UK project number	450003
Project lead and author	Low Carbon Building Group, Oxford Brookes University for West Sussex County Council
Report date	2014
InnovateUK Evaluator	Peter Tse (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Public library	Crawley Library	Design and build	2008
Floor area (GIA)	**Storeys**	**EPC / DEC 2010**	**BREEAM rating**
4,468 m^2	4	A (25) / D (90)	Very good

Purpose of evaluation

The key objectives were to analyse and report on the actual in-use measurement and change over time of the variables (including energy use). The study also analysed the occupant satisfaction, with analysis triangulated with internal (and external) environmental conditions and energy use. Despite high sustainability standards the design aspirations were compromised by commissioning, handover and usability issues. While the design achieved an EPC Grade A the building scored only a Grade D on its first DEC. The BPE study also revealed difficulties with the building management system.

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

Thermal (gas) 35.3 kWh/m² per annum, electricity 104.9 kWh/m² per annum. In terms of gas consumption the building performed 73% better (lower) than the raw CIBSE *TM46* benchmark and 73.5% better than the DEC benchmark. In terms of electricity consumption the building performed 39% worse (higher) than the raw CIBSE *TM46* benchmark and 31% worse than the DEC benchmark The biomass and gas boilers were connected to the BMS system but no metering data was captured. Faults appeared often and the biomass boiler needed frequent maintenance. It was out of order from April 2009 until December 2011.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	43 of 59	71%

The BUS survey revealed a positive opinion of the staff members towards the building with the quality of light and the modern design found to be the most appreciated elements. However, a significant number of comments related to the high temperatures during summer throughout several spaces and the lack of proper ventilation throughout the whole year. The latter had a negative effect on comfort and seems to also have potential implications for some respondents' perceived health and productivity. Perception of summer overheating may have been aggravated by the lack of control over windows and ventilation systems.

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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

Phase 2 of the Technology Strategy Board (TSB) funded Building Performance Evaluation (BPE) project is designed to evaluate the in-use condition of Crawley Library.

This detailed in-use BPE study of Crawley Library will contribute towards the evidence-base for understanding the real energy consumption in civic (public) buildings, given the fact that about 18% of the UK's CO_2 emissions come from energy use in public and commercial buildings.

The key objectives of the Phase 2 research programme are:

- Analyse and report on the actual in-use measurement and change over time of the variables (including energy use) in the Library to represent its occupied performance
- Analyse and report on the occupant response and satisfaction
- Analysis to be grounded in triangulation of internal (and external) environmental conditions, energy use and occupant response.

Crawley Llibrary was built to provide a range of county council services including a central library, office and accommodation for administrative and social services. The building is arranged in a prominent four-storey volume facing the Crawley town centre, stepping down to two storeys at the rear. The gross internal floor area is 4,468 m^2. The library covers the three first floors of the four–storey volume around a central atrium while the upper floor accommodates West Sussex County Council (WSCC) social services arranged in an open plan office space. On the ground floor, the two-level volume houses social service cellular offices and on the first floor register services offices and ceremony rooms.

Aiming for sustainability and comfort, the building holds a series of passive building design features paired with a highly efficient services design. The range of low carbon measures and principles embedded in the design has led to the achievement of several sustainability awards along with a BREEAM Very Good and an EPC A rating.

The review of the design intentions as described Stage C and D showed that most of the initial services strategies and intentions have been incorporated into the actual building. However, despite the high sustainability standards the design aspirations were compromised by a series of commissioning, handover and usability issues and while the design achieves an EPC Grade A rating the building has scored only a Grade D on its first DEC. The initial findings of the BPE study revealed difficulties related with Building Management System (BMS) operation and unintended consequences resulting from occupant behaviour.

1.1 Building services and energy systems

The review of the energy systems revealed several discrepancies between the Building Log book, Pre-visit Questionnaire, BMS logs and actual meter readings. Sub-meters were difficult to find since the drawings with the metering and sub-metering arrangements were missing from the BAM electrical and mechanical specification documents and as-built drawings and the Building logbook. The FM manager did not have any plan of the metering and sub-metering arrangements either and their position was located during a walkthrough within the building. In addition, although the BMS is in operation it was found that the Facilities Manager of the building has not been trained to use it therefore cannot control the various systems connected, adjust the environmental parameters or monitor the energy performance data to enable energy savings to be targeted.

The BPE research revealed that the BMS system was not properly connected to the sub-meters and that it did not perform efficiently. Subsequently, actions were taken by the WSCC Energy Officer to re-commission the BMS system. The BPE research team liaised with WSCC and Pureworld Technologies Ltd who on 8th July re-commissioned the BMS system, upgraded the BMS software, connected all the existing sub-meters to the BMS and ensured that the data is being recorded on the front end PC in five minute intervals. All the sub-meters were successfully connected to the BMS on 3rd October 2013.

1.2 Occupants survey

The Building User Survey (BUS) questionnaire method was used to map the library's staff reactions on whether the building meets their needs, including comfort and control. In addition to the BUS survey, semi-structured interviews with occupants and walkthroughs took place in September 2013, in order to further investigate any underlying issues regarding the building's performance and overall user experience.

The overall picture of the BUS survey revealed a positive opinion of the staff members towards the building with the quality of light and the modern design found to be the most appreciated elements. However, a significant amount of comments were given related to the high temperatures during summer months throughout several spaces and the lack of proper ventilation throughout the whole year. The latter had a negative effect on the comfort rating and seems to also have potential implications on the health and productivity of some of the staff.

Occupants reported that the building overheats during the summer months and the lack of control over windows and ventilation further aggravates the problem. In terms of control over heating, cooling, lighting, noise and ventilation, the majority stated to have no control at all over their comfort conditions. This fact is highly reflected in the requests for changes which were mainly related to heating, cooling and ventilation needs. Additionally, limited storage space has been reported together with restricted office space for individual workers in the building.

1.3 Aftercare, operation, maintenance and management

Inspection has revealed that the maintenance and operation documentation is poor as the Logbook is not kept up to date and there is no log of breakdowns, repairs and maintenance procedures. Lack of maintenance contract for the BMS system results in serious issues regarding the operation of the cooling and heating systems and severely undermine the fine-tuning of the building. Facilities management has identified several problematic issues with the building systems, the operation of controls and their functionality. Lack of knowledge and training also creates many issues with regards to usability, functionality and interface with controls. The management team has limited understanding of building controls and their purpose and no understanding of the BMS system.

Additionally, several technologies incorporated in Crawley library building regularly fail or do not function sufficiently. Maintenance of these systems is provided; however problems are rarely resolved effectively, as equipment keeps failing. The biomass boiler has encountered an excessive amount of failures due to low quality biomass fuel. Maintenance team and sub-contractors fixed the problems; however, the system regularly fails due to the problematic supply of woodchips. Overall, the heating and cooling strategies in Crawley library do not appear to be functioning according to the initial design intent.

Following action of the BPE team and WSCC, the BMS system has been re-commissioned and updated. However, the fact that the maintenance contract for the BMS system has not been renewed is one of the reasons undermining the performance the BMS system. It is highly recommended that WSCC sets up a new maintenance contract for the BMS system that would ensure its performance is up to standard.

1.4 Energy use

Given the issues with the BMS system and the lack of sub-metering data it was only possible to give a general picture using the simple building assessment procedure of CIBSE TM22 2011 version.

Looking at the total energy supplied to the building, the emissions figure of 77.4 $kgCO_2$ /m^2 is only 6% worse (higher) than the raw CIBSE TM46 benchmark and almost equal to the DEC benchmark.

In terms of Gas consumption the building performs 73% better (lower) than the raw CIBSE TM46 benchmark and 73.5% better than the DEC benchmark. In terms of Electricity consumption the building performs 39% worse (higher) than the raw CIBSE TM46 benchmark and 31% worse than the DEC benchmark.

Sub-metering data is available from 3rd October 2013. Total electricity consumption from 3rd October 2013 to 14th February 2014 is 176,000 kWh. Total monthly electricity consumption ranges between 39,000-41,000 kWh from October 2013 to January 2014. Monthly electricity consumption ranges between 12,000-12,8000 kWh for lighting and between 7,500-9,000 kWh for small power.

An analysis of the electricity consumption by end-use shows that during the monitoring period 31% of the electricity consumed in the building was used for lighting, 20% was used by small power, 12% was used by the chiller and 9% was used by the fans and pumps of the plant rooms.

1.5 Technical issues

Technical issues were revealed from the review of building services and energy systems, from interviews with occupants and management and were verified by on-site inspection of the systems. As a result of the BPE study several issues were revealed Some of these issues were addressed as a result of the BPE study while others still remain to be resolved.

- The biomass and gas boilers are connected to the BMS system but no metering data is being captured.
- Faults appear quite often and the biomass boiler needs frequent maintenance. According to the facilities manager the faults are a result of the poor quality of woodchip.

- Before the BMS system was re-commissioned on 8th July 2013 the heating system was not optimised and the heating could come on even during hours when the building was not occupied. An optimiser was added to the system providing a self-adaptive routine that learns the characteristics of the building by monitoring and comparing the outside air temperature against the inside space temperature. The system then calculates the optimum start time that the system should be switched on before occupation of the building to achieve the desired internal temperature setpoint. It will also calculate the optimum time that the system can switch off before the end of occupancy whilst maintaining the desired setpoint.

- The biomass boiler was found to be selected OFF and the gas boiler was found to be selected HAND (manual control). Both of them were switched to AUTO by the external contractor who re-commissioned the BMS system. The variable temperature compensated setpoint slope was adjusted to increase energy efficiency.
- No historic data logging was configured for any of the meters on the BMS software or even within the IQ controllers. This was configured on 8th July 2013.
- Inspection from the external contractor who re-commissioned the BMS system revealed that the pulses from eight electricity meters were not being registered within the controller and as such, no cumulative values are accruing. This issue was resolved on 3rd October 2013 when they were connected to the BMS system.
- The trend logging facility (963 Supervisor software) is installed in the computer of the facilities manager. Although its purpose is clear, the manager is not familiar with it and does not know how to use it.
- TREND thermostats can be found in some spaces but there is no indication of what they control. There is no indication of system response.
- The BMS control panel is clearly labelled and provides warning of any faults of the system. The panel can only be programmed and operated by experts. The facilities manager is not qualified to operate the BMS system. The trend logging facility is installed in the computer of the facilities manager. Although its purpose is clear, the manager is not familiar with it and does not know how to use it.
- The BMS system is not properly connected to the sub-meters.
- Solar thermal and chiller controls are only meant to be used by experts but facilities manager is not very well familiar with these systems. The solar thermal control is complex and its purpose is not clearly labelled.
- The main board that controls the chilled water primary and secondary pumps is clearly labelled and switches are easy and intuitive to use. This control can only be operated by the facilities manager. Any system faults are indicated on the board.
- The purpose of the sub-meters is clear but it is not clear what each sub-meter is connected to. Existing labelling is not good enough as it uses codes to indicate what each sub-meter is measuring without providing information what these codes actually stand for.
- Their purpose of the electrical sub-meter displays is clear but the user interface is complex and only meant to be used by experts. Some of the displays are showing zero values and some do not seem to be working properly. They need to be checked and probably re-commissioned.
- Light controls and switches are intuitive and easy to use in most areas. Different lighting strategies are used in different parts of the building.
- Mechanically opened windows controls are not easy to use and not very intuitive. Users reported that the controls break down quite often and that they struggle to use the key.

The following Chapters present detailed information on all the issues mentioned above.

2 Details of the building, its design and delivery

2.1 Background to the case study building

The building is owned by West County Council and opened its doors in December 2008. The new Crawley library was built to provide a range of county council services including a central library, office and accommodation for administrative and social services. Facing a new public square, the four-storey building, which has a stone and glass facade, was designed to be a landmark for Crawley town centre and a low carbon best practice case study. The scheme was built on a 'brownfield site', an existing car park. The mature existing trees at the south west corner of the site were retained. The scheme is located in a very central area, on Southgate Avenue, directly opposite the County Mall, and is within walking distance from Crawley train station.

2.1.1 Location

The scheme is in a central location to the south of Haslett Avenue (A2220), the north of Telford Place bounded to the west by Southgate Avenue (A2004) and an access road which serves Denvale Industrial Park to the east (Figure 1). The site is adjacent to the main town centre, in particular, the County Mall Retail Centre and is close to the Crawley Railway Station and the local bus facilities in Friary Way and The Broadway. To the north of the site on the other side of Haslett Avenue is the Central Sussex College Campus. Located within the Town Centre area the site connects to a network of footways which link to the surrounding area.

The Crawley Railway Station is located within some 600m walking distance from the site using the signal controlled pedestrian crossing facilities at the Southgate Avenue/Station Way Junction. To the western boundary of the site on Southgate Avenue is the Town Centre East Bus Stop (Southbound) which serves Metro Bus route 20 Fastway. The nearest stop (Town Centre South) on the western side of Southgate Avenue is located to the south of the Station Way junction some 100 m walking distance from the site. Local buses run every 20 minutes. Car parking spaces have been reduced to 1 car parking space for every 4 building users. The site has designated cycleways to both the northern and western boundaries to the site which connect to a wider network of routes. Signal controlled cycle facilities are included within the signal controlled junction of Southgate Avenue with Haslett Avenue.

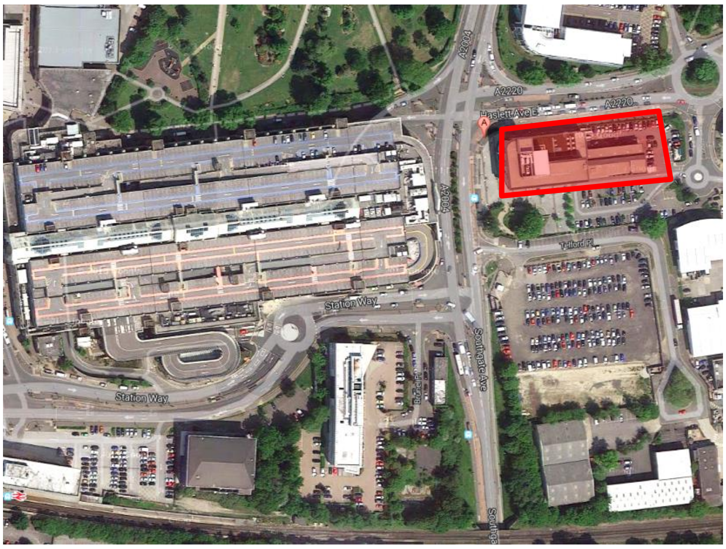


Figure 1 Aerial view of site

2.1.2 Design and layout

The design intent was guided by the following key drivers:

- Landmark building
- Facilities to serve the needs and aspirations of the local community and WSCC members
- Flexible and functional accommodation
- Welcoming and inclusive design
- Sustainable planning, construction and operation
- Minimised disruption to existing services and staff

The building is arranged in a prominent four-storey volume facing the Crawley town centre, stepping down to two storeys at the rear (Figure 2). The gross internal floor area is 4,468 m2 (2,678 m2 library, 502 m2 register services, 378 m2 public social services and 910 m2 administration).The library covers the three first floors of the four–storey volume around a central atrium while the upper floor accommodates West Sussex County Council (WSCC) social services arranged in an open plan office space (Figures 3, 4, 5). On the ground floor, the two-level volume houses social service cellular offices and on the first floor register services offices and ceremony rooms.

Each floor cantilevers slightly over the level below, creating a gentle overhang that shelters and shades the south and west facades. The register office has a separate entrance, also off the square. The first floor ceremony rooms open onto a terrace that can be used for photography and outdoor gatherings. The building has a high thermal mass, controlled daylighting, a flexible mixed mode ventilation system and a biomass boiler and solar water heating.

The public entrances to the Library and Register Offices are easy to identify, located at deep overhangs along this southern elevation on either side of a café in the ground floor of the Library area. The cafe is located to be able to open out into the public square south of the building. The elevational treatment uses a palette of natural stone, render and glass curtain walling set out in a rhythmic composition. Ground floor elevations to public library areas are heavily glazed to showcase the facilities and welcome visitors. More private ground floor areas are clad in engineering brickwork to form a robust dark coloured plinth contrasting with the lighter coloured upper floors.

2.1.3 Occupancy schedules

The building is occupied from Monday to Friday 8am – 5pm. On Saturday only the library is open from 9am until 7pm. The library is closed on Sunday. Normal cleaning hours are Monday to Friday at 6am – 8am. The nature of the building means that staff can access it 24hrs and there is security 24hrs/day. The building is not rented out for any other activities and there are no out-of-hours activities.

Approximately 75 – 100 people in total work for West Sussex County Council (WSCC). However actual occupancy numbers are variable, as approximately 50 people are permanent and 50 people do not occupy the building every day; working on projects and meetings out of office. It is estimated that about 1,000 people per day visit the library. There is a footfall counter in the library entrance that counts the number of people that walk through the door. Occupancy varies significantly during the day.

There is no uniform spread pattern of people in the building spaces, due to the transient character of the building use.

Figure 2 Left: View from North-West, Right: View from South-West

Figure 3 Crawley library. Left: South elevation. Right: Main atrium

Figure 4 Aspects of internal atrium

Figure 5. Crawley library building uses.

2.1.4 Sustainability features

Aiming for sustainability and comfort, the building holds a series of passive building design features paired with a highly efficient services design. The design includes thermal zoning, and uses orientation and high performance coated glass to minimise solar gains, whilst a central north lit atrium floods the central library atrium with natural daylight. Efficient lighting controls with motion detection and daylight zoning maximise efficiency and reduce internal heat gains. Simple methods of energy conservation such as exposed thermal mass, controlled daylighting, natural stack effect and cross ventilation are used to minimise heat gains. The design is supplemented by renewable technologies such as a biomass boiler and a solar thermal system. A Building Management System (BMS) has been installed to help the Facilities Manager run the building efficiently and monitor sub-metered energy consumption. The range of low carbon measures and principles embedded in the design has led to the achievement of several sustainability awards along with a BREEAM Very Good and an EPC A rating.

Responsibly sourced materials scored well against the ‘Green Guide to Building Specification’ ensuring a long design life and low carbon life cycle. The design achieved 4 out of a possible 7 credits under the BREEAM scoring system for materials selection. This is indicative of good standards of recyclability in the materials selected. Concrete forms the principal structural frame of the building and this can be used as aggregate for a future replacement building.

Despite the high sustainability standards the design aspirations were compromised by a series of commissioning, handover and usability issues and while the design achieves an EPC Grade A rating the building has scored only a Grade D on its first DEC. The initial findings of the BPE study revealed difficulties related with BMS operation and unintended consequences resulting from occupant behaviour.

As the Pre-visit Questionnaire (PVQ) document points out many difficulties relate to end user and FM management. Frequent changes in Facilities Management (FM) staff since handover mean that the environmental control strategy, BMS and sub-metering is not well understood by end users. While sub-meter readings are now being recorded by the BMS these have not been monitored by staff and management procedures have not been developed. As a result of this BPE study, the BMS data is now properly collected and saved in a front-end computer in the FM office, however, FM officers are still not familiar with the operation of the software and do not know how to download the data. In addition to that, lack of proper commissioning of the biomass boiler has set it out of operation for almost two years.

The Crawley library BMS was commissioned by Intandem via their design and build construction contract with BAM. Since the defects period has passed, responsibility for the BMS settings and maintenance is with the building owner (WSCC) which had a BMS maintenance contract with Intandem in place. However, the maintenance contract has expired and that the BMS system is not properly maintained.

Crawley Library is a part of the Improvement and Efficiency South East (IESE) and Considerate Contractors Scheme (CCS) which aspires to a collaborative approach to project delivery. Commissioning was overseen by an independent commissioning manager. A Building User Manual/Logbook, was produced alongside the O&M manual, in order to make operation more user-friendly, and to ensure the design aspirations are realised in day to day operation, however, basic information was found to be missing from the Logbook which is not kept up to date.

2.2 Review of architects' design intent

The Stage C and D Reports submitted by Penoyre & Prasad architects during the design phase of the project were reviewed for the purpose of this report. The Stage C report sets out a series of aims and design recommendations for the project for agreement with the client. The report was produced as a result of concept stage design discussions between the client and the architects Penoyre & Prasad. In addition to the normal engineering services, this report included a list of sustainability options and highlighted headline issues that were discussed early in the project, especially with respect to renewables, sustainability and the New Building Regulations Part L (2006).

The technical targets set by the architects during stages C and D were:

- BREEAM Very Good (aspiration only)
- Energy consumption – carbon emissions 30% better than Part L 2006
- Renewables – at least a 20 to 30% contribution
- Air leakage index – 5 $m^3/(h.m^2)$ at 50 Pa
- Summertime temperatures – better than GIR 30
- Low water usage
- Good material usage

According to the architects the proposed form attempted to pull away from a deep plan design to deliver environmental benefits as well as better interiors. The proposal indicated a set of pre-requisite building measures that maximised the benefits of the design and minimised the potential for issues that increased the need for building services (Figure 6). These included:

- High ceilings
- Good day lighting
- Best possible artificial lighting
- Proposals on an IT procurement strategy
- Raised floor in library and office
- Economic good levels of Insulation
- Best glazing and solar protection measures
- Air tightness measures
- Draught lobbies
- Thermal mass – exposed concrete soffits on all floors
- Stratification and natural cross & stack ventilation measures
- Actively utilised atrium space

The architects were proposing both natural ventilation and mixed mode solutions in the building to respond to local need. As the building had a mixed strategy they looked at finding a solution for providing centralised heating and cooling in the building, involving renewable energy.

In the Stage C report the architects proposed:

- A ground coupled heat pump:
  - To deliver a seasonal base heating and base cooling load to the building
  - To minimise cycling on the biomass plant
  - To keep the biomass plant size as small as possible
- A biomass boiler:
  - A compact automated wood chip biomass heating plant
  - To meet the bulk of the seasonal heat loads
  - The heat pump also provided a back-up system to the biomass boiler
  - Below ground wood chip store (car park)

The proposal at this stage also discussed the possibility of using other renewables to enhance the scheme further by locally generating electricity, these being:

- Photovoltaics
- Wind turbine

  It was mentioned in the Stage C report that these technologies were not as appropriate as the biomass and ground coupling proposals and were also dependent on funding.
- Solar thermal (summer hot water)

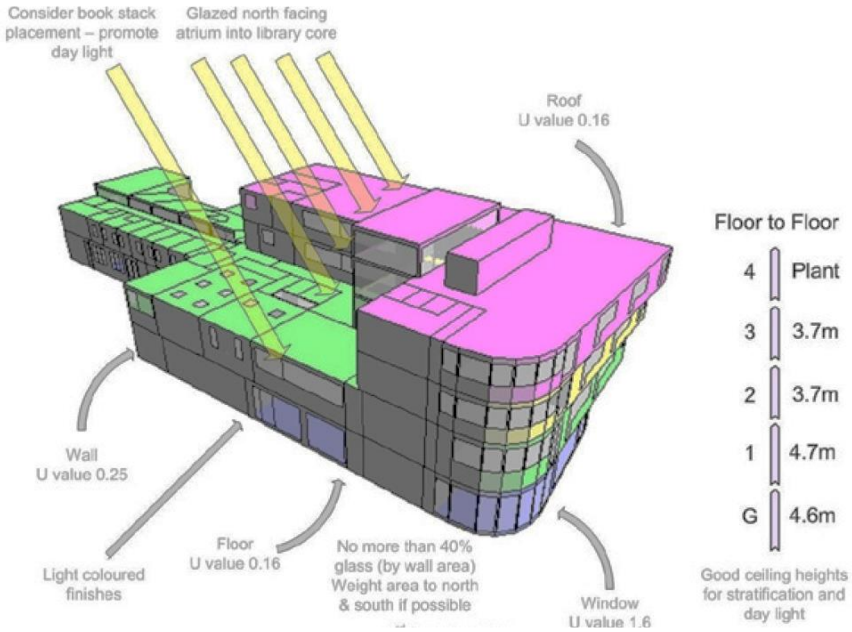
  This option was evaluated by the architects as the least valuable as the hot water estimates loads of the building were relatively low.

However, the ground coupled heat pump proposed at Stage C was dropped at Stage D due to cost pressures; a value engineering exercise carried out by the team concluded that putting the capital for this element back into maintaining the building form (storey heights) would offer better overall value to the client.

The Stage D proposals also discussed the possibility of other renewables as options to enhance the scheme further by locally generating electricity e.g. photovoltaics. As in the previous stage, it was mentioned in the report that adopting these technologies was really dependent on funding, which was never secured. Finally, the architects noted that the building form would be arranged for long term flexibility and that these technologies could also be feasibly added post contract or when the technologies become more affordable.

Unfortunately, the BPE team was not provided with information concerning the following RIBA stages (pre-construction, construction).

Following the review of the design intentions and the architects' design it can be concluded that most of the initial strategies and intentions have been incorporated into the actual building. During the design stage (Stage C and D reports) the architects set out a series of aims and design recommendations for the project and proposed a series of technologies in order to achieve the sustainability targets. With the exceptions of the ground source heat pumps, PVs and wind turbine, the rest of the systems that were proposed during that stage were incorporated in the design and formed part of the actual building's environmental and energy strategy. However, performance targets have not been met. The reasons behind this are investigated in the following sections.



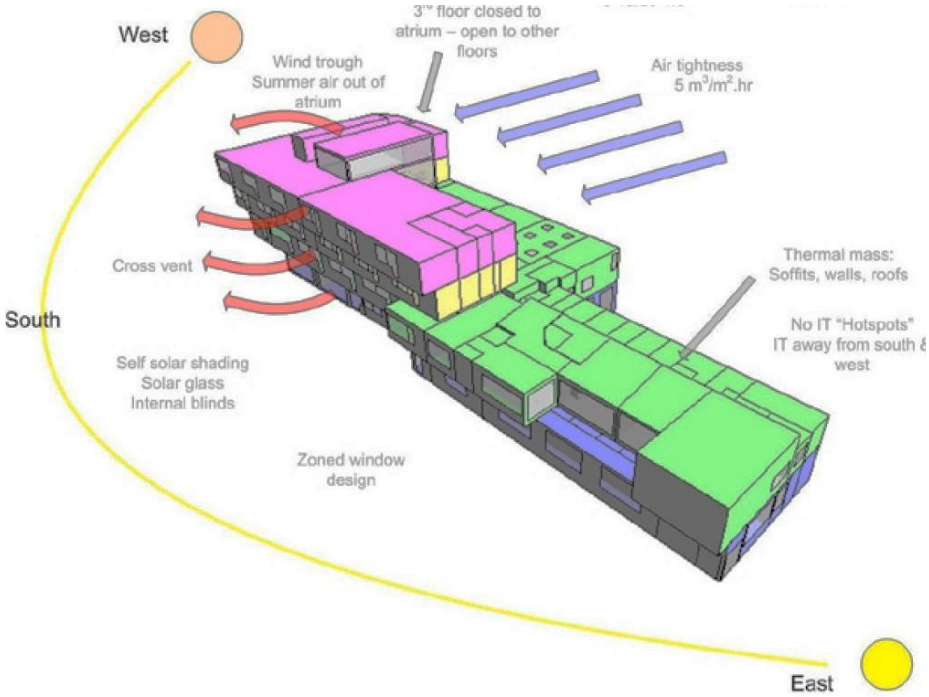


Figure 6 Building measures (taken from Stage C Report).

3 Review of building services and energy systems

3.1 Building services

This section includes a basic review of the building services and energy related systems.

3.1.1 Utility Systems

- The **gas service** enters the building within the plant room on the ground floor, at which point the meter and main isolating gas cock are located (Figure 7). The pipework runs through the plant room to serve the heating system boiler and the final connection is made utilising an isolating gas cock. An emergency solenoid valve has been installed into the pipework within the plant room and is held open by an electrical supply from the mechanical services control system. The supply is disconnected, thereby allowing the valve to close, in the event of any of the following situations:
  - The melting of the electro-thermal link positioned above both the gas and biomass boilers.
  - The activation of manual knock-off button located on the wall adjacent to the door.
  - A signal from the fire alarm system within the building.

- The **mains water service** enters the building within the plant room on the ground floor, at which point the meter and main isolating stop cock are located, together with a solenoid valve for leak detection purposes. The pipework runs through the plant room and then on throughout the building to serve various items of equipment and sanitary ware. The equipment consists of the boosted cold water service cold water storage tank located within the ground floor plant room and an electric water heater located within the Staff Room on the third floor. The sanitary ware consists of sinks within the Tea Points and the Staff Room. A main branch is also provided for the Cafe fit-out. The final connection to each item of equipment is made utilising an isolating stop cock and the final connection to each item of sanitary ware is made utilising an isolating service valve. The pipework is insulated with a foil faced mineral fibre insulation in order to reduce heat gain to the system and vapour sealed to prevent the formation of condensation on the pipe surface. Those sections within the plant room have been finished with an aluminium cladding in order to prevent damage.

Figure 7 (Left) Actaris Itron gas pulsed output meter located in the Ground Floor plant room. (Right) Main water service isolation valve in Ground Floor plant room.

3.1.2 Heating and Hot Water System

- Heating in the building is provided by a primary biomass boiler with buffer vessel, with backup condensing gas boilers (Figure 9). The low temperature hot water is located within the plantroom on the ground floor (Figure 8). The system provides primary heating for the hot water service and the underfloor heating/cooling system (Figure 10). Heat distribution through the library areas and office above (four storey section) takes place via underfloor pipework. The heat distribution in the registrar services section (two storey section) is primarily via a radiator system (Figure 11). Hot water is provided by a solar thermal array with central gas fired calorifiers as back up.

- There has only been very limited use of the biomass boiler prior to the end of the defects period due to H&S concerns related to service access. It was not commissioned properly and there were cables placed over a hatch preventing its proper use/access. By the time this was fixed by the contractors six months had passed and it needed another service at a total cost of £1,600 which WSCC could not afford so there was a need to search for another cheaper service company. Therefore, the biomass boiler had been out of order from April 2009 until December 2011.

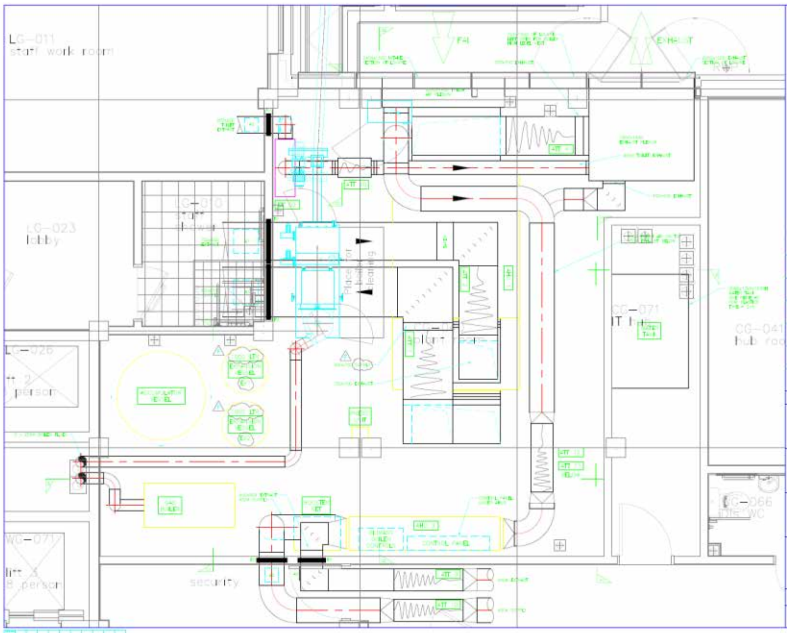


Figure 8 Plan of Ground Floor plant room

Figure 9 (Left) Gas boiler located in Ground Floor plant room. (Right) Biomass boiler located in Ground Floor plant room.

Figure 10 (Left) Low temperature hot water pipes in Ground Floor plant room. (Right) Low temperature hot water pipes in Riser A.

3.1.3 Cooling System

- A chilled water cooling system consisting of an air cooled liquid chiller located on the roof (Figure 12) serves a series of air handling units and fan coil units located throughout the building, together with providing primary cooling for the underfloor heating/cooling system.
- A close control air conditioning system serving the Hub Room consists of two floor mounted down flow internal units which are connected to two air cooled condensers located within the car park.
- Cooling in the building is not climate controlled; all cooling systems are designed for peak looping only.

Figure11 diagrammatically illustrates the heating and cooling strategies in each floor

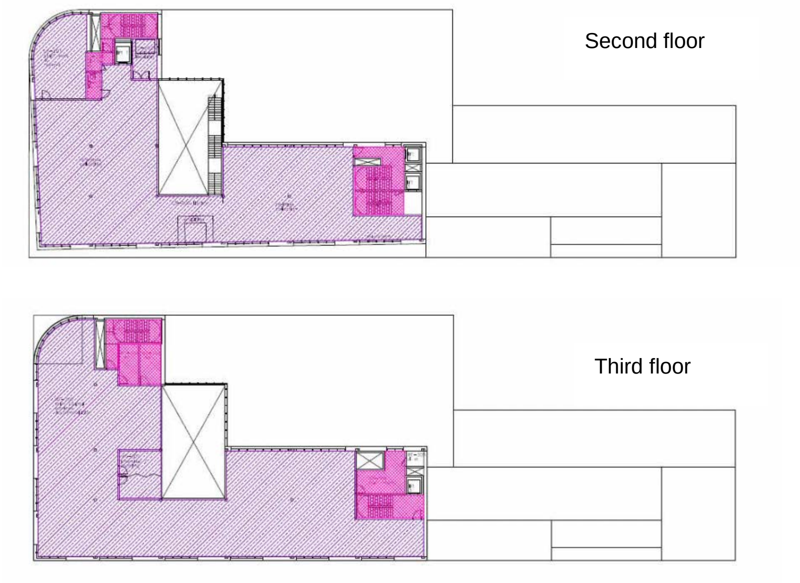


Figure 11 Heating and cooling strategies per floor.

Figure 12 Air cooled liquid chiller located on the roof.

3.1.4 Ventilation Systems

The ventilation system in the four storey section is mainly mechanically ventilation through floor voids but some offices are naturally ventilated. Ventilation in the two storey section is through a traditional ductwork system (Figure 13). Heat recovery is fitted in Air Handling Units (AHUs) to recover waste heat.

- A supply ventilation system serves the east side of the building, and consists of a combined supply and extract heat recovery air handling unit located within the plantroom on the ground floor which, in turn, serves a series of ceiling mounted supply grilles and ceiling void mounted fan coil units.
- An extract ventilation system serves the east side of the building and consists of a combined supply and extract heat recovery air handling unit located within the plantroom on the ground floor which, in turn, serves a series of ceiling mounted extract grilles and ceiling void mounted bell mouth ducts.

- A supply ventilation system serves the west side of the building and consists of a combined supply and extract heat recovery air handling unit located on the roof which, in turn, serves bell mouth ducts located within the false floor void.
- An extract ventilation system serves the west side of the building and consists of a combined supply and extract heat recovery air handling unit located on the roof which, in turn serves a wall mounted extract grille at the top of the atrium.
- A supply ventilation system serves the two-storey office and consists of a combined supply and extract heat recovery air handling unit located within the plantroom on the ground floor which, in turn, serves a series of ceiling mounted supply grilles and ceiling void mounted fan coil units.
- An extract ventilation system serves the two-storey office and consists of a combined supply and extract heat recovery air handling unit located within the plantroom on the ground floor which, in turn, serves a series of ceiling mounted extract grilles and ceiling void mounted bell mouth ducts.
- A supply ventilation system serves the third floor offices and consists of a combined supply and extract heat recovery air handling unit located on the roof which, in turn, serves bell mouth ducts located within the false floor void.
- An extract ventilation system serves the third floor offices and consists of a combined supply and extract heat recovery air handling unit located on the roof which, in turn, serves a wall mounted extract grille at the top of the atrium.
- A supply ventilation system serves the Ceremony and Waiting Rooms, and consists of an air handling unit located within the false ceiling void on the first floor which, in turn serves a series of ceiling mounted supply grilles.
- An extract ventilation system serves the Ceremony Room Toilets and consists of a twin extract fan unit located within the false ceiling void of the first floor, which serves a series of ceiling mounted extract grilles.
- An extract ventilation system serves the Riser A Toilets; it consists of a twin extract fan unit located within the plant room on the ground floor, which serves a series of ceiling mounted extract grilles.
- An extract ventilation system serves the Riser B Toilets consisting, and consists of a twin extract fan unit located on the roof, which serves a series of ceiling mounted extract grilles.

Figure 13 Ventilation strategy per floor.

3.1.5 Public Health Systems

- A boosted cold water service, consisting of a cold water storage tank and booster pump set located within the plant room on the ground floor, serves various items of sanitaryware located throughout the building, together with the Hub Room air conditioning units as well as providing make-up water for the hot water service.
- A solar thermal pre-heating hot water service, consisting of three solar collectors located on the roof, serves a twin-coil hot water calorifier located within the roof plant room. The interconnecting flow and return pipework distribution system incorporates a direct driven centrifugal circulating pump, an expansion vessel and a heat meter. The pipework is insulated with foil faced mineral fibre insulation in order to reduce heat loss from the system. The sections within the plant room have been finished with an aluminium cladding in order to prevent damage.
- A twin-coil indirect storage calorifier located within the roof plant room provides a supply of hot water to the building. The bottom coil is provided with pre-heating from the solar thermal system and the top coil is provided with primary heating from the low temperature hot water heating system. Make-up water for the system is provided from the boosted cold water service and incorporates an expansion vessel. The flow and return pipework distribution system runs from the roof plant room throughout the building generally within the building services riser shafts and false ceiling voids to serve various items of sanitary ware. The sanitary ware consists of a series of hand wash basins, sinks and showers, and the final connection to each is made utilising an isolating service valve. The pipework is insulated with foil faced mineral fibre insulation in order to reduce heat loss from the system. The sections within the plant room have been finished with an aluminium cladding in order to prevent damage.
- An above ground drainage system serves various items of equipment and sanitary ware located throughout the building and discharges into a below ground drainage system.

3.1.6 Power Systems

- An incoming mains supply, which has been provided by the regional electricity authority, serves the main distribution panel located within the switch room on the ground floor.
- A sub-mains distribution system, fed from the main distribution panel, consists of supplies to three secondary distribution panels together with the chiller, two mechanical services control

panel, the fire alarm panel, the Atrium central battery unit, the Hub Room A/C distribution board and the auto-changeover controller for Lift 3. The secondary distribution panels serve the final distribution boards located throughout the building, together with the lifts and the Hub Room UPS unit. The UPS unit is fed via an auto-changeover which is also connected to a mobile generator socket on the external face of the building.

- A small power system is fed from a series of local distribution boards, and consists of a series of switched socket outlets located at low level, above worktops and at high level or within dado trunking, floor boxes or cleaners grommets depending on the area. Open plan offices are generally served via an underfloor bus bar trunking system.
- A small equipment power system is fed from a series of local distribution boards, and consists of a series of fused connection units or isolators located adjacent to various items of fixed equipment throughout the building.

3.1.7 Lighting Systems

The majority of lighting operates on photosensor control. In the library areas there are also occupancy sensors; when an area is unoccupied lights are dimmed, so as to reduce load but maintain a lighting level.

- A general lighting system is fed from a series of local distribution boards, and consists of recessed, surface and suspended fluorescent luminaires controlled from local switching arrangements. A centralised control panel in the reception area has been installed for the circulation areas and for the Children’s area, with automatic daylight linked dimming provided for perimeter areas. The majority of the general lighting system has been installed using a lighting management/control system.
- An emergency lighting system consisting of emergency versions of certain general lighting luminaires, together with self-contained emergency exit signs, all of which incorporate emergency battery packs has been installed. The atrium is provided with specific fittings fed from a central battery unit located on the first floor.
- An external lighting system, fed from a dedicated distribution board, consists of various types of external luminaire controlled through a combination of time clock and photocell controllers.

Table 1 presents a summary of energy systems and building services.

Table 1 Snapshot of energy use and building services.

	4 Storey Section Library and Offices	**2 Storey section - registrar and Offices**
DECC 2009	80: Grade D	
DECC 2010	90: Grade D	
Electricity trend 2010-2011	61% increase	
Heat use trend 2010-2011	53% reduction	
Heating plant	149 kW Biomass boiler with 175kW gas back up boiler	
Domestic hot water	Solar thermal and central gas fired calorifiers	
Kitchen hot water	3 kW electric water heater 1.5 and 2.4 kW tea point water boilers	
Heat emitters	Underfloor provided by biomass and gas backup	Radiators provided by biomass and gas backup
Ventilation systems	Ventilation through AHU supplied	

	into spaces through underfloor voids and swirl diffusers into the occupied zone, extracted at high level. Central heat recovery	
Variable volume control (ventilation)	On / Off with a variable flow from central plant for night purge	Primarily Mechanical Vent, traditional ductwork system, with offices on first floor naturally ventilated.
Cooling	Peak looping system only. A chilled water cooling system serves a series of air handling units and fan coil units located throughout the building, together with providing primary cooling for the underfloor heating/cooling system.	In ceremony spaces only.
Variable volume control (cooling)	On / Off with a variable flow from central plant for night purge	Local control over three port motorised valves
Chillers	R407c, 150 kW output air cooled liquid Chiller	
Server and hub rooms and cooling	22.6 kW Chiller in the hub room	
Humidification	Not fitted	
Lighting management system	Photometric sensors, dimmable fluorescent lights, manual control.	Range of Photometric sensors, PIR and manual control.
Electricity sub-metering	27 electricity sub-meters	

Table 2 Summary of Pre-visit questionnaire

Pre-visit questionnaire[1] Energy and/or carbon management issues
• While the design achieves an EPC Grade A, the building has scored only a Grade D on its first DEC.
• Many difficulties relate to end user and FM management. Changes in FM staff since handover mean that the environmental control strategy, BMS and sub metering is not well understood by end users.
• While sub meter readings are recorded by BMS these have not been monitored by staff
• There has also only been very limited use of the biomass boiler prior to the end of the defects period due to H&S concerns related to cleaning access, now resolved.
• Occupants appear to have overridden daylight sensor lighting controls resulting in excessive power consumption and the Library reports staff tend to leave windows open on cold winter mornings and this conflicts with heat recovery via stack effect in the atrium.
• PIR lighting controls appear to be set to excessively long periods resulting in excessive power consumption for lighting.
• Repeat staff inductions and clarification of the building manual are required.

[1] Pre-Visit Questionnaire is a tool used by the TSB appointed evaluator to assess the energy performance of the building. It collects information on metering and sub-metering along with details on building area, occupancy and pattern of usage of the building.

3.2 Review of installed meters and sub-metering arrangements

3.2.1 Energy metering arrangements

Electricity is supplied from a single electrical feed and consumption is recorded through the electricity meter in the Ground Floor main panel (Figure 14). In addition there are twenty-seven sub meters dedicated to metering the energy consumption of chillers, fans and pumps, lighting and small power (Table 3).

Sub-meters were difficult to locate since the drawings with the metering and sub-metering arrangements were missing from the BAM electrical and mechanical specification documents. The electrical distribution schematic which was made available by Gifford provided some information on the metering location (GF Library Riser A, Switchroom) and strategy but could not be verified by a final document. The FM manager did not have any plan available of the metering and sub-metering arrangements either and their position was identified during a walkthrough within the building in the Ground Floor Switchroom and a shaft cupboard (GF Library Riser A) (Figures 15 and 16).

Gas consumption is recorded on a meter located in the ground floor plant room and serves the heating system back up boiler.

Figure 14 Entity PRI electricity meter located in the ground floor Switchroom.

The water meter is located outside the building but within the property boundary and is accessible only by the water company. After communications with the water company (Southern Water) its exact location was indicated on the building's front footpath.

Table 3 Energy metering information.

Utility meters		Comments
Grid electricity	MPAN	Entity, PRI model P3TA23 SN. P07 A22133
Grid Gas	MPRN1	Actaris, Itron Mda25 Diaphragm Gas Meter SN. M025 A01149 08 A6 2008
Water		SN. 8A101311
Renewable energy supplies	Solar thermal	Annual energy 38.13 kWh, 20 m^2 installed

Electricity sub-meters	Various	Table 4
Heat sub-meters	HM01 HM02 HM03	Biomass, BMS logs (tbc) Boiler (Gas+Biomass) to DHW Solar thermal panel output

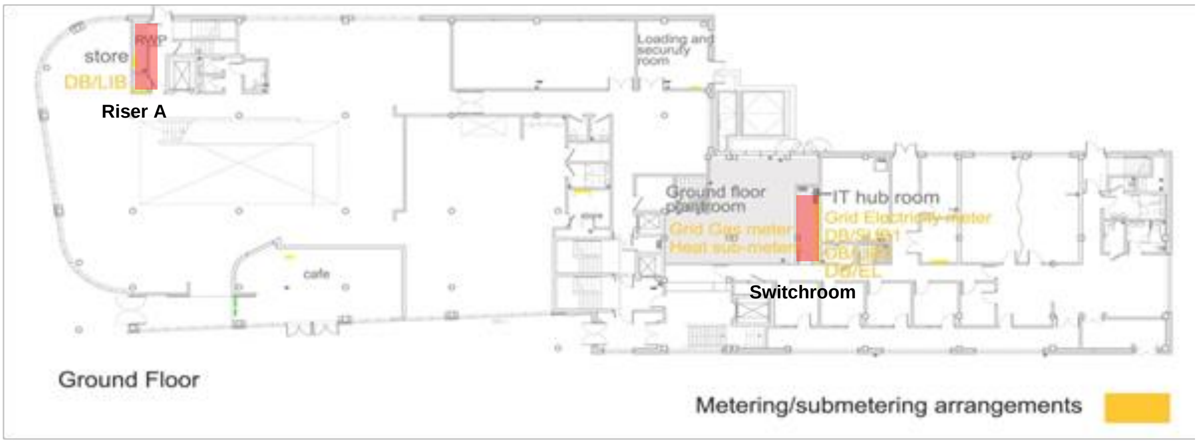


Figure 15 Metering and sub-metering arrangements in the ground floor plan.

Figure 16 Left: The sub-metering arrangement in Switchroom. Right:. DB/LIB1 sub-metering in Ground Floor Riser A.

3.2.2 Identification of problems

The main end-use of each sub-meter was not clear in the building Logbook, BMS or any other provided documentation and the information shown in Table 4 are drawn from the pre-visit questionnaire. Most of the sub-meters were logging during the initial walkthrough visit with the exception of DB-EL (Figure 17, left) which had a zero screen indication. The half-hourly profiles of the sub-meters that were connected to the BMS system were not available according to the FM manager. The Asset Planning Officer of WSCC who is responsible for the maintenance of the system explained that due to the limited memory capacity of the BMS only a few weeks (2-3) of half-hourly profiles are available. However, further inspection showed that the data from the BMS system were not been saved in a front-end computer. In addition to that, it was discovered that the eight sub-meters of DB/LIB1, located in Riser A, were not connected to the BMS system.

Table 4 Monitoring schedule.

		Energy		Meters	Method	Meter location	
	S.No	**Type of incoming energy**	**Main end-use**	**End use/ area/ system/ circuit or tenancy to be measured**	**Measurement method and calculation where appropriate**	**List of meters**	**Location**
		Grid Electricity	Incoming	Heating/Cooling, Fans, pumps & controls, lighting, lifts	Direct Measurement	Main	Main Panel
		Grid Gas	Incoming	Boiler	Direct Measurement	Boiler	Ground Floor Plantroom
		Grid water	Incoming	tea points, staff room and café, make-up water for the boosted cold water service	Direct Measurement	Water	Outside the building
		Heat	Woodchip	Biomass Boiler	Direct Measurement	Woodch ip	Ground Floor Plantroom
		Heat	Solar HWS	Solar thermal panel output HWS	Direct Measurement	Solar HWS	Roof Plantroom
		Heat	Primary HWS	Primary HWS(Gas+Biomass)	Direct Measurement	Primary HWS	Roof Plantroom
	1	Electricity Sub-metering	MCC1	Fans and pumps, Plantroom Ground floor	Direct Measurement	MCC1	Main Panel
	2	Electricity Sub-metering	MCC2	Fans and pumps, Plantroom roof	Direct Measurement	MCC2	Main Panel
	3	Electricity Sub-metering	Chiller	Cooling, External roof	Direct Measurement	Chiller	Main Panel
	4	Electricity Sub-metering	Hub Room UPS	Server room equipment, Server room ground floor	Direct Measurement	Hub Room UPS	Main Panel
	5	Electricity Sub-metering	Hub Rm A/C DB	Hub Rm A/C DB	Direct Measurement	Hub Rm A/C DB	Main Panel
DB/LIB1	6	Electricity Sub-metering	DB-LLG1	Lighting, Library Ground floor	Direct Measurement	DB-LLG1	Riser A
	7	Electricity Sub-metering	DB-LPG1	Workstation and general small power, Library Ground Floor	Direct Measurement	DB-LPG1	Riser A
	8	Electricity Sub-metering	DB-LL11	Lighting, Library 1st floor	Direct Measurement	DB-LL11	Riser A
	9	Electricity Sub-metering	DB-LP11	Workstation and general small power, Library 1st Floor	Direct Measurement	DB-LP11	Riser A
	10	Electricity Sub-metering	DB-LL21	Lighting, Library 2nd floor	Direct Measurement	DB-LL21	Riser A
	11	Electricity Sub-metering	DB-LP21	Workstation and general small power, Library 2nd Floor	Direct Measurement	DB-LP21	Riser A
	12	Electricity Sub-metering	DB-3L1	Lighting, Office 3rd floor	Direct Measurement	DB-3L1	Riser A
	13	Electricity Sub-metering	DB-3P1	Workstation and general small power, Office 3rd Floor	Direct Measurement	DB-3P1	Riser A

	14	Electricity Sub-metering	DB-LLG2	Lighting, Library ground floor	Direct Measurement	DB-LLG2	Main Panel
DB/LIB2	15	Electricity Sub-metering	DB-LPG2	Workstation and general small power, Library Ground Floor	Direct Measurement	DB-LPG2	Main Panel
	16	Electricity Sub-metering	DB-LL12	Lighting, Library 1st floor	Direct Measurement	DB-LL12	Main Panel
	17	Electricity Sub-metering	DB-LP12	Workstation and general small power, Library 1st Floor	Direct Measurement	DB-LP12	Main Panel
	18	Electricity Sub-metering	DB-LL22	Lighting, Library 2nd floor	Direct Measurement	DB-LL22	Main Panel
	19	Electricity Sub-metering	DB-LP22	Workstation and general small power, Library 2nd Floor	Direct Measurement	DB-LP22	Main Panel
	20	Electricity Sub-metering	DB-3L2	Lighting, Office 3rd floor	Direct Measurement	DB-3L2	Main Panel
	21	Electricity Sub-metering	DB-3P2	Workstation and general small power, Office 3rd Floor	Direct Measurement	DB-3P2	Main Panel
DB/SUB1	22	Electricity Sub-metering	DB-GL	Lighting, Office Ground floor	Direct Measurement	DB-GL	Main Panel
	23	Electricity Sub-metering	DB-GP	Workstation and general small power, Office Ground floor	Direct Measurement	DB-GP	Main Panel
	24	Electricity Sub-metering	DB-RL	Lighting, Register services 1st floor	Direct Measurement	DB-RL	Main Panel
	25	Electricity Sub-metering	DB-RP	Workstation and general small power, Register services 1st floor	Direct Measurement	DB-RP	Main Panel
	26	Electricity Sub-metering	DB-C	Café, Ground floor	Direct Measurement	DB-C	Main Panel
	27	Electricity Sub-metering	DB-EL	*External Lighting*	Direct Measurement	DB-EL	Main Panel

Several discrepancies were found between the Building Logbook, Pre-visit questionnaire (PVQ), BMS logs and actual meter readings:

- DB-LL21, DB-LLG1, DB-LPG1, DB- LP11, DB-LP21, DB- 3L1, DB- 3P1, DB-FL are logging in reality but were not connected to the BMS where they appeared to have a zero indication (Figure 18).
- DB-LP11 is missing from the Logbook monitoring schedule but exists in the BMS and is located in DB/LIB1 meters (Figure 19).
- DB-SEC exists in the PVQ but not in Log Book and BMS and was not found during the walkthrough.
- DB-FL exists in BMS but not in the Log Book and PVQ. It was not found in the walkthrough.
- DB-EL exists in the Log Book but not in BMS and PVQ, it was found during the walkthrough. Potentially, the above are the same meter but with different names in each case. The Log Book and BID document do not give any information on what DB-EL was supposed to be monitoring. However, there is a sub-meter in the PVQ that was supposed to measure external

lighting and should be located in the Electrical room in the Ground floor. This sub-meter is not named in the PVQ but it can be assumed that DB-EL stands for External Lighting.

- Sub-meter 5 (Hub Rm A/C) was not found in the walkthrough and does not show up in the BMS but is included in the Building Log Book which indicates that the sub-meter should have been found on the Main Panel. Instead on the Main Panel there is a sub-meter tagged 'DB-Mech' which is connected to the BMS and logging but does not appear on the BID and Log Book. Perhaps it is the same sub-meter but was renamed.
- Plantroom meters in BMS include a Mech Elect meter, a Switch Panel Elec meter, a gas meter and a water meter. The first two were not found in the Log Book or PVQ, the gas meter was not connected while the water meter reading was incorrect when compared to the actual meter reading taken from the water bill.

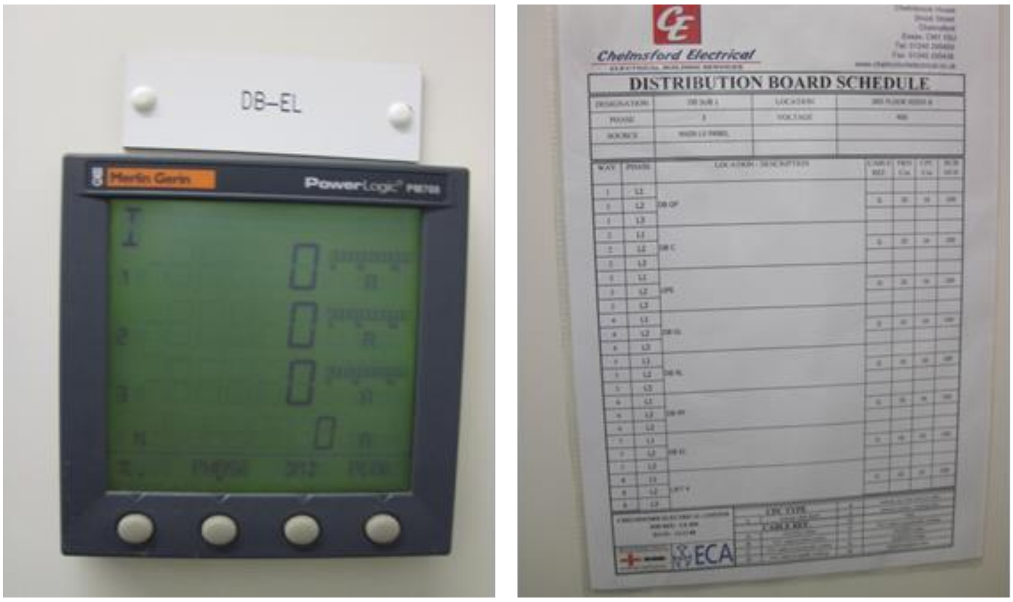


Figure 17 Left: DB-EL sub-meter probably out of function. Right: Distribution board schedule located in one of DB-SUB1.

Figure 18 Sub-meters are logging in reality but appear to have a zero indication in the BMS.

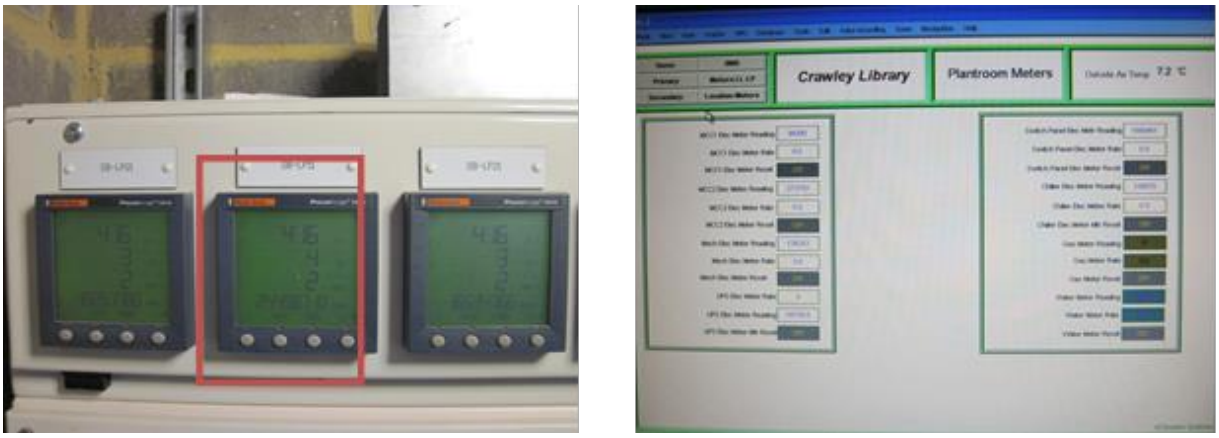


Figure 19 DB-LP11 sub-meter missing from the building's logbook metering schedule.

3.3 Review trend logging facilities of BMS system

The Crawley library BMS was commissioned by Intandem via their design and build construction contract with BAM. Since the defects period has passed, responsibility for the BMS settings and maintenance is with the building owner (WSCC) which had a BMS maintenance contract with Intandem in place. However, the maintenance contract has expired and that the BMS system is not properly maintained.

Although the BMS is in operation it was found that the Facilities Manager of the building has not been trained to use it and therefore cannot control the various systems connected, adjust the environmental parameters or monitor the energy performance data to enable energy savings to be targeted. He has only limited access to the system in order to observe the internal environmental conditions and report any abnormalities to the different space temperatures. The main reason for that is to avoid frequent changes in temperature settings as a result of occupants' requests or complaints. The person who is in charge of the BMS settings is the WSCC Energy Officer with the main responsibility of making temperature adjustments to the heating and cooling system according to the council's energy strategy.

During the course of the BPE research actions were taken by WSCC Energy Officer to re-commission the BMS system. The BPE research team liaised with WSCC and helped greatly in pushing towards that direction and in having all the sub-meters connected to the BMS data in order to acquire calibrated sub-metering data. For this purpose WSCC liaised with Pureworld Technologies Ltd who visited the site three times in order to commission the BMS system, connect all the existing sub-meters to the BMS and ensure that the data is being recorded on the front end PC.

The main meter ('Incomer') and the sub-meters DB-GP, DB-C, UPS, DB-GL, DB-RL, BD-RP, DB-LLG2, DB-LL12, DB-LL22, DB-3L2, DB-LPG2, DB-LP12, DB-LP22, DB-3P2, Chiller, DB Mech, MCC1, MCC2 were connected to the BMS and 15min data were being recorded and collected from 08/07/13 to 03/10/13. From 03/10/13 onwards 5min data are being recorded and collected. The sub-meters DB-LPG1, DB-LP11, DB-LP21, DB-3P1, DB-LLG1, DB-LL11, DB-LL21, DB-3L1 were connected to the BMS system on 03/10/13 and since then 5min data are being recorded and collected. ALL 26 sub-meters and the main meter are providing 5min data from 03/10/13.

3.4 Conclusions and key findings

- Heating in the building is provided by a primary biomass boiler with buffer vessel, with backup condensing gas boilers. Heat distribution through the library areas and office above (four storey section) takes place via underfloor pipework. The heat distribution in the registrar services section (two storey section) is primarily via a radiator system. Hot water is provided by a solar thermal array with central gas fired calorifiers as back up.

- The ventilation system in the four storey section is mainly mechanically ventilation through floor voids but some offices are naturally ventilated. Ventilation in the two storey section is through a traditional ductwork system. Heat recovery is fitted in Air Handling Units (AHUs) to recover waste heat.
- The majority of lighting operates on photosensor control. In the library areas there are also occupancy sensors; when an area is unoccupied lights are dimmed, so as to reduce load but maintain a lighting level.
- A chilled water cooling system consisting of an air cooled chiller located on the roof has been installed and serves a series of air handling units and fan coil units located throughout the building, together with providing primary cooling through the underfloor pipework (four storey section).
- While the design achieves an EPC Grade A, indicating high design aspirations, the building has scored only a Grade D on its first DEC.
- Many difficulties relate to end user and FM management. Changes in FM staff since handover mean that the environmental control strategy, BMS and sub metering is not well understood by end users. This is indicative of poor handover documentation and poor internal handover between facilities managers.
- There has also only been very limited use of the biomass boiler prior to the end of the defects period due to H&S concerns related to cleaning access, now resolved.
- Occupants appear to have overridden daylight sensor lighting controls resulting in excessive power consumption and the Library reports staff tend to leave windows open on cold winter mornings and this conflicts with heat recovery via stack effect in the atrium. This indicates that occupants are not well familiar with the systems of the building. This results from lack of occupant training and understanding of the processes that take place in the buildings.
- PIR lighting controls appear to be set to excessively long periods resulting in excessive power consumption for lighting.
- Discrepancies were noted between Building Logbook, PVQ, BMS logs and actual meter readings.
- Sub-meters were difficult to find since the drawings with the metering and sub-metering arrangements were missing from the BAM electrical and mechanical specification documents and as-built drawings and the Building logbook. The FM manager did not have any plan of the metering and sub-metering arrangements either and their position was located during a walkthrough within the building. The Electrical distribution schematic which was made available later by Gifford provided some information on the metering location (GF library Riser 1, Switchroom) and strategy but could not be verified by a final document.
- The exact position of the water meter was unknown by the building FM since it is probably placed outside the building. After communications with the water company (Southern Water) the existence of a water meter was verified and its location was found to be on the building's front footpath.
- The main end-use of each sub-meter is not clear in the building Log book, BMS or any other provided documentation and the information provided in Table 4 is drawn from the PVQ.
- Most of the sub-meters were logging during the walkthrough visit with the exception of DB-EL which had a zero screen indication.
- The half-hourly profiles of the sub-meters that were connected to the BMS system were not available according to the FM manager. The Asset Planning Officer of WSCC who is responsible for the maintenance of the system explained that due to the limited memory capacity of the BMS only a few weeks' worth of half-hourly profiles are available. However, inspection by Pureworld Technologies Ltd revealed that the system had not been setup to record data and confirmed that if the necessary actions were taken unlimited amount of data could be saved in a front end computer.

- DB-LL21, DB-LLG1, DB-LPG1, DB- LP11, DB-LP21, DB- 3L1, DB- 3P1, DB-FL are logging in reality but are not connected to the BMS where they appear to have a zero indication. After continuous efforts of the BPE team, WSCC liaised with Pureworld Technologies Ltd who visited the site three times in order to commission the BMS system, connect all the existing sub-meters to the BMS and ensure that the data is being recorded on the front end PC. All the sub-meters are connected to the BMS as from 3rd October 2013 and the data is being recorded by the BMS software in 5 minute intervals.
- DB-LP11 is missing from the Logbook monitoring schedule but exists in the BMS and is located in DB/LIB1 meters.
- DB-SEC exists in the PVQ but not in Log Book and BMS, and was not found during the walkthrough. DB-FL Exists in BMS but not in Log Book and PVQ, was not found in the walkthrough. DB-EL exists in Log Book but not in BMS and PVQ, it was found during the walkthrough. It is assumed that it is the same meter but with different names in each case.
- Hub Rm A/C DB meter from Log Book was not found in drawings, BMS or walkthrough.
- Plantroom meters in BMS include a Mech Elect meter, a Switch Panel Elec meter, a gas meter and a water meter. The two first were not identified in the Log Book or PVQ, the gas meter had a zero indication (was not connected) while the water meter reading was found to be incorrect when compared to the meter reading taken from the water bill.

4 Key findings from occupants survey

This section cross-relates the findings from the BUS survey, semi-structured interviews with occupants and walkthrough, interview with management, spot check and recording measurements and the review of performance and usability of controls, and reveals the main findings learnt from the BPE process and the fore mentioned activities. It draws on the BPE team's forensic investigations to reveal the root causes and effects which lead to certain results in the BUS survey.

The BUS questionnaire method was used to map the library's staff reactions on whether the building meets their needs, including comfort and control. It is undertaken once during the course of the BPE study. The BUS analysis method is a quick and thorough way of obtaining feedback data on building performance through a self-completion occupant questionnaire; the results of which can be compared against a national benchmark database. The questionnaire prompts the respondents to comment on the building's image and layout, occupant control, and daily use of the building features and any general changes they have noticed since using the building. The BUS uses 'effectiveness' scales but also provides space for additional comments, if needed.

In addition to the BUS survey, semi-structured interviews with occupants and walkthroughs took place in September 2013, in order to further investigate any underlying issues with regards to the building's performance and overall user experience. A walkthrough with each one of the different key staff members followed the semi-structured interviews in order to capture the aforementioned issues during the interviews as well as other arising matters. The Registration Services manager and a Library officer were interviewed.

Furthermore, an interview with a member of management team of Crawley library was conducted on 5th June 2013. The interviewee is responsible for maintenance and facilities management and has been working in Crawley Library for one year. His views and comments has been cross-related with findings from the BUS survey and occupant interviews.

4.1 The building overall

The overall picture of the BUS survey revealed a positive opinion of the staff members towards the building with the quality of light ("good lighting, ambience") and the modern design ("attractive, open airy") found to be the most appreciated elements (Figure 20). However, a significant amount of comments that were given related to the high temperatures during summer months, throughout several spaces ("Hot and stuffy") and the lack of proper ventilation throughout the whole year ("Poor air circulation"). The latter had a negative effect on the comfort rating and seems to also have potential implications on the health and productivity of some of the staff.

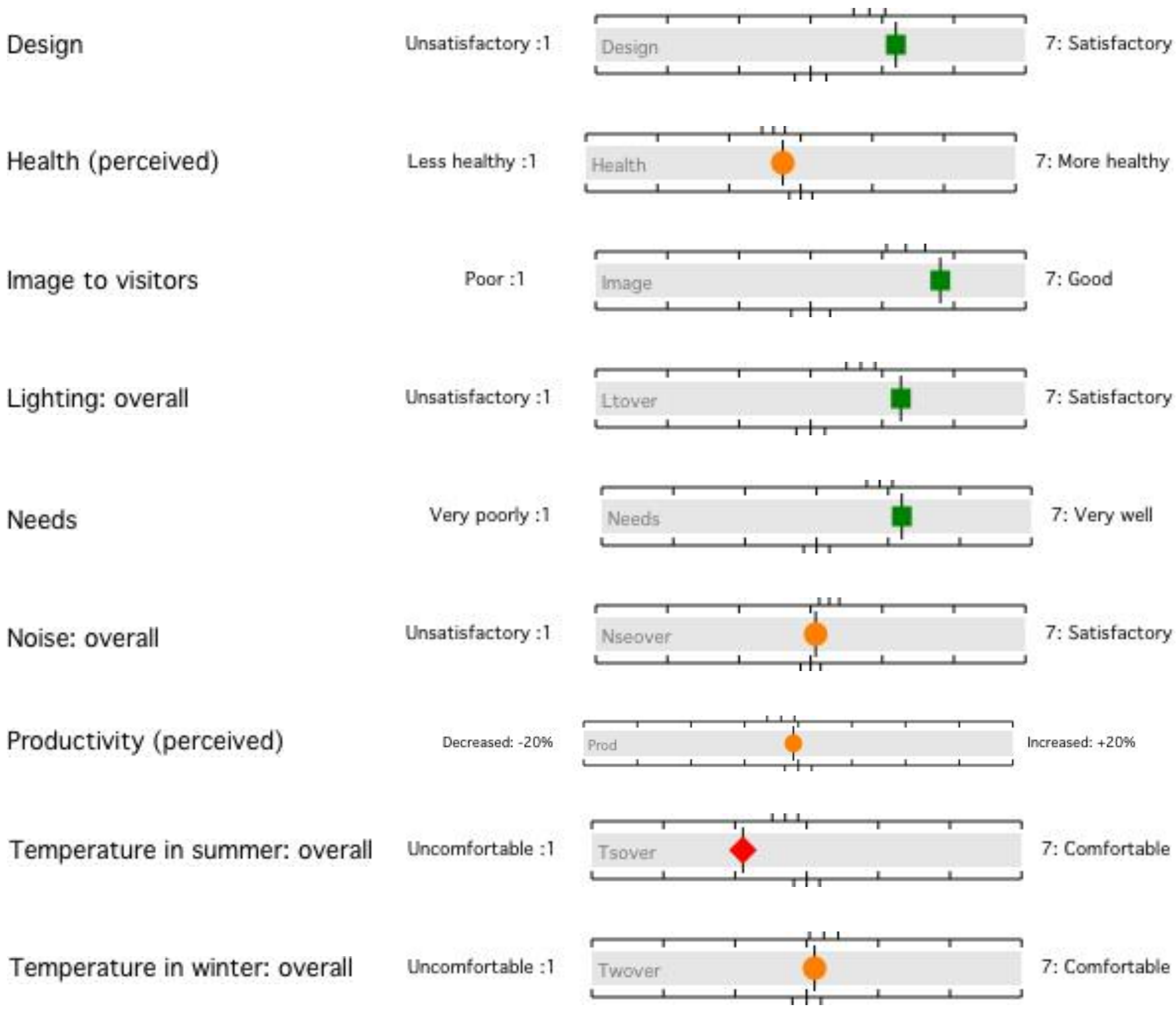


Figure 20. The building overall.

4.2 Comfort

The staff members were asked about their comfort perception within the building relating to the air temperature and quality, noise, lighting, ventilation and level of personal control of these elements. Nearly 82% of the staff felt that the building was comfortable overall (Figure 21), despite the fact that the majority of them complained about the air being stuffy during the whole year, the uncomfortably high temperatures during hot summer days and the noise coming from outside due to the opening of windows.

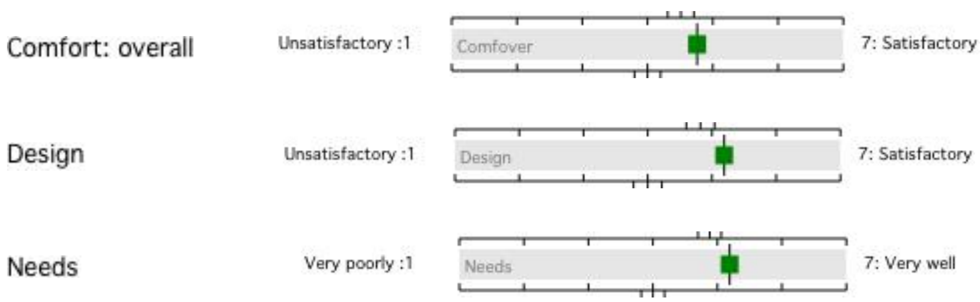


Figure 21. Overall comfort, design and needs.

Table 5 Comments received by building users on comfort.

Comments on comfort overall
• *Building can get uncomfortably hot in the summer, even with the windows open which then causes excessive road noise to be heard in the library.* • *The building overall is ok but my office is too hot in summer.* • *Hot and stuffy –why do we have air-conditioners?* • *It is mostly too stuffy and with windows opening 'six' at a time there are disagreements over how much they are open.* • *The biggest discomfort is that there is a lack of toilets, the location of the toilets and that there is no air vent or window – it's disgusting.* • *Poor access to drinking water.* • *Temperature –lack of control- generally too hot, particularly in the second floor.* • *It is a pity that you cannot open individual windows instead of a whole row at once.*

4.3 Air temperature and quality

The BUS questionnaires revealed that most people (68%) find the spaces uncomfortably hot during the summer, and comments received imply problems with the cooling system ("*lack of air-conditioning*") and control over the opening and closing of windows ("*cannot open individual windows instead of a whole row at once*"). Indoor temperature readings on the day of the survey were surprisingly high for some of the spaces such as the children's library and the first floor office reaching a peak of 25.4°C during the midday, with an external temperature of 20.4°C. This could account for a significant amount of staff experiencing air as hot and stuffy. This was corroborated in the spot measurements that took place during the summer and in the continuous environmental monitoring data showing that some spaces become overheated. Overheating is a major issue during summer; portable fans are often used by occupants as a means to increase air flow and relieve occupants from excessive heat levels developing in offices (Figure 23).

Similar observations were pointed out during the semi-structured interviews. The Registration Services Manager noted that visitors find temperature levels in the large ceremony room very low and reported that numerous issues relating to overheating or cold spaces depending on the fluctuations of the external temperature have been identified up to date. The interviewee added that overheating issues have mainly been reported in the second floor offices of Crawley Library building. Occupants report that they cannot control their own environment in terms of ventilation, as the office areas are naturally ventilated but the windows are controlled by the BMS system. The BMS settings cannot be accessed and adjusted by the facilities officers. Override switches for opening and closing of windows cannot be utilised as the staff in the office areas do not have access to the keys of these switches. Thus it may be concluded that the initial ventilation strategy (natural ventilation through BMS controlled windows) is not performing as expected.

Windows that only open in groups were identified as a source of disputes in the open plan office area creating comfort issues for individual occupants (Figure 22). Users do not have control of their own environment and there is usually either too much ventilation causing cold draughts when a row of windows is open, or the air feels stuffy and stagnant when all the windows are closed.

Staff members working on the third floor open plan office made several remarks on high noise levels, overheating during summer and the cold air flow during winter. There were complaints relating to the ventilation ducts on the wall that blow cold air directly on the staff during winter (Figure 23).

Figure 22 Usability of windows which only open only in rows and not individually was noted as a source of disputes and comfort issues in the open plan office area.

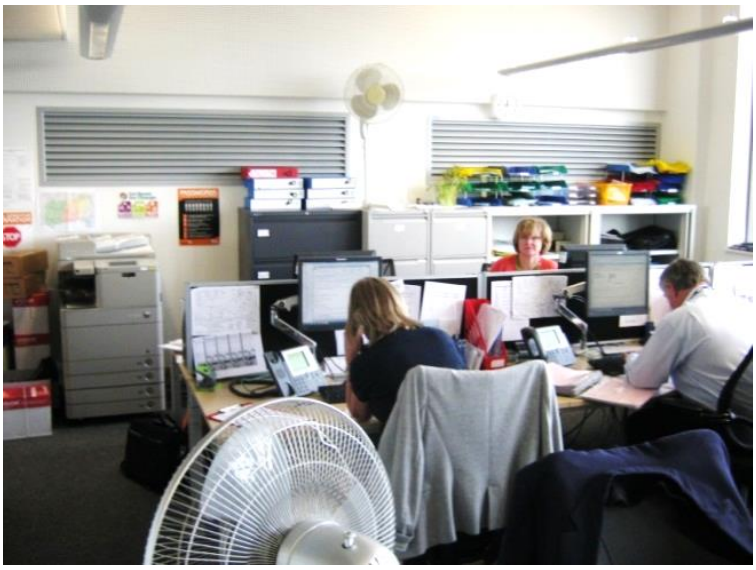


Figure 23 On the wall the ventilation ducts tend to blow cold air directly on the staff during winter. Fans are used during summer to increase comfort when the offices are overheated.

The Library officer added that there have been complaints from library staff members regarding rooms being too cold or too hot and sometimes stuffy in the mornings. The Library officer also pointed out that lack of control over the opening of windows and the failure of the under-floor cooling system to work in the library office spaces add to general discomfort issues.

The facilities manager pointed out that he lacks information and knowledge on how to provide cooling in the offices during summer and more heating during winter when requested by office users. He mentioned that limited control over the BMS systems, due to lack of knowledge, gives the FM team limited functionality. He also added that it is not possible for the FM team to target different floors individually.

The facilities manager also reported lack of cooling in the office area on the third floor and mentioned that the only way of cooling the space is to open the windows. He commented that no air flow from the underfloor heating and cooling system has been detected by the users for the past five years. This statement gives an indication of the lack of understanding and control of the facilities manager over the building systems. No action was taken from the FM team to resolve this issue.

According to the facilities manager, windows ‘seem to randomly open and close on their own’ as a result of some unknown settings in the BMS system. Windows are controlled by the BMS systems and open at unexpected times. Furthermore, the FM team does not have control over the ventilation settings and controls.

As a result of the above, building users often express their frustration to the FM team that is unable to control heating, cooling and ventilation in the building. These findings clearly indicate that poor control over systems undermines occupant comfort and environmental conditions.

As shown in Figure 25, during the summer period the temperature slightly rises above the comfort zone in all areas of the library indicating that measures might need to be taken to prevent the building from overheating (shading, cooling).

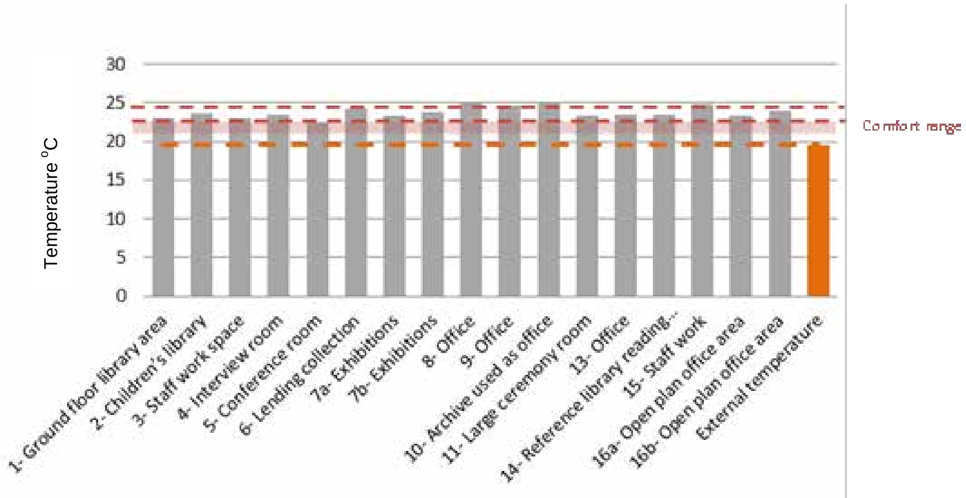


Figure 24 Temperature values in various spaces of the library during the summer spot check visit.

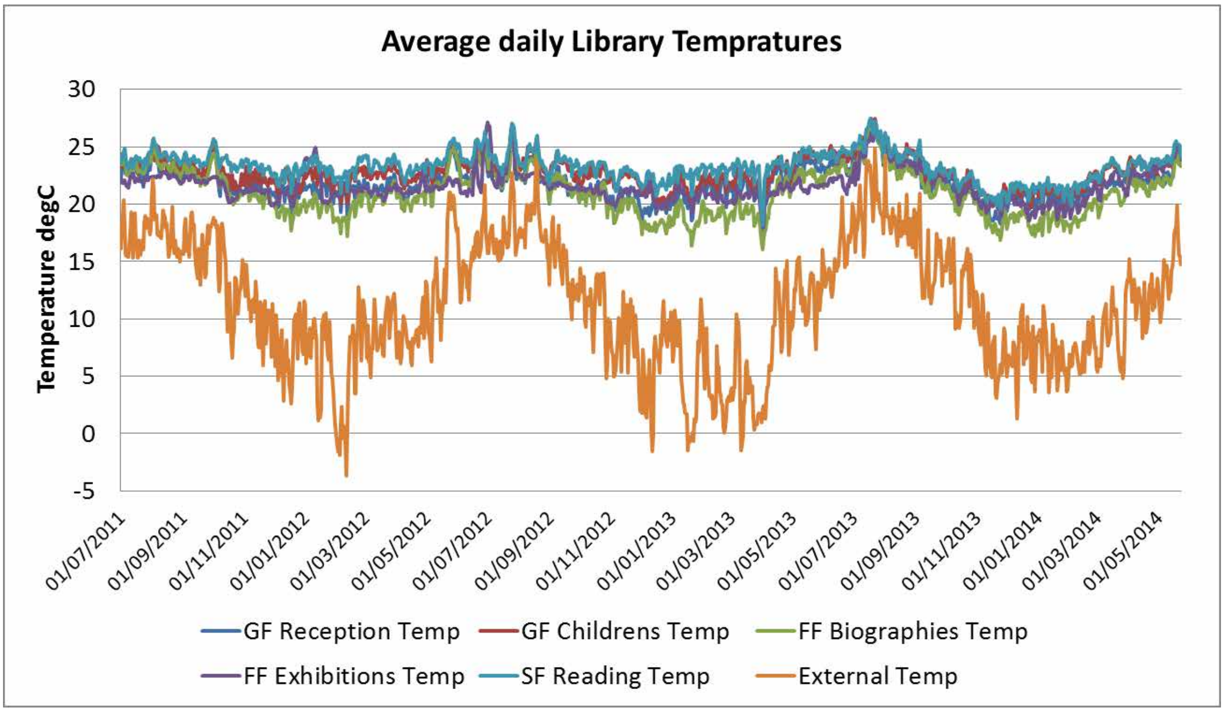


Figure 25 Temperatures in the Library area during the monitoring period (July 2011-May 2014).

The controls survey also underlined the problematic window control. It was found that the control of the mechanically controlled windows breaks down easily and is not easy to use. Furthermore, each set of controls operates entire rows of windows limiting the users' choice and lowering the level of fine control.

During the winter almost half of the respondents of the BUS questionnaire felt cold and found the air stuffy. Monitoring data and spot measurements taken during the winter show that temperatures in the building are mostly kept within the comfort zone. During a typical winter week (February 2012) it can be observed that internal temperatures ranges between 18 and 25°C whilst the external temperature is between -8.2 and 5.5°C (Figure 26).

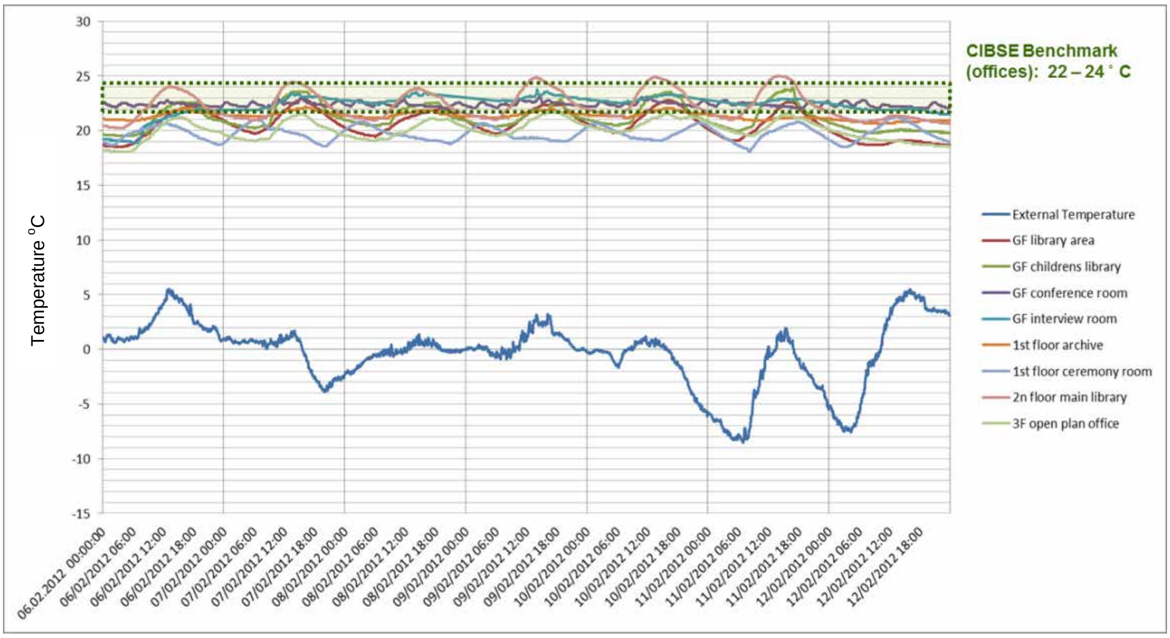


Figure 26 Internal and external temperature levels during a typical winter week (06/02/2012-12/02/2012).

Low RH levels (Figure 27) and high CO_2 levels (Figure 28) recorded explain the feeling of stuffiness expressed by occupants. This can be explained by the windows being closed all the time during winter and lack of mechanical ventilation in most of the spaces.

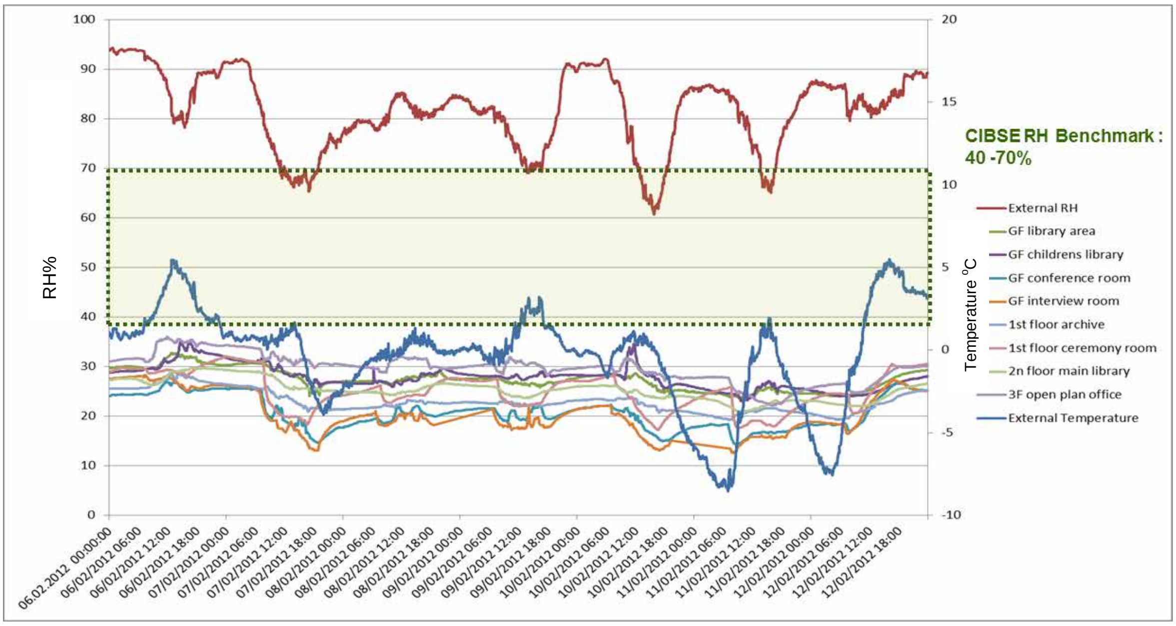


Figure 27 Relative Humidity levels during a typical winter week (06/02/2012-12/02/2012).

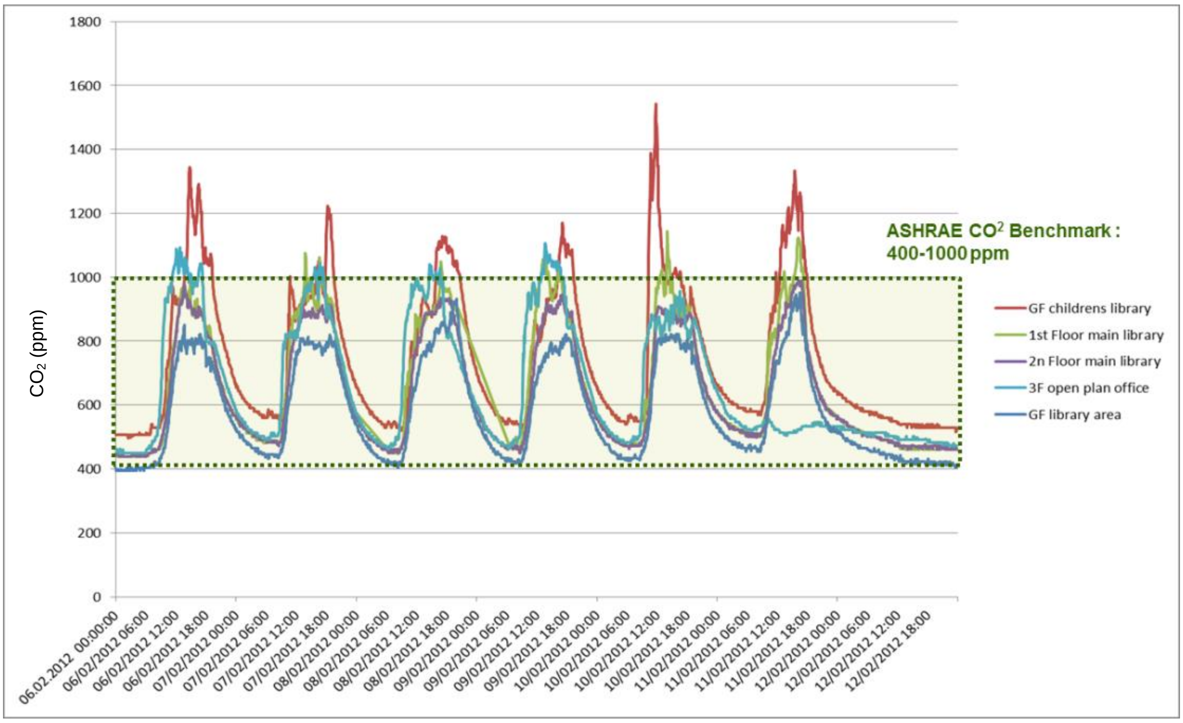


Figure 28 CO2 levels during a typical winter week (06/02/2012-12/02/2012).

4.4 Daylight

As measured during the spot measurements visit, lighting levels in the key areas of the library are good (Figure 31). This was also revealed by the BUS survey where the quality of natural light is one of the most appreciated design elements with both natural and artificial light levels considered to be satisfactory although 27% experience some degree of glare (Figure 29). Lighting levels appear to be satisfactory overall with two thirds of the respondents rating this building aspect favourably.

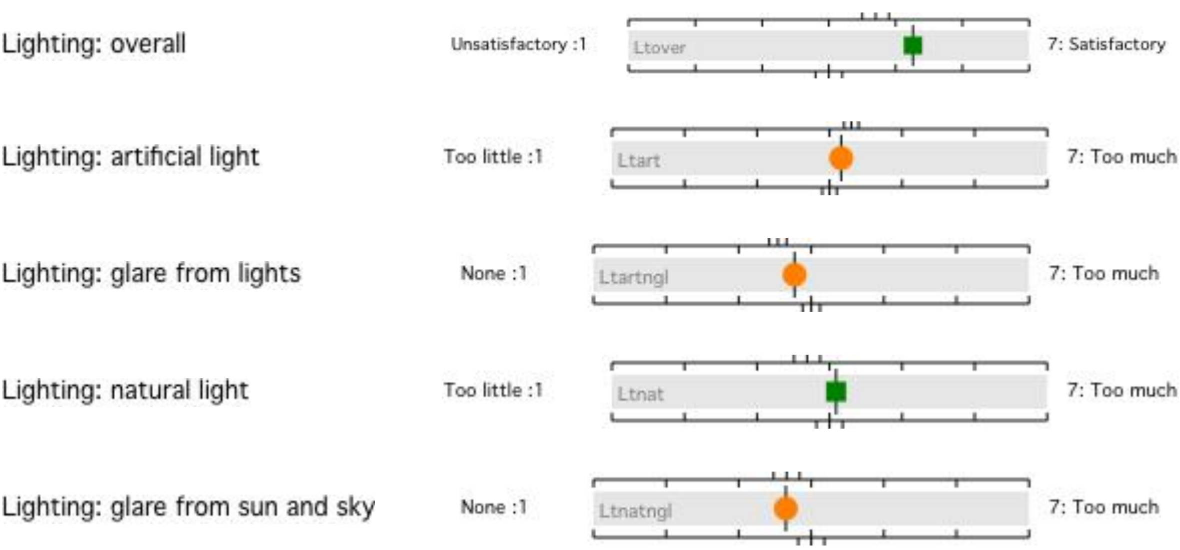


Figure 29. BUS questionnaire: Lighting

However, during the semi-structured interview the Registration Service manager mentioned there is a lack of natural light in key working spaces of the building such as offices. He mentioned that daylight in most of the offices is blocked by dark blinds and electric lights are on in order to avoid sunlight reflections on the computer screens. This was verified during the walkthrough (Figure 30, left). Additionally, even though lights in the Registration offices are automatically turned on by a PIR control, in several offices lights were still on although the rooms were unoccupied for more than 30 minutes (Figure 30, right).

Figure 30 (Left) Blinds drawn in the register offices and lights are turned on. (Right) Lights are on in registration offices even when the rooms are unoccupied.

Table 6 Comments received by building users on lighting

Comments on lighting
• *2 of 4 lighting strips have been removed making electric light satisfactory. Blinds have been added - due to natural light.* • *Lighting at desks unsatisfactory.* • *Sun shines through front windows in the evening, blinding people working on the ground floor desk. Blinds help but do not cover whole area.* • *I think the lighting is just right.*

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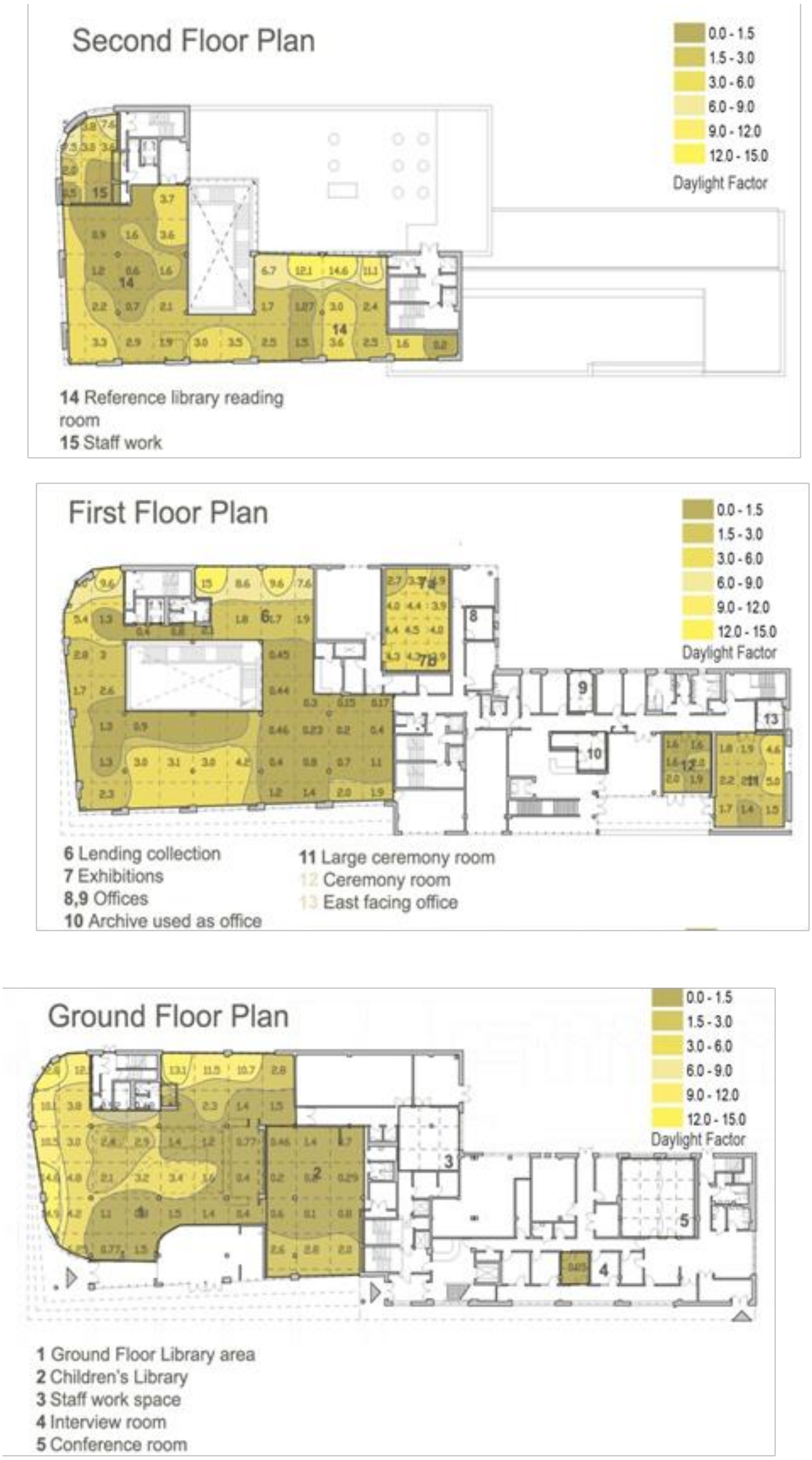


Figure 31 Floor plans with daylight factor levels during the spot check visit. Daylight in key library areas is good

4.5 Noise

As shown in the BUS questionnaires noise was clearly an issue for the staff members mainly because of the open plan spaces within the library and the external noise coming from the road when the windows are open. The staircase design and the open plan office on the third floor were considered to help noise travel through the different levels of the building while the lack of control over individual windows enhanced the traffic noise, particularly since the windows can only be opened six at a time.

This effect was verified during the summer spot measurements visit (8th August 2011) when windows were open. The highest dB levels recorded in the open plan office area highly exceeded the recommended limits (Figure 32). The noise levels were slightly high in general throughout most of the building spaces. It was noticed that the windows were open in most of the spaces and external traffic noise contributed to the higher dB levels.

During the semi-structured interview the Registration Service Manager mentioned that issues of excessive noise levels, overheating during summer and cold draughts during winter, coupled with lack of adequate office space and equipment to cover staff's needs, have been reported by occupants working in the office space on the 3rd floor of Crawley library building (Figure 33).

Occupants reported that photocopying equipment in the open plan offices area is placed very close to their working areas and produces excessive noise levels which often disrupts staff's working schedule (Figure 34).

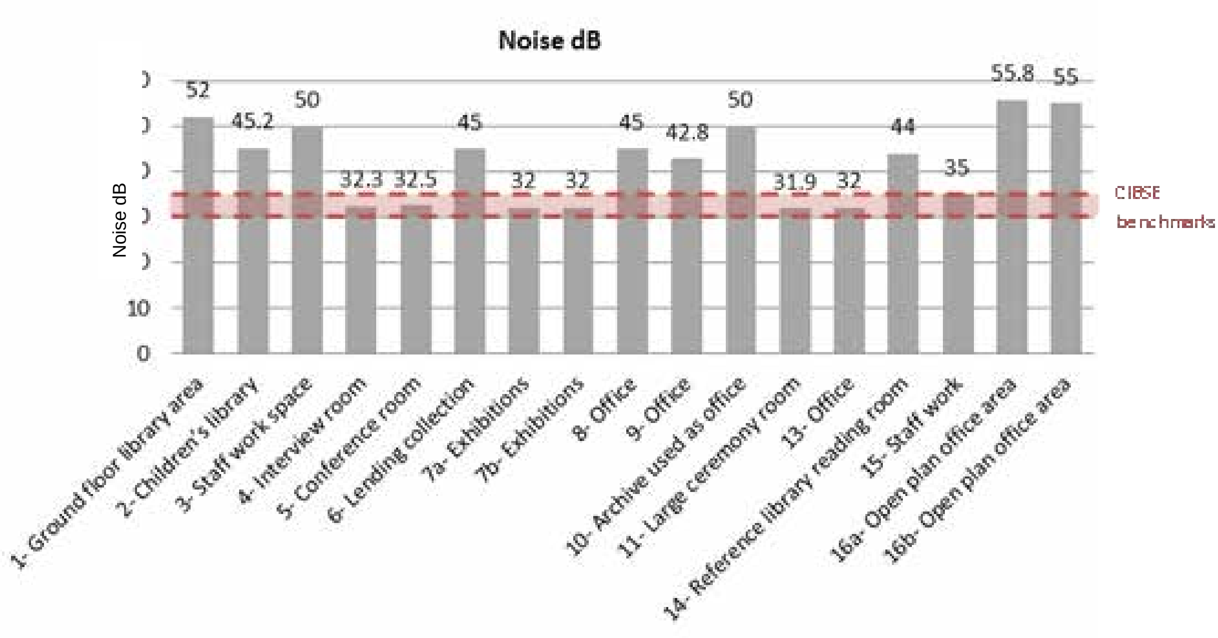


Figure 32 Noise level values in various spaces of the library during the spot check visit (08.08.2011)

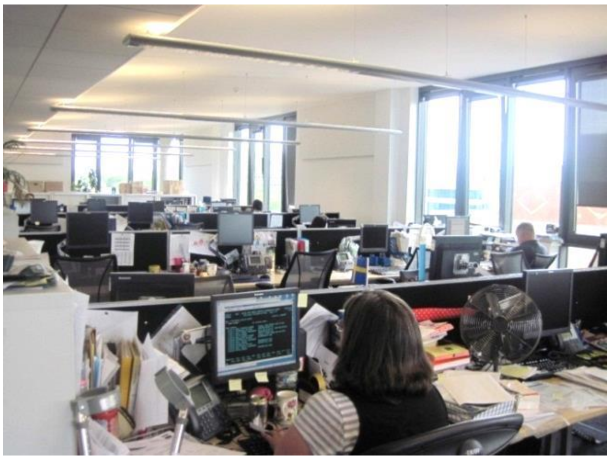


Figure 33 The open plan office on the top floor of the library.

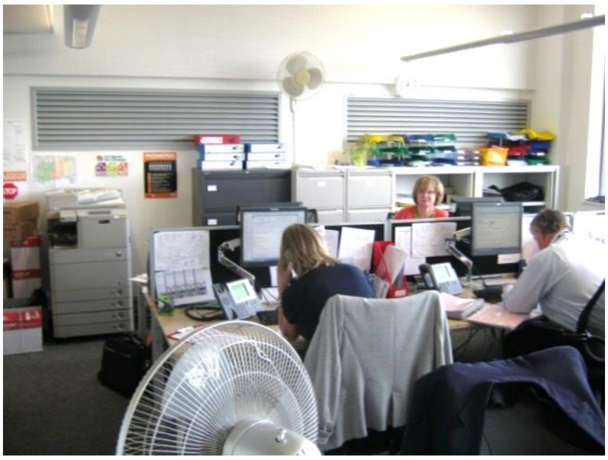


Figure 34 The photocopier is placed too close to the desks rising complaints over noise issues.

Comments on noise
• *As building is so stuffy we have to have windows open to let in air. The windows are huge so we get a lot of traffic noise and pollution in.* • *Design of staircase means noise on ground floor is very loud even on top floor especially with teenagers.* • *In summer office is very hot so windows must be open which lets in constant traffic noise. Announcements from public address system are often startling!* • *Lots of noise travels up from ground floor, but staircase blocks noise from different ends of the same floor.* • *Noise is inevitable because the job involves making many phone calls.(Open plan office)* • *To enable ventilation windows must be open next to the road. Traffic noise and car pollution (from the traffic lights) children's library windows open out to register services area.* • *Public noise from weddings and smoke.*

Table 7 Comments received by building users on noise.

4.6 Control

In terms of control over heating, cooling, lighting, noise and ventilation the majority of the people that took part in the BUS survey stated they have no control at all over their comfort conditions with the exception of ventilation, over which a third of the staff felt they had some degree of control. One of the most problematic spaces was found to be the exhibition room since the respondents mentioned it is either too hot or too cold and has no windows for proper ventilation. Respondents also felt that the ventilation in the meeting rooms was inadequate. The lack of control is also reflected by the fact that all the requests for changes have to do with the environmental conditions within the building.

The forensic survey for assessing the performance and usability of controls demonstrated that most of the library spaces were designed to be controlled by the BMS system and the facilities managers and not the individual users. Additionally, many systems, such as ventilation, lighting, doors and windows are automatic and require minimal input from the user. Therefore, very few control interfaces are actually intended to be used by the library visitors or by the staff members. This design decision is typical for a building of this size but results in a feeling of lack of control for the users that negatively impacts on their sense of comfort.

Manually operable windows are located in some of the individual office spaces and are easy and intuitive to use. On the other hand, the windows in the large office area and library areas are mechanically controlled and do not offer a good level of fine control.

During the semi-structured interviews occupants mentioned that window controls do not function properly, window control keys are difficult to use and are not provided to building occupants. Only security staff has access to keys for window controls (Figure 35). As a result, windows may remain closed which has a detrimental impact on the perceived indoor air quality by occupants. In addition, window control keys have been removed from the general staff and are used only by security for health and safety reasons. There is no occupancy control when the building is overheated.

Figure 35 The window control keys have been removed from the general staff to be used only from the security for health and safety issues.

Criteria	Poor				Excellent
Clarity of purpose				■ (green)	
Intuitive switching		■ (orange)			
Usefulness of labelling & annotation			■ (yellow)		
Ease of use	■ (red)				
Indication of system response			■ (yellow)		
Degree of fine control	■ (red)				
Accessibility		■ (orange)			

Comments

Mechanically opened windows are located in the main office areas and in the Library areas. They are not easy to use and not very intuitive. Users reported that the controls break down quite often and that they struggle to use the key. No good level of fine control as one control is used for many windows or entire areas limiting the choice of users.

Figure 36 Review of control interface for mechanically controlled windows

Table 8 Requests for changes received by building users.

Requests for changes
• *Asked for heat to be turned up during winter(x3).* • *Asked for ventilation to be put in floor, lights to be changed and blinds to be put at windows.* • *Constantly asking for air cooling system to be improved - it is very poor- customers also complain - nothing is ever done about it.* • *For heating in winter response was slow-heating was broken.* • *Requests for windows to be opened/closed(x2).* • *Requests for heating to be turned down.* • *Windows to remain open without a wedge to keep it open.*

4.7 Design and needs

Despite the various control and comfort issues the overall design of the building was highly rated with 79% of the respondents feeling satisfied and stating that the provided facilities met their needs in a large degree. The most positive comments were made on the modern design and high natural lighting levels while the number of toilets throughout the building, the storage in the children's library and the desk design were considered the most negative aspects of the building.

Interestingly, there were a significant number of comments in relation to the building design presenting particular challenges such as; the lack of doors in the children's library, which raised issues about safety; the position of the toilets opposite the ceremony room creating unwanted noise; and the use of archive rooms as office spaces. Several issues in relation to the office areas were also raised; the design of the desks was considered to be too small; the areas are felt to be lacking storage space; and the chairs are thought to be of poor quality. Respondents were also critical of the window design ("*The design of the windows makes no sense at all");* examples of which is the need for a wedge in order to keep the window open in the Register Services offices and the inability in the third floor offices to open windows individually, instead six have to be opened at once.

In relation to their specific needs, respondents feel hindered by the lack of proper ventilation in the toilets and the poor air circulation in the library. In the social services reception, the glass panel placed across the desk for protection purposes is felt to prevent clear communication and the need for the installation of microphones and speakers was noted.

Table 9 Comments received by building users on needs.

Needs
• *More ventilation would be nice in the kitchen and toilets.* • *There are not enough 'ladies' toilets.* • *In the social services, reception is very poor for communication with visitors via glass panel. Very hard to hear them via small holes. Mini microphones and speakers needed*. • *Very hot. Poor air circulation. Quiet study area upstairs gets sound from downstairs.*

Table 10 Comments received by building users on design.

Comments on design
• *Attractive, open, airy.* • *Do not like the open plan.* • *Main staircase obscures lifts and not much room for electric scooters to turn.* • *Modern, easy to keep clean, plenty of natural light to work with. Overall structure looks good.* • *No door to children's library worries about safety.* • *Much space taken up by the lifts and stairwells, but we only have access to a small lift which is no ventilated and brakes down.* • *Not enough toilets for the quantity of people.* • *Poor acoustics, sound travels upstairs.* • *The design of the windows makes no sense at all. Can't understand why one control operates a whole series of windows. It causes a lot of arguments.* • *Very badly designed. Toilets opposite ceremony room too noisy.* • *Windows would be better if they could be controlled in smaller sections.*

During the semi-structured interview the Registration Service Manager pointed out certain problems related to storage and layout. The interviewee mentioned that due to limited amount of space primarily dedicated to storage, other auxiliary spaces, such as available spaces next to staircase, are used for storage. This was observed during the walkthrough (Figure 37). Additionally, the interviewee felt that the building cannot accommodate current needs and claimed that the building layout had been based on different service structures.

The facilities manager also pointed out that there are more people in the building than the building was designed for, therefore the available space and storage areas are limited and there is limited flexibility, which in turn has an impact on the comfort levels of staff who occupy the spaces

Figure 37 The space next to the staircase in the Register area used currently as storage space.

The reception area of Registration Services is currently underused; it is a very large space which is only used as transient reception space and is not easily adoptable to future needs and changes (Figure 38). There is no flexibility for office expansion which has led to unintended solutions such as the conversion of the archive space into a working area and the moving of the ceremonies hub into third floor office space, breaking the Registration Services into two separate building parts. During the semi-structured interview the Registration Service manager mentioned that several design options for the division of the big ceremony room (Figure 39) into two different spaces, the potential of the unused space next to the staircase and the partition of the reception space were discussed between office members of the Registration Services but the architects have not been consulted.

Figure 38 Register service reception and archive space on the back currently used as a hot desk office.

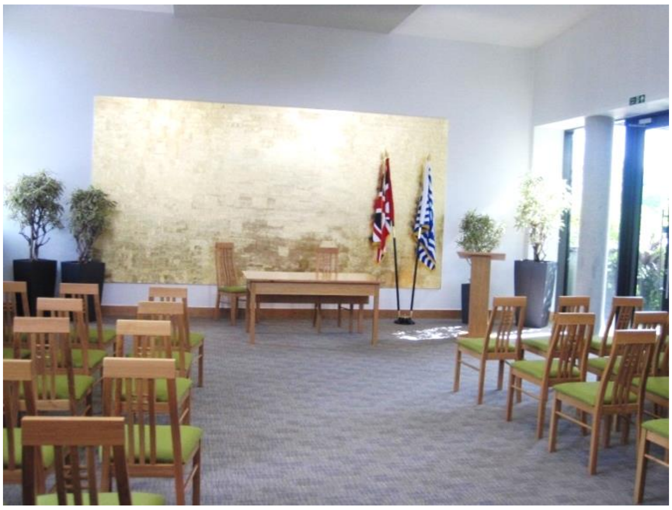


Figure 39 The possibility of dividing the underused big ceremony room was ruled out because of the spot lights placed on a plasterboard in the ceiling. Architects were never consulted on any renovation plans.

In turn, the Library officer pointed out that there are several issues with the layout and usability of furniture within the library but there is no rigid plan for improvement. During the walkthrough it was discovered that there is little flexibility in moving and rearranging furniture in the library space (Figure 40).

During the semi-structured interview, the Library officer also pointed out that lots of theft issues have been reported on the ground and first floors due to lack of proper supervision of these spaces. The walkthrough revealed that the eye-line from the reception towards the other end of the library ground and first floor is obstructed by the staircase preventing control and surveillance to hub areas located on that side of the floor (Figure 41). The design intent was for the main staircase material to be transparent but for security purposes it has been changed to wood. Additionally it was observed that operable windows in the library are placed in low height and open inwards creating issues with health and safety, usability and theft.

Figure 40 it is not easy to move and rearrange furniture in the library. Study desks in the library cannot be split up into smaller parts.

Figure 41 The eye-line from the reception towards the other end of the library ground and first floor is obstructed by the staircase preventing view to hub areas located on that side of the floor.

In the third floor open plan office area staff members complained about lack of adequate individual office space, notice boards and equipment to cover their needs (Figure 42). In particular, the registration manager mentioned that corporate office standards set by WSCC limit any options for enlarging individual office spaces.

Figure 42 A noticeboard was provided to the ‘registration hub’ after complaints on the lack of adequate space for notices.

4.8 Travel to work

The overwhelming mode of transport was by private car (69%); a few would commute by train and bus. Respondents suggested that the parking spaces were not able to cover their needs and that they wasted time searching for a space.

The facilities manager also pointed out that users complain that there are not enough car parking spaces.

4.9 Health and sense of wellbeing

The respondent's comments on health appear to relate to aspects of the building design that have failed to meet the user's needs. One third of the respondents rated the building negatively in terms of the impact it has to their sense of health and wellbeing but half did not notice any impact at all. The majority of the comments relate to the air stuffiness and poor ventilation and there are several complaints made in relation to feelings of thirst and fatigue as well as reports of headaches due to dehydration.

Similarly, 44% of the staff perceived their productivity to decrease when the atmosphere becomes too hot and stuffy mainly during the summer months. The lack of a water source within close distance, particularly in the library area was noted as was the comment that the unpleasant environmental conditions often led to impatience within staff members, which in turn had a negative impact on their customer services.

Table 11 Comments received by building users on perceived health

Health (perceived)
• The building is too hot. Ventilation is very poor. Thirsty all the time because of it. Also more drinking means more toilet breaks. • Headaches are frequent probably due to dehydration. Skin and lips crack in the winter as air is so dry. • Lack of proper ventilation in a large office with many people working together encourages germs to breed, causing higher levels of sickness absence. • Ventilation comes up in the offices from the library where we hear children and likely are exposed to germs. • No issues, I just feel cold. • When at home I do not have the stuffy, bunged up feeling I have at work. Working in this building makes me tired and gives me headache.

Table 12 Comments received by building users on productivity

Productivity (perceived)
• As a shelver, working in a stuffy, humid environment is very unpleasant and so we work slower as a result. • I don't think that my productivity is influenced by the building. • In summer productivity is reduced. Winter is ok. • No drinking water on ground or2nd floor causes excessive thirst, therefore affects productivity negatively. • Productivity would increase if ambient temperature was more controllable. • The need to obtain drinking water as the building is hot and air is dry needs staff to leave their work area often. Unpleasant WC area as no fresh air. • Too hot and no water.

4.10 Things that hinder/work well

Key aspects of the building that respondents feel positive towards are the big windows, which provide natural light and a nice ambience as well as the open space layout. The reception and security were also found to work well and the tidy workspace and housekeeping were considered positive too. Negative comments mainly related to issues with overheating and lack of control over windows.

The facilities manager had also pointed out that no security issues were identified by the management team. Access to certain building areas and offices is controlled and there is a swipe card system as well as a 24hour security guard.

Table 13 List of things that hider according to building users

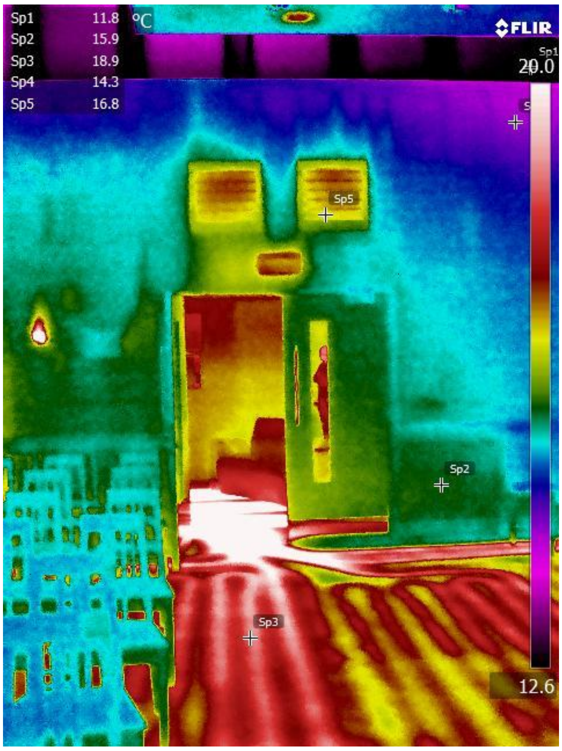
Things that hinder
• Ground floor layout is poor. Public should be able to see information desk as soon as they come in and not have to search for it. • Heat in office in summer is too high to use the office space to meet clients. Lighting in the office has been too bright but now it is better. • Electrical socket boxes are badly sited under the desk. • The doors that break frequently can hinder working as moving a trolley around the building becomes more difficult. • There is no provision for buggies in the junior section. The children can easily escape into main road as there are no doors to children's library and main door is sensor driven. • Time is wasted because there is minimal staff parking for workers and there is a need to travel a distance by foot to get to the vehicles. • Windows do not let in ventilation but do let in smoke, pollution, noise.

Table 14 List of things that work well according to building users

Aspects that work well
• Customer lifts. • Good facilities, tidy workspace, good housekeeping. • Good lighting, comfortable chairs. • Good shelf layout. • Good use of reception and security. • I like the big windows. • I think that compared to other libraries we have a lot of space. • Interaction with colleagues. • Light, ambience. • Lots of light because of large sized windows. • Security are very friendly and helpful if there is a problem. • We have adapted our routines to fit the building. They now work relatively well.

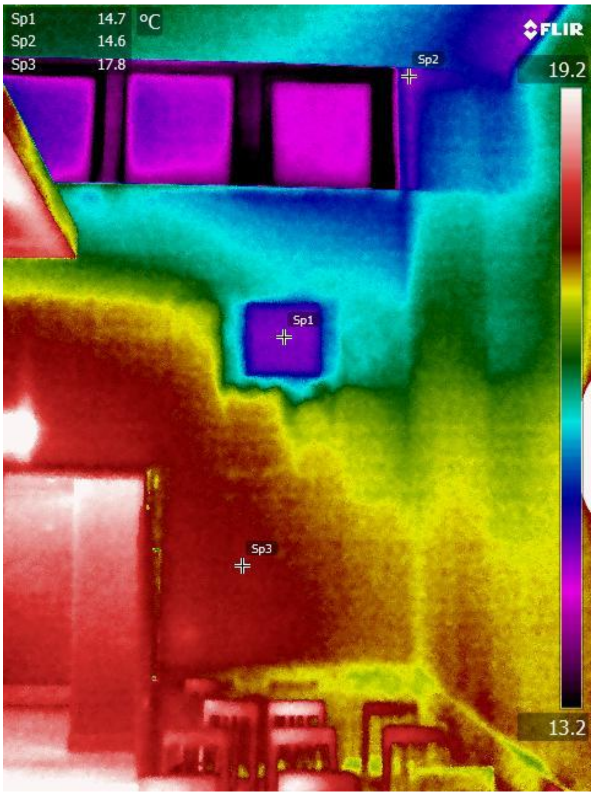
4.11 Thermographic survey

A thermographic survey carried out in the Library building on 6th December 2011 revealed a limited number of abnormalities matching with the staff's comments relating to cold draughts and unheated spaces. Figure 43 reveals cold air draughts entering the small ceremony room, through the high level windows. The 'leaky' windows explain the lower room temperatures in comparison to the rest of the building spaces. Figure 44 and Figure 45 indicate similar conditions in the large ceremony room where cold bridging is also shown in the room corner possibly due to the geometry of space. Further problems included cold bridging due to material inconsistency or lack of insulation in the exhibition and conference rooms and generally poorly insulated window frames.



Measurements	*ºC*
Sp1	11.8
Sp2	15.9
Sp3	18.9
Sp4	14.3
Sp5	16.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ^{o}C
Room temperature:	17 ^{o}C

Figure 43 Small ceremony room thermogram. Possibly the top left windows are leaky creating draughts since the temperature captured is very low (Sp1). A flow of cold air dropping from the windows can be noticed while the grilles over the door are also blowing cold air into the unoccupied room.



Measurements	*ºC*
Sp1	14.7
Sp2	14.6
Sp3	17.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ºC
Room temperature:	17.5 ºC

Figure 44 Large ceremony room thermogram. An irregular cold air fringe is dropping from the top windows indicating a cold bridge due to the geometrical elements or lack of insulation on that place. Cooling is on in as in the first ceremony without the rooms being occupied.

Measurements	*ºC*
Sp1	13.0
Sp2	14.6
Sp3	19.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ^{o}C
Room temperature:	17.5 ^{o}C

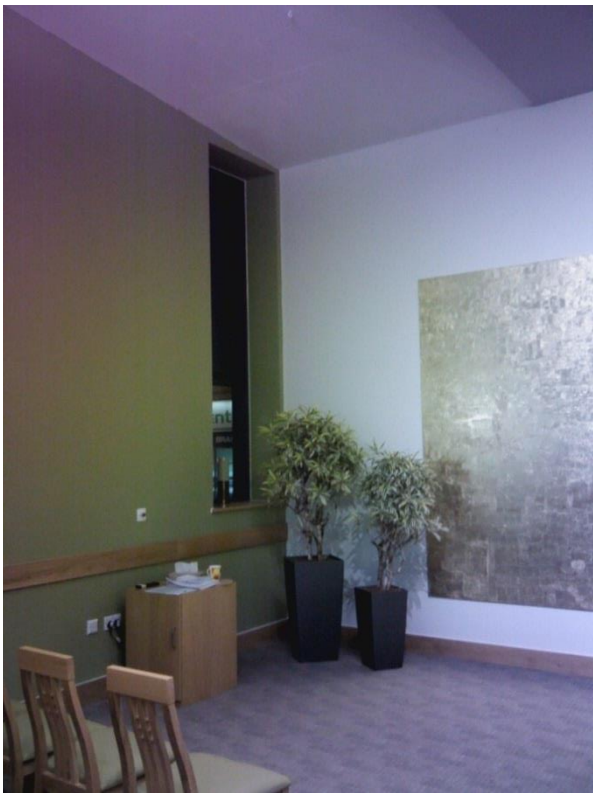


Figure 45 Large ceremony room thermogram. A cold bridge probably due to geometry of building elements can be identified in the room corner.

4.12 Conclusions and key findings

4.12.1 Key findings from BUS survey

- The quality of natural light that the windows offer is one of the most appreciated design elements.
- The building overheats during the summer months and lack of control over windows and ventilation further aggravates the problem.
- The exhibition room on the first floor was felt to be either too warm or too cold and the ventilation in the meeting rooms was described as inadequate.
- Noise was clearly an issue for the staff members, mainly due to the open plan spaces within the library and the external noise coming from the road when the windows are open.
- The design of the desks was considered to be too small, lacking storage space with the chairs felt to be of a poor quality.
- In terms of control over heating, cooling, lighting, noise and ventilation, the majority stated to have no control at all over their comfort conditions, with the exception of ventilation over which a third of the staff felt they had some degree of control. This fact is highly reflected in the requests for changes which were mainly related to heating, cooling and ventilation needs.
- The lack of adequate parking space is felt by social services staff to lead to wasted working hours, as they need to be mobile frequently during the day for work reasons but often return to find no parking available.
- One third of the respondents rated the building negatively in terms of the impact it has to their sense of health and wellbeing whilst half of them did not notice any impact at all. The majority of the comments were related to the stuffiness of the air and poor ventilation which was felt to lead to feelings of thirst and fatigue, as well as having negative effects on productivity.
- Positive comments were made on the security and housekeeping services.

4.12.2 Key findings from semi-structured interviews

- It is imperative to address any issues with regards to building usage and spaces adoptability in the register office, 3rd floor open plan offices and library.
- Limited storage space has been reported together with restricted office space for individual workers in the building.
- Ventilation in many building spaces is inadequate; the location of ventilation inlets has been indicated to be very close to occupancy areas which fact creates major discomfort issues to staff member that work in those particular parts of the building.
- Low levels of natural ventilation due to limited access to windows controls create overheating issues during summer and cold draughts during winter period.
- Security issues have been identified in ground floor library space. Design and technology solutions are important to be addressed (e.g. different furniture arrangement, installation of surveillance cameras, new item control system) to prevent thefts incidents from remote library areas.
- Lighting controls need to be revised to avoid any unnecessary use of artificial lighting and meet the actual lighting requirements in relation to daylight levels in spaces with glazing areas.
- BMS system is not properly connected with building systems and controls.

- Lack of feedback and reporting mechanisms has created major delays in addressing important issues, such as environmental controls and limited functionality of systems.

4.12.3 Key findings from the thermographic survey

- Thermograms revealed heating and cooling being on in unoccupied spaces (e.g. interview spaces, ceremony room). This shows poor control of heating and cooling system leading to unintended energy losses.
- Clerestory windows in the atrium, windows of both ceremony rooms and conference room appear to not be properly sealed, which can lead to cold air draughts entering the building.
- The exhibition space, conference room and ceremony room were found to have cold bridges possibly due to discontinuous insulation/material.

4.12.4 Key findings from the walkthrough

- The windows are designed to open inwards but lacked a stop or an inclination mechanism in order to adjust its opening to a desired position.
- Lights were on, with some of the windows open whilst blinds were found in several positions indicating a variation of comfort level conditions within the open plan office.
- The archive spaces in the ground floor library and first floor Register Services area have been turned into offices even though there are no windows for natural lighting and ventilation in both rooms.

4.13 Recommendations

4.13.1 Recommendations to Library, Register Services and FM team members

- Create a team of representatives from Library, Registration service, Social services and FM team to liaise with the architects team (P&P) regarding space usage and room adoptability issues in the register office, 3rd floor open plan offices and library.
- Create a communication and feedback platform between the key members of staff and the FM team with scheduled meetings where all the issues can be discussed and solutions can be granted between the different library end users and the maintenance team.
- Facilities management need to have better control of heating and cooling over unoccupied spaces especially the two ceremony rooms. Staff should also be incentivised to turn off the heating when they plan to leave a room.

4.13.2 Recommendations to Register Services manager

- Liaise with the FM team in order to identify a new location for the photocopier, provide office partitions to create more individual space and surface for notices and resolve the cold air blow issue in the open plan office 'registration hub' desks.
- Liaise with the architects and the FM team to identify possible design solutions for the reception, the large ceremony room and the unused space behind the staircase.
- Provide initiatives to the members of staff living in the area to encourage the use of public transport or bicycle to travel to work to minimise the parking problem as well as lead to 'greener' attitudes.

4.13.3 Recommendations to Library manager

- Review the operation status of the IT suite computers in the library with the computer maintenance service to avoid having them on when the room is not in use.
- Liaise with the architects and the FM team to identify possible design and technology solutions (e.g. different furniture arrangement, installation of surveillance cameras, new item control system) to prevent thefts from the remote library areas.
- Provide initiatives to the members of staff living in the area to encourage the use of public transport or bicycle to travel to work to minimise the parking problem as well as lead to 'greener' attitudes.

4.13.4 Recommendations to building designers

- Review the window design in order to be able to keep them open without the need of a wedge. In addition individual window control should be considered instead of six windows in a row with the same control.
- The ventilation strategy for the toilets in the library and open place office areas should be reviewed.
- Thermal bridging due to geometry or insulation/material inconsistencies needs to be discussed with the project architects to further indicate the causes and identify the actions that may need to be taken in order to minimise this effect.

4.13.5 Recommendations to FM team and manager

- Review and revise PIR control settings in offices in order to meet the actual lighting needs.
- Check heating, cooling and ventilation regimes in the library function rooms.
- Review the option of providing drinking fountains on the library ground and second floor.
- Identify the responsible party for the cleaning of the biomass boiler ash residues and set up a maintenance schedule.
- Identify the responsible party for the fix and maintenance of the solar thermal panels and review hot water needs.
- Occupants' comments and ratings on air temperature and quality imply the need to check heating and cooling strategies in the open plan office space, the ceremony rooms, and the library offices as well as the common space.
- The library and open plan office toilet's ventilation should be reviewed, and amended, if required.
- The children's library entrance needs to be secured properly, in order to avoid children getting out of the building through the sliding main entrance doors.
- The installation of microphones and speakers in the social services reception should be considered due to issues with clear communication because of the protective glass panel.
- Consider providing freestanding water coolers in the key areas of the building that are easily accessible to staff during working hours.
- Investigate storage needs in different departments and provide drawers and cupboards where needed.

- Alarm systems connected to the disabled toilets need to be examined. The flashing light indicating a person needs help is hidden; it would be preferable to have this in full view of the persons working at the enquiry desks.

4.13.6 Recommendations to BMS system provider

- Review the BMS system in order to send alarm messages in case of system defects.
- Provide a BMS User Guide and BMS training to the FM team.
- Establish remote access and interrogation to the site BMS system.

5 Details of aftercare, operation, maintenance and management

5.1 Review of the O&M manual and Logbook

The 'Operating and Maintenance' (O&M) manual was prepared by BAM and its purpose is to offer the personnel concerned with the operation and maintenance of the services within the building, assistance in the performance of their duties. The manual is to be used to assist skilled engineers, experienced in the operation and maintenance of the building services, to provide them with a comprehensive knowledge of the various systems installed within the project.

During onsite inspection it was found that the printed copy of O&M manual located in the facilities manager's office had missing volumes. Volume 7 'Maintenance Instructions and Logbooks' did not exist and Volume 8 'Fault tracing Charts' was found to be empty. However, the digital file provided to the BPE team is complete and includes all the necessary information.

The FM team was unable to provide the BPE team with an updated Logbook as they appear to be unfamiliar with the Logbook. The study has revealed that the Logbook is not kept up to date and that there is not log of breakdowns, repairs and maintenance.

Sub-meters were difficult to locate since the drawings with the metering and sub-metering arrangements were missing from the BAM electrical and mechanical specification documents. The FM manager did not have any plan available of the metering and sub-metering arrangements either and their position was identified during a walkthrough. The main end-use of each sub-meter was not clear in the building Logbook, BMS or any other provided documentation.

In addition to this, the BPE team could not find written confirmation that all systems were installed as documented in the O&M manual. These findings indicate that the documentation of management, maintenance and operation is poor.

5.2 Review of operation and maintenance of BMS system

The Crawley library BMS was commissioned by Intandem via their design and build construction contract with BAM. Since the defects period has passed, responsibility for the BMS settings and maintenance is with the building owner (WSCC) which had a BMS maintenance contract with Intandem in place. However, the maintenance contract has expired and that the BMS system is not properly maintained.

Onsite inspection by Intandem in November 2012 revealed several issues regarding the heating and cooling system and BMS. The inspection was part of a training session, funded by the BPE team. The main purpose of the training was to enable the facilities managers and the BPE researchers to access and utilise the BMS system.

The training was delivered in 3 sessions.

Session 1: Plant room tour

During this session the role of various kit (Gas and Biomass boilers; cold and hot water tank; water mains; AHU; water pumps;) was explained along with repairs and maintenance requirements. The FM was informed about the location of various controls, alarms and isolation switches. Tips on finding out the current status of equipment were explained along with trouble shooting methods.

The main findings in this session, for immediate action were:

- LED lights on the main control panel to be replaced
- Leak above Accumulator Shunt Pump P9 to be repaired
- Gas boiler was left on standby and therefore did not start when the biomass boiler switched off, boiler must not be left on standby.
- Chimney cleaning for Biomass boiler was overdue
- Filters need changing in 2 AHU units

Session 2: Review of front end (PC) of the BMS system

The controls available at the front end PC were explored. The facilities managers were not familiar with the software.

The main findings at the time were the following:

- No system to switch off heating etc. on holidays
- External temperature based switching of cooling needs to be set up; the cooling chiller pumps were still on in late November.
- Temperatures in some rooms on the first floor (small, large ceremony rooms) are much higher or lower than the average. One room was 24 deg C, while another was 19 deg C. This was reported as due to solar gains. Perhaps set point temperatures for each zone need to be set in accordance with the internal gain and solar gain conditions of each zone.
- Temperature sensors need to be re-calibrated.
- Air quality is described in units of '%', varying widely between rooms.
- Sub-metering data not feeding correctly into the BMS, the meters need to be reconciled, Intandem engineers found the password to be 00000. Sub-metered data needs to be recorded and the FM needs to know how this can be used.
- Recording of internal temperatures has been set up, recording of energy consumption and other variables needs to be set up.
- Product data sheets and wiring diagrams have been loaded into the PC.

Session 3: Building tour

The main findings during the building tour were:

- Manifolds & actuators heads have come off in certain areas preventing heat getting to that zone, this needs to be resolved. A demonstration on how to detect if the heating is working was given.
- Solar thermal system not working – may be due to a fault with the pump.
- The lighting system is based only on occupancy; they are switched on even when daylight conditions are sufficient and cannot be controlled by the user in most offices.

Despite the findings of the inspection been presented to the FM team no action was taken regarding the BMS system. After continuous efforts of the BPE team, WSCC liaised with Pureworld Technologies Ltd who visited the site three times in order to commission the BMS system, connect all the existing sub-meters to the BMS and ensure that the data is being recorded on the front end PC.

However, no maintenance contract has been setup between Pureworld and WSCC despite the fact that the BPE study has pointed out its necessity.

5.3 Structured interview with management

An interview with a member of management team of Crawley library was conducted on 5th June 2013. The interviewee is responsible for maintenance and facilities management and has been working in Crawley Library for one year. The following sections include a summary of his views on building performance, operation, maintenance and management.

5.3.1 Building operations – heating, cooling, lighting and other services

5.3.1.1 Users' requirements

- The building design layout seems to be fit for purpose and current use patterns.
- Library is quite an open space; people can walk up and down and it is very wide; there are accessible lifts and toilets; the interviewee rates it as good design for a library.
- The separate entrance for registration also works well together with a dedicated entrance, reception desk and dedicated facilities.

5.3.1.2 Building operations and controls

- The FMs have expressed a lot of complaints about the BMS system.
- They do not feel that the BMS is functioning adequately and members of management team do not know how to use it. Therefore management staff often override the BMS settings by using the control panel in the plant room.
- The management staff do not have the skills, the training, or the knowledge to connect into the BMS and resolve any heating, cooling and ventilation issues in Crawley library; therefore they have no option, but to manually override settings in the plant room.
- Almost all building systems and controls seem to perform badly. The facilities management team has no control over the building.
- Lighting controls seem to be working well since no significant complaints have been addressed. PIR sensors activate electrical lighting in most building spaces.
- Occupants don't have sufficient control over their environment; they can't make any significant changes and they rely on automatic sensors throughout the rooms and remotely fixed environmental conditions.
- Electric fan heaters are used during winter to provide additional warmth and portable electric fans are also used during summer to provide adequate ventilation.
- The overall feeling is that the building has failed in terms of comfort and user control and as the BMS is not used and working correctly the occupants have to bring portable devices to control their own environment.

5.3.1.3 Issues with heating and cooling and control systems

- There is a gas supply providing (if necessary) heating and hot water, but the primary biomass system should take priority. However due to an excessive amount of issues, the heating seems to be running predominantly using the gas boiler and not the biomass.
- The biomass boiler requires repairs regularly, often because of inadequate or incorrect fuel; the woodchips are not the right size or there are foreign objects inside the biomass fuel.
- It was indicated that all building users have expressed major complaints regarding the heating and control systems of Crawley library building.
- The TREND BMS system should be fully controllable and facilities managers should be able to control all areas of the building, however, the facilities managers cannot see, monitor and adjust the majority of the building's elements.
- There is a TREND system, which is not correctly connected; engineers have occasionally visited the building to have a look at the BMS but they have never been appointed to fix it.
- The air-conditioning system cannot be controlled through the BMS and the facilities managers do not know how to operate the air conditioning in this building.
- Settings in the BMS were made before occupants moved in but since then no one knows how to operate the BMS and the building in general and the settings have not been altered.
- Maintenance staff is called in to repair specific elements of the building system, but they do not know how to operate the controls and BMS.
- There is no person who has an overall knowledge of all technologies.

- The only demonstration the facilities management team have received on the BMS system, was provided by the Oxford Brookes BPE team one year ago. In 2012 the BPE team felt that the BMS system was not connected properly to the building services.
- The facilities management team member also expressed a complaint about the lack of demonstrations. He stated that he does not know how to use and fix the building systems, as no one has provided an overall demonstration of how the building works.
- The interviewee only knows roughly where 75% of the equipment is located and lacks knowledge of where other controllers are, e.g. controls for heating and air conditioning.
- Many windows had started to fail at the same time creating a health and safety issue. On two occasions, the chain located inside the window frame has been disconnected and the windows have completely fallen apart; fortunately without causing any injuries. The contractors (BAM) were requested to check the problem and advised to keep them closed until an expert came to review the problem. This has resulted in very high indoor temperatures during summer and a range of staff complaints leading to the temporary positioning of about 20 desk fans throughout library spaces. The window expert advised that a special pin that holds the chain had to be replaced and the special compartments had to be ordered by the manufacturer who is based in Germany. After six weeks the pins were delivered to Crawley library but their installation took time. Due to the complexity of installation a risk assessment and a method statement was provided by BAM.
- In the past year, during a routine boiler inspection the plumber found that there was a hot water leakage in the underfloor pipes.
- Despite the heating being switched off, the hot water was still being diverted under the floor due to the settings being incorrect; and the gas boiler was still in operation. This incident was attributed to plumber's limited experience in reviewing Crawley library building's systems.
- The solar panels on roof are out of operation resulting in hot water shortage during summer. Neither the plumbing nor the air-conditioning department admit responsibility.

5.3.1.4 Building energy efficiency

- It is a common understanding that Crawley library building does not meet the initial design intentions of being a building of high energy efficiency.
- The solar thermal system on the roof could have been sized more carefully to utilise the enormous roof space and provide a higher contribution to hot water demand.

5.3.2 Energy and water consumption management

- The facilities management team has no involvement in energy and water consumption management.
- WSCC has its own carbon management team based in Chester that is advising all buildings in terms of energy management.

5.3.3 Catering, IT. Specific processes and other systems

- All electronic devices and lights are switched off during the night. If any equipment is identified as having been left on, the security staff turn it off.
- All staff use laptops that are turned off during the night and there is a power-save mode on printers and photocopies.
- The new FM Officer was not aware whether the library computer equipment turns on/off manually or automatically; the reason stated was that the computer maintenance is provided by another company.

5.3.4 Operation, maintenance and management

- Problems are reported to the facilities management team via e-mails or through telephone communication.
- There is a monitored e-mail box as well as phones provided to management team that are active all day and night.
- If the issues can't be resolved by facilities officers on-site, then the problem is reported to WSCC. WSCC uses Scottish and Southern Electricity (SSE) for all maintenance issues.
- SSE either sends an electrician, plumber, or a gas engineer, or if there is something they can't resolve, they are able to contact specialist sub-contractors.
- The maintenance company's office hours are typical office hours (8am – 5pm) but they do have an emergency 24/7 number.
- The new FM officer was not aware of the past biomass boiler history.
- There is no official maintenance schedule for the cleaning of the biomass boiler creating confusion and delay trying to verify the responsible party to remove the biomass ash residues (caretakers, FM team or an external company).
- The solar thermal and biomass boiler have both been out of order for an unknown amount of time. The FM team seem to struggle keeping the facilities running properly.

5.3.5 Targets, feedback systems, corrective actions, improvement

- There is no feedback mechanism in Crawley library building to report all the aforementioned building issues.
- Building managers are not aware of any energy use benchmarks that may be used for the building's good operation and environmental performance.
- Energy consumption (electricity and gas) of Crawley Library is monitored by the Carbon Management Engineer of WSCC through a dedicated smart metering system.

5.4 Conclusions and key findings

5.4.1 Key findings from the review of the O&M manual and Logbook

- The printed copy of O&M manual located in the facilities manager's office had missing volumes. Volume 7 'Maintenance Instructions and Logbooks' did not exist and Volume 8 'Fault tracing Charts' was found to be empty.
- The Logbook is not kept up to date and that there is not log of breakdowns, repairs and maintenance.
- Sub-meters were difficult to locate since the drawings with the metering and sub-metering arrangements were missing from the BAM electrical and mechanical specification documents. The FM manager did not have any plan available of the metering and sub-metering arrangements.
- The FM team is unfamiliar with the Logbook.
- The documentation of management, maintenance and operation is poor.

5.4.2 Key findings from the review of the operation and maintenance of the BMS system

There is no maintenance contract (Proactive Preventive Maintenance) setup resulting in serious problems regarding the operation of the heating and cooling system.

The training day in November 2012 funded by the BPE study revealed that the facilities managers were not well familiar with many of the controls and operation of systems. Onsite inspection by Intandem in November 2012 revealed several issues regarding the heating and cooling system and BMS:

- Gas boiler was left on standby and therefore did not start when the biomass boiler switched off, boiler must not be left on standby.

- The facilities managers were not familiar with the BMS software.
- No system to switch off heating etc. on holidays
- Temperature sensors need to be re-calibrated.
- Sub-metering data is currently not feeding correctly into the BMS, the meters need to be reconciled.
- Recording of internal temperatures has been set up, recording of energy consumption and other variables needs to be set up.
- Manifolds & actuators heads have come off in certain areas preventing heat getting to that zone, this needs to be resolved. A demonstration on how to detect if the heating is working was given.
- Solar thermal system not working – may be due to a fault with the pump.
- The lighting system is based only on occupancy; they are switched on even when daylight conditions are sufficient and cannot be controlled by the user in most offices.

Despite the findings of the inspection been presented to the FM team no action was taken regarding the BMS system. After continuous efforts of the BPE team, WSCC liaised with Pureworld Technologies Ltd who visited the site three times in order to commission the BMS system, connect all the existing sub-meters to the BMS and ensure that the data is being recorded on the front end PC.

5.4.3 Key findings on usability and interface with controls

Although the overall building layout and design is satisfactory, facilities management has identified several issues with building systems, the operation of controls and their functionality. Lack of knowledge and training also creates many issues with regards to usability, functionality and interface with controls.

The BMS system does not have a comprehensive interface and building managers and curators are not able to use and adjust the majority of the building's controls and settings.

- BMS settings and controls are not accessible by the facilities management team.
- Defective commissioning of the BMS system and its trend logging facility has resulted in managers not being able to control heating, ventilation and cooling levels throughout the building.
- No demonstrations have been provided to building managers and users on how to operate the existing controls.
- The management team has limited understanding of building controls and their purpose.

5.4.4 Key findings on reliability, maintenance and maintainability

Several technologies incorporated in Crawley library building regularly fail or do not function sufficiently. Maintenance of these systems is provided; however problems are rarely resolved effectively, as equipment keeps failing.

- The biomass boiler has encountered an excessive amount of failures due to low quality biomass fuel. Maintenance team and sub-contractors fixed the problems; however, the system regularly fails.
- Therefore, biomass heating in Crawley library is perceived by the management team as unreliable and very difficult to understand and maintain.
- The heating and cooling strategies in Crawley library do not appear to be functioning according to the initial design intent; while the systems regularly failing, the mechanical equipment is either too expensive or too difficult to maintain.
- There have been several attempts to resolve issues with BMS system in Crawley library building in the past, but the engineers that visited the site have not been able to tackle the problems effectively, due to initial faulty system installation and commissioning. Following action of the BPE team and WSCC the BPE system has been re-commissioned and updated. However, the maintenance contract for the BMS system has expired and has not been renewed. This is one of the reasons why the BMS system was not performing efficiently.

5.5 Recommendations

5.5.1 Recommendations to the FM team

- Ensure proper training of all members of the FM team and develop Handover documentation and robust procedures in case of changes in the FM team.

- Monitor the electricity consumption of the building by analysing the sub-metering data now available on the BMS system.

- Follow the operation and maintenance procedures described in the O&M manual and keep the Logbook updated. Keep a log of all faults, breakdowns, repairs and maintenance taking place.

- Create robust feed backloops to report problems quickly in the first year of occupation.

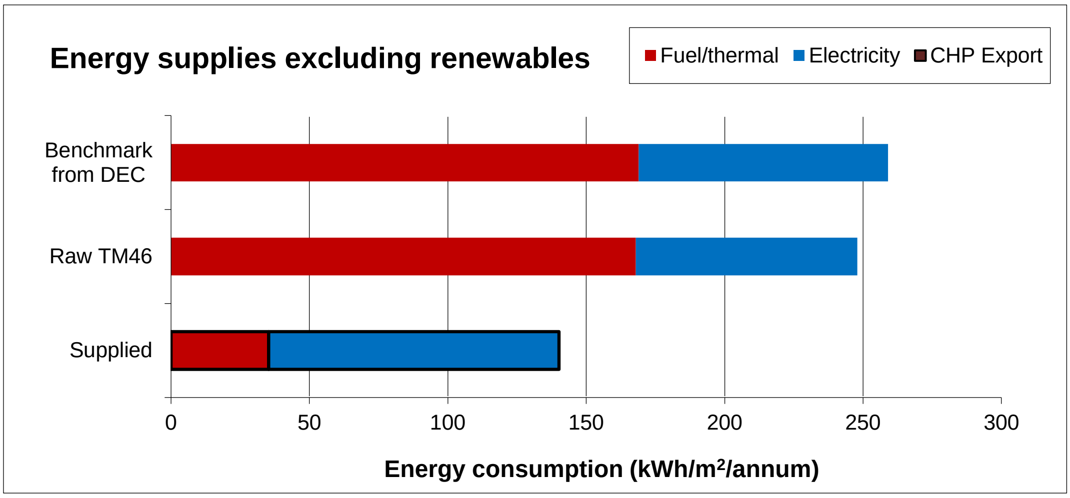
5.5.2 Recommendations to WSCC

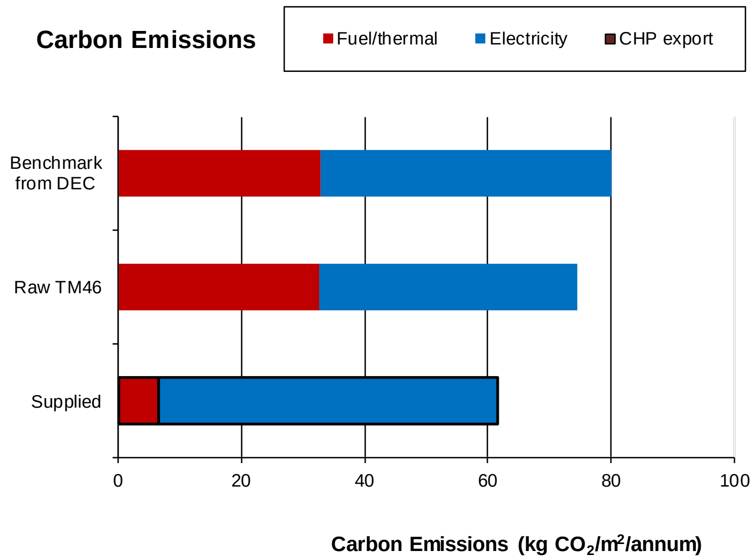
- It is highly recommended that WSCC sets up a new maintenance contract for the BMS system that would ensure its performance is up to standard.
- Ensure proper training of new members of FM team.
- Re-commissioning of systems is recommended along with seasonal commissioning.

6 Energy use

6.1 CIBSE TM22 simple assessment and benchmarking (October 2013 –September 2014)

Data on gas and electricity from October 2013 to September 2014 were taken from the web database **www.stark.co.uk.** This provides half hourly data on gas and electricity consumption. Information on the building floor area was provided by the design drawings.





CO_2 factors used in assessment:	kg CO_2 /kWh
Natural gas	0.184
Electricity (grid)	0.525
Biofuels	0.025
Solar thermal	0

Benchmark CO_2 factors:	kg CO_2 /kWh
Electricity (grid)	0.525
Gas	0.194

Figure 46 CIBSETM22:2011 simple assessment tables (January – December 2012).

Based on the total energy supplied to the building, the associated carbon emissions figure of 61.6kgCO_2/m^2 is lower than the raw CIBSE TM46 benchmark and 25% lower than the DEC benchmark (Figure 46).

In terms of gas consumption the building performs 80% better (lower) than the raw CIBSE TM46 and DEC benchmarks. However in terms of electricity consumption, the building performs 23% worse (higher) than the raw CIBSE TM46 benchmark and 14% worse than the DEC benchmark (Figure 46).

Table 15 CIBSE TM22:2011 simple assessment table.

Absolute values	Energy supplied (kWh)		Carbon dioxide emissions (kg CO_2)		
	Fuel/thermal	Electricity	Fuel/thermal	Electricity	TOTAL
Supplied less separables	157,563	468,640	28,992	246,036	275,028

Unit values	Energy supplied (kWh/m^{2}TADA)		Carbon dioxide emissions (kg CO_2/m^2 TADA)		
	Fuel/thermal	Electricity	Fuel/thermal	Electricity	TOTAL
Supplied less separables	35.3	104.9	6.5	55.1	61.6
Raw TM46	167.9	80.0	32.6	42.0	74.6
User Specified	0.0	0.0	0.0	0.0	0.0
Exported CHP	0.0		0.0		
Benchmark from DEC	169.0	90.0	32.8	47.3	80.0

Table 16 CIBSE TM22:2011 CO_2 emissions from supplied energy compared to BRUKL predicted emissions.

Unit values	Energy supplied (kWh/m^2 GIA)		Carbon dioxide emissions (kg CO_2/m^2 GIA)			BRUKL predicted kg CO_2/m^2	
	Gas	Electricity	Gas	Electricity	TOTAL	Target CO_2 emission rate TER	Building CO_2 emission rate BER
Supplied	35.3	104.9	6.5	55.1	61.6	28	13

TM22 Notes:
Carbon emissions associated with renewable heating fuels/supplies are included in the fuel/thermal total.

The per m^2 indicators in this table are calculated against the whole building's GIA including areas for separables. Carbon emissions for fuel/thermal fuel use are calculated in the same way for the benchmarks and the actual data - the carbon factor used is the average carbon factor for the building's overall fuel/thermal mix. This differs from the approach used in the calculation of DEC ratings, where the DEC benchmark assumes gas as the only fuel/thermal supply for the calculation of benchmark carbon emissions from fuel/thermal supplies.

Table 17 Discrepancies between 'as designed' and 'in-use' energy performance through BRUKL, EPC and DEC energy assessment ratings and Crawley energy data from www.stark.co.uk.

Unit values	Energy use(kWh/m^2 GIA)		Carbon dioxide emissions (kg CO_2/m^2 GIA)			Operational rating
	Fuel/ Thermal	Electricity	Fuel/ Thermal	Electricity	TOTAL	
BRUKL TER (Target Emission Rate)					28	
BRUKL BER (Building emission rate)					13	
EPC 8/2009			6.2	11.3	17.5	25 (A)
DEC 2/2010	55	123				90 (D)
DEC 10/2009	103	76				80 (D)
Actual consumption (Energy bills May 2010-May 2011)	44.8	131.9	8.2	69.2	77.4	
Benchmark from DEC	169.0	90.0	31.0	47.2	78.2	

6.2 Comparison with other buildings and benchmarks

Comparison is made with other library buildings and civic buildings studied as part of the TSB Building Performance Evaluation programme. Overall Crawley Library uses more energy than Visby library (Sweden) and other civic buildings, despite being designed to high sustainability standards. Interestingly while annual gas consumption per square meter of Crawley library is much less than any of the peers, the electricity use is higher than almost all the peers (apart from Gloucester library building) by 2-3 times, indicating issues with energy management (Figure 47), excessive lighting energy use and small power. When compared to the typical and good practice benchmarks for library buildings (CIBSE Guide F), Crawley Library is performing well in terms of energy use, consuming less than the Good Practice benchmark. However annual carbon emissions of Crawley Library are higher than the typical benchmark, and most other buildings as a result of the high electricity use (Figure 48).

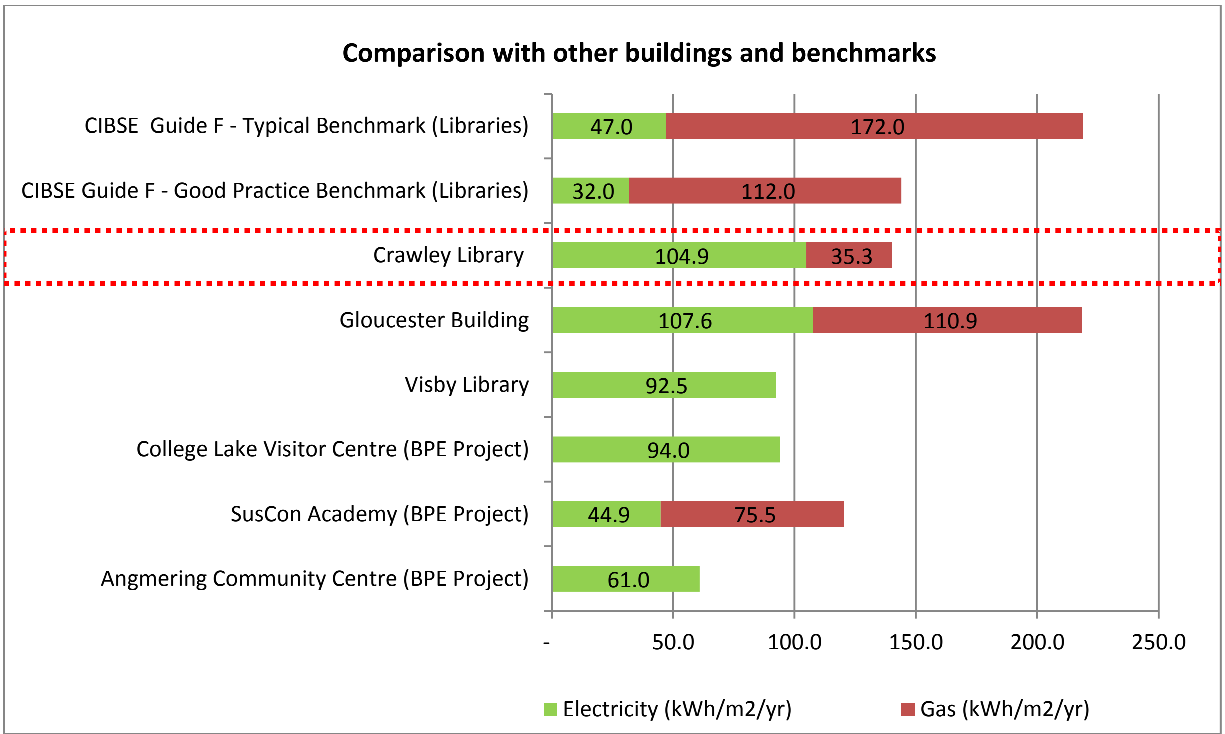


Figure 47 Comparison of Crawley library energy use with other buildings and CIBSE Guide F benchmark

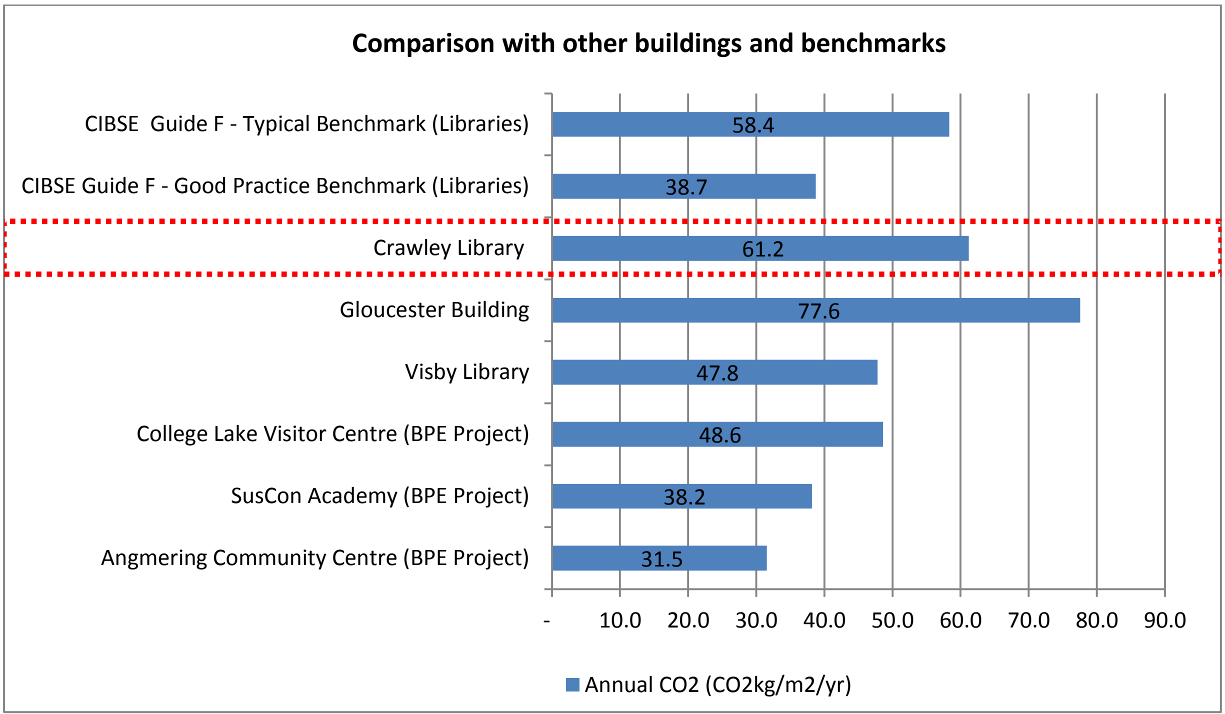


Figure 48 Comparison of Crawley library CO_2 emissions with other buildings and CIBSE Guide F benchmark (Carbon Factors: Gas 0.198 $kgCO_2e$, Electricity 0.517 $kgCO_2e$)

6.3 Analysis of energy consumption

6.3.1 Weekly meter readings (sMeasure)

The metered electricity and gas consumption values of Crawley library were entered in the online SMeasure tool (http://smeasure.com**)** which helped to visualise the building's consumption and calculated the related figures for CO_2 emissions and money spent.

Figure 48 indicates that weekly electricity consumption is much higher that the weekly gas consumption. Weekly electricity consumption ranges between 10,000 and 14,000 kWh. Weekly electricity consumption remains quite stable throughout the year. An incremental trend can be observed since the end of 2012. In winter 2012 weekly electricity consumption ranges between 9,000-11,000kWh, whereas in winter 2013 it rises to 13,000-15,000kWh.

Weekly gas consumption ranges between 0 and 10,000kWh. The graph reveals a very irregular pattern of weekly gas consumption. As expected consumption is higher during the winter months and reaches 0-1,000 kWh per week during the warmer months. A comparison between winter 2012 and 2013 reveals a big discrepancy between the two. In winter 2012 gas consumption ranges between 6,000 - 10,000kWh per week, whereas in winter 2013 weekly consumption rises greatly reaching 15,000kWh.

These changes, which have occurred since the end of 2012, can be explained by a change in the management of the building and the fact that the new management is not as familiar with the technologies and controls in the building. Additionally, several breakdowns of the biomass boiler during the past year have led to it being underused and to an increased use of the backup gas boiler. Additionally, it should be taken into account that winter was colder in 2013 than the previous year. This can be observed in the graph of heating degree days from January 2012 to October 2013 (Figure 49)

In addition, the correlation between weekly weather and weekly energy consumption for heating is poor (R=0.33) (Figure 50). This indicates that the heating system and the controls do not follow closely the changes in external temperature and that the efficiency of the heating system is poor.

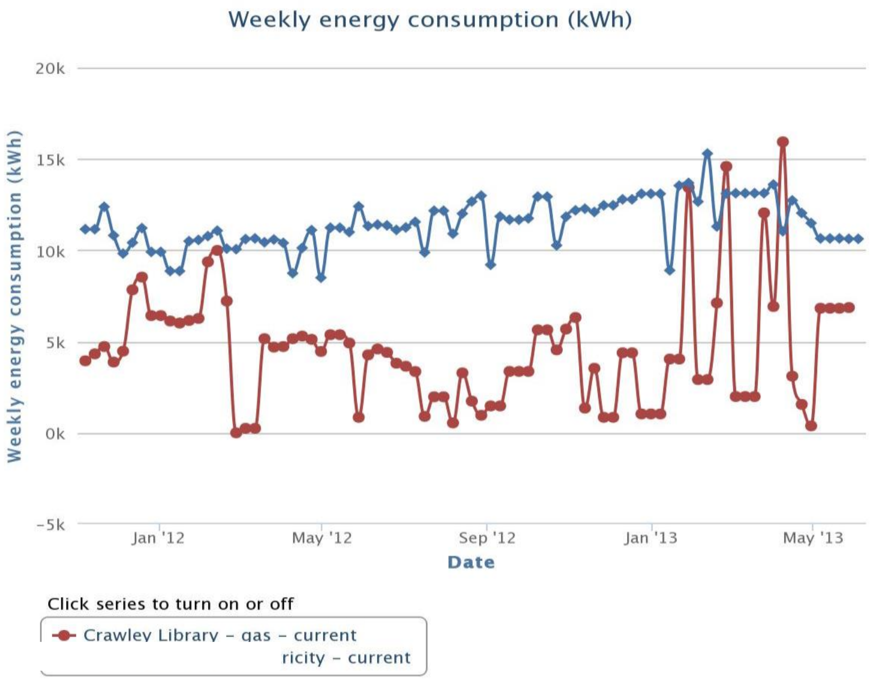


Figure 49 Weekly gas and electricity consumption (KWh) from November 2011 to May 2013

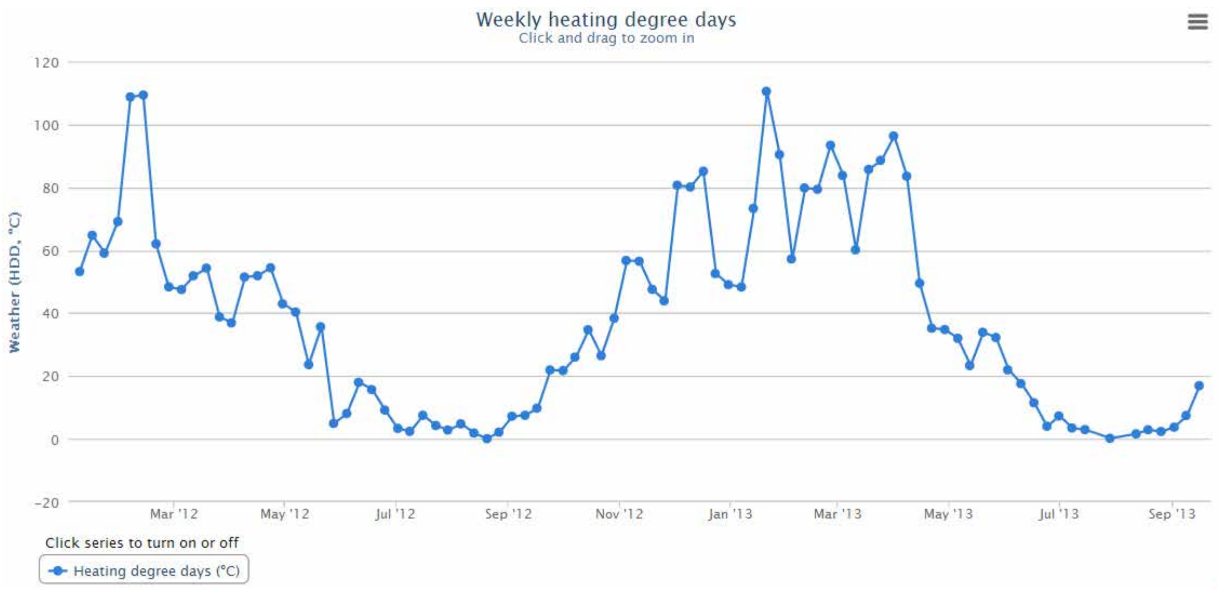


Figure 50 Weekly heating degree days from January 2012-October 2013.

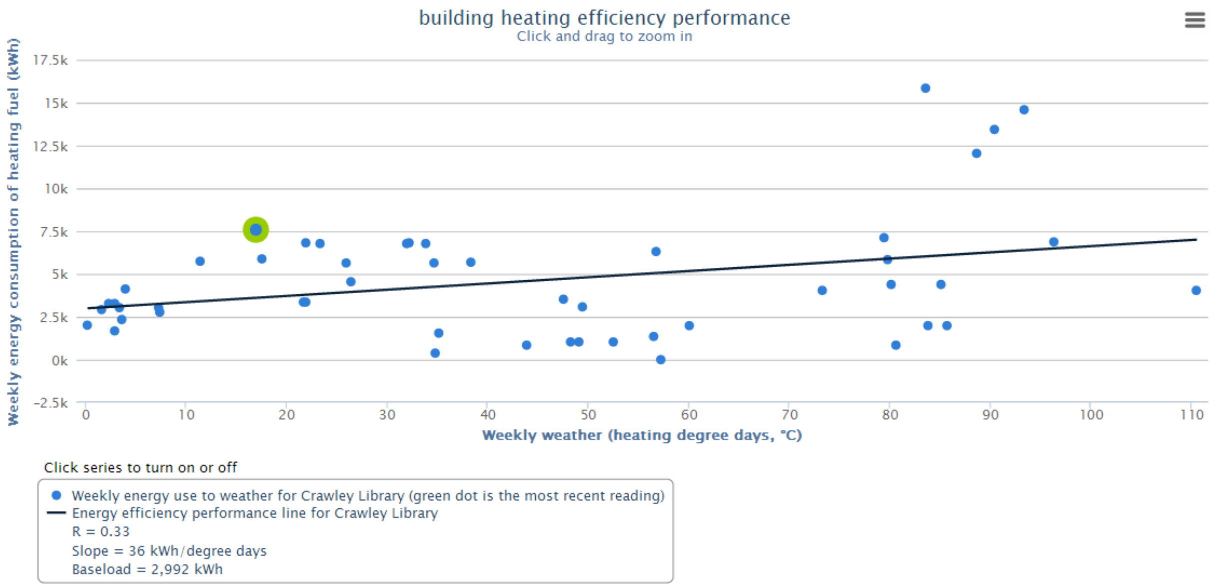


Figure 51 Heating efficiency performance. The correlation between weekly weather and weekly energy consumption for heating is poor (R=0.33). This indicates that the heating system and the controls do not follow closely the changes in external temperature.

6.3.2 Electricity and gas monitoring data

Electricity and gas consumption of the library are metered through an independent metering system logging half-hourly profiles into a web database. Half hourly electricity and gas data are being uploaded online (http://stark.co.uk/) by West Sussex County Council.

In 2012 the total annual electricity consumption was 587,698kWh which reduced slightly to 572,919kWh in 2013. On the other hand the total annual gas consumption was 199,976kWh in 2012 which increased to 233,122kWh in 2013 (Table 1), possibly due to colder temperatures in 2013 in comparison to the previous year and also to possible changes in control settings brought about by the new facilities management. The operation of the biomass boiler might have also contributed to this pattern, however no log is kept of when the biomass boiler is being used.

Table 18 Total electricity use in 2012 and 2013.

Year	Total Electricity Use (kWh)	Total Gas Use (kWh)
2012	587,698	199,976
2013	572,919	233,122

Figure 52 shows the monthly electricity and gas consumption from January 2012 to February 2014. Gas consumption presents great variation from one year to another, likely to be related to the intermittent use of the biomass boiler (due to frequent breakdowns). Electricity use, on the other hand seems to be steadily reducing since June 2013 following the first calibration of the BMS system. Since October 2013, following the calibration of the heating settings on the BMS system electricity use during winter was further reduced.

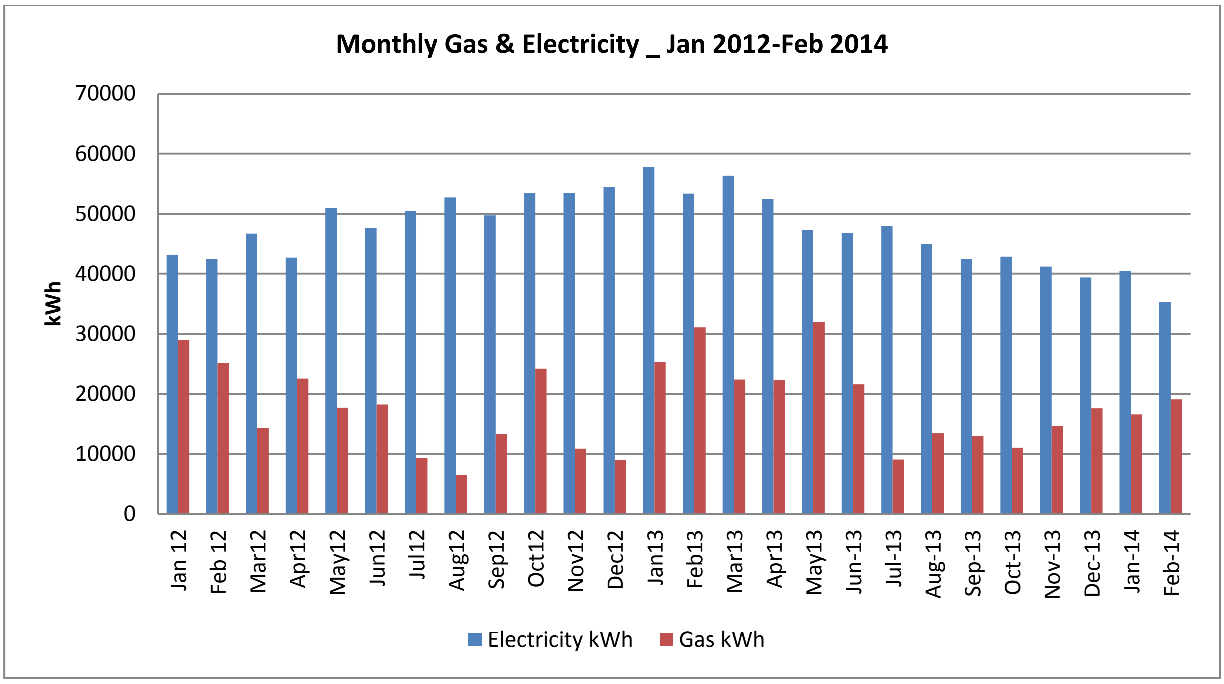


Figure 52 Comparison of monthly gas and electricity consumption from January 2012 to February 2014.

The monthly gas consumption of both winter periods is quite similar (Jan 2012: 28,900kWh, Jan 2013 25,000kWh). Electricity consumption during that period ranges between 35,000-58,000 kWh/month. Monthly gas consumption ranges from 6,500kWh in August 2012 to 32,000kWh in May 2013 related to the frequent breakdowns of the biomass boiler. During the winter months, gas consumption ranges between 15,000-27,000 kWh in 2012 and between 22,000 and 32,000kWh in 2013. Interestingly from December 2013 to February 2014, gas consumption ranges between 16,500-19,000 kWh (lower than previous years) as the BMS system is working (since October 2013) and used actively by the building management team.

The building is occupied from Monday to Friday 8am - 5pm. On Saturday only the library is open from 9am until 7pm. The library is closed on Sunday. Normal cleaning hours are Monday to Friday at 6am – 8am. The nature of the building means that staff can access it 24hrs and there is security 24hrs a day. The building is not rented out for any other activities and there are no out-of-hours activities.

The average weekday and weekend half-hourly loads are plotted in Figures 53 and 54 respectively. The average weekday half-hourly load is around 110kW from 9:30 to 16:30. The average weekend half-hourly load is around 66kW from 9:30 to 16:30. After hours half-hourly load is around 35kW during both weekdays and weekends.

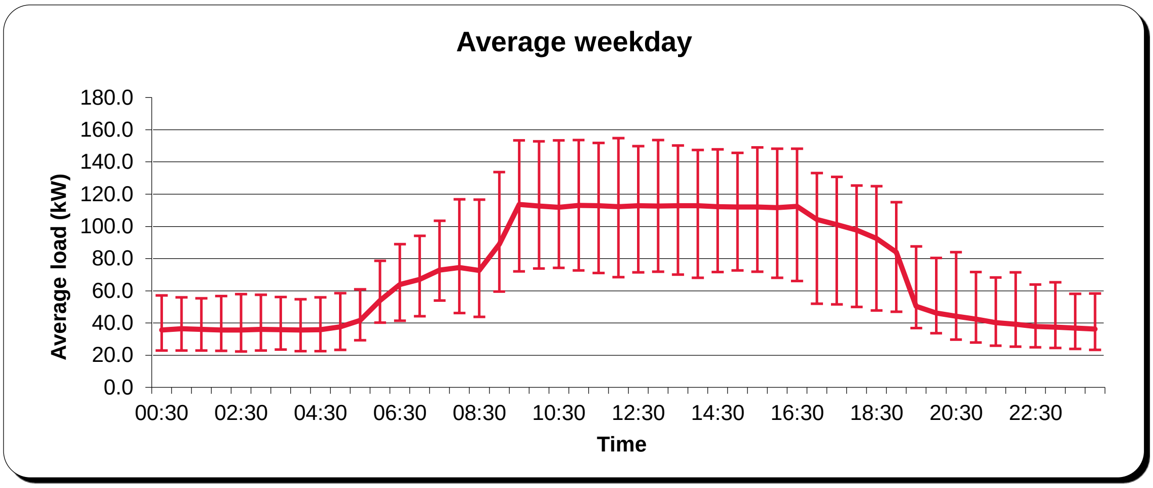


Figure 53 Average half-hourly weekday load (January-December 2013).

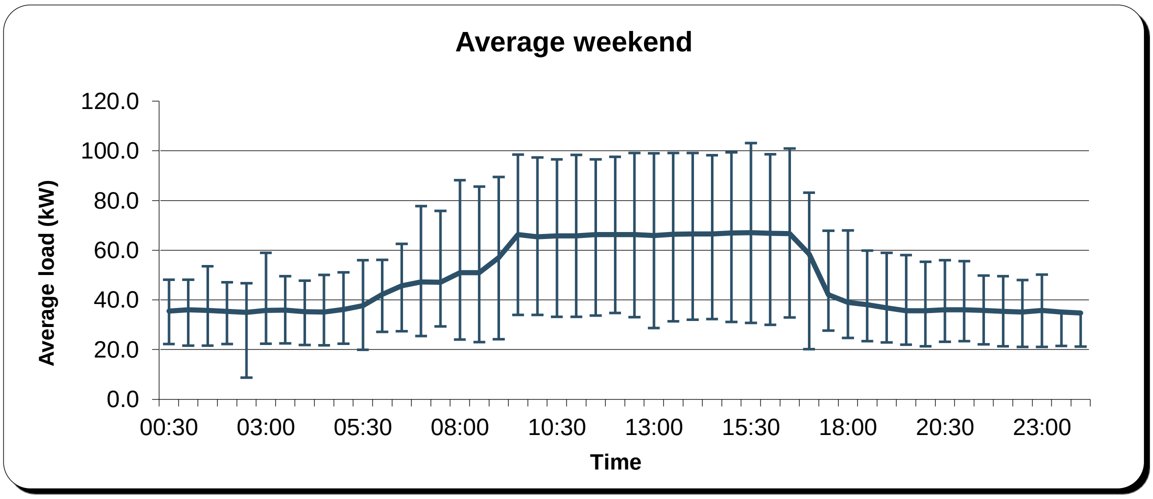


Figure 54 Average half-hourly weekend load (January-December 2013)

6.3.3 Analysis of electricity sub-metering (October 2013 – September 2014)

Electricity sub-metering (5 minute intervals) data is available from 4th October 2013 when all sub-meters were connected to the BMS system. Total electricity consumption from 4th October 2013 to 5th October 2014 is 468,640 kWh. Table 19 shows the sub-meter measurements taken from the BMS system. An analysis of the electricity consumption by end-use shows that during the monitoring period 31% of the electricity consumed in the building was used for lighting, 18% was used by small power, 11% was used by the chiller and 10% was used by the fans and pumps of the plant rooms (Figure 55). This is despite the fact that the building was designed to maximise the use of day-light. The 'unregulated' loads for small power, catering and computer equipment rooms and associated air conditioning (not included in the Part L calculations) make up 36% of the total electricity use. The Library Hub room that includes a large server and its AC system consumes 9% of the total electricity use.

Table 19 Electricity by end-use

S.No	Main end-use	End use/ area/ system/ circuit or tenancy to be measured	Annual consumption	Electricity use by end-use
1	MCC1	Fans and pumps, Plantroom Ground floor	7,174	Fans and pumps 46,685

2	MCC2	Fans and pumps, Plantroom roof	39,510	
3	Chiller	Cooling, External roof	53,696	Cooling 53,696
4	Hub Room UPS	Server room equipment, Server room ground floor	11,555	Hub Room 43,571
5	Hub Rm A/C DB	Hub Rm A/C DB	32,016	
6	DB-LLG1	Lighting, Library Ground floor	17,056	Library Lights 97,953
14	DB-LLG2	Lighting, Library ground floor	27,121	
8	DB-LL11	Lighting, Library 1st floor	21,031	
16	DB-LL12	Lighting, Library 1st floor	8,627	
10	DB-LL21	Lighting, Library 2nd floor	16,498	
18	DB-LL22	Lighting, Library 2nd floor	7,620	
22	DB-GL	Lighting, Office Ground floor	14,172	Office Lights 31,044
12	DB-3L1	Lighting, Office 3rd floor	6,110	
20	DB-3L2	Lighting, Office 3rd floor	10,762	
24	DB-RL	Lighting, Register services 1st floor	16,764	Register Lights 16,764
7	DB-LPG1	Workstation and general small power, Library Ground Floor	14,748	Library Small Power 47,094
15	DB-LPG2	Workstation and general small power, Library Ground Floor	3,601	
9	DB-LP11	Workstation and general small power, Library 1st Floor	8,174	
17	DB-LP12	Workstation and general small power, Library 1st Floor	12,121	
11	DB-LP21	Workstation and general small power, Library 2nd Floor	5,507	
19	DB-LP22	Workstation and general small power, Library 2nd Floor	2,942	
23	DB-GP	Workstation and general small power, Office Ground floor	7,961	Office Small Power 28,932
13	DB-3P1	Workstation and general small power, Office 3rd Floor	9,475	
21	DB-3P2	Workstation and general small power, Office 3rd Floor	11,496	
25	DB-RP	Workstation and general small power, Register services 1st floor	7,925	Register Small Power 7,925
26	DB-C	Café, Ground floor	41,940	Cafe 41,940
27	DB-EL	*External Lighting*	Not logging	-

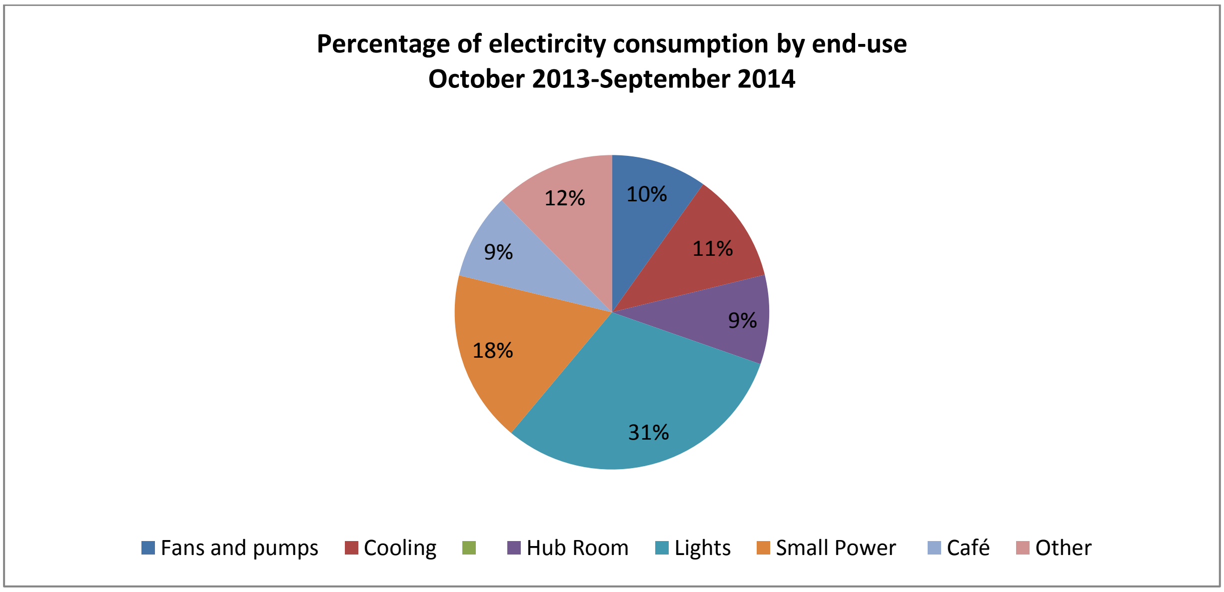


Figure 55 Percentage of electricity consumption by end use (October 2013-September 2014)

The end use electricity data of lighting, equipment, cooling, catering and mechanical services were calculated using the TM22 spreadsheet. Figure 56 shows the electrical energy demand by end-use, with electrical lighting consuming the highest amount of energy followed by appliances and cooling. The actual electricity use has exceeded the equivalent TM46 benchmark.

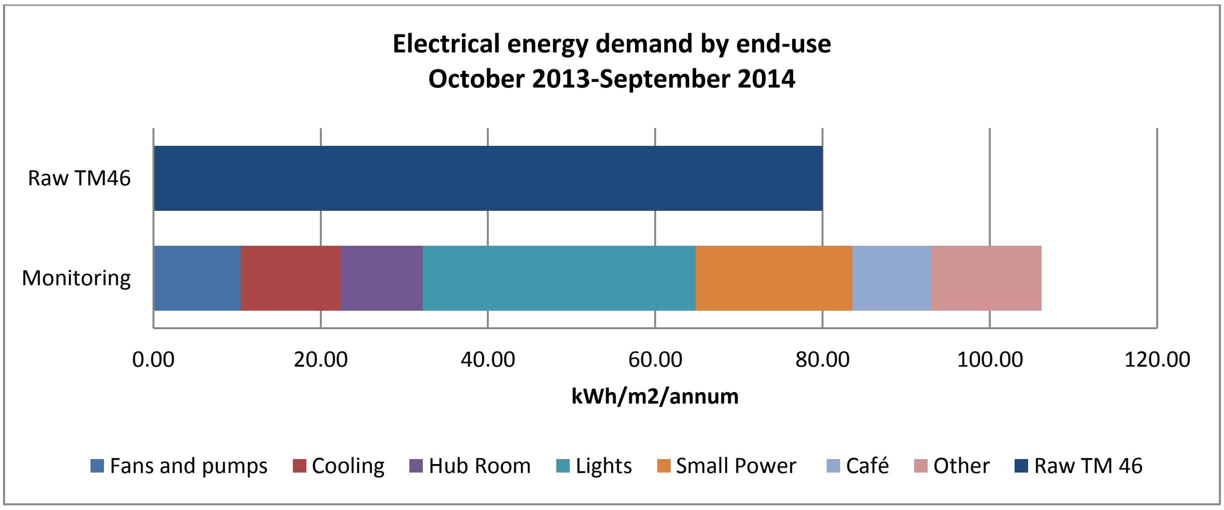


Figure 56 Electrical energy demand by end-use (October 2013-September 2014)

The electricity use for lighting and small power per space are plotted in Figures 57 and 58 respectively. Electricity use for lighting is higher in the Library (37 kWh/m^2/annum), followed by the Registry office spaces on the 1st floor (33 kWh/m^2/annum) and the office spaces on the 3rd floor (24 kWh/m^2/annum). Lights in the Library are on for longer as the Library stays open after the offices are closed and is also open on Saturday. Additionally, the lights in the registry offices are on more often than the lights on the 3rd floor offices due to the lower daylight levels in the register offices. Small power electricity use presents a slightly different profile as it is higher in the 3rd floor offices (22 kWh/m^2/annum) where each desk has a computer and a telephone and there are six printers in use. Small power electricity use in the Library (18 kWh/m^2/annum) can be mainly attributed to the more than forty public computers available in the Library that are occasionally used by visitors but remain switched on.

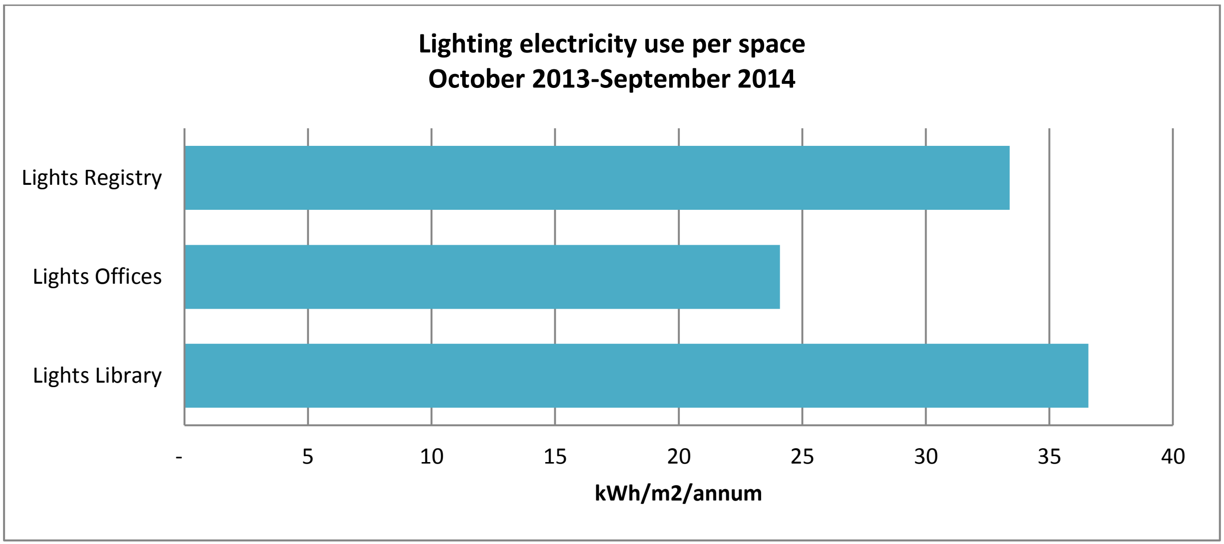


Figure 57 Lighting electricity use per space (October 2013-September 2014)

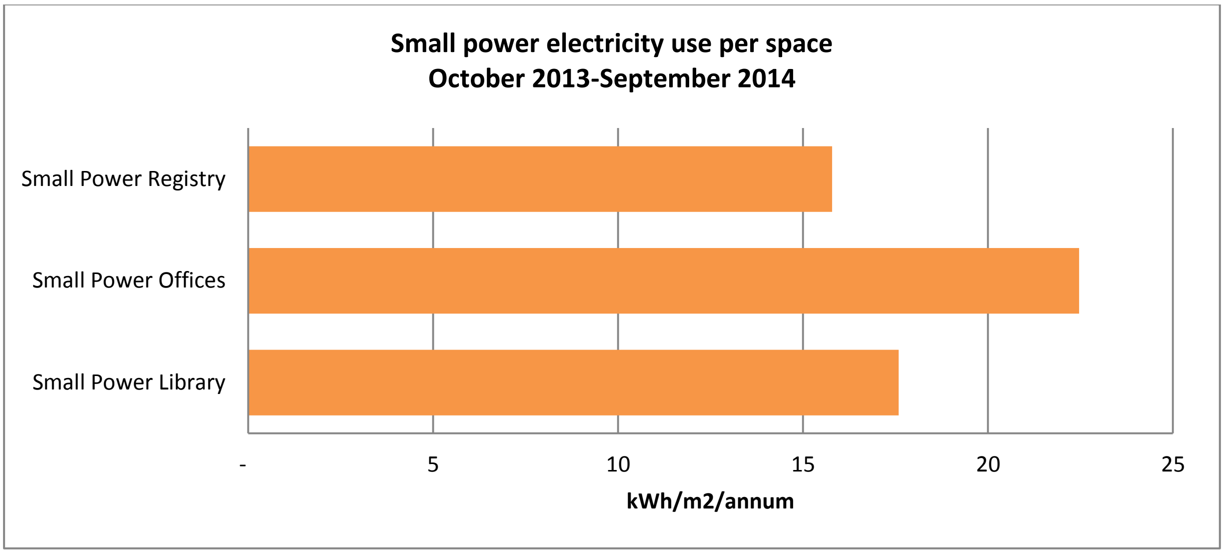


Figure 58 Small power electricity use per space (October 2013-September 2014)

Hourly lighting and small power electricity consumption in the building areas are shown in Figures 59 and 60 respectively. Lights are on from 5:00 to 19:00 in all spaces. Library lights consume around 19kWh per hour, office lights consume around 5kWh per hour and register office lights consume around 3kWh per hour. Base load lighting consumption is around 1kWh in all the office and registrar spaces and around 3kWh per hour in the Library.

Small power consumption starts rising after 8:00 in all spaces and reduces after 17:00 in the offices and register office and after 6pm in the library. Peak consumption is around 13:00 in all spaces. The base load from small power is around 2kWh per hour in the Library, whereas in the office spaces it is around 3kWh per hour and around 1kWh in the register office spaces indicating that equipment is left on or in standby mode in the offices. During the day small power consumption in the Library is around 13kWh per hour whereas in the offices it is around 5kWh per hour.

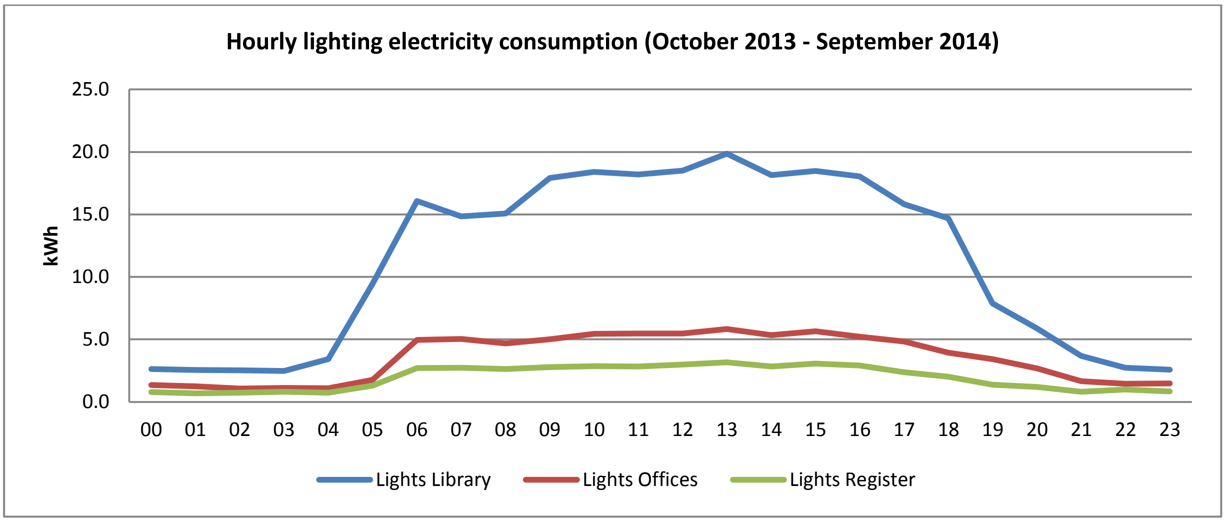


Figure 59 Average hourly lighting electricity consumption (October 2013-September 2014)

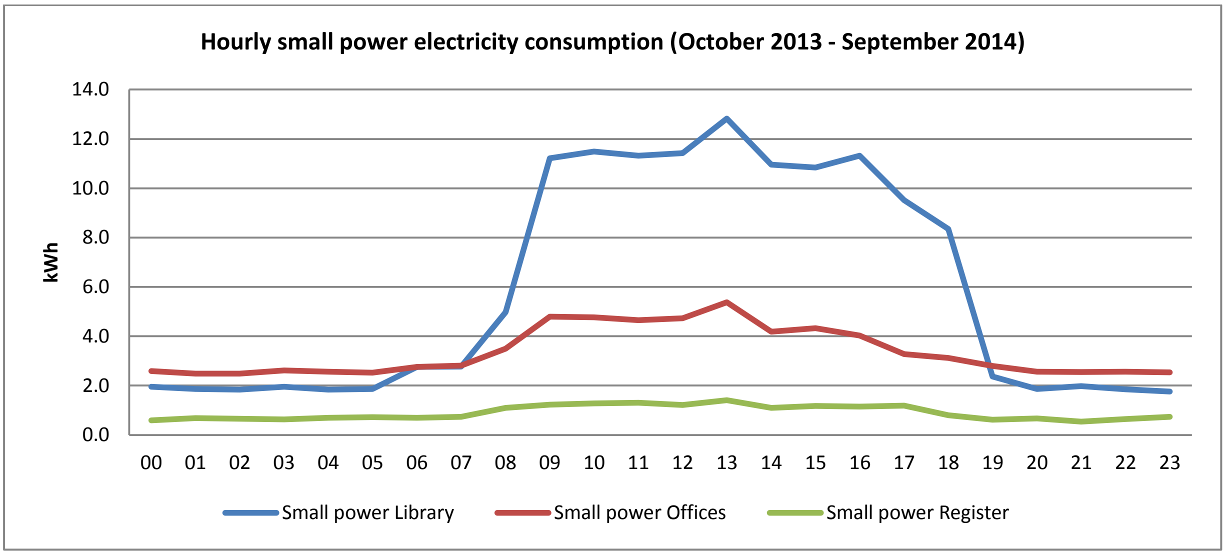


Figure 60 Average hourly small power electricity consumption (October 2013-September 2014)

6.3.3.1 Lighting profiles

Figures 61 and 62 show the average half hourly weekday and weekend lighting load in the Library. On weekdays average load is around 20kW. On weekends average load is around 11kWh. Baseload is around 3kW.

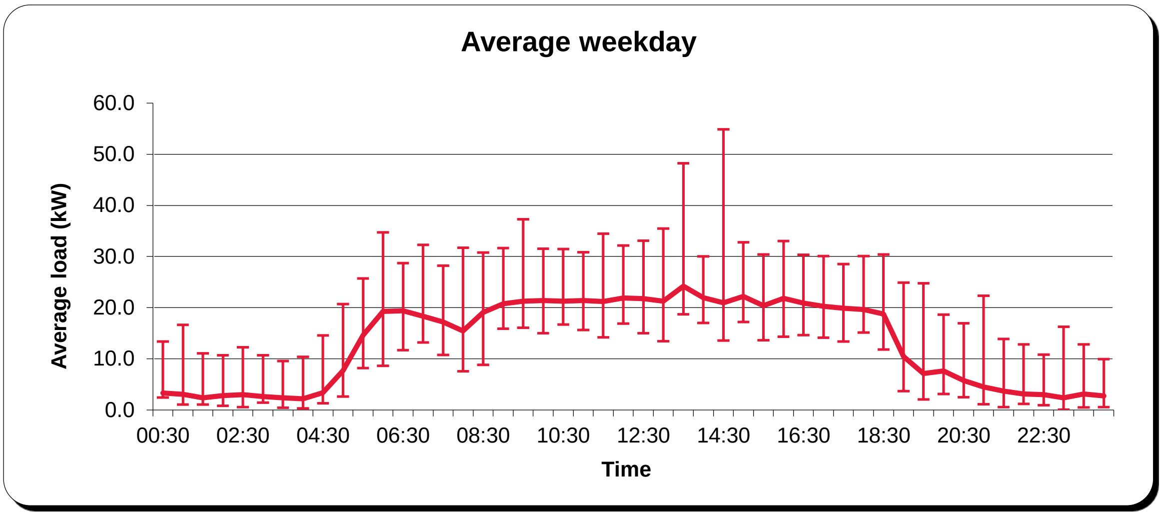


Figure 61 Average half-hourly weekday lighting load in Library (October 2013-September 2014)

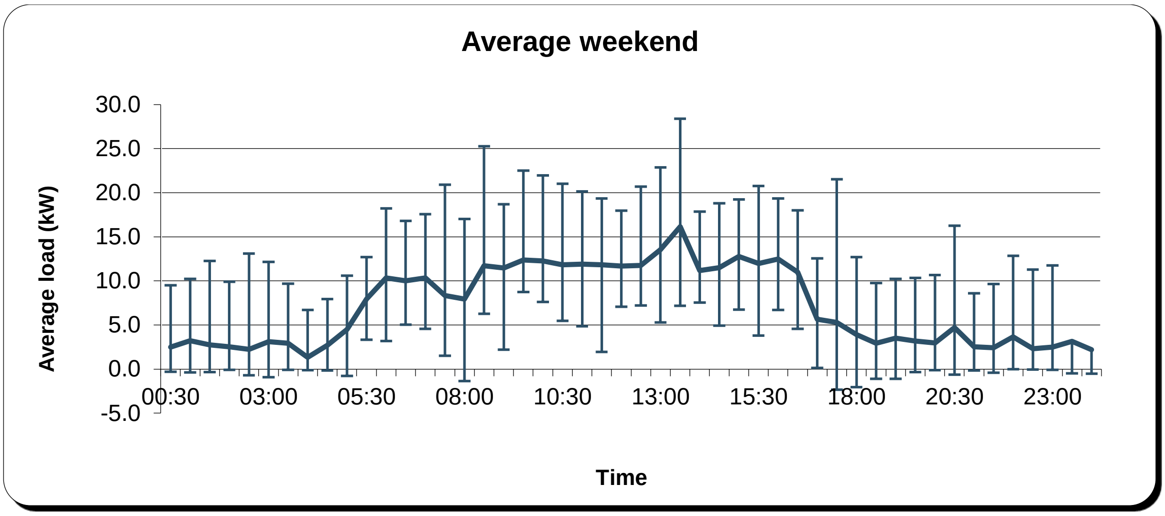


Figure 62 Average half-hourly weekend lighting load in Library (October 2013-September 2014)

Figures 63 and 64 show the average half hourly weekday and weekend lighting load in the offices. On weekdays, average electricity load is around 7kW. However on weekends, the average load is similar to the baseload, as the offices are closed. .

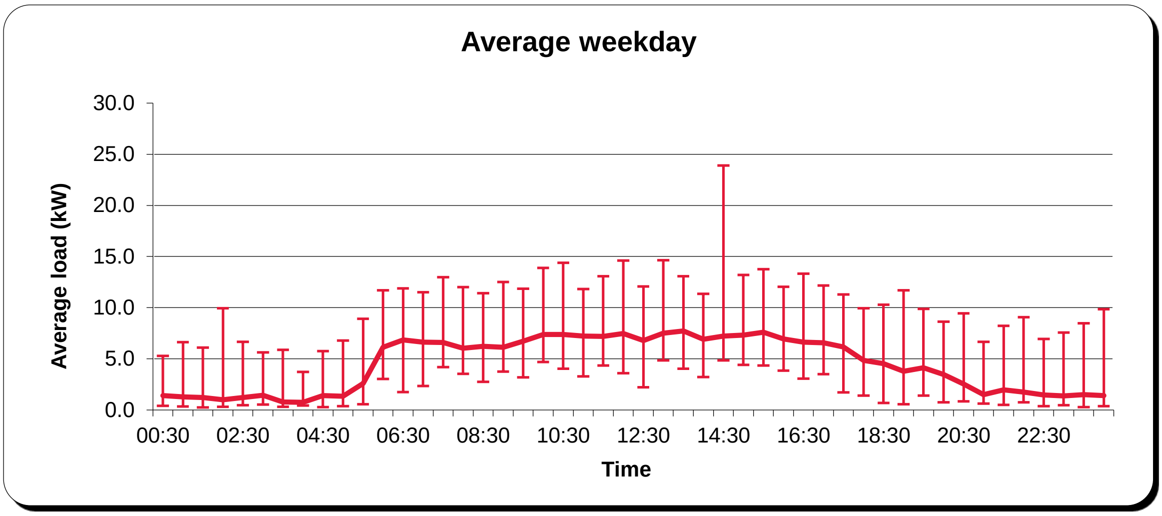


Figure 63 Average half-hourly weekday lighting load in offices (October 2013-September 2014)

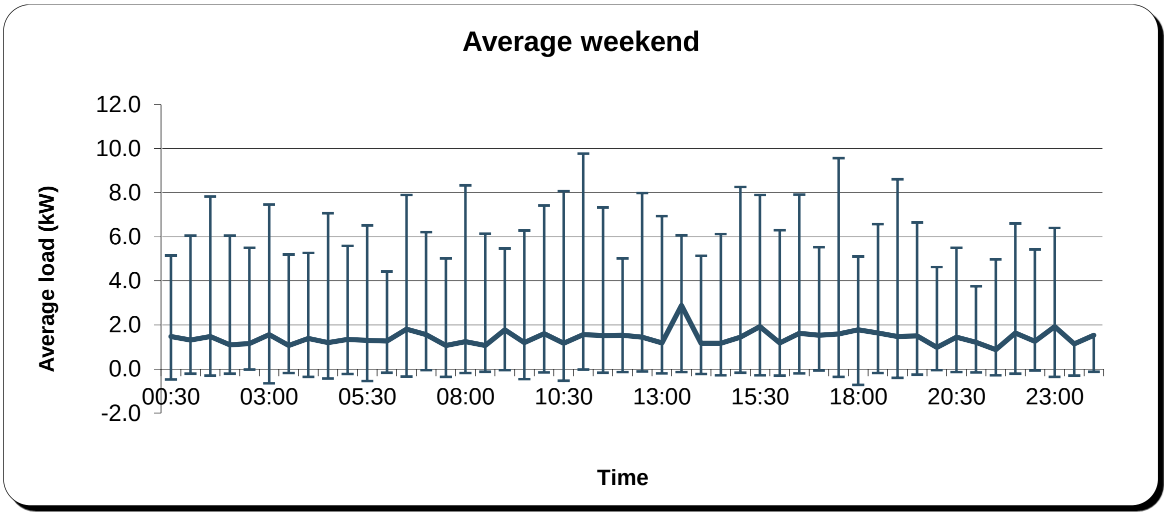


Figure 64 Average half-hourly weekend lighting load in offices (October 2013-September 2014)

Figures 65 and 66 show the average half hourly weekday and weekend lighting load in the Registry. On weekdays average load is around 3.5. Baseload is around 1kW.On weekends average load is similar to baseload as the Registry is closed.

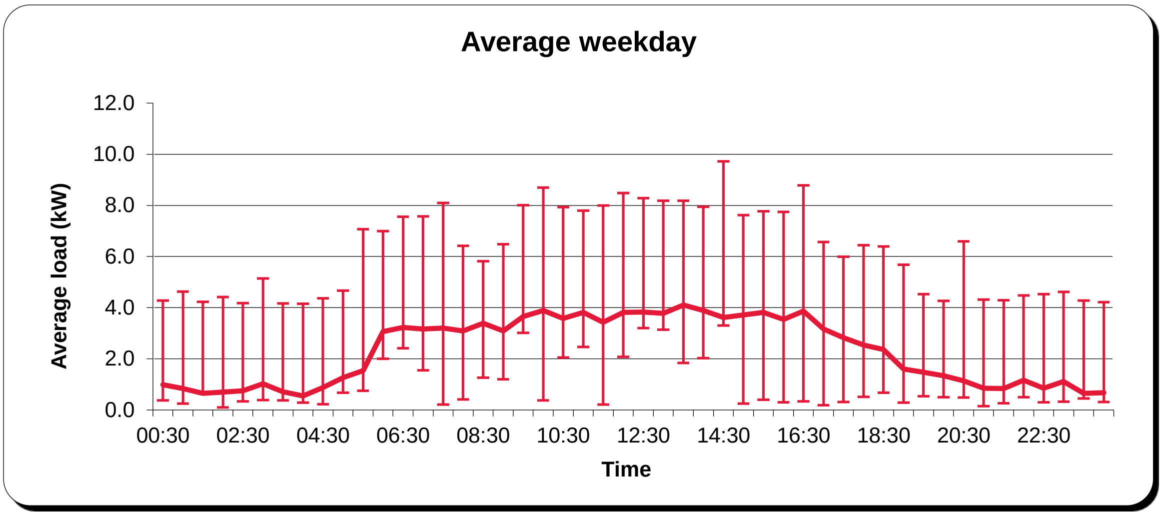


Figure 65 Average half-hourly weekday lighting load in Registry (October 2013-September 2014)

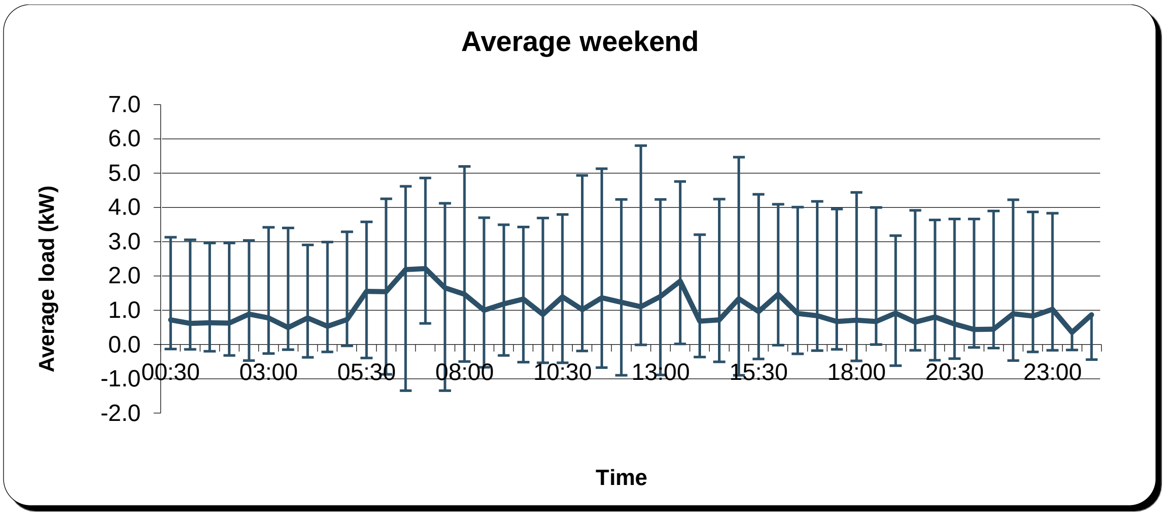


Figure 66 Average half-hourly weekend lighting load in Registry (October 2013-September 2014)

6.3.3.2 Small power profiles

Figures 67 and 68 show the average half hourly weekday and weekend small power load in the Library. On weekdays when the library is open average load is around 15kW. On weekends when the library is open average load is around 9kWh. Baseload is around 2kW.

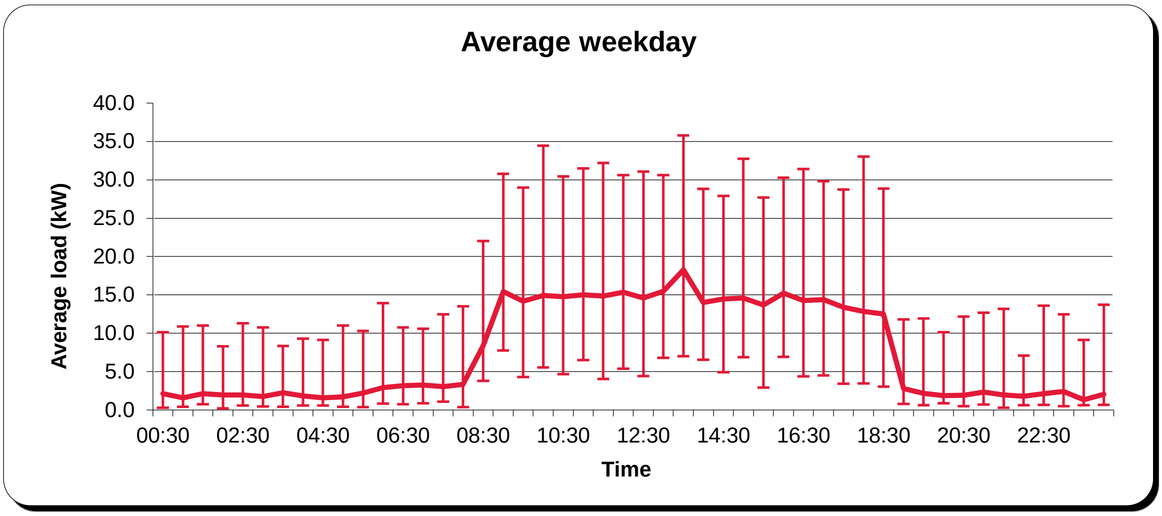


Figure 67 Average half-hourly weekday small power load in Library (October 2013-September 2014)

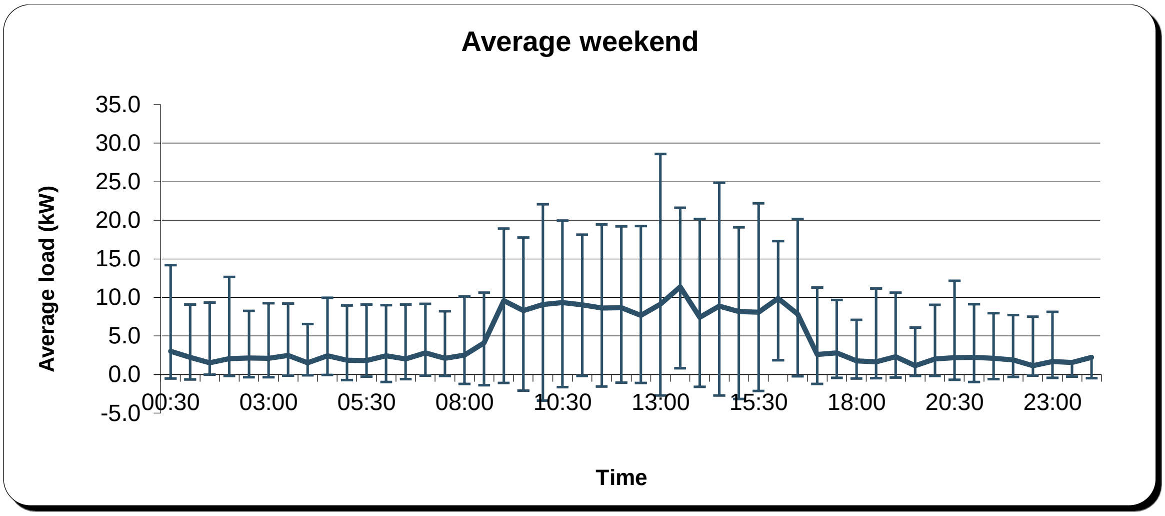


Figure 68 Average half-hourly weekend small power load in Library (October 2013-September 2014)

Figures 69 and 70 show the average half hourly weekday and weekend small power load in the offices. On weekdays during occupancy hours average load is around 6kW. Baseload is around 2.5kW. On weekends the offices are closed.

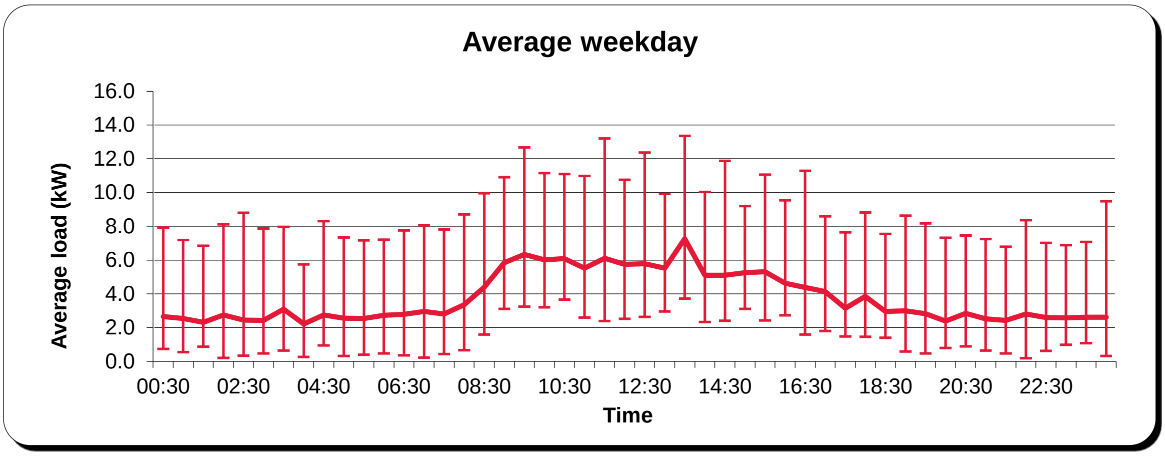


Figure 69 Average half-hourly weekday small power load in offices (October 2013-September 2014)

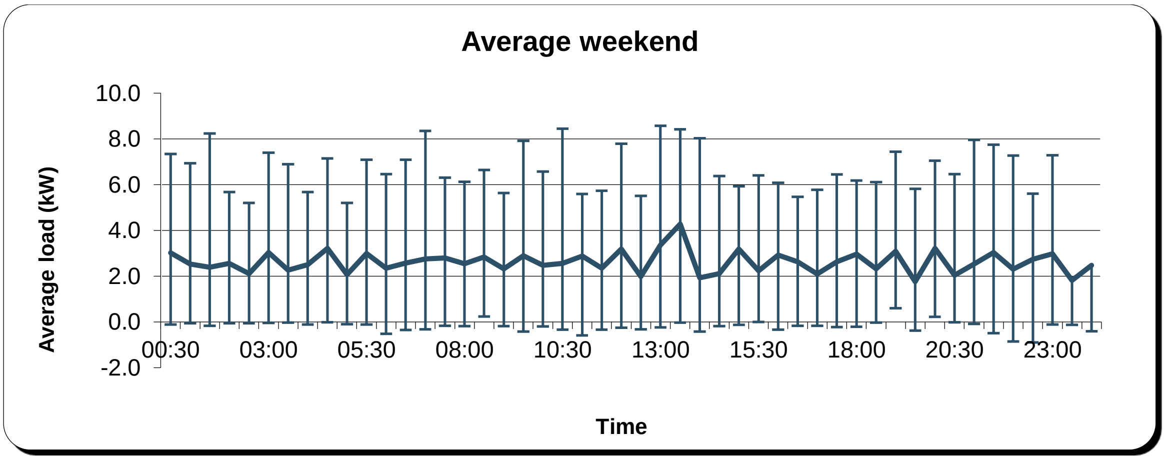


Figure 70 Average half-hourly weekend small power load in offices (October 2013-September 2014)

Figures 71 and 72 show the average half hourly weekday and weekend small power load in the Registry. On weekdays during occupancy hours average load is around 1.5kW. Baseload is around 0.5kW. On weekends the Registry is closed.

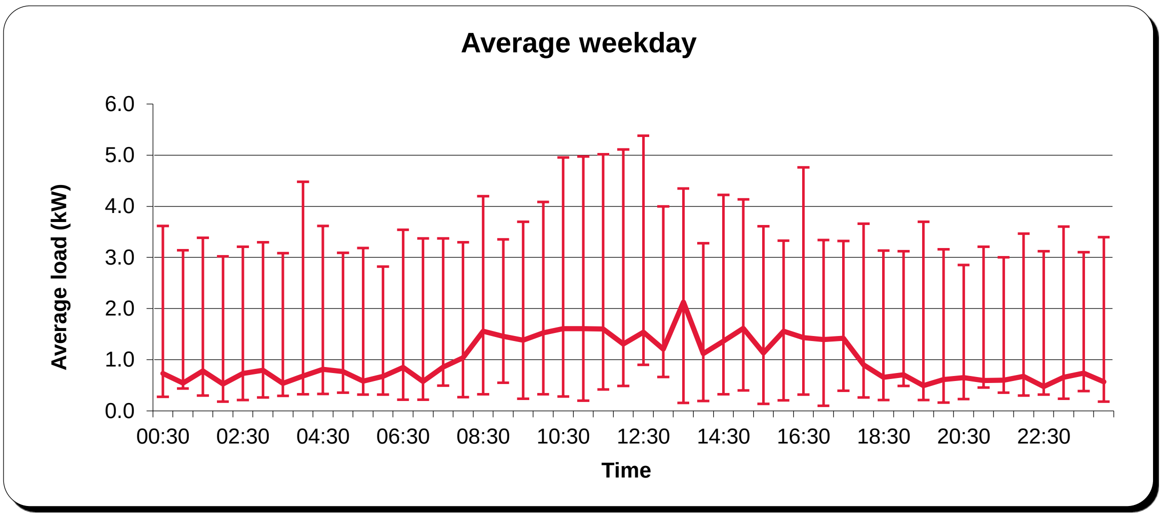


Figure 71 Average half-hourly weekday small power load in Registry (October 2013-September 2014)

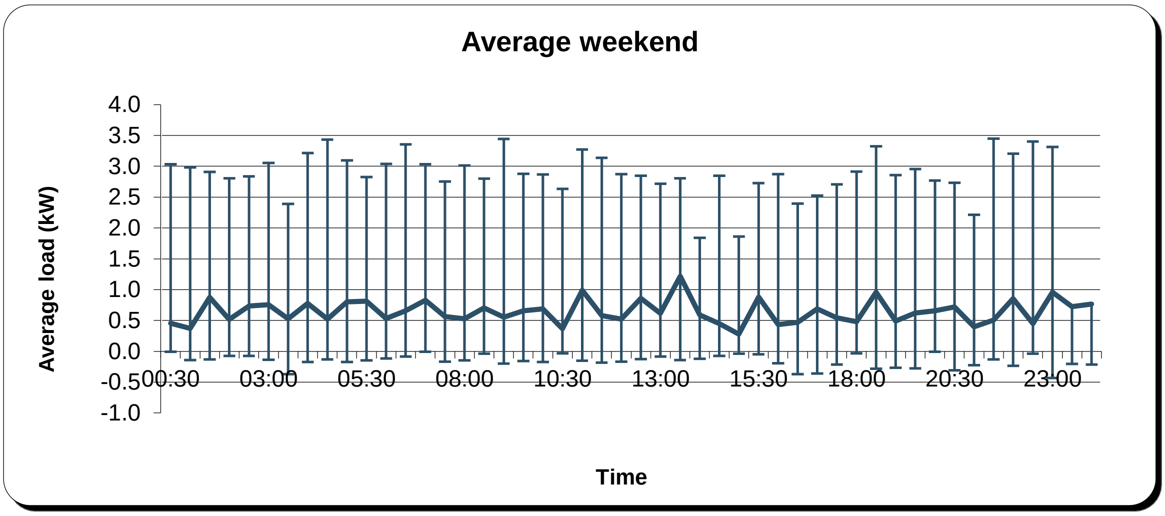


Figure 72 Average half-hourly weekend small power load in Registry (October 2013-September 2014)

6.4 Conclusions and key findings

- The building's total emissions of 61.6 $kgCO_2/m^2$/year are lower than the raw CIBSE TM46 benchmark and 25% lower than the DEC benchmark.

- In terms of gas consumption, the building performs 80% better (lower) than the raw CIBSE TM46 and DEC benchmarks due to better building fabric standard and possibly due to intermittent use of biomass boiler. However electricity use of the the building is 23% worse (higher) than the raw CIBSE TM46 benchmark and even 14% worse than the DEC benchmark

- Crawley Library Centre uses more energy than most other buildings of similar uses and other similar case study projects in the TSB Building Performance Evaluation programme. When compared to typical and good practice benchmarks for library buildings (CIBSE Guide F), overall gas usage of Crawley Library is lower than the benchmarks. However, CO_2 emissions of Crawley Library are higher than the typical benchmark because of high electricity use.

- During the winter months, gas consumption ranges between 15,000-27,000 kWh in 2012 and between 22,000 and 32,000kWh in 2013. Electricity consumption from January 2012 to August 2013 ranges between 41,000-58,000 kWh/month.

- An analysis of the electricity consumption by end-use shows that during the monitoring period about 31% of the electricity consumed in the building was used for lighting, 20% was used by small power, 12% was used by the chiller and 9% was used by the fans and pumps of the plant rooms.

7 Technical Issues

Technical issues were revealed from the review of building services and energy systems, from interviews with occupants and management and were verified by an on-site inspection of the systems. Several issues were resolved as a result of the BPE study and the re-commissioning of the BMS system.

7.1 Review of performance and usability of systems and controls

An on-site inspection of the systems, during the forensic survey for assessing the performance and usability of controls, revealed that the systems installed match the descriptions given in the O&M manual and are the result of the architect's proposals as described in stage C and D reports. However, several problems were identified related to poor understanding and managements of systems and controls. Inspection also revealed that information was missing from the Logbook and the printed copy of the O&M document stored in the facilities manager's office. In the O&M manual Volume 7 'Maintenance Instructions and Logbooks' did not exist and Volume 8 'Fault tracing Charts' was found to be empty. The study revealed that the FM manager is not well familiar with the Logbook and the procedures required for keeping it up to date. Poor documentation results in poor communication between the FM team members which is even more aggravated by the constant changes in the facilities management personnel. One of the key issues identified was the lack of adequate internal handover from one building manager to another.

The main conclusions that were drawn from the forensic survey for assessing the performance and usability of systems and their controls are the following:

7.1.1 Heating and hot water

- Heating and hot water is achieved by a biomass boiler with a backup gas boiler.
- The biomass and gas boilers are connected to the BMS system but no metering data is being captured.
- Faults appear quite often and the biomass boiler needs frequent maintenance. According to the facilities manager the faults are a result of the poor quality of woodchip.
- The facilities manager of the building is not well familiar with the control panel of the biomass boiler.
- Before the BMS system was re-commissioned on 8th July 2013 the biomass boiler was found to be selected OFF and the gas boiler was found to be selected HAND (manual control). Both of them were switched to auto by the external contractor who re-commissioned the BMS system.
- Several issues were discovered during the re-commissioning which was promoted by the BPE team:
    - The pump fail rotation software did not operate. This issue was addressed.
    - Software found to be incorrect, badly configured or inefficient was re-written and commissioned.
    - No Optimiser was found to be configured within the software for the heating systems. This was added to the software. The software optimiser provides a self-adaptive routine that learns the characteristics of the building by monitoring and comparing the outside air temperature against the inside space temperature. The system then calculates the optimum start time that the system should be switched on before occupation of the building to achieve the desired internal temperature setpoint. It will also calculate the optimum time that the system can switch off before the end of occupancy whilst maintaining the desired setpoint. Before this was

implemented the system was not optimised and the heating could come on even during hours when the building was not occupied.

- The Outside Air Temperature heating hold off setpoint was reduced. When the outside air temperature rises above the setpoint (currently set to 16°C) at any time, the heating systems will be inhibited from operation.
- The variable temperature compensated setpoint slope was adjusted to increase energy efficiency.
- The Gas Boiler temperature control loop was modified such that it now uses the Return Temperature sensor rather than the Flow Temperature sensor. This reduces the boiler flow temperature from 82°C to 71 °C when there is little or no Delta T load on the system.
- Graphing the historical temperature data it was observed that during occupancy the hot water temperature was operating 5°C to 15°C below the required setpoint of 60°C. This has implications for Legionella. The HWS was also seen to reach setpoint during unoccupied hours when it should be OFF. The software was not configured correctly. This was rewritten and commissioned. The hot water system is now controlling to setpoint in occupation and is OFF during unoccupied hours.
- No historic data logging was configured for any of the meters on the BMS software or even within the IQ controllers. This was configured on 8th July 2013.
- The OSS Optimiser which had been integrated between the Trend BMS and the Gas Boiler was interfering with the BMS integral control. The Trend BMS control Loop and boiler enable have now been correctly configured. There is no requirement for an additional boiler optimiser with a correctly configured BMS system. The OSS Optimiser has been bypassed and is no longer used.

- The heating and hot water controls are located in the externally accessible plant room.
- No frost or fabric protection was found to be configured within the software.
- The biomass boiler controls panel is not clearly labelled. The control is quite complex and only to be programmed and operated by those with expertise in the system and controls.
- The gas boiler control panel is located at the side of the gas boiler but is not easily accessible as the space is quite narrow. The control is not intuitive to use and labelling is written in German.
- TREND thermostats can be found in some spaces but there is no indication of what they control; there is no indication of system response and it is not clear to the user if they are supposed to operate it in order to change the temperature of the room.
- Radiators can be found in some spaces of the Register Services area’s office spaces. These can be controlled to suit user needs through an easy and intuitive valve. Despite this, the valve is not clearly labelled to indicate which of the settings is the highest. Indication of system response is given by clicking sound.

- Individual thermostats can be found in the meeting rooms of the Register Services area. They are located next to the room door and are easy and intuitive to use. They are clearly labelled with a ‘^{o}C’. Indication of system response is provided by a clicking sound.

7.1.2 BMS system

- The BMS system controls the heating, cooling and hot water of the building. The BMS control panel is located in the externally accessible plant room.
- Inspection from the external contractor who re-commissioned the BMS system revealed that the pulses from eight electricity meters were not being registered within the controller and as such, no cumulative values are accruing. This issue was resolved on 3rd October 2013 when they were connected to the BMS system.

- The Gas meter, HWS Heat meter and EL meter do not pulse to the BMS. Further action needs to be taken in order to connect them to the BMS.
- The BMS control panel is clearly labelled and provides warning of any faults of the system. A touch screen control is connected to the BMS software but the panel can only be programmed and operated by those with expertise in the system and controls.
- The facilities manager has not been trained to operate the BMS system.
- The BMS software (963 Supervisor) was outdated and had to be upgraded from version v3.01 to version v3.50. This version has a number of new features and bug fixes associated with data recording and displaying historic data.
- The trend logging facility is installed in the computer of the facilities manager. Although its purpose is clear, the manager is not familiar with it and does not know how to use it. The computers that have access to the BMS logging facility are located in the facilities manager office and are easily accessible. The facilities manager has not received training in the operation of the logging facility.

7.1.3 Solar thermal & chiller

- The solar thermal and chiller controls are located on the rooftop of the Library.
- The Chiller was seen to be indicating a fault. There was also no CHW (Chilled Water) provision likely relating to the indicated fault. As such there was no CHW available to cool the building.
- The AHU's are packaged controlled and not under the control of the Trend BMS. They are available on the network using a web browser. This however requires a user name and password of which nobody on site was able to advise.
- The solar thermal and chiller controls are only meant to be used by those trained in their use. However, the facilities manager is not very familiar with these systems.
- The solar thermal control is complex and its purpose is not clearly labelled. Instructions are needed in order to operate the control and additional labelling would be useful.
- The main board that controls the chilled water primary and secondary pumps is clearly labelled and switches are easy and intuitive to use. This control can only be operated by the facilities manager. Any system faults are indicated on the board.
- The solar thermal main switch is located next to the control at the roof top of the Library area. It is clearly labelled and it is easy and intuitive to use. There is no direct indication of system response.

7.1.4 Electrical equipment

- The electricity mains meter is not clearly labelled and is located on the ground floor of the Register Services area.

- The purpose of the electrical and lighting distribution boards is clear. Labelling is good and the switches are intuitive and easy to use. Most boards are located on the ground floor of the Register Services area, next to the facilities manager office.
- The purpose of the sub-meters is clear but it is not clear to what each sub-meter is connected to. Existing labelling is not good enough as it uses codes to indicate what each sub-meter is measuring without providing information what these codes actually stand for.
- The purpose of the electrical sub-meter displays is clear but the user interface is complex and only meant to be used by those with expertise in the field. They are located in the ground floor of the Register Services area next to the facilities manager office. Instructions are needed in order to operate the control. Some of the displays are showing zero values and some do not seem to be working properly. They need to be checked, and potentially re-commissioned. The

facilities manager reported that most of the sub-meters are not properly connected to the BMS system; the zero values shown are indicative of this.

- Lighting controls are intuitive and easy to use in most areas. Different lighting strategies are used in different parts of the building. The Library areas have a combination of PIR sensors and manually operable light switches. The Register Services areas are mostly controlled by PIR sensors but some office and meeting rooms have switches that can be operated by individual users. In some areas lights are dimmable but this option is not immediately obvious to the user.
- Electric switches are intuitive and easy to use in most areas. In office spaces, switches are conveniently placed at desk height whereas in the Library, the switches are placed inside boxes on the floor. Whilst this gives the area more flexibility in terms of space and furniture layout, the lids of the boxes can be hard to open.

7.1.5 Kitchen Appliances

- Kitchen appliances provided in the staff kitchenettes are well labelled and are easy and intuitive to use.
- The control of the fridge is quite basic and intuitive to use. The thermostat offers 5 settings but there was no indication which setting was the coldest and which one was the warmer.
- Fixed Hydroboil devices provide instant boiling water to staff members. Their purpose is clearly labelled and their use is easy, with an intuitive user interface. The device does not provide any options regarding the temperature of the water.

7.1.6 Water services

- Hand-basin and kitchen taps are clearly labelled and easy to use. The hand-basin taps do not have high degree of fine control as their flow is set and they are not mixing taps.
- The mains water isolation valve is located in the plant room and is clearly labelled. However, it is not very easily accessible.
- A sophisticated water leak detection system is installed in the building. The control of this system is not very intuitive but it is well labelled and gives visual warnings of any leakages. The water leak detection system control is located in the plant room, where it is easily accessible as it is situated next to the external entrance door. The control interface is labelled but additional information is needed in order to set it up. Lights indicate whether the system is operating well or if a leakage has been detected.

7.1.7 Fire and security alarms

- The building's fire and security alarm systems include smoke detectors, emergency call points, and fire alarm points, which are placed in various points throughout the building.
- The primary fire alarm panel is fairly complex and can only to be used by experienced users such as the facilities manager. Its purpose is clear due to appropriate labelling and annotation.
- Emergency call points are placed throughout the building and are easily accessible. They are well labelled and easy to use. Clear instructions are placed next to each call point informing visitors on how to use them in case of an emergency.
- The purpose of the fire alarm points is clear, with additional information placed above the fire alarm points offering guidance on what to do in the event of a fire. Fire alarm points are located in various points throughout the building and are easily accessible.

- Smoke detectors are installed in all areas of the building. A small light indicates that each of them is working properly. Their purpose is clear, despite the lack of labelling indicating their function.
- The fire door release control buttons for exiting the building in the event of a fire are easy and intuitive to use. Their purpose is clear due to the use of labelling and annotation. The actual release buttons are located adjacent to the doors and are very easily accessible.

7.1.8 Doors and windows

- The main entrance to the building has a set of automatic doors; the controls for which are poorly labelled and not particularly intuitive to use. Only members of staff are allowed to operate these controls, of which there is a range of operating modes for the doors. Additional labelling and information would be useful.
- Mechanically operated windows are located in the main office areas and in the Library areas. They are not easy to use and not very intuitive. Users report that the controls break down quite often and that they struggle to use the key override. In addition to this, one control operates more than one window, even entire rows of individual rows, which limits the potential for individual adjustments to the internal environment by separate users occupying the same area.
- Manually operated windows can be found in some spaces. Whilst these are easy and intuitive to use, they can only be opened partially.

7.1.9 Shading devices

- Manually controlled blinds are used in most spaces in the Library, Register Services and Office areas in order to provide internal shading. The blinds are easy to use and intuitive, and provide a fairly high level of user control.
- In the Library exhibition area, the high level blinds are operated by a remote control. The remote operates all the blinds at once but different blind positions can be achieved for different windows, depending on user requirements. There is no fixed place for the remote, which can cause issues due to the regular turnover in user, and the fact that the purpose of the remote is not clear as there is no indication on it that it is for operating the blinds.

7.2 Conclusions and key findings

- Inspection revealed that information was missing from the Logbook and the printed copy of the O&M document stored in the facilities manager's office. In the O&M manual Volume 7 'Maintenance Instructions and Logbooks' did not exist and Volume 8 'Fault tracing Charts' was found to be empty. The study revealed that the FM manager is not well familiar with the Logbook and the procedures required for keeping it up to date.
- The biomass and gas boilers are connected to the BMS system but no metering data is being captured.
- The facilities manager of the building is not well familiar with the control panel of the biomass boiler.
- Lack of adequate internal handover from one building manager to another.
- The BMS system controls the heating, cooling and hot water of the building. The BMS control panel is located in the externally accessible plant room.
- Before the BMS system was re-commissioned on 8th July 2013 the biomass boiler and heating system were not optimised.

- Several changes were made in order to optimise the system, reconfigure setpoints, re-balance sensors and improve energy savings.

- No historic data logging was configured for any of the meters in the BMS software or even within the IQ controllers. This was configured on 8th July 2013.
- TREND thermostats can be found in some spaces but there is no indication of what they control; there is no indication of system response and it is not clear to the user if they are supposed to operate it in order to change the temperature of the room.
- Inspection from the external contractor who re-commissioned the BMS system revealed that the pulses from eight electricity meters were not being registered within the controller and as such, no cumulative values are accruing. This issue was resolved on 3rd October 2013 when they were connected to the BMS system.
- The BMS software (963 Supervisor) is installed in the computer of the facilities manager. Although its purpose is clear, the manager is not familiar with it and does not know how to use it.
- The Chiller was seen to be indicating a fault. There was also no CHW provision likely relating to the indicated fault. As such there was no CHW available to cool the building.
- The solar thermal and chiller controls are only meant to be used by those trained in their use. However, the facilities manager is not very familiar with these systems.
- The purpose of the electrical and lighting distribution boards is clear. Labelling is good and the switches are intuitive and easy to use. The purpose of the sub-meters is clear but it is not clear to what each sub-meter is connected to. The BPE study has helped clarify what each electricity sub-meter is monitoring.
- Lighting controls are intuitive and easy to use in most areas. Different lighting strategies are used in different parts of the building. The Library areas have a combination of PIR sensors and manually operable light switches. The Register Services areas are mostly controlled by PIR sensors but some office and meeting rooms have switches that can be operated by individual users. In some areas lights are dimmable but this option is not immediately obvious to the user.
- Fire and security alarms and controls are according to specifications.
- Mechanically operated windows are located in the main office areas and in the Library areas. They are not easy to use and not very intuitive. Users report that the controls break down quite often and that they struggle to use the key override. In addition to this, one control operates more than one window, even entire rows of individual rows, which limits the potential for individual adjustments to the internal environment by separate users occupying the same area.
- Manually controlled blinds are used in most spaces in the Library, Register Services and Office areas in order to provide internal shading. The blinds are easy to use and intuitive, and provide a fairly high level of user control.

7.3 Recommendations

The BMS contractor appointed by WSCC and the BPE team to re-commission the BMS system has provided recommendations in order to provide significant implications for energy savings, provide more accurate control around design setpoints, provide early warning of problems, minimise down time and improve running costs whilst reducing the likelihood of future breakdowns.

- It is recommended that the BMS system is maintained periodically under a Planned Preventative Maintenance contract. Managed support would ensuring estate wide reporting and management, to maximise the effectiveness of the BMS.

- It is recommended that a Trend modem or a Trend Ethernetwork is installed to allow remote access and interrogation to the site BMS system.

- No frost or fabric protection was found to be configured within the software. It is recommended that the following is written in and commissioned:
  - **Stage 1 Frost Protection** – When the outside air temperature falls below the Stage 1 Frost setpoint (currently set to 3°C) outside of occupied times, the BMS enables all heating and cooling pumpsets for a period of 15 minutes and then off for 15 minutes, the cycle then repeats. In addition all Heating and Cooling valves will be driven to 75% open to ensure flow through all ports. Global IC Network communications have been configured using address module attributes to deliver the enable signal to all associated devices.

  - **Stage 2 LTHW Protection** – Should the LTHW (Low Temperature Hot Water) return temp fall below the Stage 2 Frost setpoint (currently set to 10°C) during a Stage 1 Frost Protection condition the BMS will enable the boilers until a return temperature of 40°C (setpoint adjustable) is measured.

  - **Fabric Frost Protection** – Should internal zone temperatures drop below the Fabric Protection setpoint (currently set to 8°C) outside of occupied times, the BMS enables all zone associated heating and primary ventilation plant until a 2°C temperature increase has been measured whereby the plant will revert back to its previous status. AHUs installed with hard wired frost stats shall be made to inhibit the AHU operation. This is also utilised to initiate operation of the associated circuit pumpset and LTHW boilers to normal operating setpoints.

- Once enabled the AHU's operate under the dictates of their own packaged controls. It is recommended that the functionality of these packaged units is checked to determine if they could be used for overnight cooling.
- The Gas meter, HWS Heat meter and EL meter do not pulse to the BMS. This issue would have to be investigated by the maintenance team but there is no maintenance contract setup up to this date.
- CP1 Accumulator Shunt Pumps 1 & 2 are indicating an E11 Fault. This alarm indicates that there is air around the pumps. The unit needs to be bled.
- The Chiller was seen to be indicating a fault. It is recommended that the Chiller is returned to service.
- It is recommended that the CHW and LTHW systems are balanced.
- Improve the control interface of mechanically operated windows and allow for more flexibility by adding more controls and reducing the number of windows controlled by each control.
- Train the facilities manager to be able to fully operate all controls and the BMS software.

8 Key messages for the client, owner and occupier

8.1 Key messages

Table 21 presents a summary of the key initial findings associated with the BPE study elements.

Table 20 Key findings across BPE study elements

<table>
<tr><th>BPE Study Elements</th><th>Findings</th><th>Key messages</th></tr>
<tr><td>Assessment of annual energy use</td><td>• Insufficient handover training and documentation. No information on how to operate the BMS system and software.
• Lack of metering and sub-metering data for a full CIBSE TM22 assessment
• Discrepancy between logbook metering details and on-site arrangements.
• Poor commissioning of heating system and controls related to BMS.</td><td rowspan="4">Inadequate handover training and documentation and frequent FM staff changes compromised the effectiveness of low carbon technologies.

Unplanned changes to ‘as designed’ space usage according to current needs led to poor internal environmental conditions.

Lack of proper system commissioning and installation led to the underperformance of systems and construction defects.

Change in the facilities management lead to lack of understanding of the services and systems installed.

BMS system not properly commissioned and connected to submeters leads to problems in monitoring the energy consumption of the building

Occupants were found to have a lack of understanding of the building sustainability</td></tr>
<tr><td>Analysis of energy demand profiles using data from BMS</td><td>• Changes in FM staff since handover affected their level of understanding and control of BMS and sub metering plan
• Limited memory of BMS for long data history storage
• Secondary gas and electricity sub-metering available but not connected to the BMS
• High night-time and weekend energy consumption</td></tr>
<tr><td>Spot checks and recording measurements</td><td>• Inadequate natural lighting and ventilation in library and registrar was noticed in the spaces that were changed from archives into offices.
• Thermographic survey indicated cold air draughts entering the building through the atrium clerestory, ceremony and conference room windows due to lack of proper sealing or the displacement of seals.</td></tr>
<tr><td>Review of the performance and usability of controls and BMS</td><td>• Most of the initial services strategies and intentions were incorporated in the building
• The facilities manager of the building is not very familiar with the control panel of the biomass boiler.
• Faults appear quite often as the biomass boiler needs frequent maintenance.
• BMS system not properly connected to the sub-meters. The facilities manager is not qualified to operate the logging facility and has not received proper training. BMS system is working though it has not been properly commissioned.
• Poor commissioning of BMS system. Lack of maintenance contract.</td></tr>
</table>

		features.
Occupant satisfaction survey using BUS questionnaires	• Complains of summer overheating of spaces (especially in the library) and lack of control over windows and ventilation. • Children's library entrance does not protect from children getting out of the building through the sliding main entrance doors (although this was as per clients requirements)	Visitors and staff reported lack of control over the environmental conditions.
Interviews with occupants and management	• Low levels of natural ventilation due to limited access to windows controls create overheating issues during summer and cold draughts during winter period. • Heating, cooling and ventilation controls need to be demonstrated to building management team that currently lacks of essential understanding of what systems exist in the building, their function and how they can be controlled. • Inability to control heating, cooling and ventilation discomfort issues to building occupants; overheating and air stuffiness is the main reported issue.	
Technical review of building and equipment performance	• Office equipment was on or a standby mode even in unoccupied spaces.	

The investigation into the discrepancies between the as-designed and in-use performance of the Crawley building has revealed insufficient handover training and documentation, unintended space usage and usability issues of controls and windows.

The lack of proper building handover and complete documentation had obvious implications from the first months of the building operation, exacerbated by an inadequate understanding of the BMS system by the facilities management team. A proper facility and building manager's handover training is vital to enable effective management and operation of the building. Careful selection and continuity of FM staff from the initial stages of the building operation is required to get the best of the handover process and training.

Furthermore, the low carbon technologies specified are suffering from poor maintenance and are underperforming. The need for frequent maintenance, lack of maintenance contracts and the unfamiliarity of the FM team with such technologies led to the building not being operated as specified. The use of a biomass boiler added unmanageable complexity to the design. The boiler has been out of operation for extended periods of time due to breakdowns caused by the use of chip wood that did not comply with its specifications.

The changes in the use of certain spaces such as archive and storage rooms to cover the needs in office space led to complaints over comfort levels due to the lack of proper ventilation and natural lighting. Notwithstanding extensive briefing with client and users, major changes of use should be considered in consultation with the design team. Constant monitoring and feedback and preventative maintenance is crucial for fine-tuning the building's operation and achievement of its environmental and service delivery targets.

8.2 Recommendations

8.2.1 Recommendations for WSCC

- Ensure proper training of new members of FM team.
- Liaise with FM team to ensure that operation and maintenance of systems is according to specifications and that the Logbook is kept up to date.
- It is recommended that the BMS system is maintained periodically under a Planned Preventative Maintenance contract. Managed support would ensuring estate wide reporting and management, to maximise the effectiveness of the BMS. It is highly recommended that WSCC sets up a new maintenance contract for the BMS system.
- It is highly recommended that the issues pointed out by Pureworld after the re-commissioning of the BMS system are immediately addressed.
- It is recommended that a Trend modem or a Trend Ethernetwork is installed to allow remote access and interrogation to the site BMS system.

8.2.2 Recommendations for building designers

- Review the window design in order to be able to keep them open without the need of a wedge. In addition individual window control should be considered instead of six windows in a row with the same control.
- The ventilation strategy for the toilets in the library and open place office areas should be reviewed.
- Thermal bridging due to geometry or insulation/material inconsistencies needs to be discussed with the project architects to further indicate the causes and identify the actions that may need to be taken in order to minimise this effect.

8.2.3 Recommendations for M&E consultants

- Review the BMS system in order to send alarm messages in case of system defects.
- Provide a BMS User Guide and BMS training to the FM team.
- It is recommended that a Trend modem or a Trend Ethernetwork is installed to allow remote access and interrogation to the site BMS system.
- No frost or fabric protection was found to be configured within the BMS software. It is recommended that the following is written in and commissioned:

  b) **Stage 1 Frost Protection** – When the outside air temperature falls below the Stage 1 Frost setpoint (currently set to 3°C) outside of occupied times, the BMS enables all heating and cooling pumpsets for a period of 15 minutes and then off for 15 minutes, the cycle then repeats. In addition all Heating and Cooling valves will be driven to 75% open to ensure flow through all ports. Global IC Network communications have been configured using address module attributes to deliver the enable signal to all associated devices.

  c) **Stage 2 LTHW Protection** – Should the LTHW (Low Temperature Hot Water) return temp fall below the Stage 2 Frost setpoint (currently set to 10°C) during a Stage 1 Frost Protection condition the BMS will enable the boilers until a return temperature of 40°C (setpoint adjustable) is measured.

d) **Fabric Frost Protection** – Should internal zone temperatures drop below the Fabric Protection setpoint (currently set to 8°C) outside of occupied times, the BMS enables all zone associated heating and primary ventilation plant until a 2°C temperature increase has been measured whereby the plant will revert back to its previous status. AHUs installed with hard wired frost stats shall be made to inhibit the AHU operation. This is also utilised to initiate operation of the associated circuit pumpset and LTHW boilers to normal operating setpoints.

- The Gas meter, HWS Heat meter and EL meter do not pulse to the BMS. This issue would have to be investigated by the maintenance team.
- CP1 Accumulator Shunt Pumps 1 & 2 are indicating an E11 Fault. This alarm indicates that there is air around the pumps. The unit needs to be bled.
- The Chiller was seen to be indicating a fault. It is recommended that the Chiller is returned to service.
- It is recommended that the CHW and LTHW systems are balanced.
- Improve the control interface of mechanically operated windows and allow for more flexibility by adding more controls and reducing the number of windows controlled by each control.
- Create robust feedback loops to report problems quickly in the first year of occupation.

8.2.4 Recommendations for FM team and manager

- It is recommended that the BMS system is maintained periodically under a Planned Preventative Maintenance contract. Managed support would ensuring estate wide reporting and management, to maximise the effectiveness of the BMS.
- It is recommended that a Trend modem or a Trend Ethernetwork is installed to allow remote access and interrogation to the site BMS system.
- Review and revise PIR control settings in offices in order to meet the actual lighting needs.
- Check heating, cooling and ventilation regimes in the library function rooms.
- Review the option of providing drinking fountains on the library ground and second floor.
- Identify the responsible party for the cleaning of the biomass boiler ash residues and set up a maintenance schedule.
- Identify the responsible party for the fix and maintenance of the solar thermal panels and review hot water needs.
- Occupants' comments and ratings on air temperature and quality imply the need to check heating and cooling strategies in the open plan office space, the ceremony rooms, and the library offices as well as the common space.
- The library and open plan office toilet's ventilation should be reviewed, and amended, if required.
- The children's library entrance needs to be secured properly, in order to avoid children getting out of the building through the sliding main entrance doors.
- The installation of microphones and speakers in the social services reception should be considered due to issues with clear communication because of the protective glass panel.

- Consider providing freestanding water coolers in the key areas of the building that are easily accessible to staff during working hours.
- Investigate storage needs in different departments and provide drawers and cupboards where needed.
- Alarm systems connected to the disabled toilets need to be examined. The flashing light indicating a person needs help is hidden; it would be preferable to have this in full view of the persons working at the enquiry desks.

8.2.5 Recommendations for Library, Register Services and FM team members

- Create a team of representatives from Library, Registration service, Social services and FM team to liaise with the architects team (P&P) regarding space usage and room adoptability issues in the register office, 3rd floor open plan offices and library.
- Create a communication and feedback platform between the key members of staff and the FM team with scheduled meetings where all the issues can be discussed and solutions can be granted between the different library end users and the maintenance team.
- Facilities management need to have better control of heating and cooling over unoccupied spaces especially the two ceremony rooms. Staff should also be incentivised to turn off the heating when they plan to leave a room.

8.2.6 Recommendations for Register Services manager

- Liaise with the FM team in order to identify a new location for the photocopier, provide office partitions to create more individual space and surface for notices and resolve the cold air blow issue in the open plan office ‘registration hub’ desks.
- Liaise with the architects and the FM team to identify possible design solutions for the reception, the large ceremony room and the unused space behind the staircase.
- Provide initiatives to the members of staff living in the area to encourage the use of public transport or bicycle to travel to work to minimise the parking problem as well as lead to ‘greener’ attitudes.
- Ensure adequate handover from one building manager to another in case of change of personel.

8.2.7 Recommendations for Library manager

- Review the operation status of the IT suite computers in the library with the computer maintenance service to avoid having them on when the room is not in use.
- Liaise with the architects and the FM team to identify possible design and technology solutions (e.g. different furniture arrangement, installation of surveillance cameras, new item control system) to prevent thefts from the remote library areas.
- Provide initiatives to the members of staff living in the area to encourage the use of public transport or bicycle to travel to work to minimise the parking problem as well as lead to ‘greener’ attitudes.

The Crawley library BPE study has revealed several issues regarding commissioning of low carbon systems and BMS, inadequate handover, missing logbooks, poor management and maintenance, that are confounded by lack of training of the FM team to run the building effectively. Regular changes in FM staff since handover has meant that the environmental control strategy, BMS and sub-metering have not been properly understood by the FM team. Lack of user guidance together with minimal individual control over heating, ventilation and lighting has further undermined occupant comfort, thereby leading to excessive energy use in the library and office spaces. Going forward, rigorous training of the FM team to use the BMS system, as well as proper maintenance of the biomass and solar thermal technologies is necessary to improve control over the building systems and environmental conditions.

These findings highlight common trends and problems that are often encountered in civic buildings. The study has therefore provided wider lessons for industry including designers, constructors, building owners, developers, building operators and the supply chain, as follows:

Although renewable energy systems are chosen to get credits with BREAM or EPC, it is vital that only tried and tested low/zero carbon systems are specified and installed without adding unmanageable complexity (such as the biomass boiler in the library building), since CO_2 reductions from renewables may not be achieved without considerable effort. The design team should also have an understanding of the maintenance regimes, operation and control of these systems as well as their implication for building operators. This is particularly relevant for civic buildings where due to budget cuts, dedicated building managers for individual buildings are being replaced by a centralised building management function within councils that is responsible for energy management of multiple buildings.

- A systematic documentation of ‘design intent’ and ‘as built’ information should be made mandatory for effective management of buildings during the operation phase. Commissioning records of services and systems should be used to check the performance of heating and ventilation systems.
- Sub-metering arrangements should be carefully designed according to end use and zones, so that energy management can be undertaken. Sub-meters also need to be installed as designed, properly commissioned and calibrated. Calibration of sub-meters and their data quality should be checked after handover through reconciliation with the mains incoming meter and building management system to correct problems quickly.
- Joints, junctions and thresholds should be carefully designed and constructed to avoid ‘weak links’ in the building fabric. Weaknesses in thermal performance of building fabric can be identified using a combination of thermal imaging and air-tightness testing especially for early detection of problems. There is also a growing recognition in the industry to develop shared resource of robust construction details for different types of building systems.
- Accurate ‘as-built’ models (already required under Building Regulations) should become mandatory and enforced rigorously for all projects of all scales. This could ensure that SAP/SBEM worksheets and drawings are updated to record design and/or procurement changes that could affect the energy use.
- Aftercare matters in delivering good performance. Maintenance regime of heating and ventilation system should be clarified at the installation and commissioning stage so that the perception of ‘fit and forget’ does not exist. If necessary, maintenance (service) contracts should be set up for unfamiliar low carbon systems such as biomass boilers, solar thermal, BMS.

- Design teams should ensure that easy-to-understand user guides for public buildings are made available just before handover operation for management teams and occupants. These guides should offer clear guidance on the daily and seasonal operation of systems and controls.
- Occupants and FM team of the buildings also need to be trained through graduated and extended handover which involves FM team and users trying out systems and controls in the presence of architects and specialist contractors (of BMS, low carbon technologies).
- It is important to have a balance between automation and occupant control. Control interfaces need to be intuitive, labelled and properly designed, and installed in an accessible location that encourages occupants to interact with their environment in an adaptive and positive manner.
- It is clear that BPE studies not only help in understanding the reasons behind the energy performance gap, but also to identify various faults with systems and services, that would otherwise go unnoticed and transform into bigger issues at a later stage requiring expensive and possibly disruptive remedial works.

10 Appendices

10.1 BUS questionnaires

The BUS questionnaire method was used to map the library's staff reactions on whether the building meets their needs, including comfort and control. It is undertaken once during the course of the BPE study. The BUS analysis method is a quick and thorough way of obtaining feedback data on building performance through a self-completion occupant questionnaire; the results of which can be compared against a national benchmark database.

The questionnaire prompts the respondents to comment on the building's image and layout, the control over, and daily use of the environmental features and any general changes they have noticed since using the building. The BUS uses 'effectiveness' scales but also provides space for additional comments, if needed.

The issuing of the questionnaires took place on a visit on 8th September 2011, between 10:00am and 2:00pm, and as such, will gage the staff's responses in relation to 'warm' weather conditions. The building occupies approximately 100 members of staff but this can vary by around 10% according to seasonal needs. The response rate of the survey was 71%, with 43 out of 59 staff members available during that day completed and returned a questionnaire.

The external temperature during those hours was between 17.7°C and 20.2°C; the humidity levels were between 41 and 50%RH. Inside the building, the temperature varied in the different spaces from 21.5°C (the ground floor conference room) to 25.4°C (first floor east facing library office).

Table 21. Internal and external temperature and humidity values in Crawley library on 8th September 2011,at the time of the BUS questionnaire survey (12.00pm).

Space	Temperature (°C)	Relative Humidity (%RH)
External	20.2	42.9
Children's library	24.6	40
1st floor library	24	40
Staff work space	24.8	40
Exhibition space	22.3	41
First floor office	25.4	40
Ground floor conference room	21.5	42
Ceremony room	22.4	40
Second floor open plan office	24.3	40

Background information

According to the collected demographic data, the staff that responded to the questionnaires can be split into three main categories based on their department within the building; the library staff, the registry service and those working for the adult and children social services. Table 23 shows the breakdown of respondents from different library departments. Each user category occupies a different building area (Figure 73) therefore variation in responses may be noticed in some cases and recommendations regarding each area are made.

Table 22 Breakdown of BUS questionnaire respondents from different departments.

	Library	Registration service	Social service	Security service	Not stated
Responses	14	4	18	1	6
Total			**43**		

The majority of the respondents were women (37 female and 4 male respondents) and the typical age rate was over 30.

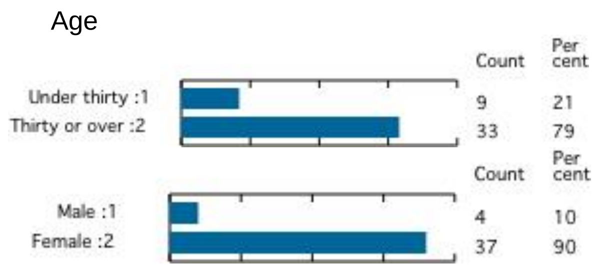


Figure 73. Crawley library building uses.

10.1.1 The building overall

The overall picture of the survey revealed a positive opinion of the staff members towards the building with the quality of light ("*good lighting, ambience*") and the modern design ("*attractive, open airy*") found to be the most appreciated elements (Figure 74). However, a significant amount of comments that were given related to the high temperatures during summer months, throughout several spaces ("*Hot and stuffy")* and the lack of proper ventilation throughout the whole year ("*Poor air circulation")*. The latter had a negative effect on the comfort rating and seems to also have some potential implications on the health and productivity of some of the staff.

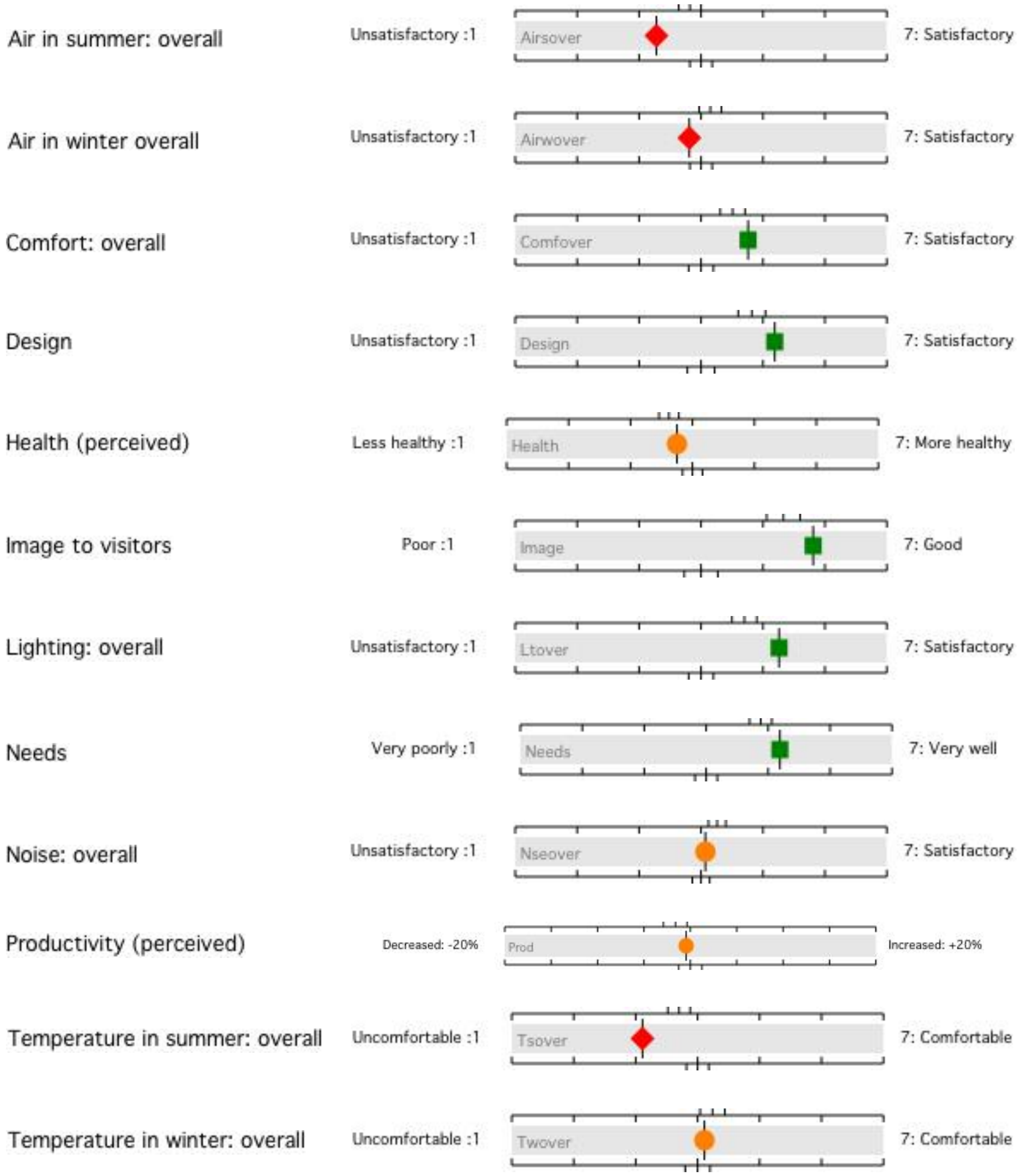


Figure 74. The building overall.

10.1.2 Comfort

The degree of comfort that users experience within a building is a very important parameter of post occupancy evaluation. The staff members were asked about their comfort perception within the building relating to the air temperature and quality, noise, lighting, ventilation and level of personal control of these elements.

Nearly 82% of the staff felt that the building was comfortable overall (Figure 75), despite the fact that the majority of them complained about the air being stuffy during the whole year, the uncomfortably high temperatures during hot summer days and the noise coming from outside due to the opening of windows.

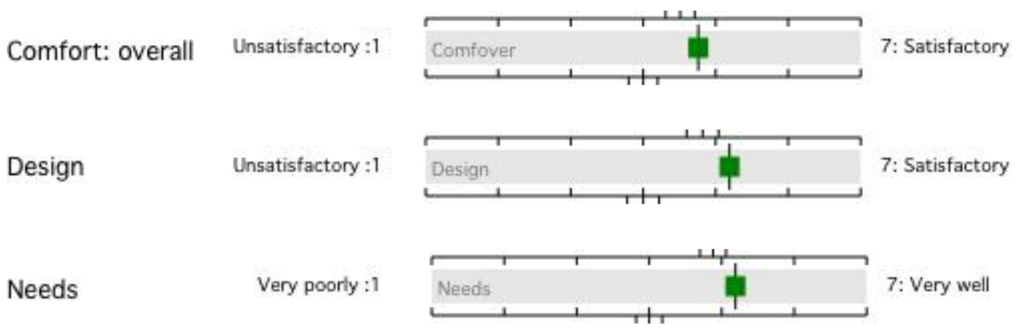


Figure 75. Overall comfort, design and needs.

Table 23 Comments received by building users on comfort.

Comfort overall
• Building can get uncomfortably hot in the summer, even with the windows open which then causes excessive road noise to be heard in the library.
• The building overall is ok but my office is too hot in summer.
• Hot and stuffy –why do we have air-conditioners?
• It is mostly too stuffy and with windows opening 'six' at a time there are disagreements over how much they are open.
• The biggest discomfort is that there is a lack of toilets, the location of the toilets and that there is no air vent or window – it's disgusting.
• Poor access to drinking water.
• Temperature –lack of control- generally too hot, particularly in the second floor.
• It is a pity that you cannot open individual windows instead of a whole row at once.

10.1.3 Air temperature and quality

Comments about uncomfortably hot spaces over summer were made by 68% of the respondents implying problems with the cooling system ("*lack of air-conditioning*") and control over the opening and closing of windows ("*cannot open individual windows instead of a whole row at once*") (Figure 76, Figure 77). Indoor temperature readings on the day of the survey were surprisingly high for some of the spaces such as the children's library and the first floor office reaching a peak of 25.4°C during the midday, with an external temperature of 20.4°C. This could account for a significant amount of staff experiencing air as hot and stuffy.

The exhibition room on the first floor was found to be either too warm or too cold by the respondents and the ventilation in the meeting rooms was felt to be inadequate.

Comments were slightly more positive in terms of winter temperatures, although almost half of the respondents still felt cold and found the air stuffy.

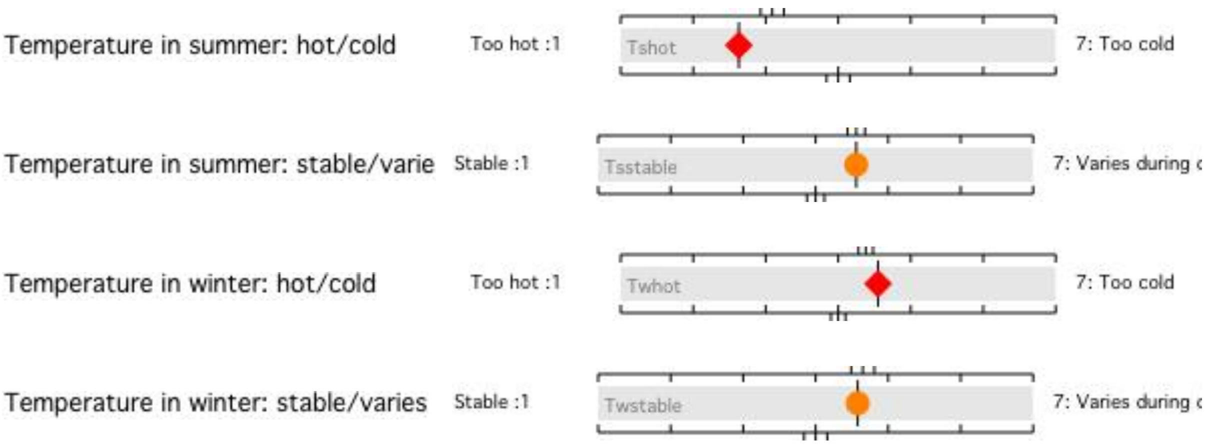


Figure 76. Air temperature in summer and winter.

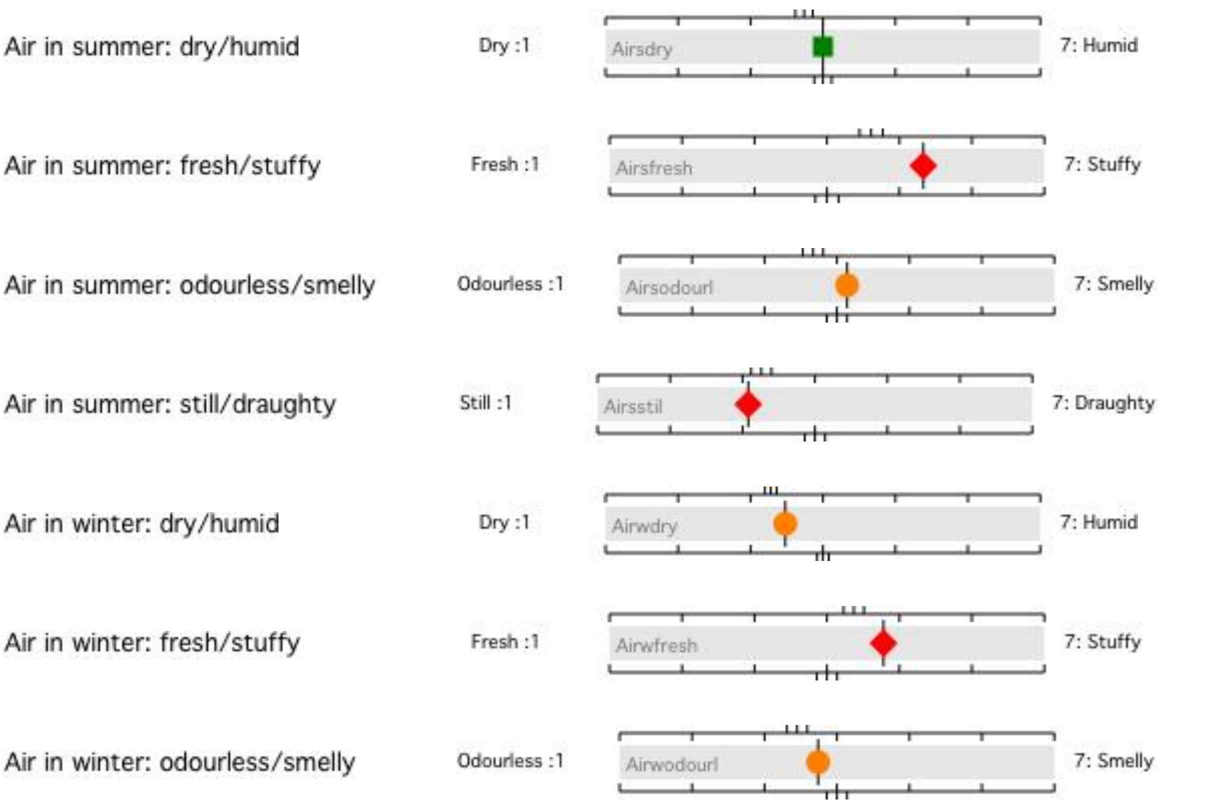


Figure 77. Air quality in summer and winter.

10.1.4 Lighting

Lighting levels appear to be satisfactory overall with two thirds of the respondents rating this building aspect favourably (Figure 78). The quality of natural light was one of the most appreciated elements of the building and both natural and electric light levels considered to be satisfactory, although 27% of the respondents experienced some degree of glare.

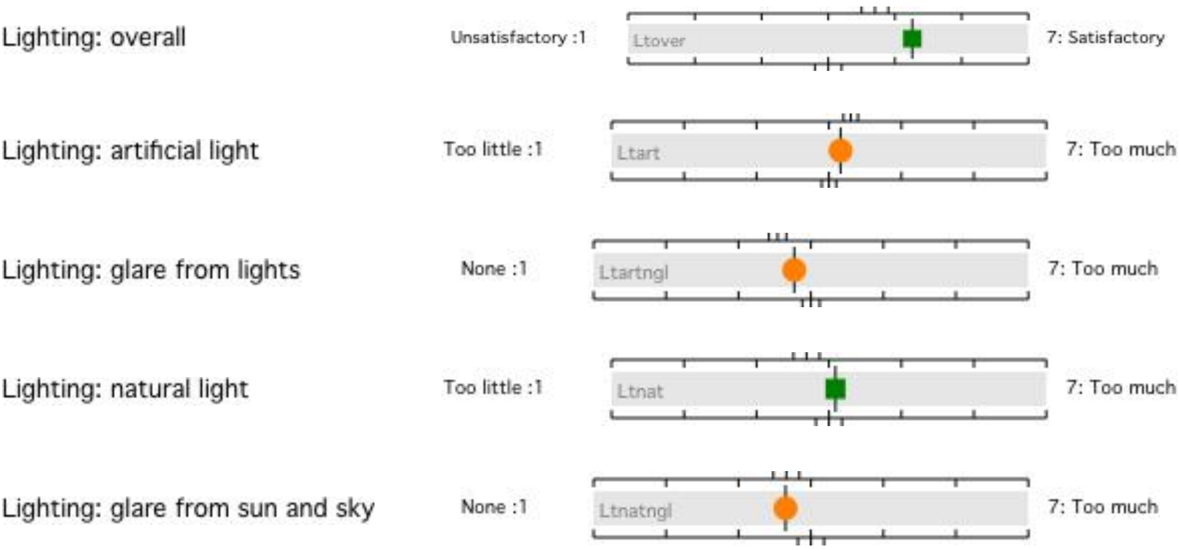


Figure 78. Lighting

Table 24 Comments received by building users on lighting

Lighting
• 2 of 4 lighting strips have been removed making electric light satisfactory. Blinds have been added - due to natural light. • Lighting at desks unsatisfactory. • Sun shines through front windows in the evening, blinding people working on the ground floor desk. Blinds help but do not cover whole area. • I think the lighting is just right.

10.1.5 Noise

Noise was clearly an issue for the staff members mainly because of the open plan spaces within the library and the external noise coming from the adjacent road when the windows are open (Figure 79). The staircase design and the open plan office on the third floor were considered to help noise travel through the different levels of the building while the lack of control over individual windows enhanced the traffic noise due to the necessity of opening at least six windows at a time.

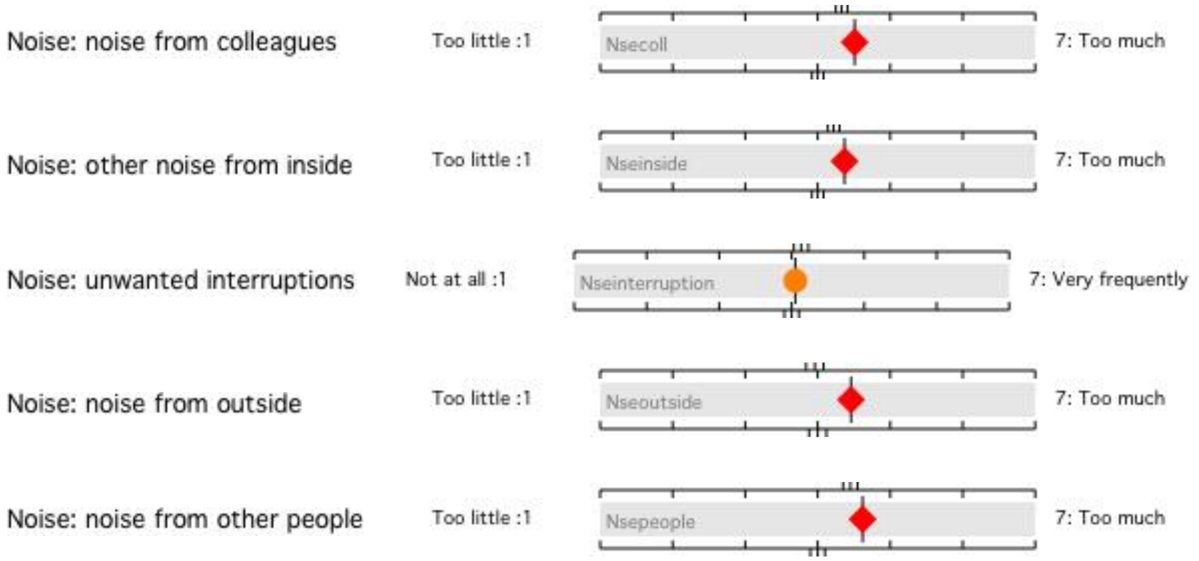


Figure 79. Noise

Table 25 Comments received by building users on noise.

Noise
• As building is so stuffy we have to have windows open to let in air. The windows are huge so we get a lot of traffic noise and pollution in. • Design of staircase means noise on ground floor is very loud even on top floor especially with teenagers. • In summer office is very hot so windows must be open which lets in constant traffic noise. Announcements from public address system are often startling! • Lots of noise travels up from ground floor, but staircase blocks noise from different ends of the same floor. • Noise is inevitable because the job involves making many phone calls.(Open plan office) • To enable ventilation windows must be open next to the road. Traffic noise and car pollution (from the traffic lights) children's library windows open out to register services area. • Public noise from weddings and smoke.

10.1.6 Personal control

In terms of control over heating, cooling, lighting, noise and ventilation the majority stated to have no control at all over their comfort conditions with the exception of ventilation over which, a third of the staff felt they had some degree of control (Figure 80). One of the most problematic spaces was found to be the exhibition room since it is either too hot or too cold, due to having no windows for adequate ventilation.

The lack of control is also reflected by the fact that all the requests for changes noted have to do with the environmental conditions within the building.

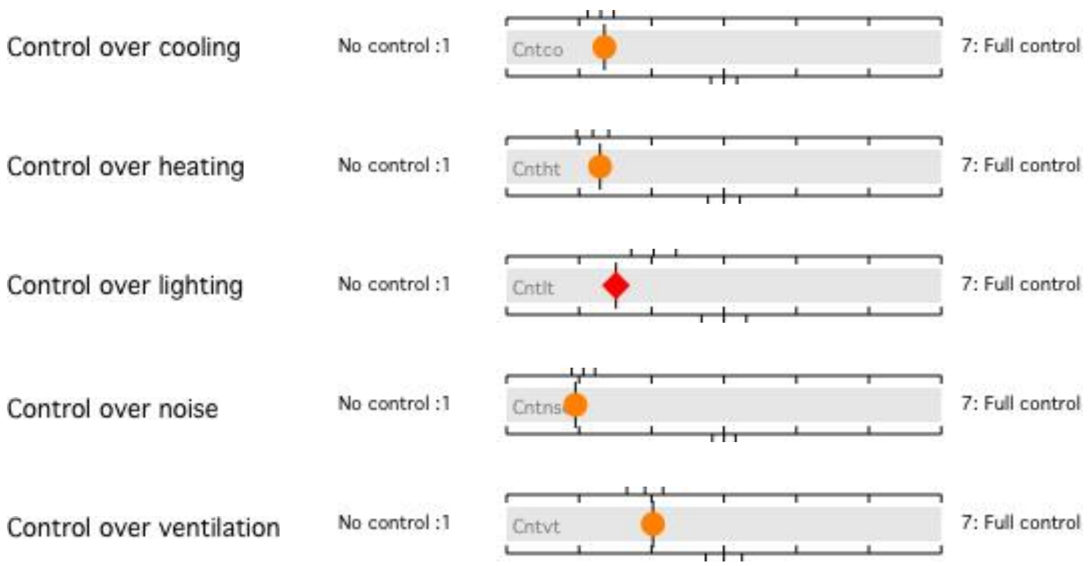


Figure 80. Personal control.

Table 26 Requests for changes received by building users.

Requests for changes
• Asked for heat to be turned up during winter. • Asked for ventilation to be put in floor, lights to be changed and blinds to be put at windows. • Asked for heating to be turned up during cold winter but declined. Asked for windows to be shut but declined. • Building can be cold in the winter and hot in summer. Support to address offered promptly. • Constantly asking for air cooling system to be improved - it is very poor- customers also complain - nothing is ever done about it. Alarm systems connected to disabled toilets need to be examined. The flashing light indicating a person needs help is hidden - It needs to be in full view of enquiry desks. • For heating in winter response was slow-heating was broken. • Requests for windows to be opened/closed. Requests for heating to be turned down. • Security and premises staff always respond immediately to such requests. • Windows to remain open without a wedge to keep it open. • Wouldn't listen if we did. They took away water etc.

10.1.7 Design and needs

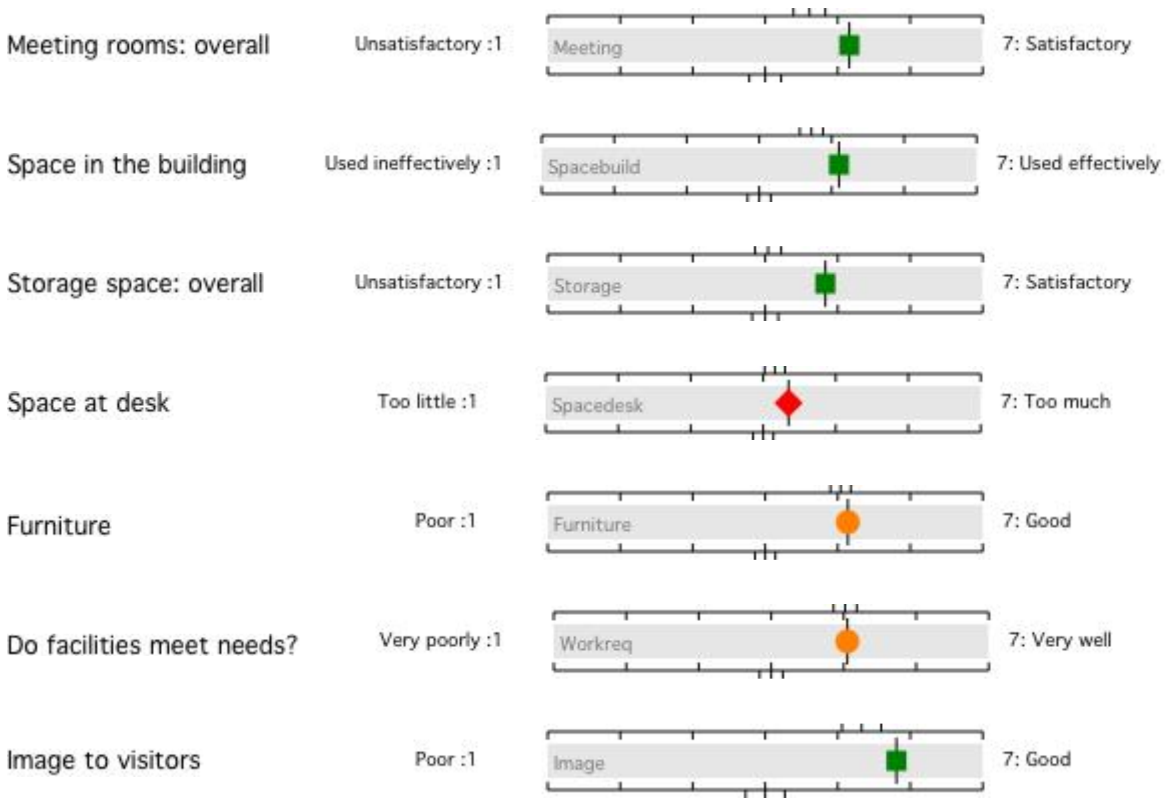


Figure 81. Design and needs.

Despite the various control and comfort issues the overall design of the building was highly rated with 79% of the respondents feeling satisfied and stating that the provided facilities met their needs in a large degree. The most positive comments were made on the modern design and high natural lighting levels while the number of toilets throughout the building, the storage in the children's library and the desk design were considered the most negative aspects of the building.

Interestingly, there were a significant number of comments in relation to the building design presenting particular challenges such as; the lack of door in the children's library, which raised issues about safety; the position of the toilets opposite the ceremony room creating unwanted noise; and the use of archive rooms as office spaces. Several issues in relation to the office areas were also raised; the design of the desks was considered to be too small; the areas are felt to be lacking storage space; and the chairs are thought to be of poor quality. Respondents were also critical of the window design ("*The design of the windows makes no sense at all"*); examples of which are the need for a wedge in order to keep the window open in the Register Services offices, and the inability in the third floor offices to open windows individually, instead six have to be opened at once.

In relation to their specific needs, respondents feel hindered by the lack of proper ventilation in the toilets and the poor air circulation in the library. In the social services reception, the glass panel placed across the desk for protection purposes is felt to prevent clear communication and the need for the installation of microphones and speakers was noted.

Table 27 Comments received by building users on needs

Needs
• More ventilation would be nice in the kitchen and toilets.

• There are not enough 'ladies' toilets. • In the social services, reception is very poor for communication with visitors via glass panel. Very hard to hear them via small holes. Mini microphones and speakers needed. • Very hot. Poor air circulation. Quiet study area upstairs gets sound from downstairs.

Table 28 Comments received by building users on design.

Design
• Attractive, open, airy. • Do not like the open plan. • Main staircase obscures lifts and not much room for electric scooters to turn. • Modern, easy to keep clean, plenty of natural light to work with. Overall structure looks good. • No door to children’s library worries about safety. • Much space taken up by the lifts and stairwells, but we only have access to a small lift which is no ventilated and brakes down. • Not enough toilets for the quantity of people. • Poor acoustics, sound travels upstairs. • The design of the windows makes no sense at all. Can’t understand why one control operates a whole series of windows. It causes a lot of arguments. • Very badly designed. Toilets opposite ceremony room too noisy. • Windows would be better if they could be controlled in smaller sections.

10.1.8 Travel to work

The overwhelming mode of transport was by private car (69%); a few would commute by train and bus (Figure 82). Respondents suggested that the parking spaces were not able to cover their needs and that they wasted time searching for a space.

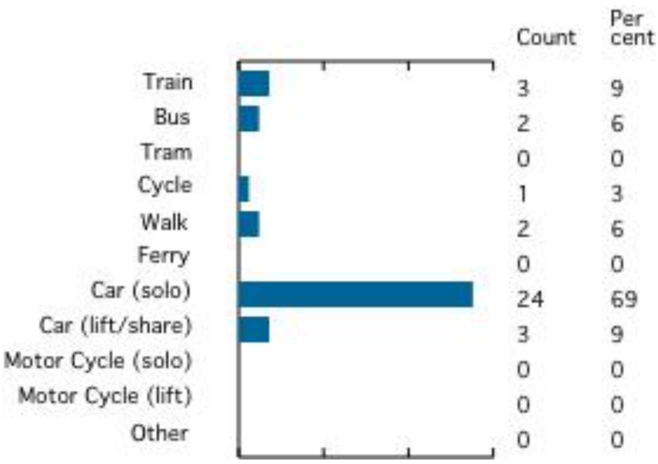


Figure 82 Journey to work.

10.1.9 Health and sense of wellbeing

Figure 83. Health and wellbeing.

The respondent's comments on health appear to relate to aspects of the building design that have failed to meet the user's needs (Figure 83). One third of the respondents rated the building negatively in terms of the impact it has to their sense of health and wellbeing but half did not notice any impact at all. The majority of the comments relate to the air stuffiness and poor ventilation and there are several complaints made in relation to feelings of thirst and fatigue as well as reports of headaches due to dehydration.

Similarly, 44% of the staff perceived their productivity to decrease when the atmosphere becomes too hot and stuffy mainly during the summer months. The lack of a water source within close distance, particularly in the library area was noted as was the comment that the unpleasant environmental conditions often led to impatience within staff members, which in turn had a negative impact on their customer services.

Table 29 Comments received by building users on perceived health.

Health (perceived)
• The building is too hot. Ventilation is very poor. Thirsty all the time because of it. Also more drinking means more toilet breaks. • Headaches are frequent probably due to dehydration. Skin and lips crack in the winter as air is so dry. • Lack of proper ventilation in a large office with many people working together encourages germs to breed, causing higher levels of sickness absence. • Ventilation comes up in the offices from the library where we hear children and likely are exposed to germs. • No issues, I just feel cold. • When at home I do not have the stuffy, bunged up feeling I have at work. Working in this building makes me tired and gives me headache.

Table 30 Comments received by building users on productivity.

Productivity (perceived)
• As a shelver, working in a stuffy, humid environment is very unpleasant and so we work slower as a result. • I don't think that my productivity is influenced by the building. • In summer productivity is reduced. Winter is ok. • No drinking water on ground or2nd floor causes excessive thirst, therefore affects productivity negatively. • Productivity would increase if ambient temperature was more controllable. • The need to obtain drinking water as the building is hot and air is dry needs staff to leave their work area often. Unpleasant WC area as no fresh air. • Too hot and no water.

Table 31 Comments received by building users on behavioural change because of the conditions in the building.

Behavioural change because of the conditions in the building
• Clothing choices change. Excessive heat can lead to impatience. • I do become weary if it gets too stuffy. • I just work through the conditions but I know I 'm not giving my best service to customers. • None apart from getting irritated regarding the situation of the toilets. • Wear summer clothes in winter - not ideal. Need to apply moisturisers regularly. • Wear warmer clothes in winter and sit by electric heater.

10.1.10 Things that hinder/work well

Key aspects of the building that respondents feel positive towards are the big windows, which provide natural light and a nice ambience as well as the open space layout. The reception and security were also found to work well and the tidy workspace and housekeeping were considered positive too.

Negative comments mainly related to issues with overheating and lack of control over windows. The children’s library was considered problematic in terms of storage space and lack of safe and secure access control from the building to the outside.

Table 32 List of things that hinder according to building users

Things that hinder
• Ground floor layout is poor. Public should be able to see information desk as soon as they come in and not have to search for it. • Heat in office in summer is too high to use the office space to meet clients. Lighting in the office has been too bright but now it is better. • Electrical socket boxes are badly sited under the desk. • The doors that break frequently can hinder working as moving a trolley around the building becomes more difficult. • There is no provision for buggies in the junior section. The children can easily escape into main road as there are no doors to children’s library and main door is sensor driven. • Time is wasted because there is minimal staff parking for workers and there is a need to travel a distance by foot to get to the vehicles. • Windows do not let in ventilation but do let in smoke, pollution, noise.

Table 33 List of things that work well according to building users

Aspects that work well
• Customer lifts. • Good facilities, tidy workspace, good housekeeping. • Good lighting, comfortable chairs. • Good shelf layout. • Good use of reception and security. • Hot desking when there is a desk! • I like the big windows. • I think that compared to other libraries we have a lot of space. • Interaction with colleagues. • Light, ambience. • Lots of light because of large sized windows. • Security are very friendly and helpful if there is a problem. • We have adapted our routines to fit the building. They now work relatively well.

10.2 Installation of monitoring equipment and data acquisition

The monitoring equipment was installed by BSRIA on 29th June 2011 in order to monitor the environmental conditions in several building spaces, providing half hourly temperature, relative humidity (RH) and CO_2 data as well as information on the lighting usage and window opening behaviours (Table 35) through data-loggers.

All the data are collected and transmitted via a wireless data-hub (Figure 84) to an on-line database in the form of CSV files and are accessible through the following link: **http://obu.global-net.eu**

Because of the large size of the building and its concrete mass construction there was a need to install a secondary hub in order to receive the signal from all the sensors installed throughout the building.

The monitored spaces were initially selected with the guidance of the building architects and finalised in the kick-off meeting in discussions with the Librarian, Registrar and Facilities manager. The four-storey library spaces, offices of different types and uses (e.g. open plan office in the third floor, cellular offices in the registrar's area, interview rooms), the ceremony room and a conference room were the main monitored areas (Figure 85). The two hubs were placed in the ground floor staff work space and the third floor kitchen to achieve better reception and avoid missing data.

Table 34. Monitoring equipment.

Monitoring Equipment Description	Quantity	Project activity
Internal temperature/humidity wireless transmitters	15	Monitoring of internal and external environmental conditions
External temperature/humidity transmitter	1	
Internal CO2 transmitter (powered via PSU /3 pin 230V socket)	5	
Pulse transmitter	1	Monitoring of the lights use

Open closed window and door sensors	2	Monitoring of openings
Wi5 Data hub GPRS (WiFi) enabled for collection of 5 minute data and GPRS SIM card for transmission of information onto a secure server	2	Data acquisition

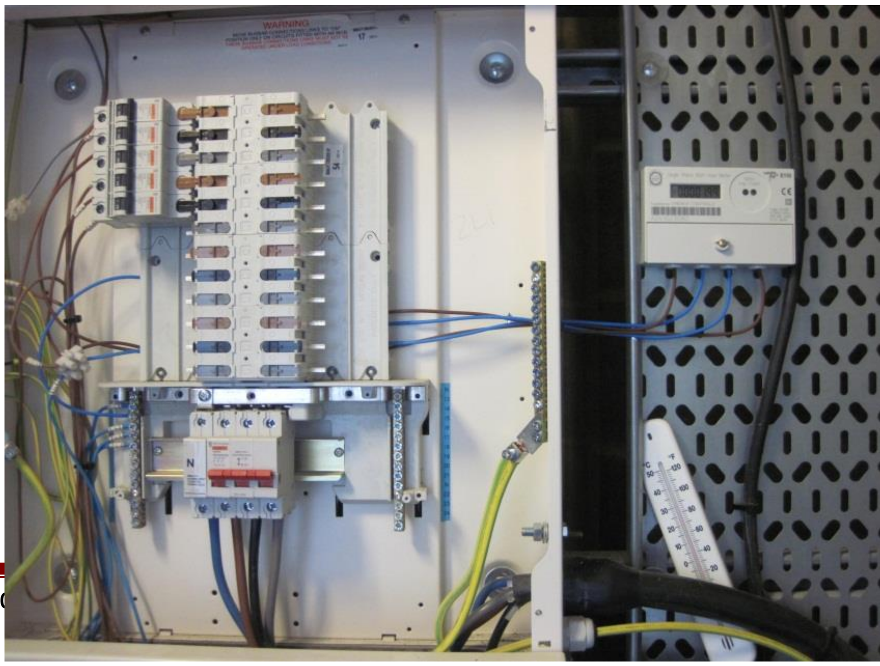
Figure 84 Left: The Wi5 data hub, the Internal Temperature/Humidity and CO_2 transmitters and the external temperature/humidity transmitter. Right: One of the two data hubs was placed in the 3rd floor kitchen.

Figure 85 Monitoring position equipment

The fitting and set up of the monitoring equipment (data-hubs, transmitter and sensors) lasted one day and presented no particular difficulties. The installation of the KWh meter with pulse output had to be undertaken by the library's qualified electrician due to the need to access locked electrical shafts and the need to have knowledge of the existing electric circuits.

The temperature, RH and CO_2 sensors were placed next to the existing thermostats on the walls so that their presence would be less noticeable to the public and prevent any interaction that would damage or set them out of order (Figure 86).

Figure 87. Left: Windows opening and closing activity sensors were placed in the windows to monitor the use of the openings during summer and winter season. Right: Window sensor.



10.3 Monitoring of environmental conditions

10.3.1 Temperature, Relative humidity and CO2 levels (July 2011-May 2014)

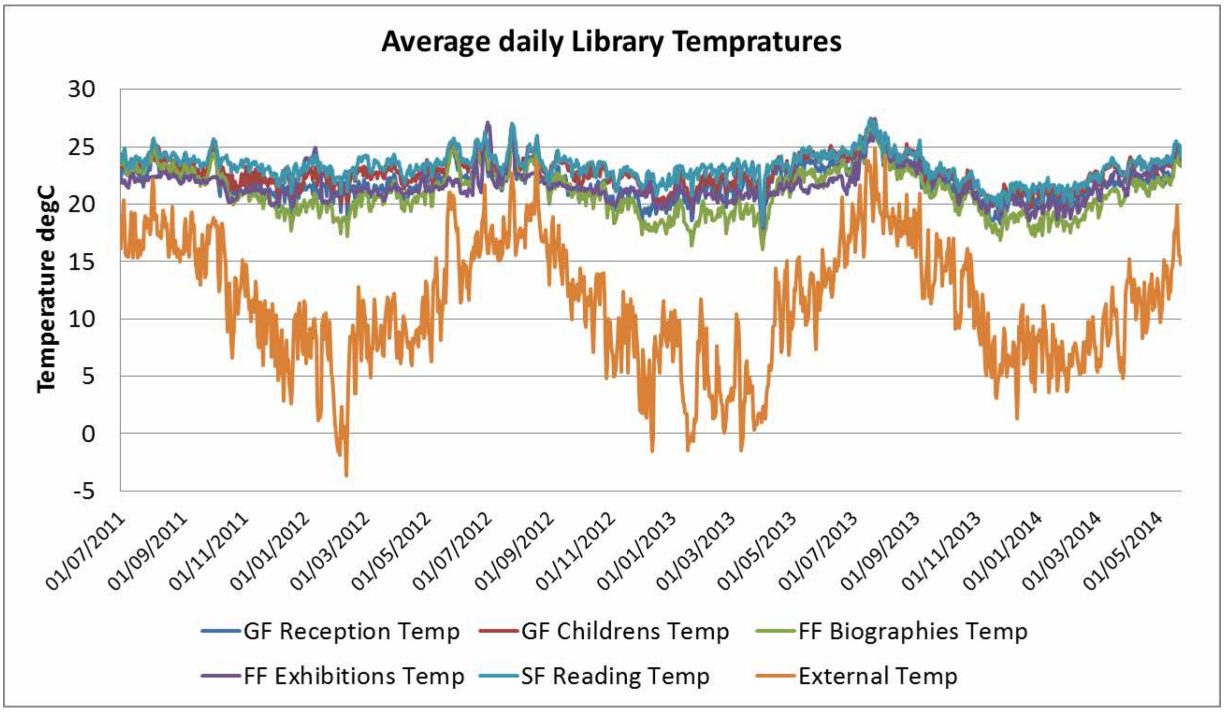


Figure 89 Temperatures in the Library area during the monitoring period (July 2011-May 2014).

- Internal temperatures fluctuate between 20 and 25 °C while external lies between -2.4 and 22°C. The internal temperatures in most of the spaces remain between the comfort levels (21-23°C) (Figure 89).
- Most of the spaces presented a stable temperature pattern (children's library, first floor (FF) archive, ground floor (GF) conference room.
- The highest temperatures are noticed in the second floor main library possibly during solar gains and heat rising up through the stairwell's open atrium.
- The graph indicates the robustness of the building. The internal temperatures tend to follow the fluctuations of the external temperature but remain close to the comfort zone and are overall fairly consistent.
- The first floor exhibitions room and the first floor Library area present the lowest temperature during the whole period falling slightly below the comfort zone during the coldest periods (Jan-Feb).
- During the summer period the temperature rises slightly above the comfort zone indicating that measures might need to be taken to prevent the building from overheating (shading, cooling).

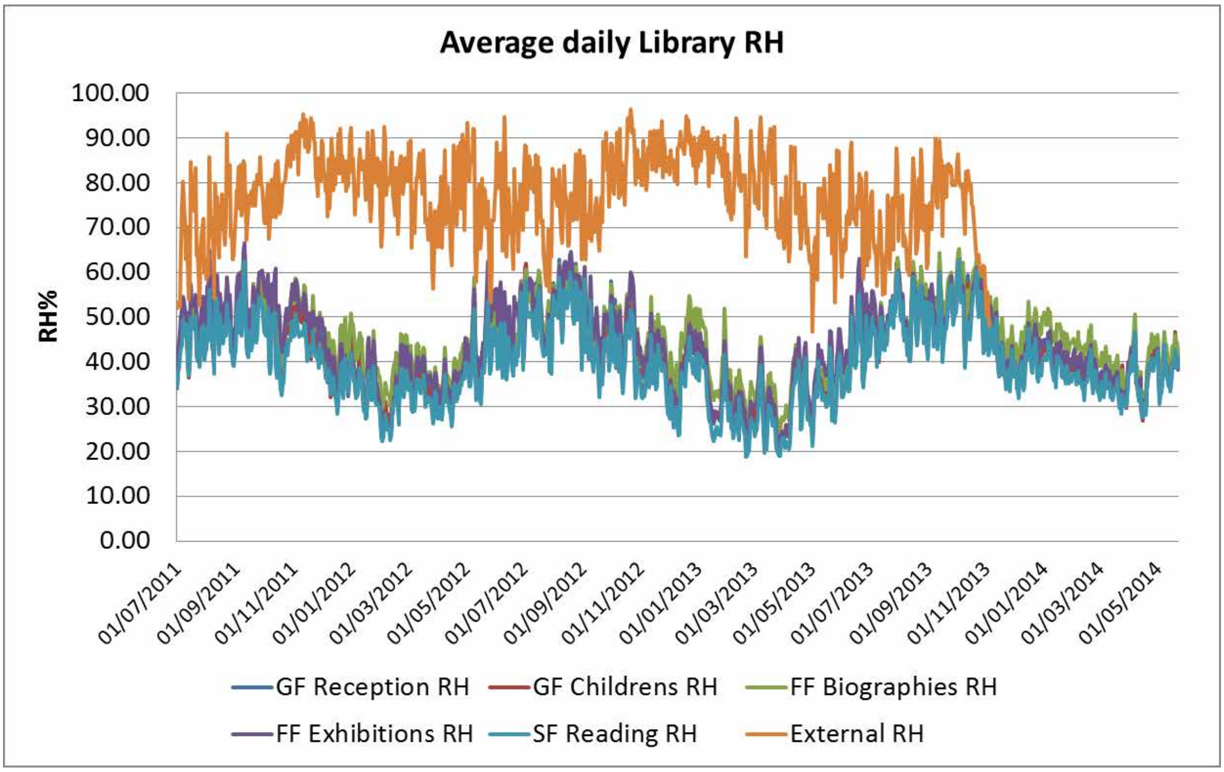


Figure 90 Relative humidity in the Library area during the monitoring period (July 2011-May 2014).

- Relative humidity (RH) generally stays between 25 – 60%, where 40% is most common (Figure 90). Humidity in the range of 40-70% is generally acceptable (CIBSE Guide A) but in case of sustained cold weather values under 40% are also considered up to standard. Humidity of 30% or lower may be acceptable but precautions should be taken to limit the generation of airborne irritants and dust and prevent static discharge from occupants (CIBSE Guide A).

- The lowest values in RH are noticed in the second floor of the Library where higher temperatures were recorded. This is probably due to solar gains and heat rising up through the open atrium of the stairwell area.

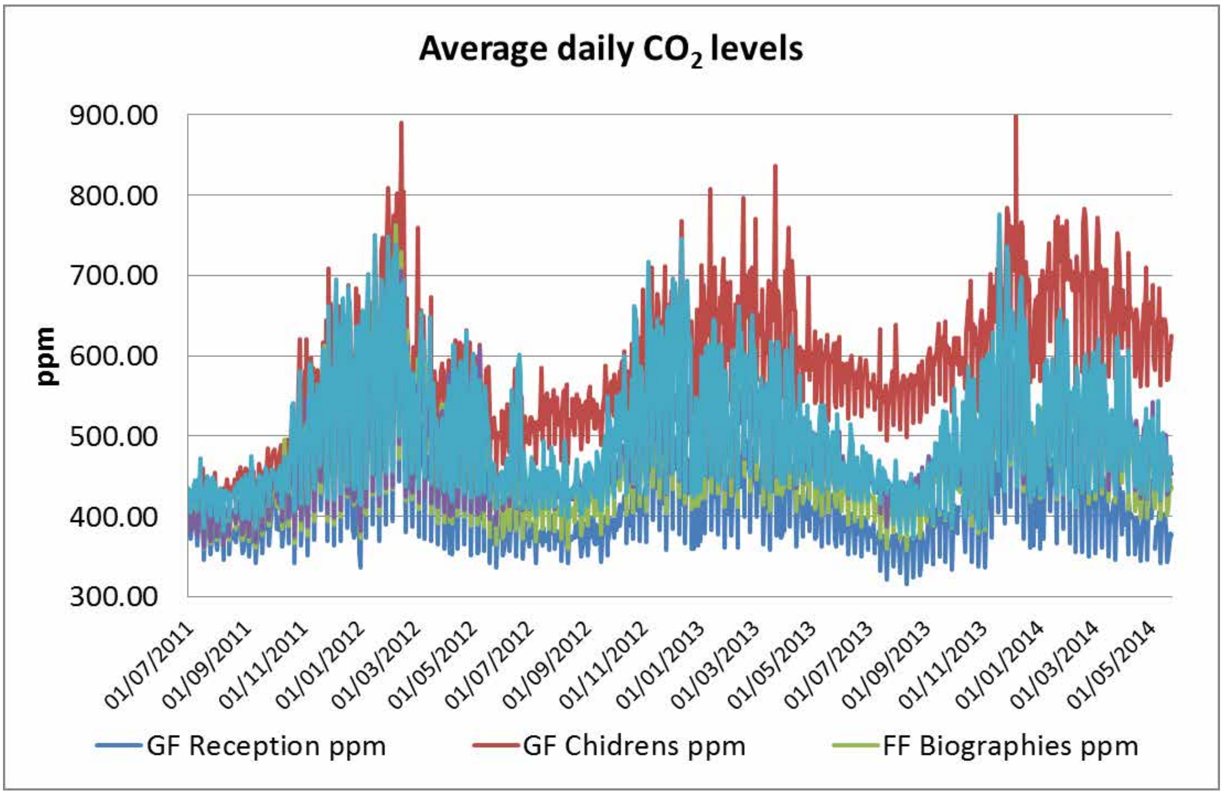


Figure 91 CO_2 levels in the Library area during the monitoring period (July 2011-May 2014).

- The CO_2 levels in the children's library are the highest and are typically between 500ppm and 800ppm (Figure 91). CO_2 readings between 1000ppm and 2000ppm are generally related to perceptions of poor air quality or stuffiness and suggest inadequate ventilation but in this case the values, such levels are not found anywhere, and when CO_2 levels rise, they quickly degrade again to acceptable levels. The CO_2 daily variation is more obvious in the third floor open plan office due to the large concentration of people during office hours.
- CO_2 levels are generally higher during the winter period when the building is mechanically ventilated suggesting that more ventilation might be needed in more densely occupied spaces.

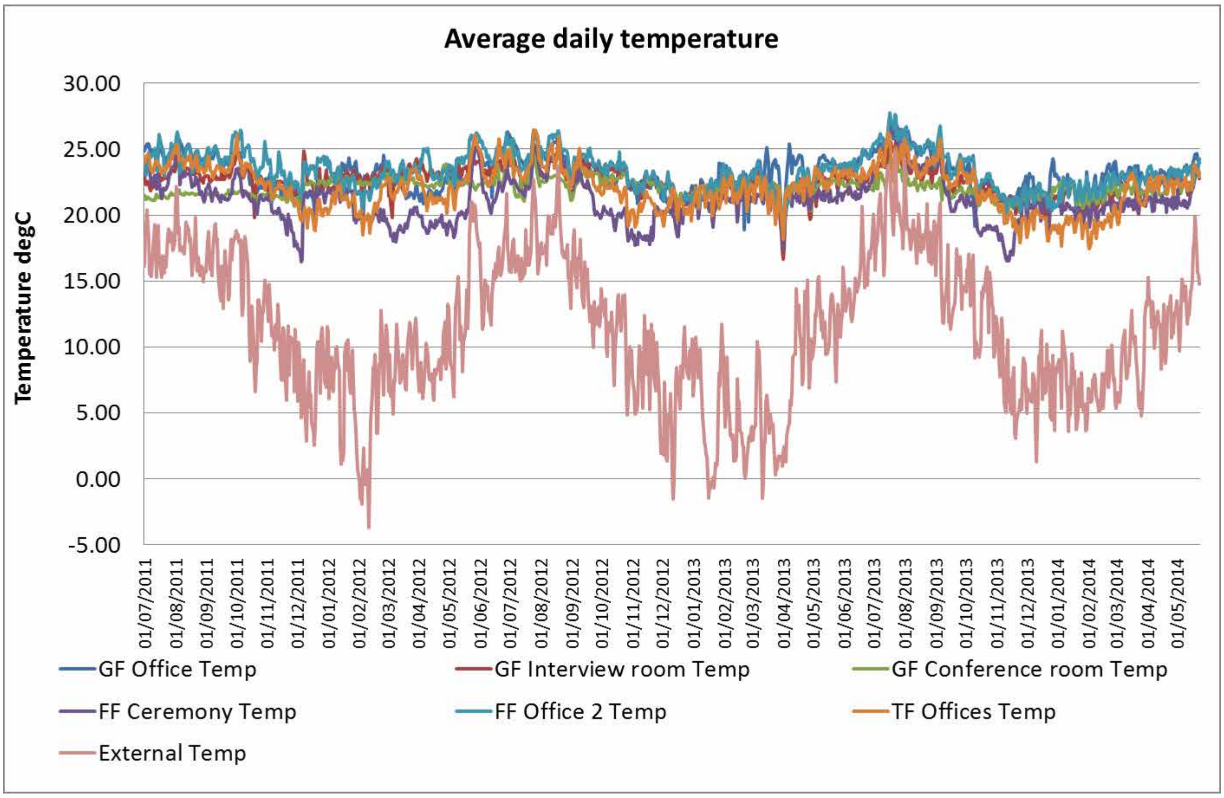


Figure 92 Temperatures in the Registry service and Office areas during the monitoring period (July 2011-May 2014).

- Internal temperatures fluctuate between 20 and 25°C while external lies between -2.4 and 22°C. The internal temperatures in most of the spaces remain between the comfort levels (21-23°C) (Figure 92).
- Most of the spaces presented a stable temperature pattern with the exception of the first floor Ceremony space.
- The highest temperatures are noticed in the first and third floor office spaces, possibly due to high internal gains from office equipment and people.
- The graph indicates the robustness of the building. The internal temperatures generally tend to follow the fluctuations of the external temperature but remain close to the comfort zone.
- The first floor ceremony room presents the lowest temperature during the whole period falling slightly below the comfort zone during the coldest periods (Jan-Feb) possibly due to the fact that it remains unoccupied most of the time.
- During the summer period the temperature slightly rises above the comfort zone indicating that measures might need to be taken to prevent the building from overheating (shading, cooling).

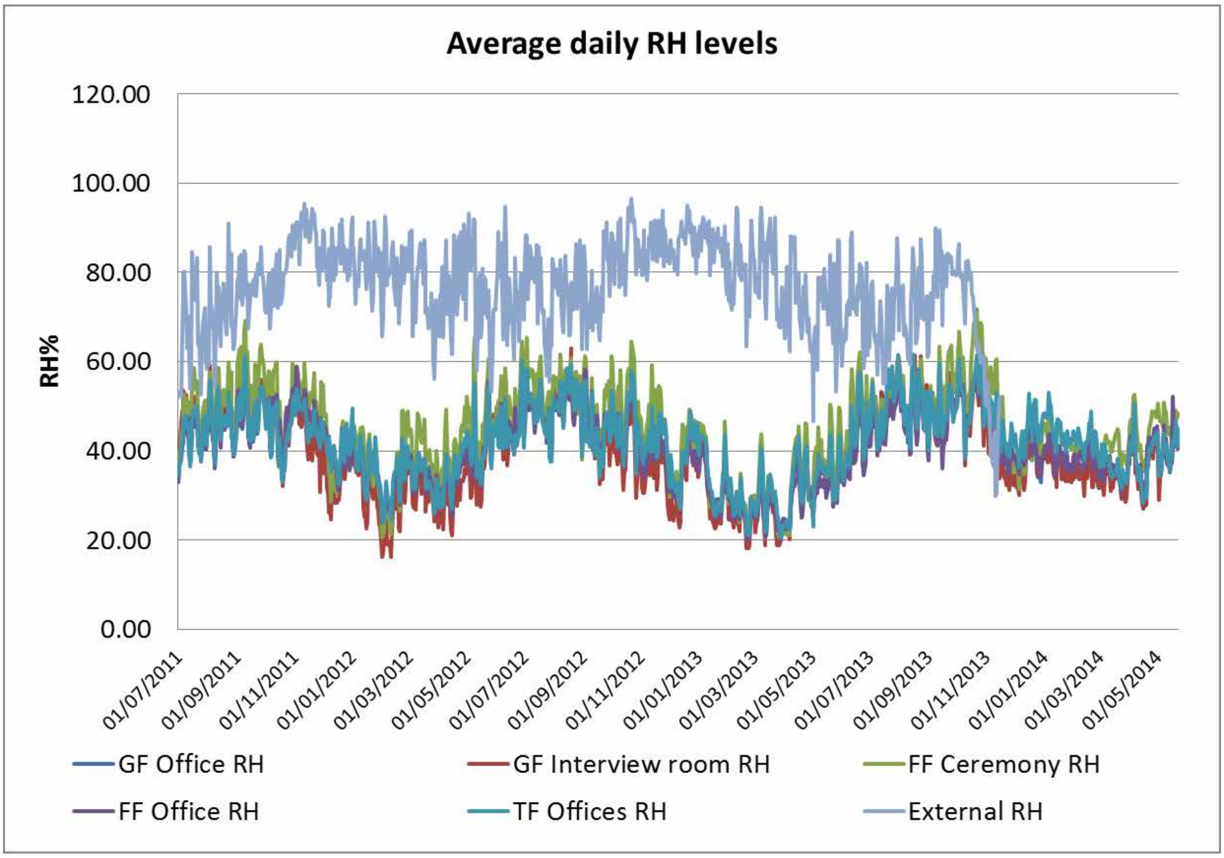


Figure 93 Relative humidity in the Registry service and Office areas during the monitoring period (July 2011-May 2014).

- Relative humidity generally stays between 20 – 60%, where 40% is most common (Figure 93). Humidity in the range of 40-70% is generally acceptable (CIBSE Guide A) but in cases of sustained cold weather values under 40% are also considered adequate. Humidity levels of 30% or lower may be acceptable but precautions should be taken to limit the generation of airborne irritants and dust and prevent static discharge from occupants (CIBSE Guide A).

- The lowest values are noticed in the third floor offices where higher temperatures were also recorded. This is probably due to high internal gains from people and office equipment.

- RH levels inside the building do not directly follow the fluctuations of the external RH but tend to drop during the heating season and rise during the summer period. This shows that RH levels are significantly impacted on by the heating and ventilation strategy of the building, particularly during the winter.

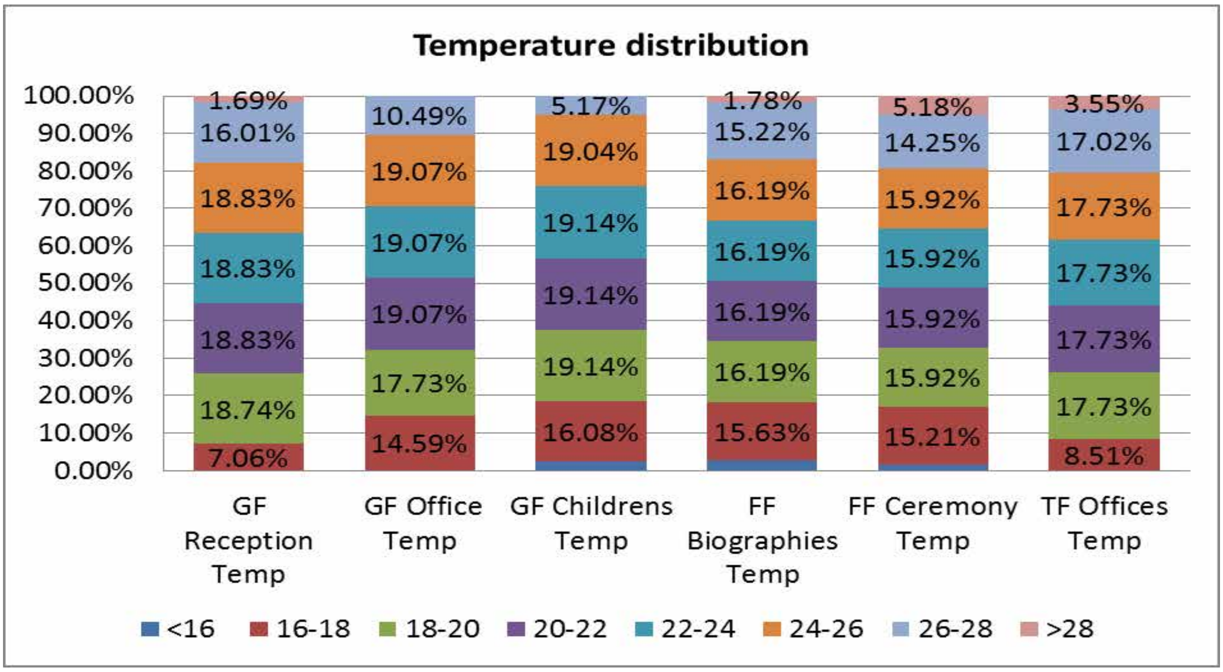


Figure 94 Temperature distribution (July 2011 – May 2014) .(Comfort zone ranging between 20-25°C)

- Temperatures remain within the comfort zone.
- Spaces remain above 26oC between 15-20% of the time
- Similar temperature distribution across all spaces

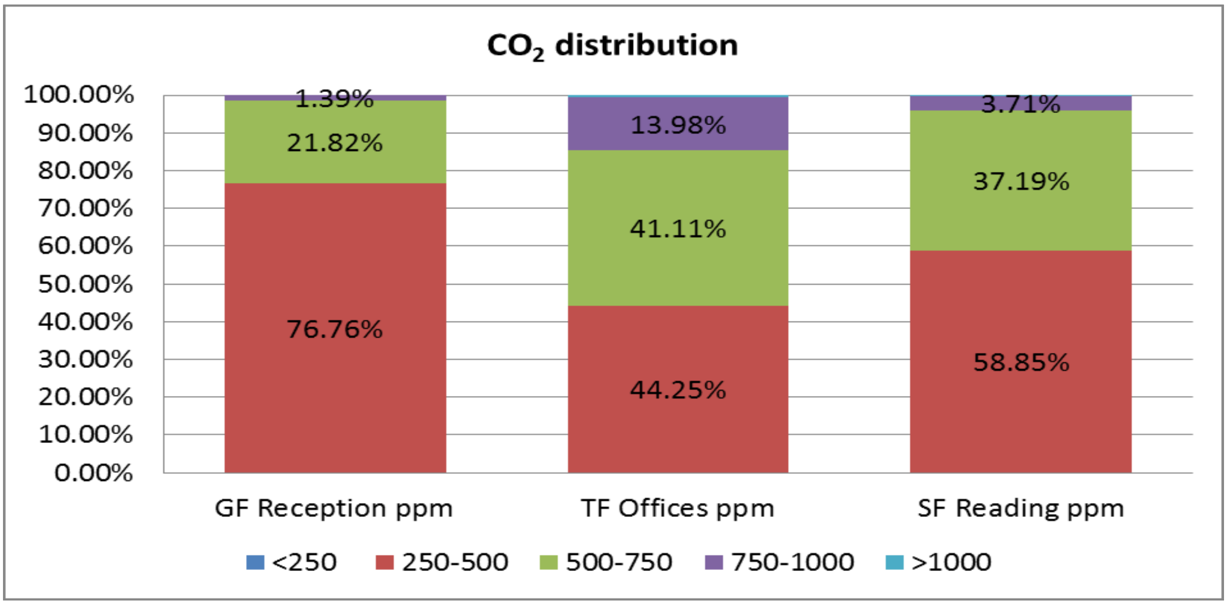


Figure 95 CO_2 distribution (July 2011 – May 2014). (ASHRAE recommended limit is 1000ppm)

CO2 levels remain well below the recommended levels in all spaces.

10.3.2 Temperature and humidity levels (Winter) (January 2012)

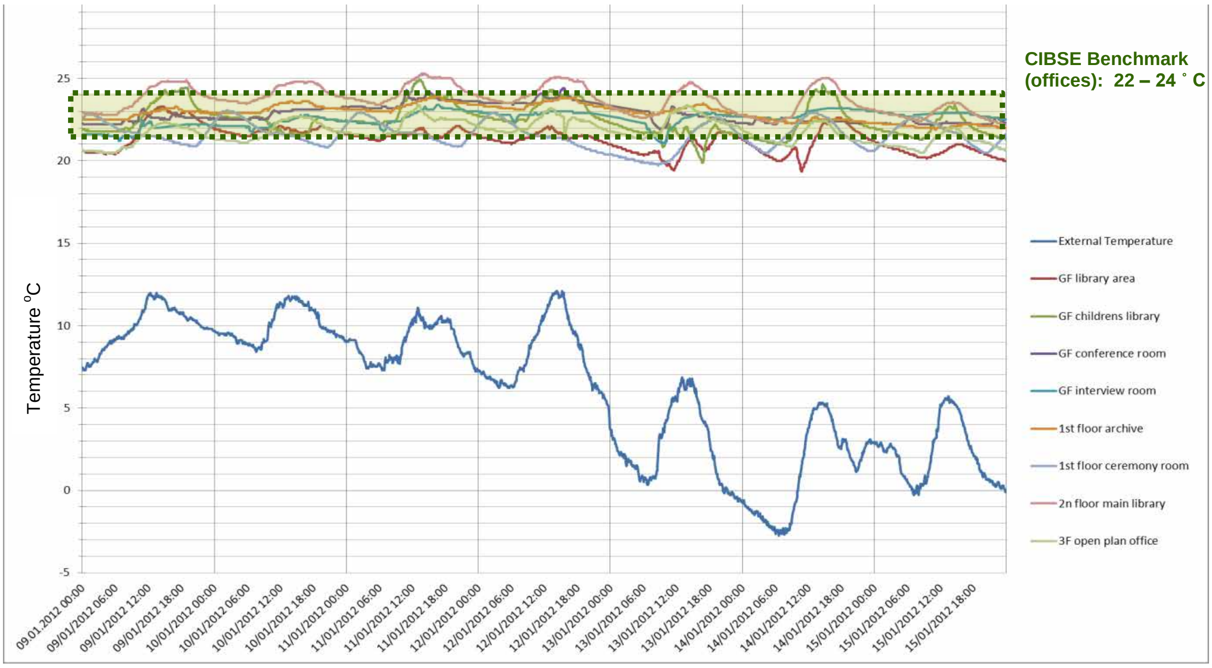


Figure 96 Temperature graph of a typical winter week (09/01/2012-15/01/2012)

- Internal temperature fluctuates between 20 and 25°C while external lies between -2.4 and 12.8°C. The internal temperatures in most of the spaces remain between the comfort levels (21-23°C) (Figure 96).

- Most of the spaces present a stable temperature pattern peaking during the afternoon, around 23°C (children's library, first floor archive, GF conference room, third floor open plan office). The pattern remains the same during the weekend indicating that the building is heated although some spaces are not in use (offices, interview room, and conference room).

- The highest temperatures are noticed in the second floor main library where during midday temperature rises up until 25°C possibly during solar gains and heat rising up from the staircase open atrium.

- During the coldest day (14/01/2012), the lowest temperature value is 19.8°C in the ground floor library. This could possibly be caused by the automatic entrance doors bringing cold air draughts directly into the library space.

- The first floor ceremony room revealed an interesting heating pattern during this week, where the temperature peaked at 1.00am, at 23°C, and gradually fell throughout the day to 21°C during the evening, before rising again. This pattern changes towards the weekend where the temperature peak moves around midday. This is potentially related to the activities that take place in this space during weekdays and the BMS settings that control the temperature and ventilation in the space. The room is occupied Monday-Thursday from 14:00-16:00 and Friday – Sunday 12:00-16:00 and the mechanical ventilation settings in this are set to maintain a cooler temperature due to potential intensive activities that may take place in here. This may account for the continuous drop in temperature during the day, but also points at the heating being on unnecessarily, when the room is unoccupied. Unfortunately, there are no details of the BMS settings at this time known to the researchers, and contradictory information has been given regarding the settings of both the heating and mechanical ventilation so the reasons for the unusual peak time cannot be fully validated. Despite this, a further investigation to ensure that the heating and ventilation strategies are combined would be advised.

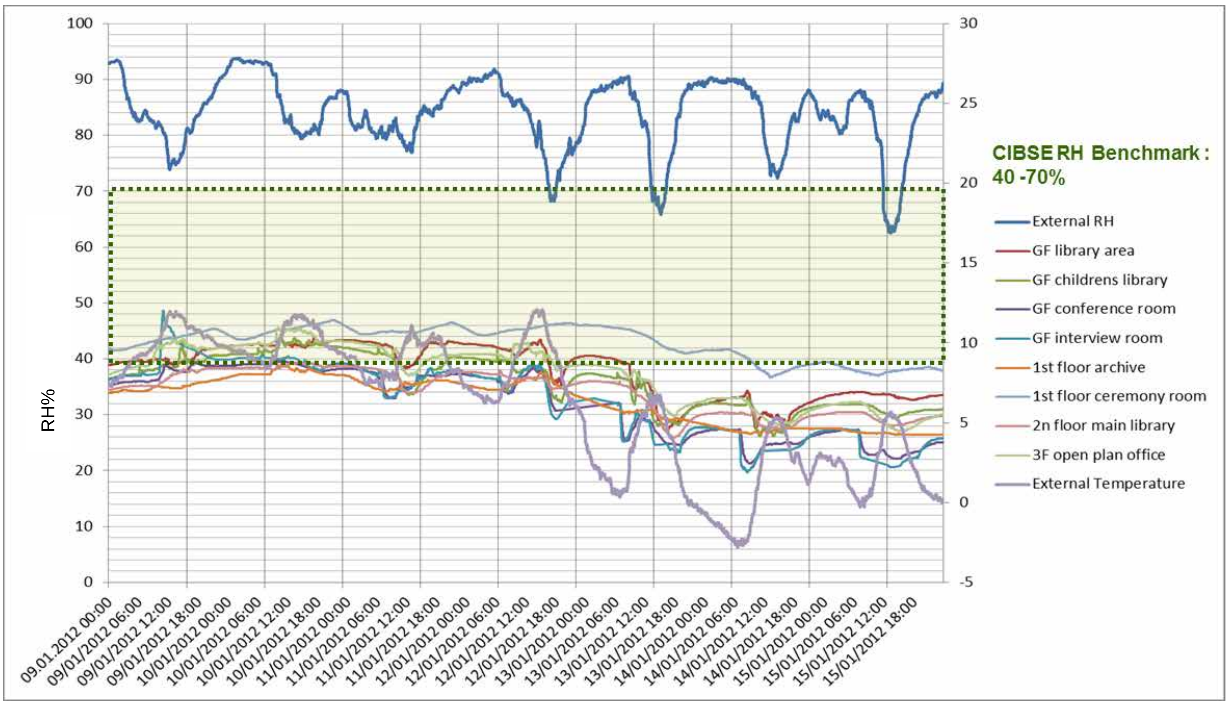


Figure 97 Relative Humidity levels during a typical winter week (09/01/2012-15/01/2012).

- Relative humidity generally stays between 25 – 45%, where +/-35% is most common. Humidity in the range of 40-70% is generally acceptable (CIBSE Guide A) but in case of sustained cold weather values under 40% are also considered tolerable. The lowest values are noticed in the conference and interview room reaching 21% in the early morning of 14th January 2012 while the external RH was 89%. The space temperature during that time was 22.5 °C in both spaces while external temperature was below zero reaching -2.5 °C (Figure 97).
- The ceremony room has the most stable RH levels lying between 40-45%, most likely due to the use of mechanical ventilation for that space.

10.3.3 Internal CO2 levels (Winter) (January 2011)

- The CO2 in the children's library is typically between 500ppm and 800ppm with two high peaks of 1,370ppm (9th January 2012, 14:45) and 1,150ppm (13th January 2012, 10:40) during gathering activities in the monitored space, highlighting the impact of occupancy on CO2 levels. Despite this, the levels quickly drop again to more acceptable levels and are never constantly high. The CO2 daily variation is more obvious in the third floor open plan office fluctuating between 450ppm and 1,050ppm during the peak office hours (12:00 – 15:00) (Figure 98).

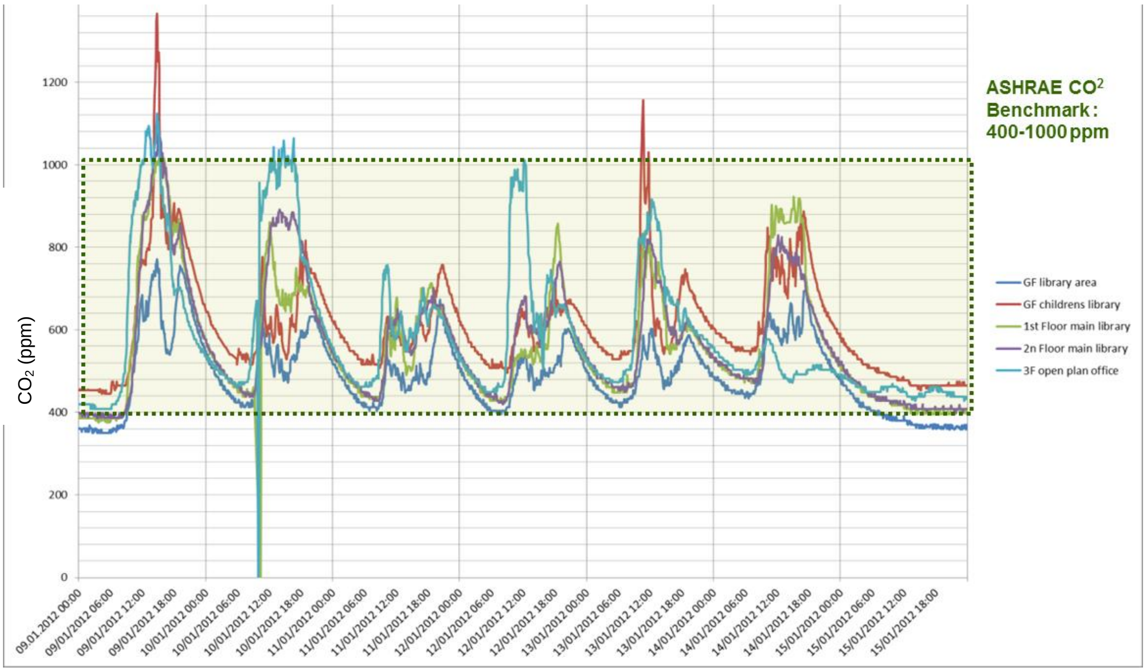


Figure 98 CO2 levels during a typical winter week (09/01/2012-15/01/2012).(Drop indicates error in data).

10.3.4 Internal temperature and humidity (February 2012)

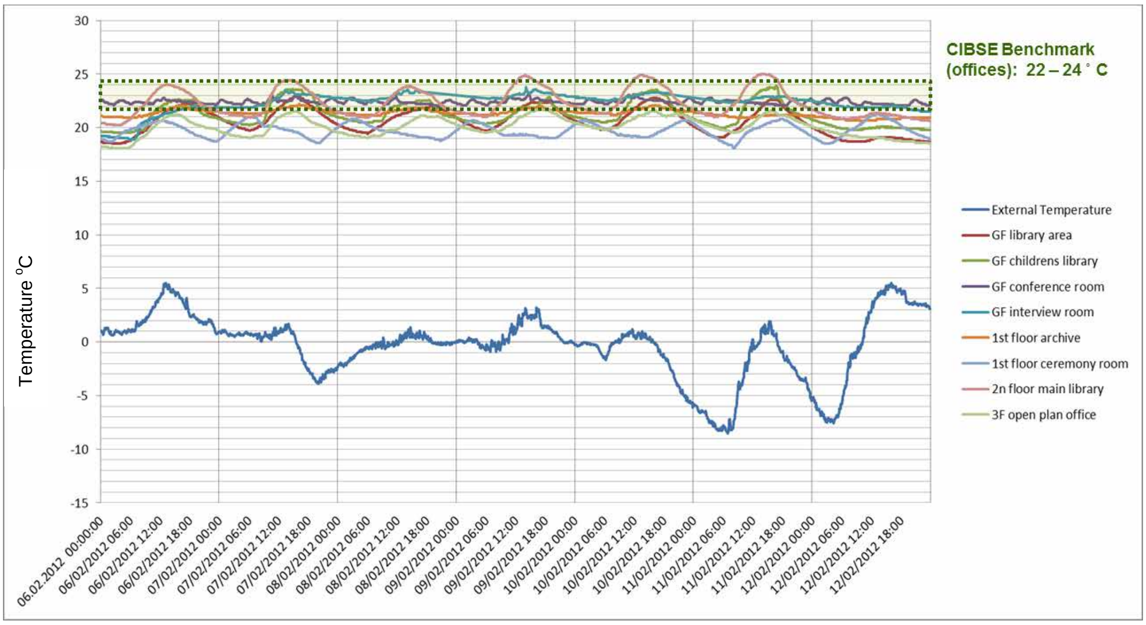


Figure 99 Internal and external temperature levels during a typical winter week (06/02/2012-12/02/2012).

- The external temperature ranges between -8.2 and 5.5°C while internal temperatures lie between 18 and 25°C (Figure 99).
- The ceremony room presents a stable variation pattern between 18 and 21°C. It is noticeable that the mechanical ventilation continues to work during weekends due to ceremonies taking place at that time.
- In the third floor open plan office, the heating is on during Saturday indicating either that some activity is taking place, and the space is occupied, or the heating has been left on.

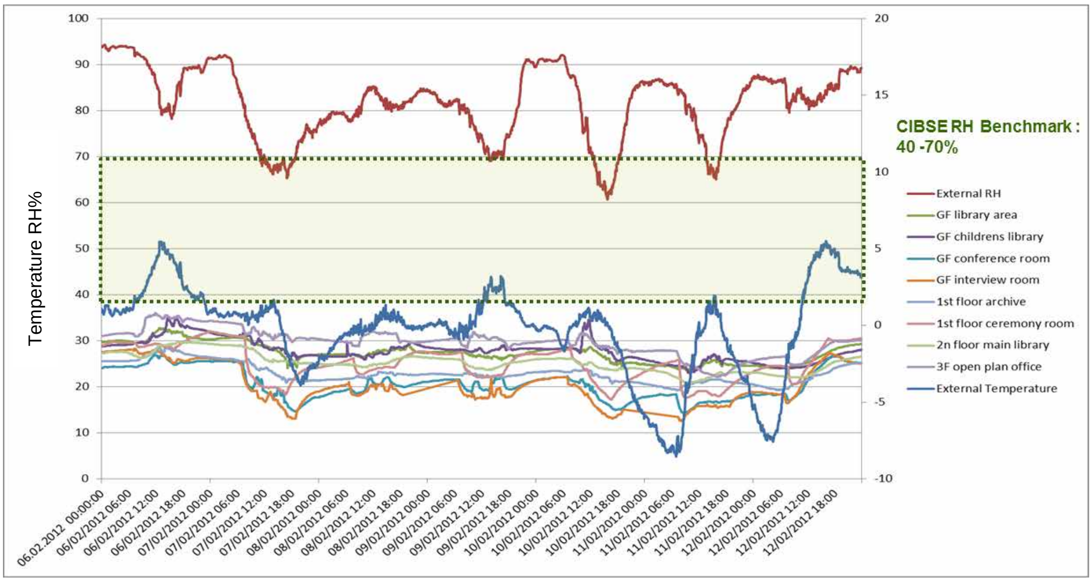


Figure 100 Relative Humidity levels during a typical winter week (06/02/2012-12/02/2012).

- Relative humidity stays mainly under 30%. This can be explained by the very low outdoor temperatures and lack of mechanical ventilation in most of the spaces (Figure 100).
- The conference room, interview room and first floor archive present the lowest values. In this case it has to be noticed that the last two spaces do not have windows so natural ventilation is not possible.

10.3.5 Internal CO2 levels (February 2012)

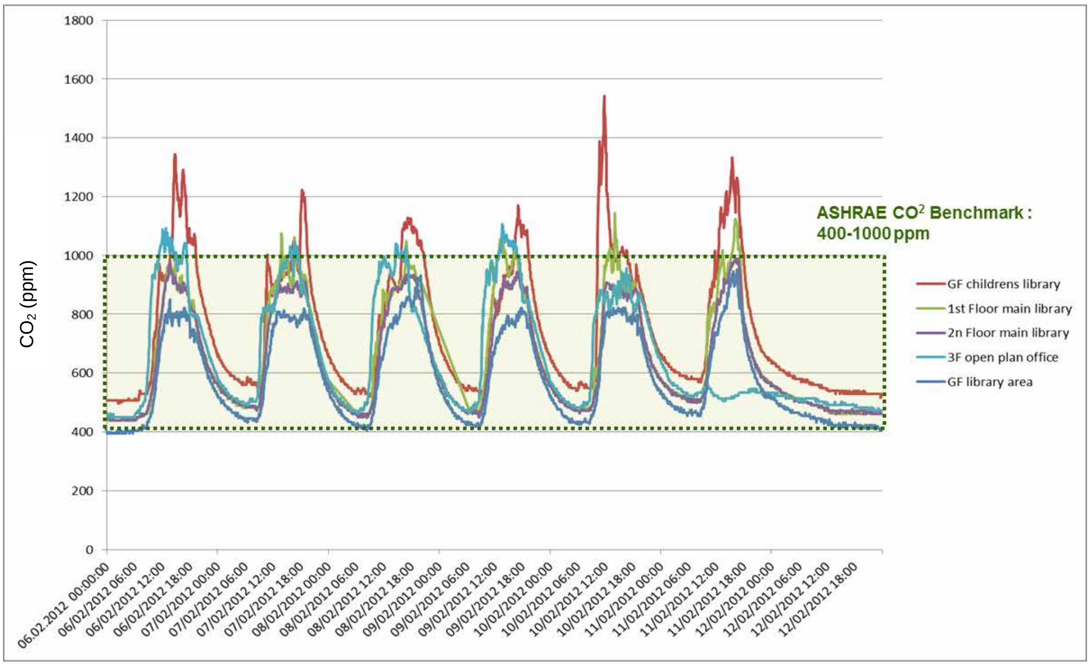


Figure 101 CO2 levels during a typical winter week (06/02/2012-12/02/2012).

- CO2 values during the day range between 600ppm and 1,100ppm in most areas (Figure 101).
- In the children's library, the levels are higher, with peaks between 1,300 and 1,500ppm on Monday, Friday and Saturday, which is when the space concurrently has peak occupancy.

10.4 Site visits for spot checks

The spot checks activity took place once during a weekday in early August (8th August 2011) (Annex 1), December (6th December 2011) and February (11th February 2013). The measurements consisted of; temperature (ºC), relative humidity (%RH), illuminance (lux) and noise levels (dB). In each area, the spot checks were taken close to the position of the existing monitoring equipment.

Table 36 gives general guidance and recommendations according to CIBSE Environmental Design Guide A on suitable winter and summer temperature ranges (together with maintained illuminance and noise ratings) for a range of room types in library and office buildings.

Table 35. Recommended comfort criteria for specific applications. Source: CIBSE Guide A, 2009.

Building/ Room type	***Winter operative temperature range (°C)***	***Summer operative temperature range (°C)***	***Maintained illuminance (lux)***	***Noise ratings (dB)***
Libraries:				
- **Lending/reference areas**	19-21	21-23	200	30-35
- **Reading rooms**	22-23	24-25	500	30-35
- **Store rooms**	15	-	200	-
Offices:				
- **Executive**	21-23	22-24	300-500	30
- **General**	21-23	22-24	300-500	35
- **Open-plan**	21-23	22-24	300-500	35

10.4.1 Temperature

There is no statutory limit to the upper temperature in workplaces. The Workplace (Health, Safety and Welfare) Regulations 1992 (Statutory Instrument 1992 No, 3004) require only that: 'During working hours, the temperature in all workplaces inside the building shall be reasonable.' Section 1 (Environmental criteria for design) of CIBSE Guide A: Environmental design, suggests that for offices the temperature range for comfort should be 21-23ºC in winter and 22-24 ºC in summer. The latter range applies to air conditioned buildings. Higher temperatures may be acceptable in non-air conditioned buildings.

10.4.1.1 1st Summer Visit (8.08.2011)

Figure 102 Floor plan with coloured temperature scale

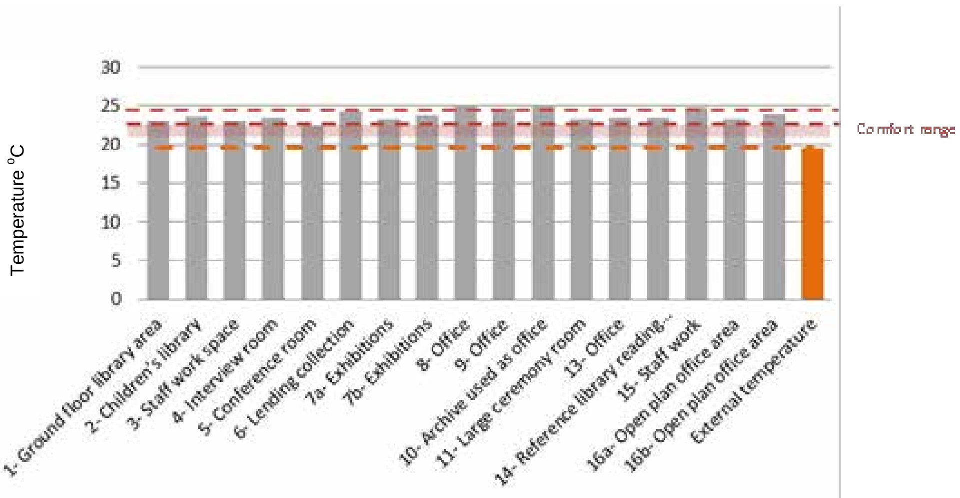


Figure 103 Temperature values in various spaces of the library during the spot check visit.

- The majority of the library spaces were found to have a temperature within the comfort range of 22-24 ºC while the external temperature was 19.9 degrees.
- It was noticed that in the first and second floor office spaces the temperature slightly exceeded the 25ºC having a temperature difference of 5ºC with the external temperature.
- The archive space in the first floor which has been converted into an office, had a temperature of 25.2 ºC which combined with a very low humidity of 43% and illuminance levels of 280 lux indicates the unsuitability of the space for its current use.
- A temperature difference of about 2ºC was noticed between the ground floor and the upper floors; indicating a slight overheating of the top floors during summer.

10.4.1.2 1st Winter Visit (6.12.2011)

Figure 104 Floor plan with coloured temperature levels.

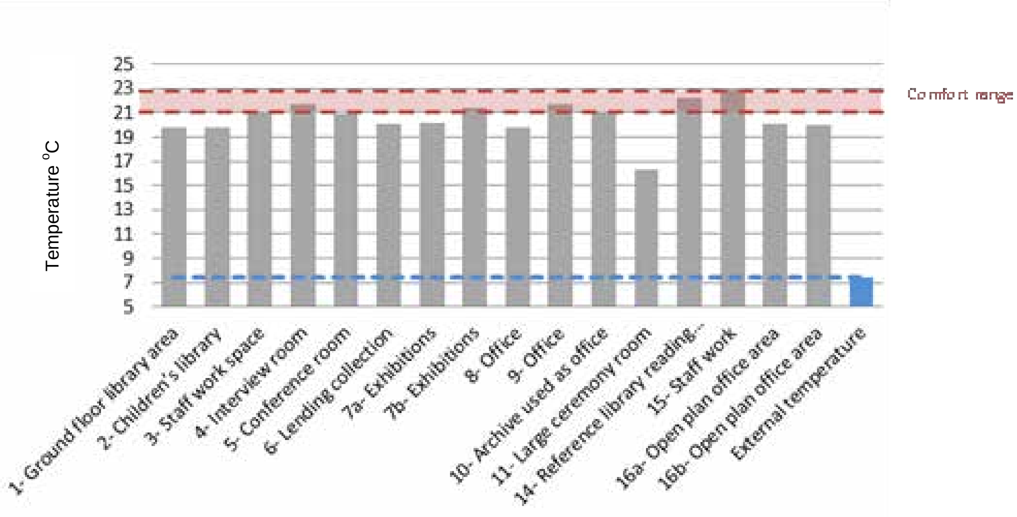


Figure 105 Temperature values in various spaces of the library during the spot check visit.

- The majority of the library spaces were found to have a temperature slightly below the comfort range of 21-23 ºC with the library reading space on the second floor being the warmest space with 23ºC (Figure 105). All the office spaces presented homogenous temperatures with the exception of the small east facing office on the second floor where the temperature was slightly over 19 ºC.
- A temperature difference of about 2ºC was noticed between the ground floor and the second floor (the uppermost floor of the atrium) indicating that hot air is rising up the atrium during the winter months as was intended by the design concept.
- The coldest room within the building was found to be the large ceremony room where the temperature was below 17 ºC. This is explained by the fact that mechanical ventilation is on even during the winter to avoid the room being too warm during the various ceremonies.
- A temperature difference of 1ºC between two corners of the exhibition space has been noted explaining the staff remarks of the space being draughty and colder on the one side. This difference is also supported by the infrared photographs of the room revealing a cold bridge on the ceiling on northern side of the room.

10.4.1.3 2nd Winter Visit (11.02.2013)

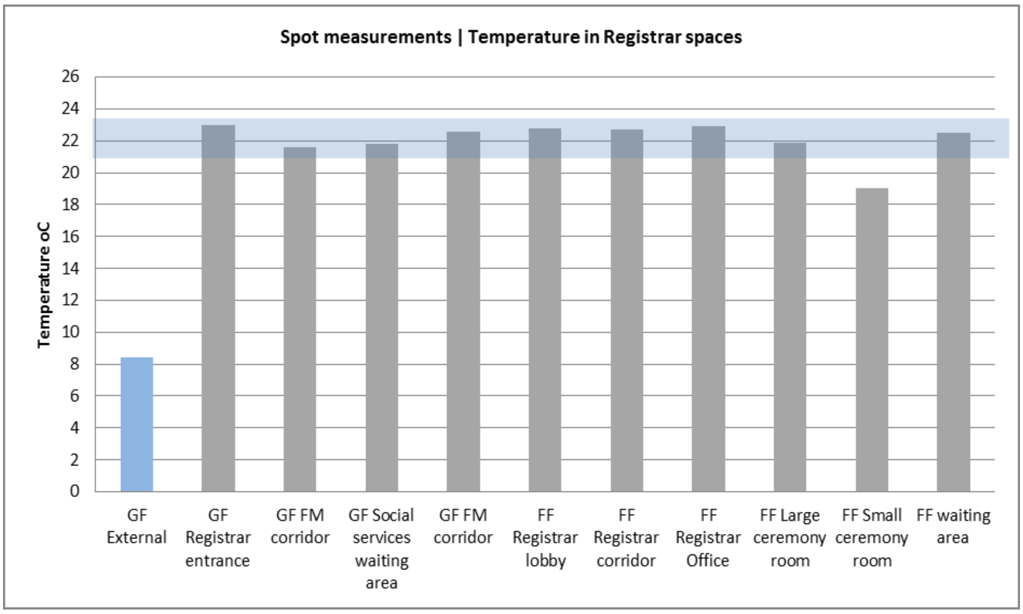


Figure 106 Temperature values in various spaces of the registrar building during the 2nd winter spot check visit (11.02.13)

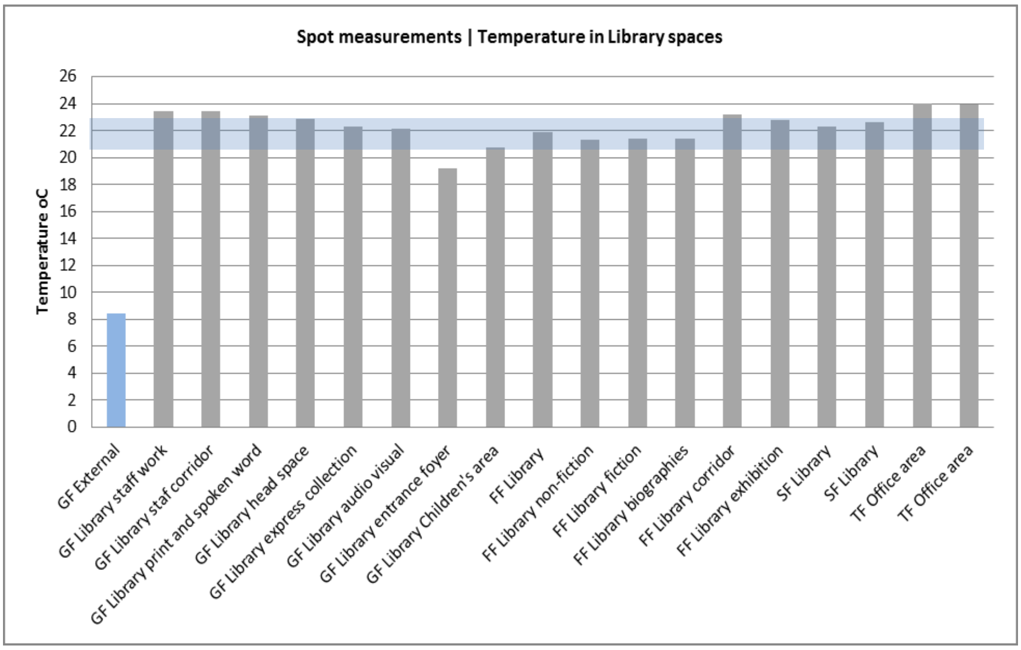


Figure 107 Temperature values in various spaces of the library during the 2nd winter spot check visit (11.02.13)

- The majority of the library spaces were found to have a temperature within the comfort range of 21-23 ºC with the office space on the third floor being the warmest space with 24 ºC. All the office spaces presented homogenous temperatures.
- The coldest room within the building was found to be the first floor large ceremony room where the temperature was below 19 ºC. This is explained by the fact that cooling is on even during the winter to avoid the room being too warm during the various ceremonies. However, cooling remains on all the time irrespective of the event schedule and the use of the room because there is not individual switch in the room to adjust or turn it off but is set on as a default.

10.4.2 Relative humidity

Relative humidity in the range 40–70 %RH is generally acceptable (CIBSE, 2009). Lower humidity is often acceptable for short periods of time. Humidity of 30% RH or below may be acceptable but precautions should be taken to limit the generation of dust and airborne irritants and to prevent static discharge from occupants.

10.4.2.1 1st Summer Visit (8.08.2011)

Figure 108 Floor plan with relative humidity coloured levels during the summer spot check visit.

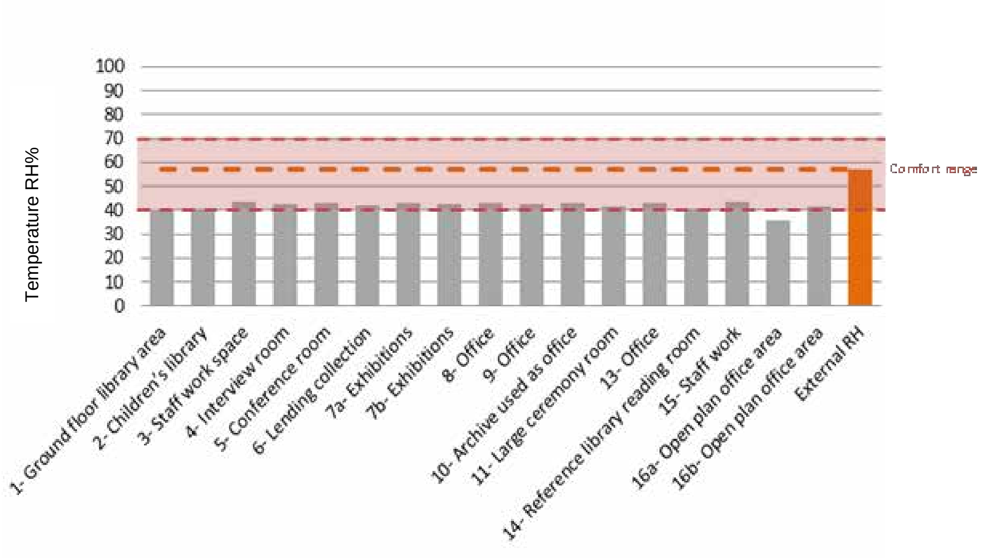


Figure 109 Relative humidity values in various spaces of the library during the summer spot check visit.

- Humidity levels for most of the spaces were fluctuating between 35.8% and 43.8% slightly below the external rate that was 57%. The range is considered as normal for a typical summer day of 20ºC.
- The lowest value was detected on the east side of the open plan office area on the third floor where it was 35.8% in comparison with the 41.7% on the north side, possibly due to more windows being open in this area at the time, bringing in moist external air and less direct sunlight available.

10.4.2.2 1st Winter Visit (6.12.2011)

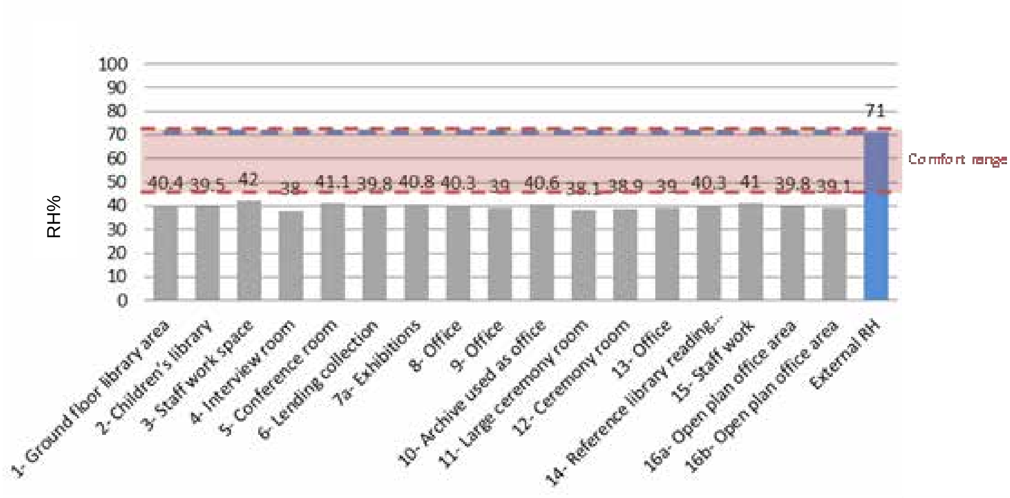


Figure 110 Relative humidity values in various spaces of the library during the spot check visit.

Figure 111 Floor plan with relative humidity coloured levels during the winter spot check visit.

- The building seemed to have normal humidity levels during the winter visit, with %RH ranging between 38% and 42%; significantly lower than the external RH measurement of 71%. This can be explained by the use of heating inside the building and the windows being closed almost all of the time.
- The lowest value was detected in the interview room on the ground floor and the ceremony spaces on the first floor. Although the difference with the rest of the spaces is minor, in the case of the interview room this can be explained by the fact that the space has no windows so fresh air can come only through the corridors. The low humidity levels in the large ceremony room are most likely due to the increased air movement caused by the mechanical ventilation. The mechanical ventilation was designed to prevent overheating in the summer by providing fresh air when the

occupancy increases during a ceremony. However, it is still in operation in the winter, even when the space is unoccupied. This is the most likely cause of the measured low temperatures and low humidity levels. There are no controls for this mechanical ventilation within the room.

- There is an indirect correlation between humidity and internal temperature. It was found that although the second floor recorded the maximum temperatures, the humidity levels at 40.3% are comfortable and higher than other less hot spaces. This could be due to windows being opened occasionally allowing fresh moist external air to enter. It may also demonstrate that the heating system optimally operates without drying out the air.

10.4.2.3 2nd Winter Visit (11.02.2013)

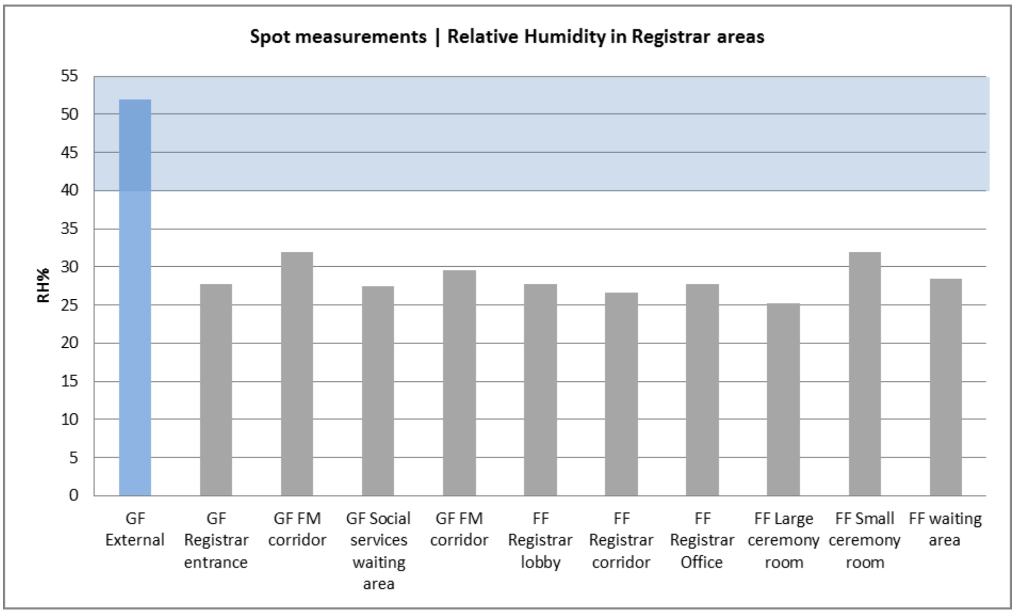


Figure 112 Relative humidity values in various spaces of the Registrar building during the 2nd winter spot check visit (11.02.13)

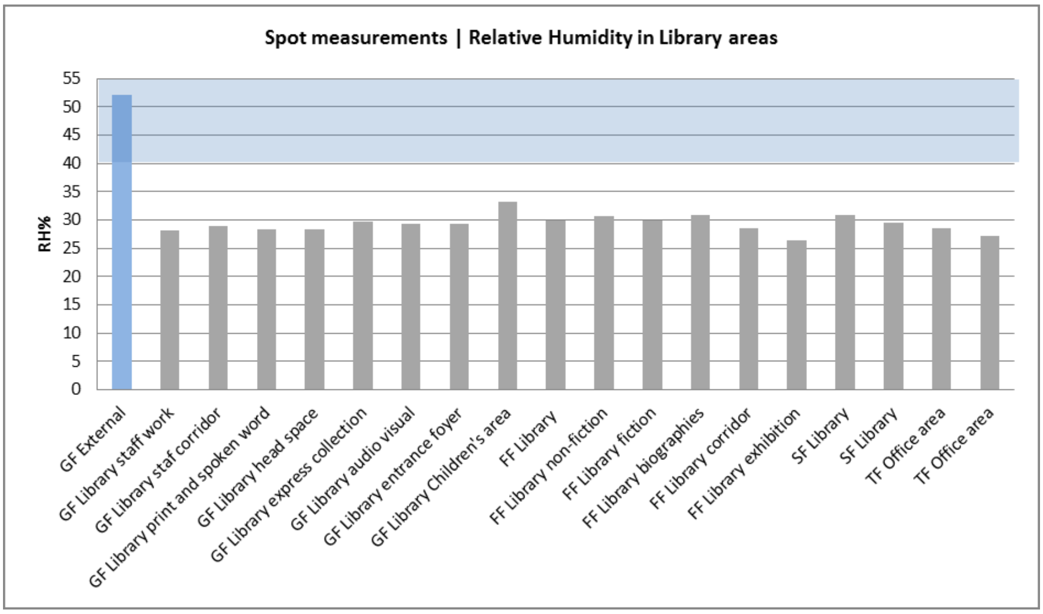


Figure 113 Relative humidity values in various spaces of the library during the 2nd winter spot check visit (11.02.13)

- The building seemed to have low humidity levels during the second winter visit, with values ranging between 27%RH and 31%RH; significantly lower than the eternal 52%RH. This can be explained by the use of heating inside the building and the windows being closed almost all the time.

- As in the first winter visit the lowest value was detected in the ceremony spaces on the first floor. The low humidity levels in the large ceremony room are most likely due to the increased air movement caused by the mechanical ventilation. The mechanical ventilation was designed to prevent overheating in the summer by providing fresh air when the occupancy increases during a ceremony. However, it is still in operation in the winter, even when the space is unoccupied. This is the most likely cause of the measured low temperatures and low humidity levels. There are no controls for this mechanical ventilation within the room.

10.4.3 **CO_2 levels**

10.4.3.1 2nd Winter Visit (11.02.2013)

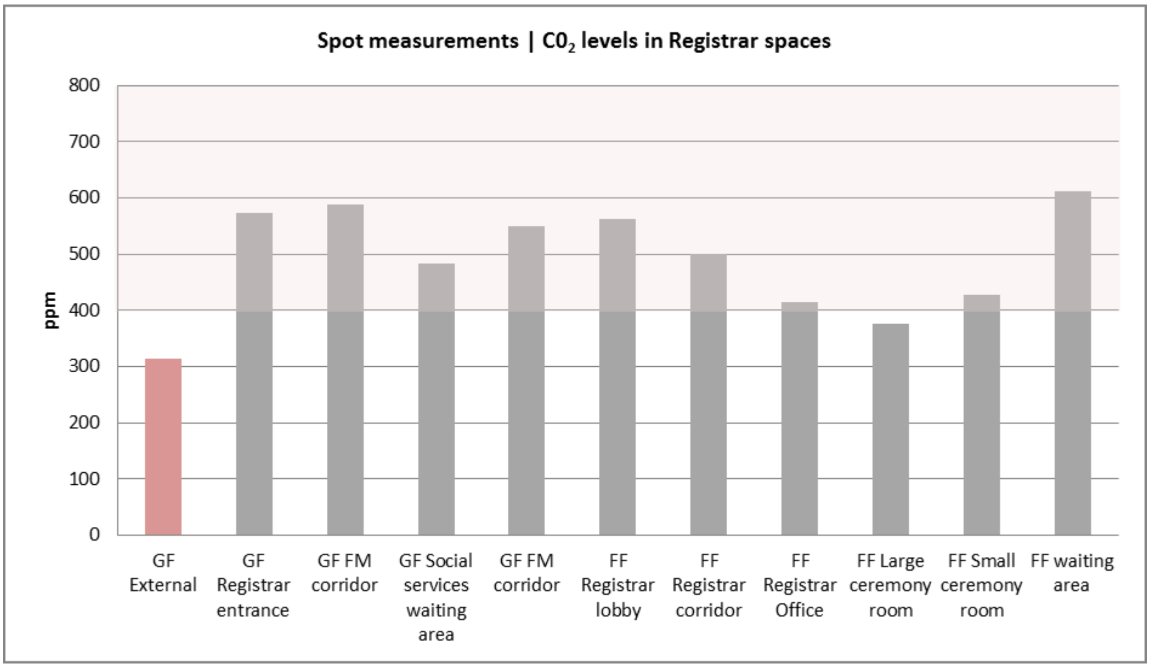


Figure 114 CO_2 values in various spaces of the Registrar building during the 2nd winter spot check visit (11.02.13)

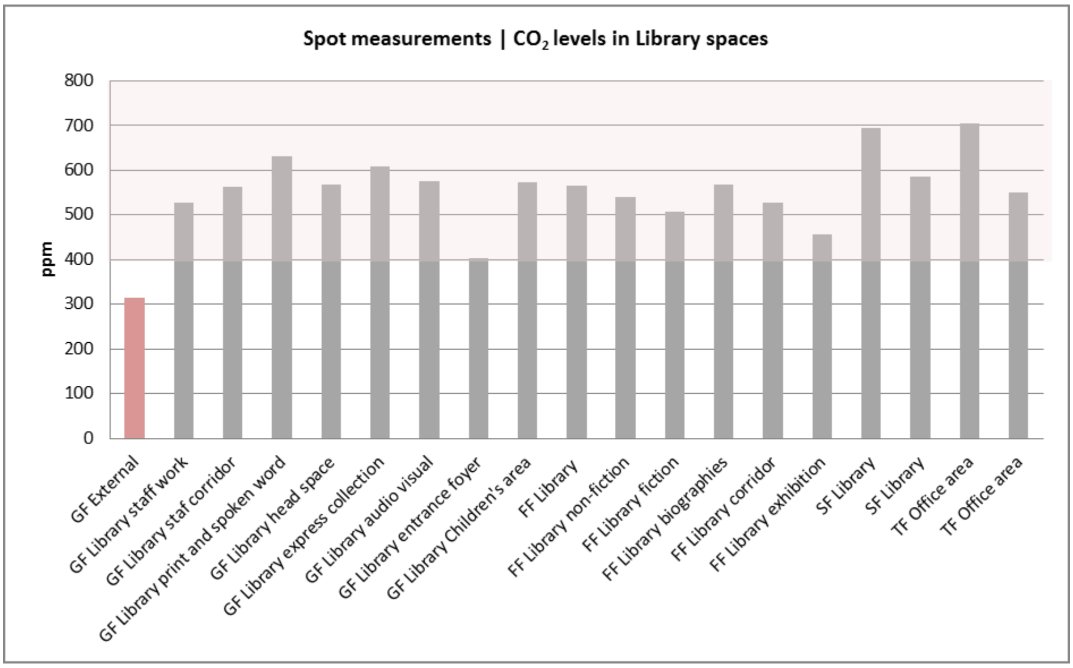


Figure 115 CO_2 values in various spaces of the library during the 2nd winter spot check visit (11.02.13)

- The CO_2 levels in most spaces range between 400 to 600ppm. Higher values were only measured in the second floor of the Library and in the third floor offices.
- The lowest values were recorded in the Register Services areas and the ceremony rooms, which were empty during the measurements.
- During the measurement the spaces were occupied but not many visitors were in the Library. The office areas were half occupied that day. Windows were closed in all spaces.

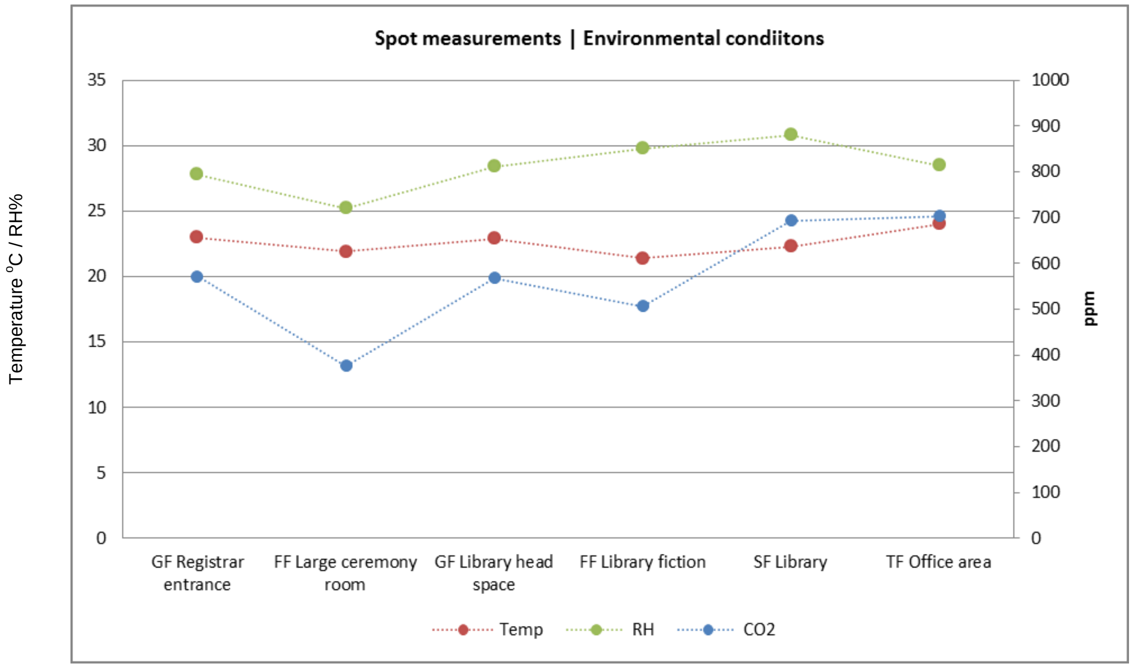


Figure 116 Temperature, Relative Humidity and CO2 levels in various spaces of the building during the 2nd winter spot check visit (11.02.13)

Most spaces present similar environmental conditions. Figure 116 shows a comparison of key spaces of the library. Temperatures are quite homogeneous throughout the Library but RH and CO_2 levels vary. The Lowest RH levels were measured in the large Ceremony room possibly due to the mechanical ventilation. The highest temperatures were recorded in the 2nd floor of the Library as a result of the warm air rising up through the atrium. The highest CO_2 levels were recorder in the 3rd floor office area which is highly occupied.

10.4.4 **Light levels**

'The first and most obvious thing to understand is that daylight is variable: it varies with the season of the year, the time of day, and the weather; for this reason the means of calculation are based on relative rather than absolute values, and this is usually defined in terms of the relationship between the light available outside, and that available at different positions inside, a proportion known as the daylight factor. By calculating the DF at a number of points throughout a space, an average DF can be assessed.

The average daylight factor is a measure of the amount of skylight in a room. If the room is not too deep or obstructed an average daylight factor of 5% or more will ensure that an interior looks substantially daylit, except early in the morning, late in the afternoon or on exceptionally dull days. An average daylight factor below 2% generally makes a room look dull; electric lighting is likely to be in frequent use.

The rule of thumb is based on achieving an average daylight factor of 2% at table-top level in the room. (The 'daylight factor' is the amount of daylight at a point expressed as a percentage of the daylight falling on an unobstructed horizontal surface outside, excluding direct sunlight.)

In cloudy climates, the average daylight factor indicates the likely daylit appearance of a room:

In less than 2%

– room looks gloomy under daylight alone

– full electric lighting often needed during daytime

– electric lighting dominates daytime appearance

In 2%-5%

– windows give a predominantly daylit appearance but supplementary electric lighting needed

– usually the optimum range of daylighting

for overall energy use n 5% or more

– the room is strongly daylit

– daytime electric lighting rarely needed

– major thermal problems from large windows'

DETR 1998. Desktop guide to daylighting -for architects. GOOD PRACTICE GUIDE 245. DETR ENERGY EFFICIENCY BEST PRACTICE PROGRAMME PUBLICATIONS.

The CIBSE Code for Lighting recommends a maintained illuminance of 500 lux for library reading rooms and general offices (e.g. writing, typing, reading, data processing, etc.) and for work stations and conference/meetings rooms. Where the main task is less demanding, e.g. filing, lending and reference areas a lower level of 300 lux is recommended.

10.4.4.1 1st Winter Visit (6.12.2011)

The daylight factor was estimated based on the outdoor lux reading of 5,200 lux taken at 13.30 pm. The lux level spot checks were done immediately the measurement of the outdoor light levels and followed by a walkthrough where internal temperature, %RH and CO_2 readings were taken within different spaces. At the end of the internal spot check activities the outdoor light conditions had radically changed to 265 lux. The survey took place with the artificial lights were switched off and the blinds drawn in most spaces except where the blinds were stuck in a down position. Occupants and staff expressed a feeling of gloom when the artificial lights were turned off, although some areas did not need the artificial lighting to achieve satisfactory levels. Daylight levels could not be measured in spaces which were artificially lit by PIR systems, since the override control could not be found.

In the building, wide variations in light levels (up to 750 lux) between the areas closest to windows and the interior areas in the same room were observed (Figure 117).

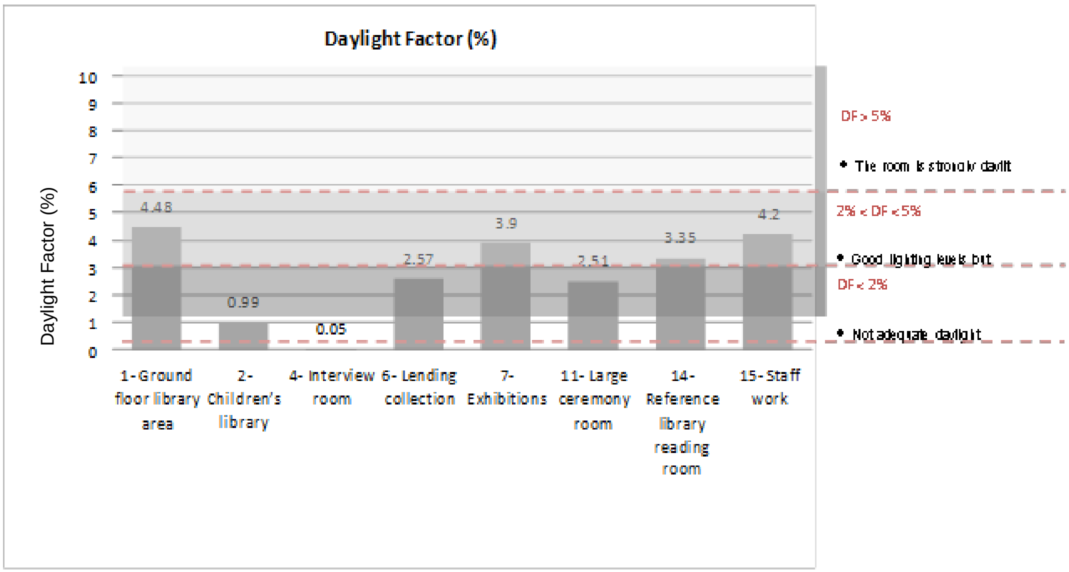


Figure 117 Illuminance level values in various spaces of the library during the spot check visit

Figure 118 Children's library space. Blinds are up but light levels decrease behind the book stalls.

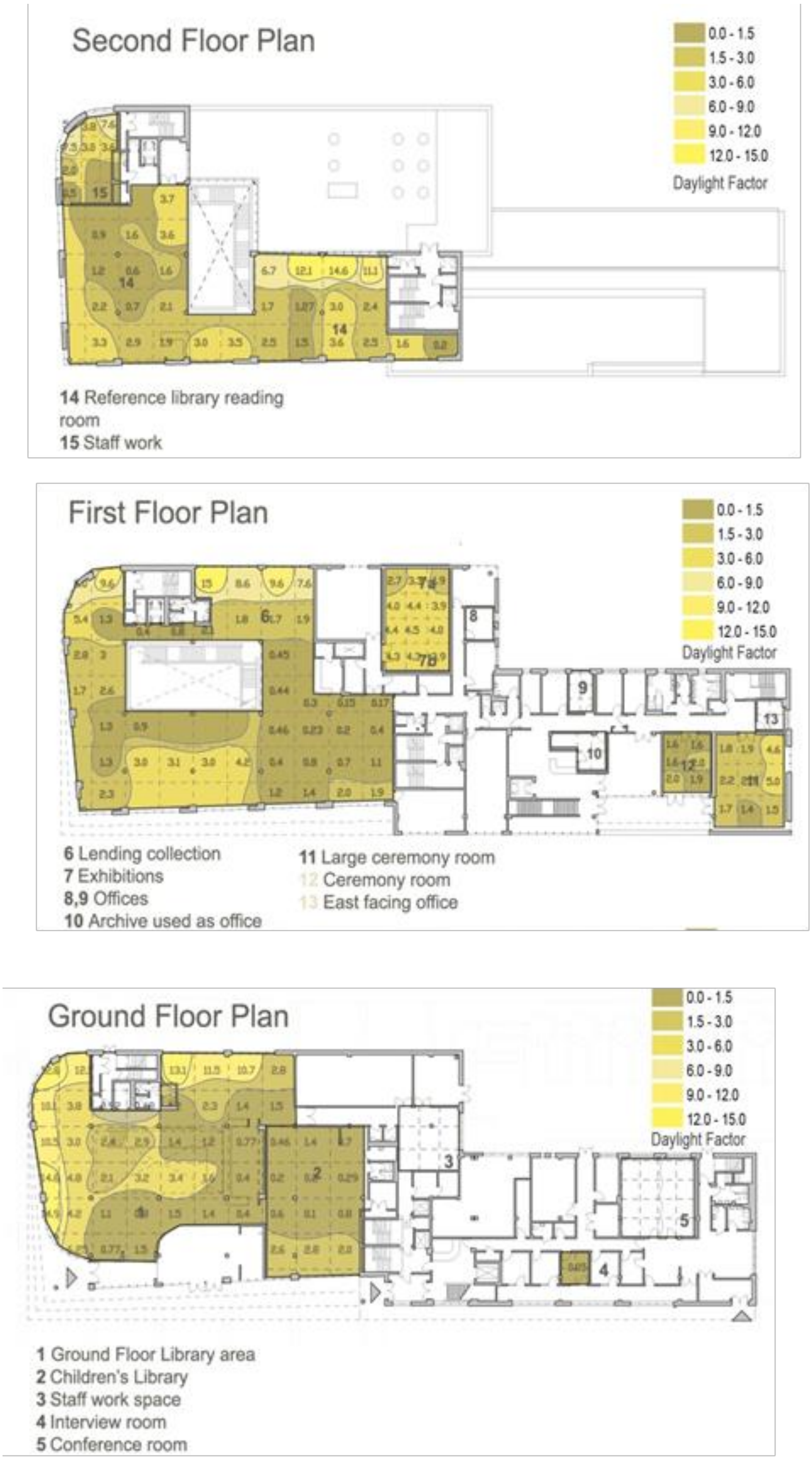


Figure 119 Floor plans with daylight factor levels during the spot check visit.

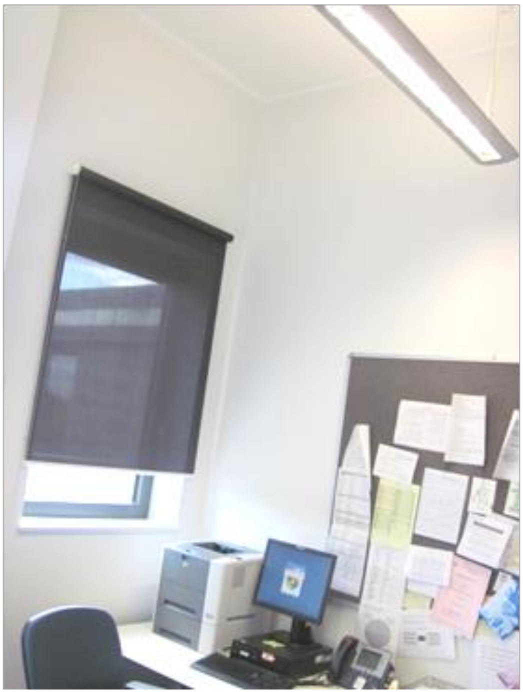


Figure 120 Left: Ground floor library view. Right: First floor office space. The office was found empty with the blinds down and the light is turned on.

Key findings

- The daylight factors inside the library and offices varied between 0.05 and 14.9%. The wide range of values has resulted in good average daylight factors for some spaces although the general daylight levels were mainly below the accepted standards.
- The ground floor reception area and children's library were found to have significantly low lux levels and required artificial lighting despite an exterior lux level of 5,200 lux. Daylight factors in the children's library are as low as 0.1 and the current furniture arrangement further decreases the amount of light reaching interior spaces.
- The interview room on the ground floor received almost no natural light in cloudy overcast conditions with a DF of 0.5%.
- Furniture arrangement around the GF lending collection reception area reduced the day lighting levels to 0.4-0.7%.
- Day lighting levels in the first floor exhibition space were uniform and bright due to the skylights on the ceiling. The average electric lighting level was 583 lux. The offices were found to have slightly low lighting levels but it was noted that the blinds were down and the electric lighting on.
- The staff work office on the second floor has good daylight levels. The low lighting levels are a result of large storage cabinets.
- Light controls were poor with little indication of the areas they controlled and their dimming functions; the second floor lighting can be controlled from the ground floor in contrast with the first floor which has the light controls on the same floor. Unlabelled controls were a source of confusion and many members of staff did not know the location of some light controls.

- Override controls for PIR lighting were not accessible.

Key recommendations

- Spaces closer to the windows need to have separate light controls, since the lighting levels are so varied within the space.

- There is a need for clear control annotation to avoid confusion and waste of energy.

10.4.5 Noise

The dBA measure is often used as an indicator of human subjective reactions to noise across the full range of frequencies audible to humans. This index is simple to measure using a sound level meter incorporating an A weighting network. 'A-weighted' sound pressure levels were measured to assess noise levels in the Crawley library. CIBSE Guide A provides a list of suggested maximum permissible background noise levels generated by building services installations for different spaces (41-46 dBA).

10.4.5.1 1st Summer Visit (8.08.2011)

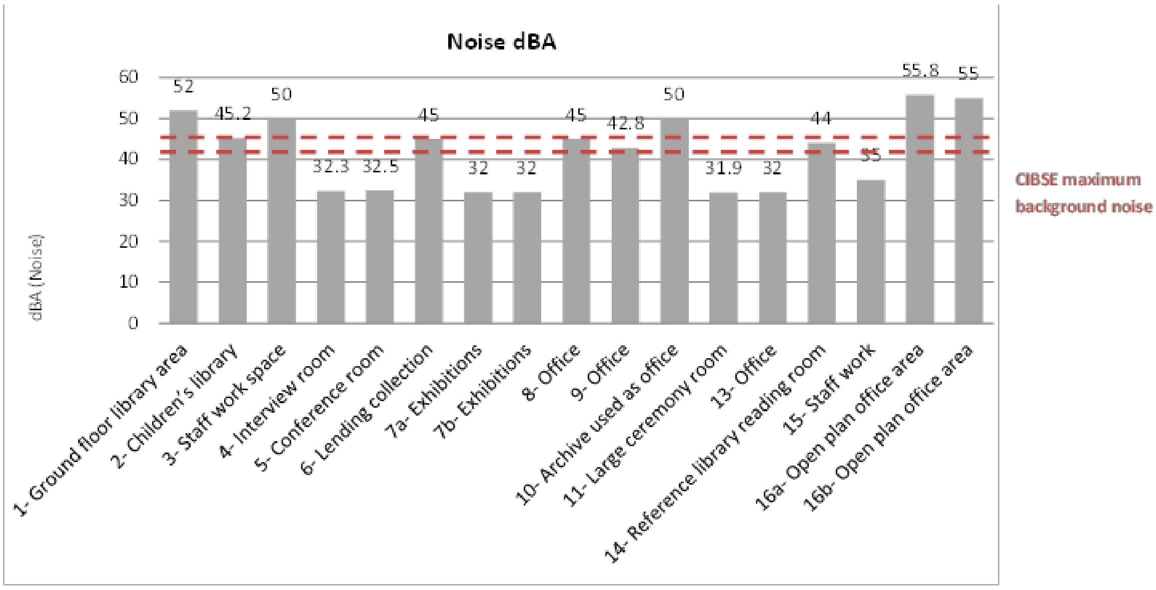


Figure 121 Noise level values in various spaces of the library during the spot check visit

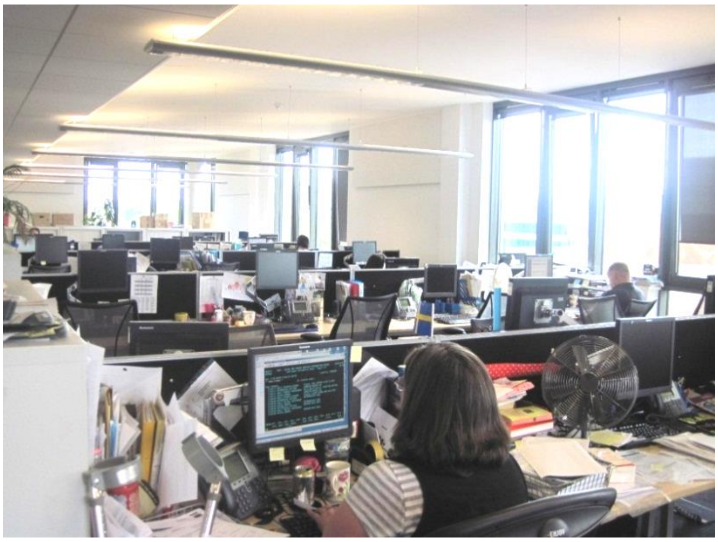


Figure 122 The open plan office on the top floor of the library.

Key findings

- The noise levels were slightly high in general throughout the most of the building spaces. It was noticed that the windows were open in most of the spaces and traffic noise contributed to the higher dBA levels.

- The highest dBA levels were recorded in the open plan office area. It should be noted that the offices were occupied when the measurements were taken.

10.4.5.2 1st Winter Visit (6.12.2011)

The high sound levels in the ground floor library, first floor offices and ceremony room, second floor reference room, third floor office could be attributed to the fact that the spaces were occupied during the spot check. All other measurements were taken in empty rooms.

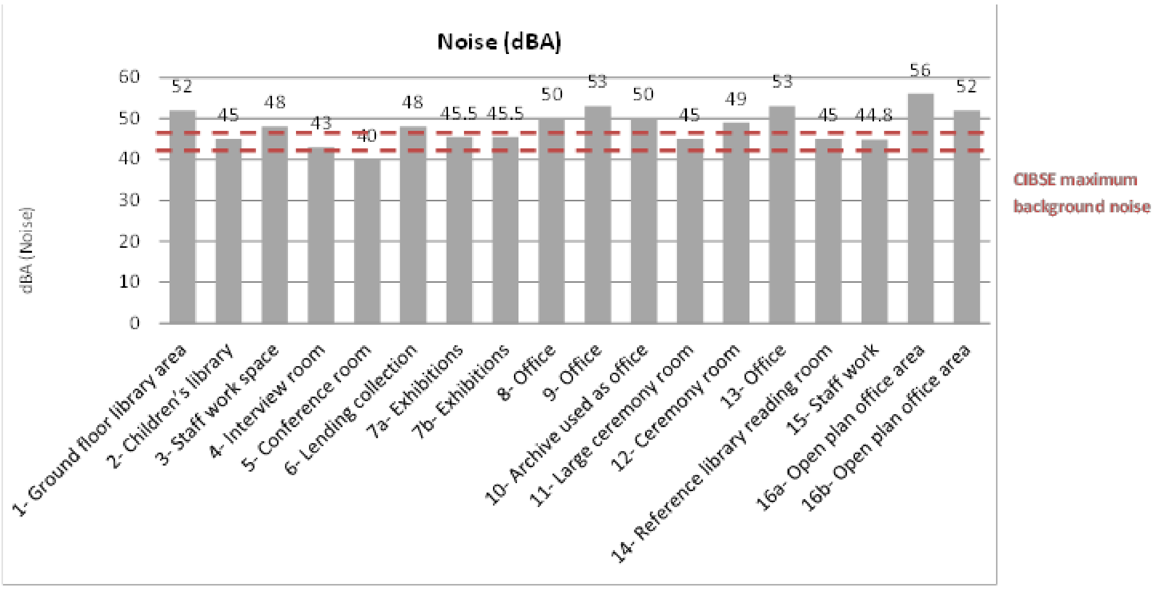


Figure 123 Noise level values in various spaces of the library during the spot check visit.

2nd Winter Visit (11.02.2013)

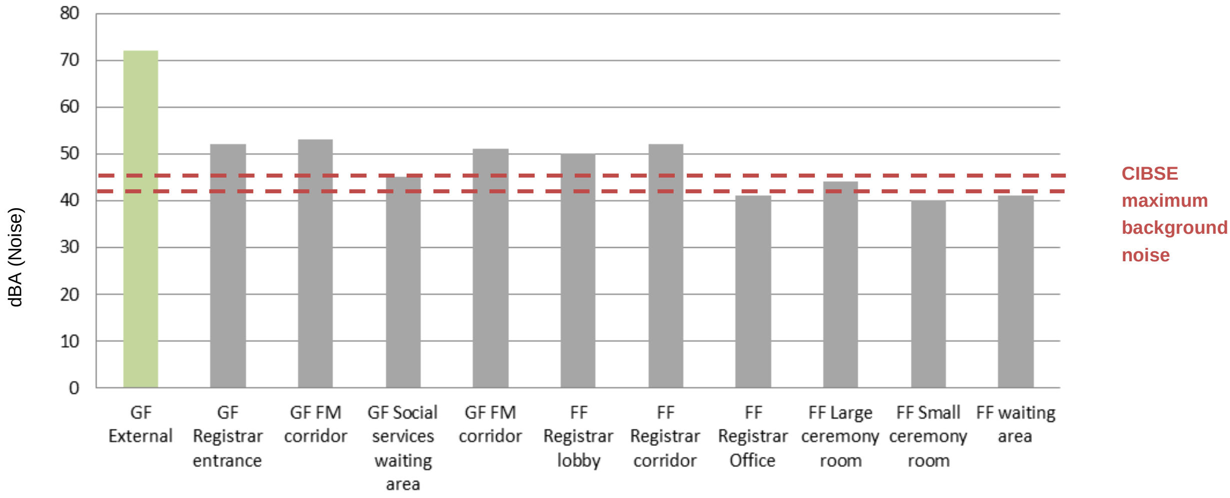


Figure 124 Noise level values in various spaces of the Registrar area during the 2nd winter spot check visit.

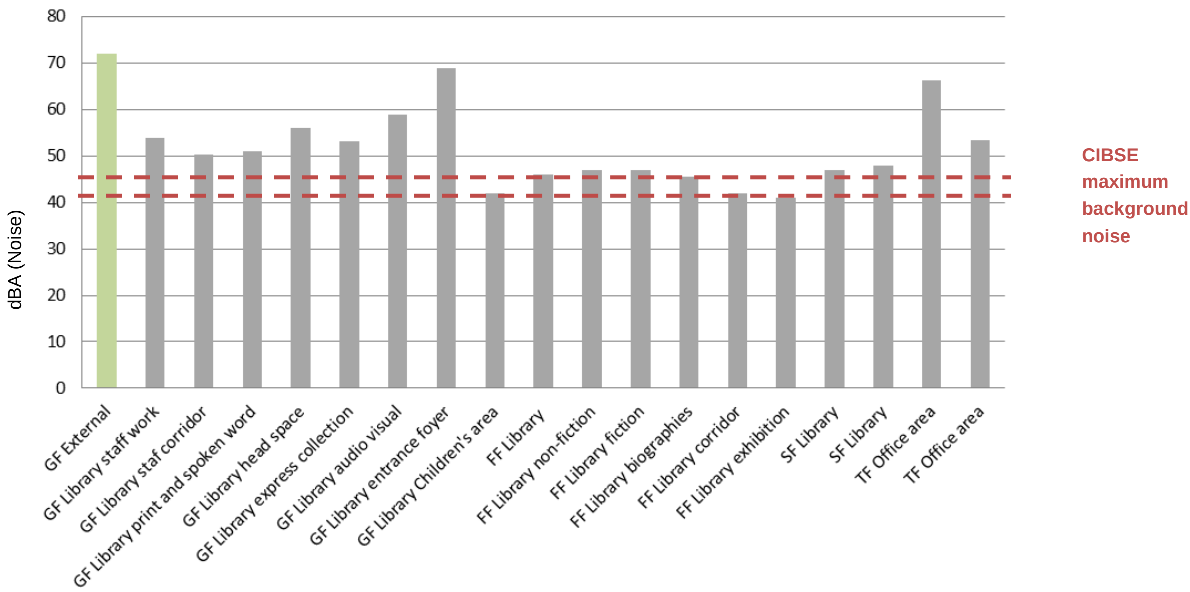


Figure 125 Noise level values in various spaces of the library during the 2nd winter spot check visit.

Key findings

- The noise levels were slightly elevated in some parts of the building although most windows were closed. External noise levels were around 65-70 dBA.
- During the first visit the highest dBA levels were recorded in the occupied open plan office area. The lowest measured value was 40dBA in the conference room due to the fact that the room was unoccupied and no other activity was taking place in surrounding rooms at the time of the spot measurement.

10.5 Thermographic survey

Thermography is a powerful tool that helps locate building defects such as missing insulation, delaminating render, condensation problems and 'see' the energy losses.

A thermographic survey was carried out in the Library building during the second spot check visit in the 6th December 2011 where a series of thermograms were taken in key parts of the building. The survey was undertaken in the evening (18.00) approximately one hour after sunset and the digital images shown are for reference purposes. The environmental conditions and building fabric properties were entered into the thermal imaging reporting software and the relevant corrections were made.

The equipment stated in Table 37 was used during the survey while the external environmental conditions are presented in Table 38.

Table 36 Infrared thermography equipment.

Manufacturer	***Model***	***Description***
FLIR	P640	640x480 pixel, 0.04K thermal resolution infrared camera set on Rainbow colour pallet

Table 37 Infrared thermography external environmental conditions.

Preceding hour (average)	
Parameter	**Measurement**
Internal temperature	21.1 ºC
External temperature	7.3 ºC
Wind speed	N/A
Precipitation	N/A

Since no additional findings (or anomalies) were revealed through a few repeated thermal images taken in November 2012, therefore only one set of detailed thermography data of 2011 is presented for the sake of clarity.

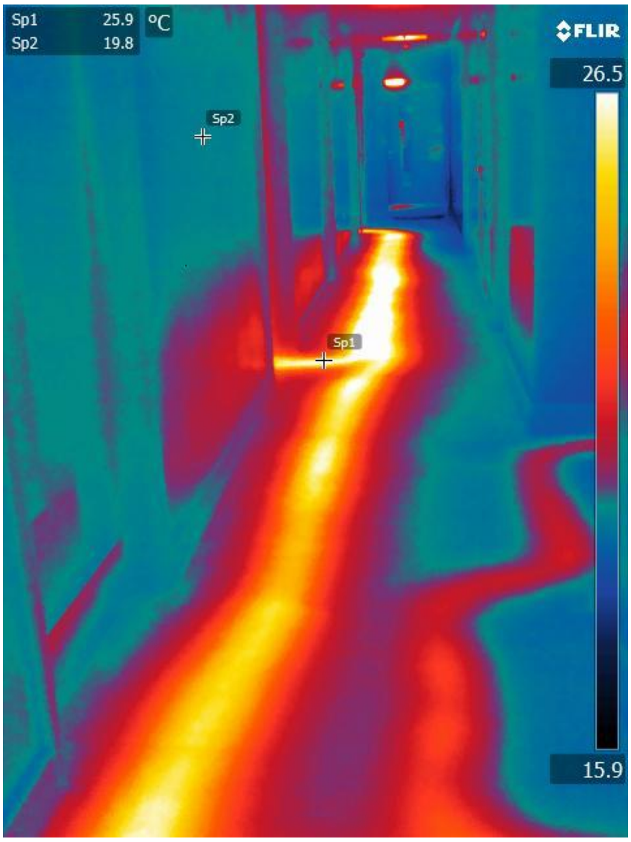
10.5.1 Survey summary

The thermograms revealed a limited number of abnormalities matching with the staff's comments relating to cold draughts and unheated spaces (more details are supplied against each image). Figure 127 shows underfloor heating being on in an unoccupied interview room. Without the infrared camera this observation would have remained unnoticed. Figure 128 reveals cold air draughts entering the small ceremony room, through the high level windows. The 'leaky' windows, in combination with the cooling being on, explain the lower room temperatures in comparison to the rest of the building spaces. Figure 129 and Figure 130 indicate similar conditions in the large ceremony room where cold bridging is also shown in the room corner possibly due to the geometry of space. Further problems included cold bridging due to material inconsistency or lack of insulation in the exhibition (Figure 132, Figure 133) and conference rooms (Figure 134) and generally poorly insulated window frames.

10.5.2 Thermograms and observations

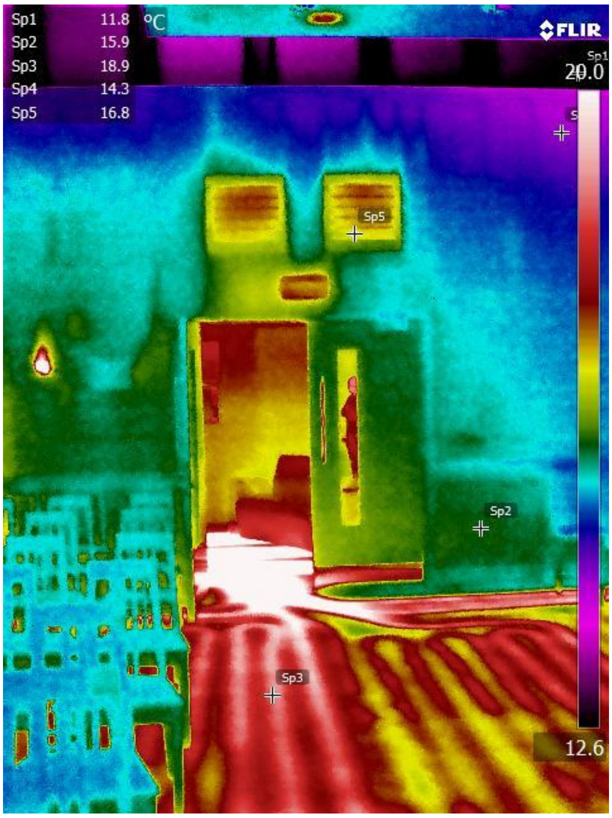
Thermograms revealing issues with key spaces are shown in this section along with the observation made.

Figure 126 **Building layout with thermogram photos locations and shooting angle.**



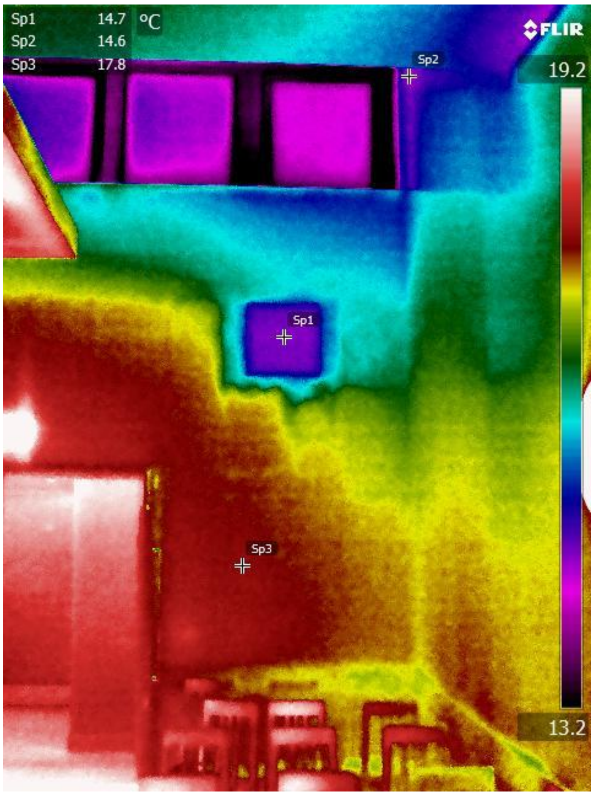
Measurements	ºC
Sp1	25.9
Sp2	19.8
Parameters	
Emissivity:	86
Refl. Apparent temp:	20 °C
Room temperature:	20.5 °C

Figure 127 Ground floor corridor thermogram. The picture shows clearly the underfloor main heating pipe branching into different directions. It leads towards an interview room although at the time the picture was taken the room was empty



Measurements	*ºC*
Sp1	11.8
Sp2	15.9
Sp3	18.9
Sp4	14.3
Sp5	16.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ^{o}C
Room temperature:	17 ^{o}C

Figure 128 Small ceremony room thermogram. Possibly the top left windows are leaky creating draughts since the temperature captured is very low (Sp1). A flow of cold air dropping from the windows can be noticed..



Measurements	*ºC*
Sp1	14.7
Sp2	14.6
Sp3	17.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ^{o}C
Room temperature:	17.5 ^{o}C

Figure 129 Large ceremony room thermogram. An irregular cold air fringe is dropping from the top windows indicating a cold bridge due to the geometrical elements or lack of insulation on that place. Cooling is on in as in the first ceremony without the rooms being occupied.

Measurements	***ºC***
Sp1	13.0
Sp2	14.6
Sp3	19.8
Parameters	
Emissivity:	0.95
Refl. Apparent temp:	20 ^{o}C
Room temperature:	17.5 ^{o}C

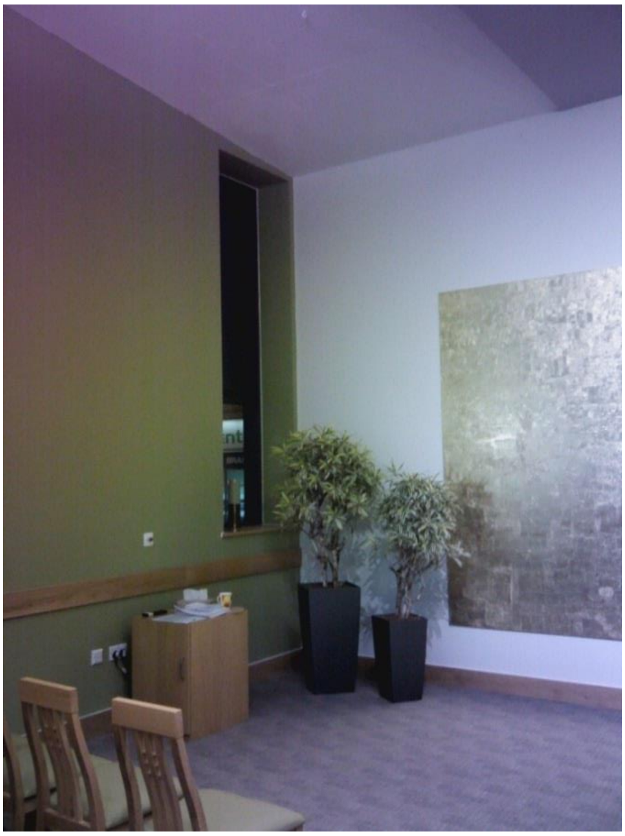
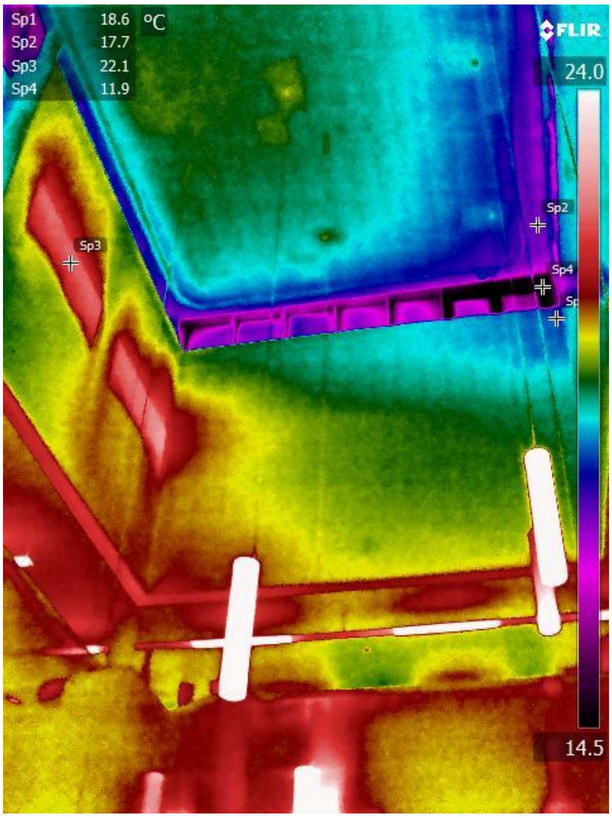
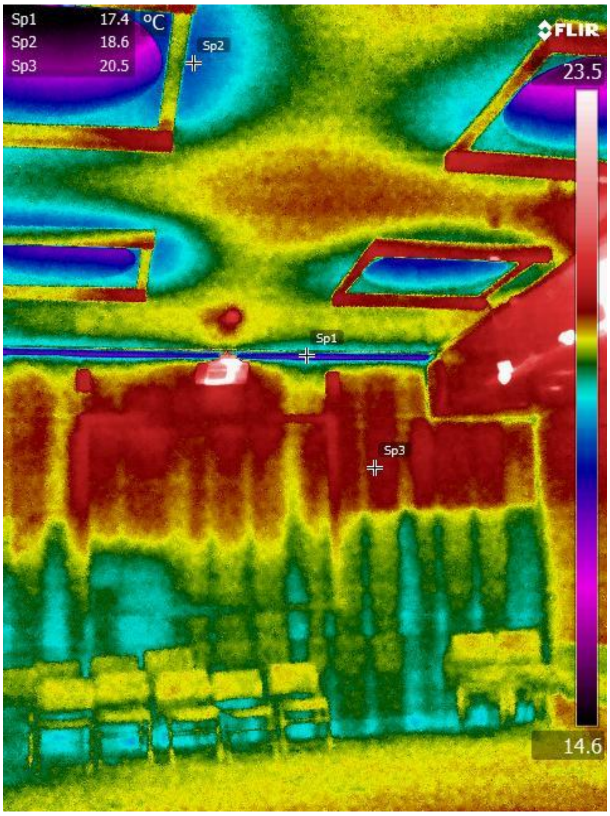


Figure 130 Large ceremony room thermogram. A cold bridge probably due to geometry of building elements can be identified in the room corner.



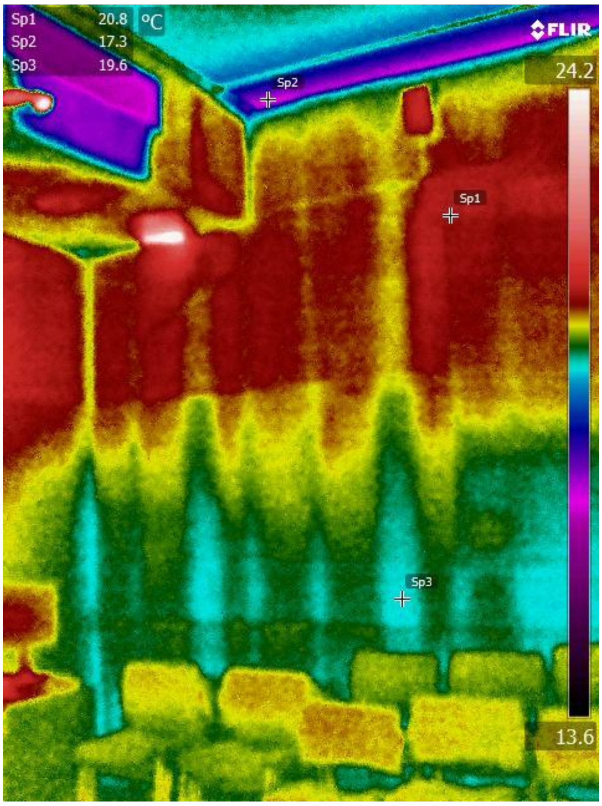
Measurements	ºC
Sp1	18.6
Sp2	17.7
Sp3	22.1
Sp4	11.9
Parameters	
Emissivity:	86
Refl. Apparent temp:	20 °C
Room temperature:	21.1 °C

Figure 131 Library atrium thermogram. Cold air dropping from the corner windows indicate air leakage and droughts. The lower temperature of the roof compared to other parts also indicates that perhaps it is not insulated



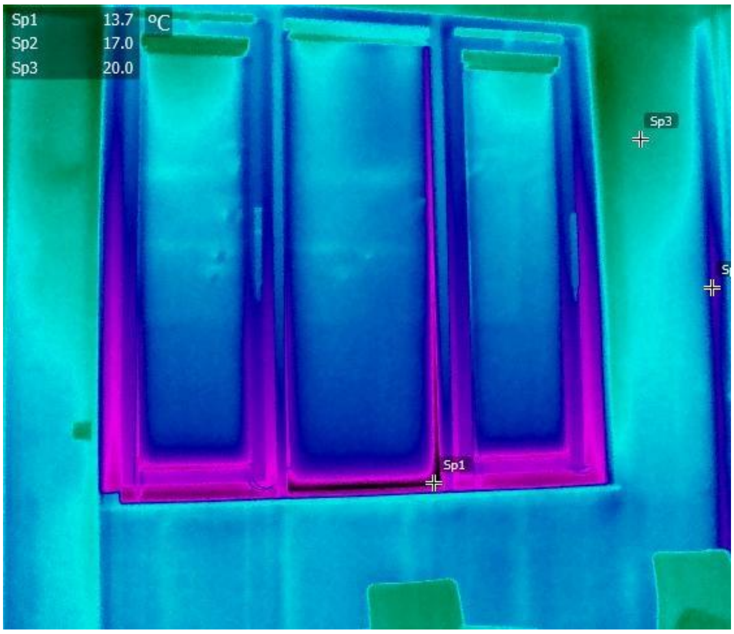
Measurements	*ºC*
Sp1	17.4
Sp2	18.6
Sp3	20.5
Parameters	
Emissivity:	0.86
Refl. Apparent temp:	20 °C
Room temperature:	20.7 °C

Figure 132 Exhibition space thermogram. Cold air draughts can be noticed around the skylights. A cold line in the connection between the ceiling and wall indicates missing insulation or a construction deficiency



Measurements	*ºC*
Sp1	20.8
Sp2	17.3
Sp3	19.6
Parameters	
Emissivity:	0.86
Refl. Apparent temp:	20 °C
Room temperature:	20.7 °C

Figure 133 Exhibition room thermogram. The cold bridge on the junction of wall and ceiling is obvious indicating material inconsistency on that part of the roof. Cooling is also on in the room with cold air blowing through the ventilation grilles.



Measurements	***ºC***
Sp1	13.7
Sp2	17.0
Sp3	20.0
Parameters	
Emissivity:	0.86
Refl. Apparent temp:	20 ^{o}C
Room temperature:	21.1 ^{o}C

Figure 134 Conference room thermogram. The dark area at the bottom of the middle window indicates that the frame is not very well sealed at that point. A vertical cold bridge can be also identified in the right room corner partly due to geometry and perhaps due to loss/gaps on the insulation continuity.

Key findings

- Thermograms revealed heating and cooling being on in unoccupied spaces (e.g. interview spaces, ceremony room). This shows poor control of heating and cooling system leading to unintended energy losses.
- Clerestory windows in the atrium, windows of both ceremony rooms and conference room appear to not be properly sealed, which can lead to cold air draughts entering the building.
- The exhibition space, conference room and ceremony room were found to have cold bridges possibly due to discontinuous insulation/material.

Recommendations

- Thermal bridging due to geometry or insulation/material inconsistencies needs to be discussed with the project architects to further indicate the causes and identify the actions that may need to be taken in order to minimise this effect.
- Facilities management need to have better control of heating and cooling over unoccupied spaces especially the two ceremony rooms. Staff should also be incentivised to turn off the heating when they plan to leave a room.

10.6 Measure key equipment energy consumption using true power meters

The key equipment's energy consumption was established by a walkthrough inside the library in order to spot and measure the energy consumption of the different office equipment devices and the data analysis using one of the aspects of CIBSE TM22:2011 tool (Figure 135).

A list was compiled according to the available information through the PVQ and updated with on-site observations noted during the walkthrough. The energy use of running appliances was calculated using a portable power meter (Figure 136). The operation schedule of each device was defined and the data were entered in the CIBSE TM22:2011 tool. The analysis did not take into account electrical loads caused by end use categories other than small power (e.g. lighting, cooling, pumps, controls, vertical transport, etc.) due to the lack of sub-metering data.

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 137).

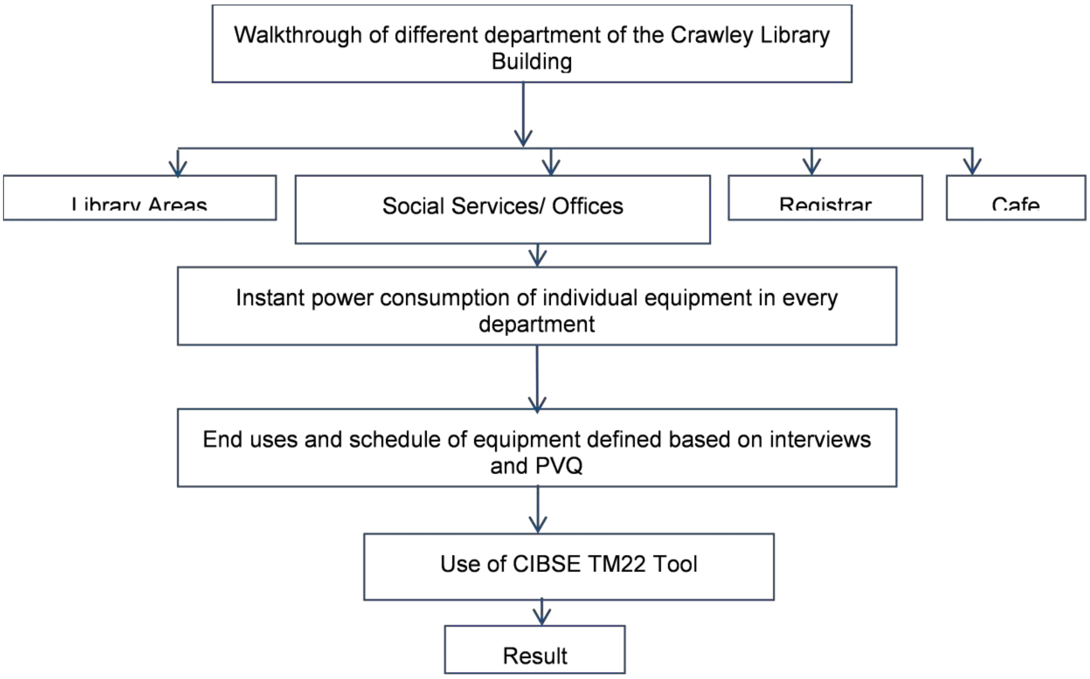
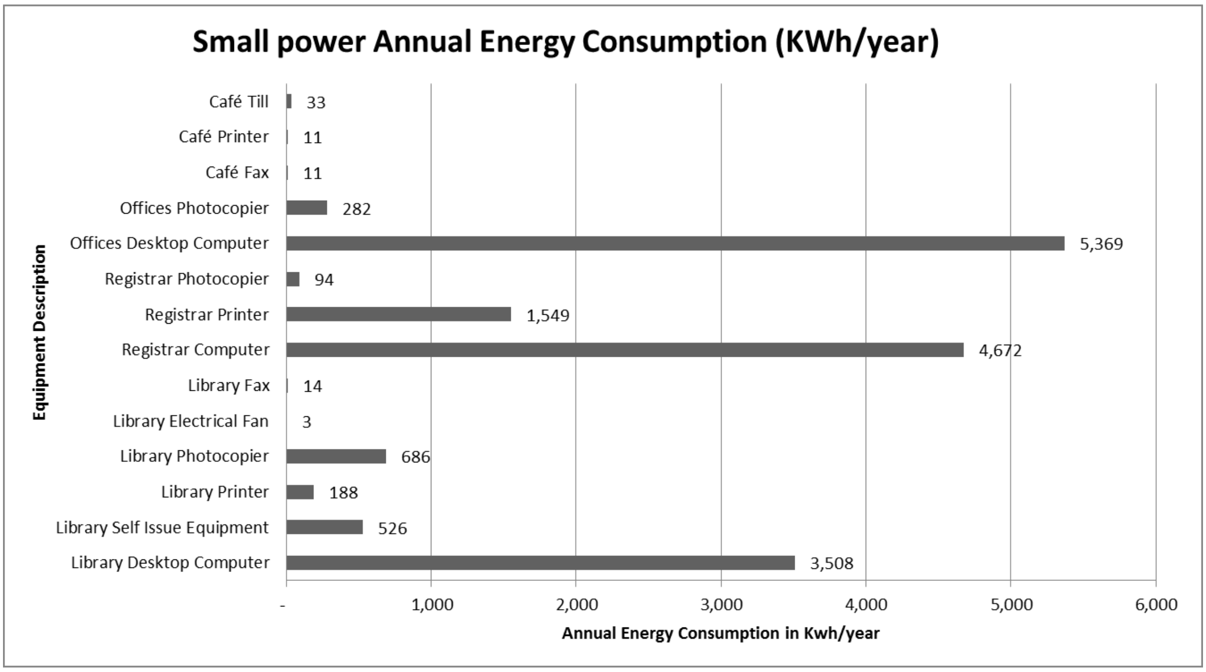


Figure 135 Calculation of key equipment's' energy consumption schematic.

Figure 136 Measure of key equipments' energy consumption using true power meters.

Description - plant item or group of plant items	kW rating (from schedule)	Profile Number	Select Profile	Profile annual hours	Usage Factor	Load Factor	Winter	Summer	Spring / Autumn	Equivalent full load hours	Full load operating kW	Energy consumption kWh/year
Library Desktop Computer	9.0	5	M-F 8-6 part weekend	3,129	0.50	0.25	1.00	1.00	1.00	391	2.2	3,508
Library Self Issue Equipment	0.4	1	24h flat 100%	8,760	0.60	0.25	1.00	1.00	1.00	1,314	0.1	526
Library Printer	0.6	5	M-F 8-6 part weekend	3,129	0.50	0.20	1.00	1.00	1.00	313	0.1	188
Library Photocopier	2.7	5	M-F 8-6 part weekend	3,129	0.40	0.20	1.00	1.00	1.00	250	0.5	686
Library Laminator	0.4	4	Monday - Friday 8 to 6	2,607	0.00	0.30	0.50	0.50	0.50	-	0.1	-
Library Electrical Fan	0.1	8	Monday to Friday3-4 hours	1,043	0.80	0.25	0.00	1.00	0.00	63	0.0	3
Library Fax	0.1	1	24h flat 100%	8,760	0.25	0.25	0.25	0.25	0.25	137	0.0	14
Registrar Computer	11.2	4	Monday - Friday 8 to 6	2,607	0.80	0.20	1.00	1.00	1.00	417	2.2	4,672
Registrar Printer	6.6	4	Monday - Friday 8 to 6	2,607	0.50	0.18	1.00	1.00	1.00	235	1.2	1,549
Registrar Photocopier	0.7	4	Monday - Friday 8 to 6	2,607	0.25	0.20	1.00	1.00	1.00	130	0.1	94
Offices Desktop Computer	12.9	4	Monday - Friday 8 to 6	2,607	0.80	0.20	1.00	1.00	1.00	417	2.6	5,369
Offices Photocopier	2.2	4	Monday - Friday 8 to 6	2,607	0.25	0.20	1.00	1.00	1.00	130	0.4	282
Café Fax	0.1	1	24h flat 100%	8,760	0.25	0.20	0.25	0.25	0.25	110	0.0	11
Café Printer	0.1	4	Monday - Friday 8 to 6	2,607	0.25	0.17	1.00	1.00	1.00	111	0.0	11
Café Till	0.1	4	Monday - Friday 8 to 6	2,607	0.80	0.20	1.00	1.00	1.00	417	0.0	33

Figure 137 Calculation of annual energy consumption for small power equipment using CIBSE TM22:2011 tool.



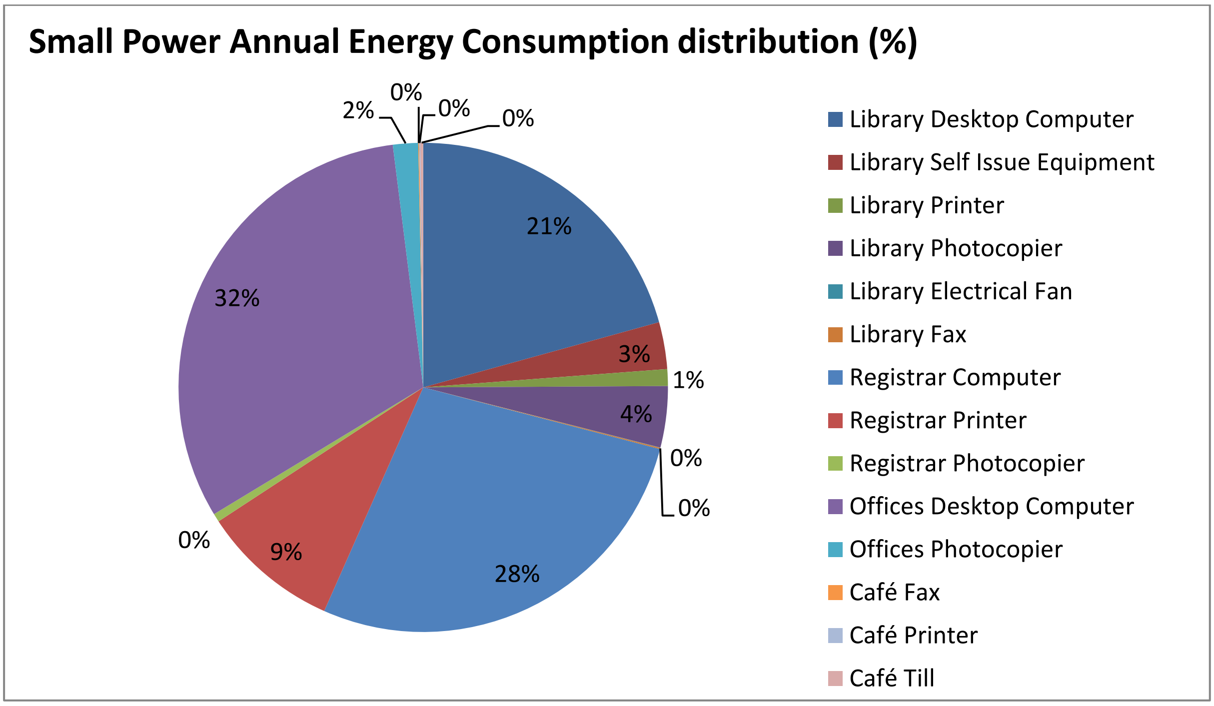


Figure 138 Small power annual energy consumption breakdown in all library spaces.

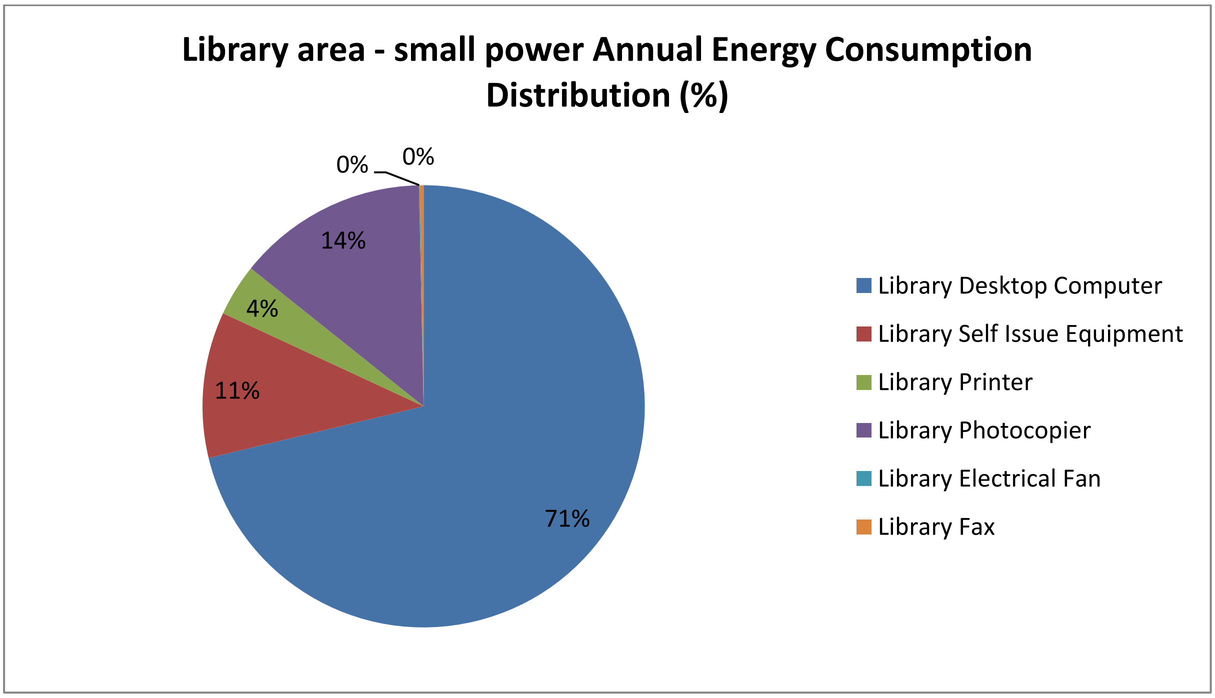


Figure 139 Small power annual energy consumption distribution in Library area.

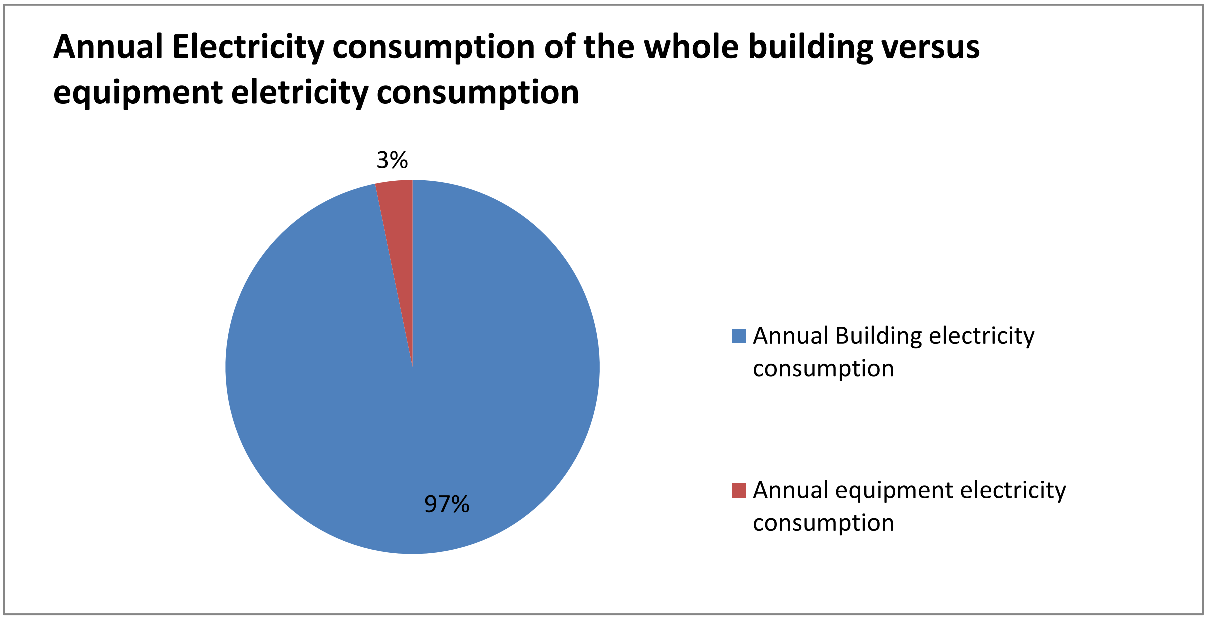


Figure 140 Small power annual energy consumption versus the total electricity consumption of the building.

Key findings

- The desktop computers in the Library department were found to consume the largest amount of electricity load followed by the computers in Register services.
- Annual electricity consumption of key equipment contributes to 3% of the total Building electricity consumption when compared with the total annual electricity consumption data of the previous year available from energy bills.
- The lighting and cooling electricity loads were unavailable due to lack of sub-metering data.

10.7 Review of controls

10.7.1 Heating and hot water controls

The heating and hot water controls are located in the externally accessible plant room. Both the heating and hot water use the biomass boiler, along with the backup gas boiler. The biomass boiler controls panel is not clearly labelled; the control is quite complex and can only to be programmed and operated by experts. The operation manual is located next to the control panel, however, the facilities manager of the building is not very familiar with the control panel. Faults appear quite often and as such, the biomass boiler needs frequent maintenance. The biomass and gas boilers are also connected to the BMS system. The gas boiler control panel is located at the side of the gas boiler but is not easily physically accessible as the space is quite narrow. The control is not intuitive to use and the labelling is written in German. The operation manual of the gas boiler is located near to the control panel.

10.7.1.1 Biomass and Gas boiler heating

Gas boiler controls

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

The control is located on the side of the gas boiler in the externally accessible plant room. However, the control is not easily accessible as the space is quite narrow. The control is not intuitive to use and labelling is written in German. Operation manual of the gas boiler was located nearby.

Biomass boiler control panel

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

The biomass boiler control panel is located in the externally accessible plant room. The purpose of the panel is not immediately obvious as there is no clear labelling of what it is. User manual can be found on the lid of the panel. The control is quite complex and only to be programmed and operated by experts. The facilities manager of the building is not very familiar with the control panel. Faults appear quite often as the biomass boiler needs frequent maintenance. The biomass boiler is also connected to the BMS system.

Individual thermostats for BMS system (TREND)

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

TREND thermostats can be found in some spaces. Their purpose is not clear at all and there is no indication of what the rotary button controls. It is not clear what the control is used for and whether the user is allowed to modify it or not. There is no indication of system response.

Heating room thermostats (in meeting rooms)

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

Comments

Individual thermostats can be found in the meeting rooms of the Register Services area. They are located next to the room door and are easy and intuitive to use. They are clearly labelled with a '°C'. Indication of system response is provided by a clicking sound.

10.7.2 BMS system controls

The BMS system controls the heating, cooling and hot water of the building. The BMS control panel is located in the externally accessible plant room. It is clearly labelled and provides warning of any faults of the system. A touch screen control is connected to the BMS software. However, the panel can only be programmed and operated by experts and the facilities manager is not qualified to operate the BMS system. The trend logging facility is installed in the computer of the facilities manager. Although its purpose is clear, the manager is not familiar with it and does not know how to use it. It appears that the BMS system is not properly connected to the sub-meters. The facilities manager has not received training in the operation of the logging facility. It should be noted that the BMS system is working, although it has not been properly commissioned. The computers that have access to the BMS logging facility are located in the facilities manager office and are easily accessible.

BMS control panel

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

Comments

The BMS control panel is located in the externally accessible plant room. Each switch is clearly labelled. Manual or automatic mode to operate the gas and biomass boilers. Faults are indicated on the panel. A touch screen control is connected to the BMS software. The panel can only be programmed and operated by experts. The facilities manager is not qualified to operate the BMS system.

Trend logging facility (BMS software)

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

Although the purpose of the trend logging facility is clear, occupants are not familiar with it and do not know how to use it. It appears that the BMS system is not properly connected to the sub-meters. The facilities manager is not qualified to operate the logging facility and has not received training. It should be noted that the BMS system is working though it has not been properly commissioned. The computers that have access to the BMS logging facility are located in the facilities manager office and are easily accessible.

10.7.3 Solar thermal & chiller controls

The solar thermal and chiller controls are located on the rooftop of the Library area. These controls are, again, only meant to be used by experts but facilities manager is not very familiar with them. The solar thermal control is complex and its purpose is not clearly labelled. The main board that controls the chilled water primary and secondary pumps is clearly labelled and switches are easy and intuitive to use. This control can only be operated by the facilities manager. Any system faults are indicated on the board.

Solar thermal control

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

The solar thermal control is located at the rooftop of the Library area. Its purpose is not clearly labeled and the control is complex, meant to be used by expert facilities managers. There is no direct indication of system response. Additional labeling would be useful.

Chilled water pumps_ main board

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

The main board that controls the chilled water primary and secondary pumps is located at the rooftop of the Library area. The board is clearly labelled and switches are easy and intuitive to use. This control can only be operated by the facilities manager. Any system faults are indicated on the board.

10.7.4 Electrical equipment controls

The electricity mains meter is not clearly labelled and is located on the ground floor of the Register Services area. The purpose of the distribution boards is clear; with good labelling and the switches are intuitive and easy to use. Most boards are located on the ground floor of the Register Services area, next to the facilities manager office. The purpose of the sub-meters is clear but it is not clear what each sub-meter is connected to. Existing labelling is not good enough as it uses codes to indicate what each sub-meter is measuring without providing information what these codes actually stand for.

10.7.4.1 Electricity mains, boards and sub-meters

Electricity mains meter

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

The purpose of the electricity main meter is not very clear. The user needs to know its purpose as there is no clear labelling or annotation to explain what it is. There is no user interface as the meter should not be tampered with. It is located in the ground floor of the Register Services area, next to the facilities manager office.

Lighting distribution boards (External lights & timer)

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

The purpose of the board is clear. Labelling is good and the switches are intuitive and easy to use. The board is located on the ground floor of the Register Services area, next to the facilities manager office.

Electrical sub-meters _ Switches

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

Their purpose is clear but it is not clear what each sub-meter is connected to. Existing labelling is not good enough as it uses codes to indicate what each sub-meter is measuring without providing information what these codes actually stand for. Sub-meters are easily accessible in the ground floor of the registrar area next to the facilities manager office.

Electrical sub-meter displays

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

Their purpose is clear but the user interface is complex and only meant to be used by experts. They are located in the ground floor of the registrar area next to the facilities manager office. Instructions are needed in order to operate the control.

10.7.5 Lighting controls and switches

In most areas, the light controls are intuitive and easy to use. Different lighting strategies are used in different parts of the building. The Library areas have a combination of PIR sensors and manually operable light switches. The Register Services areas are mostly controlled by PIR sensors and some office and meeting rooms have switches operated by individual users. In some areas, lights are dimmable but this option does not appear obvious to the user. Electric switches are intuitive and easy to use in most areas. In office spaces, switches are conveniently placed at desk height. In the Library, switches are placed inside boxes on the floor. The lid of the box can be hard to open.

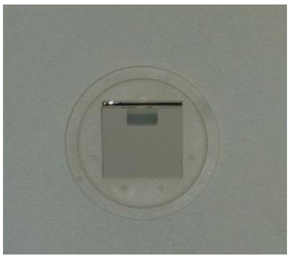
Lights in Library area

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

Three switches located in the receptionist area control the Library, Entrance and Atrium lights respectively. These are switched on by members of staff in the morning and are switched off after the Library closes in the afternoon. They are easily accessible, easy and intuitive to use.

Lights and controls_ PIR



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

PIR controls can be found in most Library and Office areas to complement the manually controlled lights. They offer a good degree of fine control. They do not have a user interface as they are automatic.

Sockets on floor

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

Comments

In the Library area sockets are hidden in various points in the floor. This is not immediately clear to visitors. The switches are easy and intuitive to use but the lid is not easy to open.

10.7.6 Water services controls

Hand basin taps and kitchen taps are clearly labelled and easy to use. Despite this, the hand basin taps do not appear to have a high degree of fine control as their flow is set and they are not mixing taps. The mains water isolation valve is located in the plant room and it is clearly labelled but it is not very accessible. A sophisticated water leak detection system is installed in the building. Whilst the control of this system is not very intuitive, it is well labelled and provides visual warnings of any leakages.

Mains water isolation valve

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

Comments

Mains water isolation is located in the externally accessible plant room. However, it is not easily accessible as various pipes are placed in front of it. Its purpose is clear thanks to a label placed on the valve.

Water leak detection system control

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

The water leak detection system control is located in the externally accessible plant room. It is easily accessible as it is situated next to the door. The control interface is labelled but extra information is needed in order to set it up. Lights indicate whether the system is operating well or if a leakage has been detected.

Sanitation – Bathroom taps

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

Bathroom hand taps do not provide a high degree of fine control as there is not a mixing valve. Switching is intuitive. Hot and cold water are clearly indicated. The time the tap runs and the flow are set per push. This helps in reducing excessive water use.

10.7.7 Fire and security alarm

The fire and security alarm systems controls are of high quality. Smoke detectors, emergency call points, fire alarm points are placed in various points throughout the building. The controls are easy and intuitive to use and, in most cases, are accompanied by a set of instructions. The fire alarm panel is quite complicated and can only to be used by experienced users/facilities managers.

Emergency call point

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

Emergency call points are placed throughout the building and are easily accessible. They are well labelled and easy to use. Clear instructions are placed next to each call point informing visitors on how to use them in case of an emergency.

Smoke detectors

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

Smoke detectors are installed throughout the building in all areas. A small light indicates that each of them is working properly. Their purpose is quite clear even though there is no labelling indicating their use.

Fire alarm panel

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

Its purpose is clear thanks to the good labelling and annotation. System is easily accessible at various points throughout the Library and the Register Services areas. The control appears quite complicated and users need to read instructions. Labelling is useful. These controls are to be used by experienced users/facilities managers.

10.7.8 Doors and windows

The controls for the main entrance automatic doors are poorly labelled and not intuitive to use. Mechanically operated windows are located in the main office areas and in the Library areas; they do not appear easy to use and are not very intuitive. Users report that the controls break down quite often and that they struggle to use the key. There is not a high level of fine control; one control is used for many windows or entire areas limiting the choice of users. Manually operated windows can be found in some spaces; these appear easy and intuitive to use but can only be opened partially.

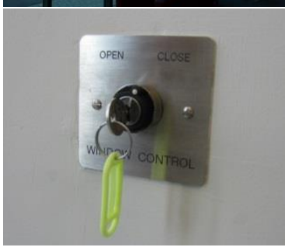
Main entrance automatic doors

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

Comments

These controls are located next to each of the main entrance automatic doors (three in total). Their purpose is not clear at all and user needs to be experienced in order to use them. They are poorly labelled and not very easy to use. User needs to be shown how to operate them. Additional instructions would be useful. They offer several modes to operate the automatic doors providing a good level of fine control.

Windows mechanically controlled



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

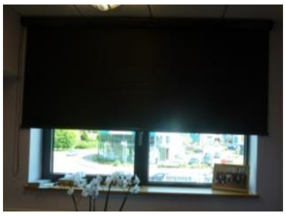
Comments

Mechanically opened windows are located in the main office areas and in the Library areas. They are not easy to use and not very intuitive. Users reported that the controls break down quite often and that they struggle to use the key. No high level of fine control as one control is used for many windows or entire areas limiting the choice of users.

10.7.9 Shading devices

Blinds offer a good degree of fine control over shading and are easy to use and intuitive. In the Library exhibition area, the blinds are operated by a remote control. The portable remote control unit operates all the blinds at once but different blind positions can be achieved for different windows. There is no fixed place for the remote control unit, which can cause issues as different users may store it in a variety of locations. The fact that there is no indication of what the remote unit controls, on the unit itself, can also hinder operations.

Offices and meeting rooms blinds



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

Comments

Blinds are effective and easy to operate. They were found to be accessible in most spaces. There is no labelling or annotation but they are intuitive.

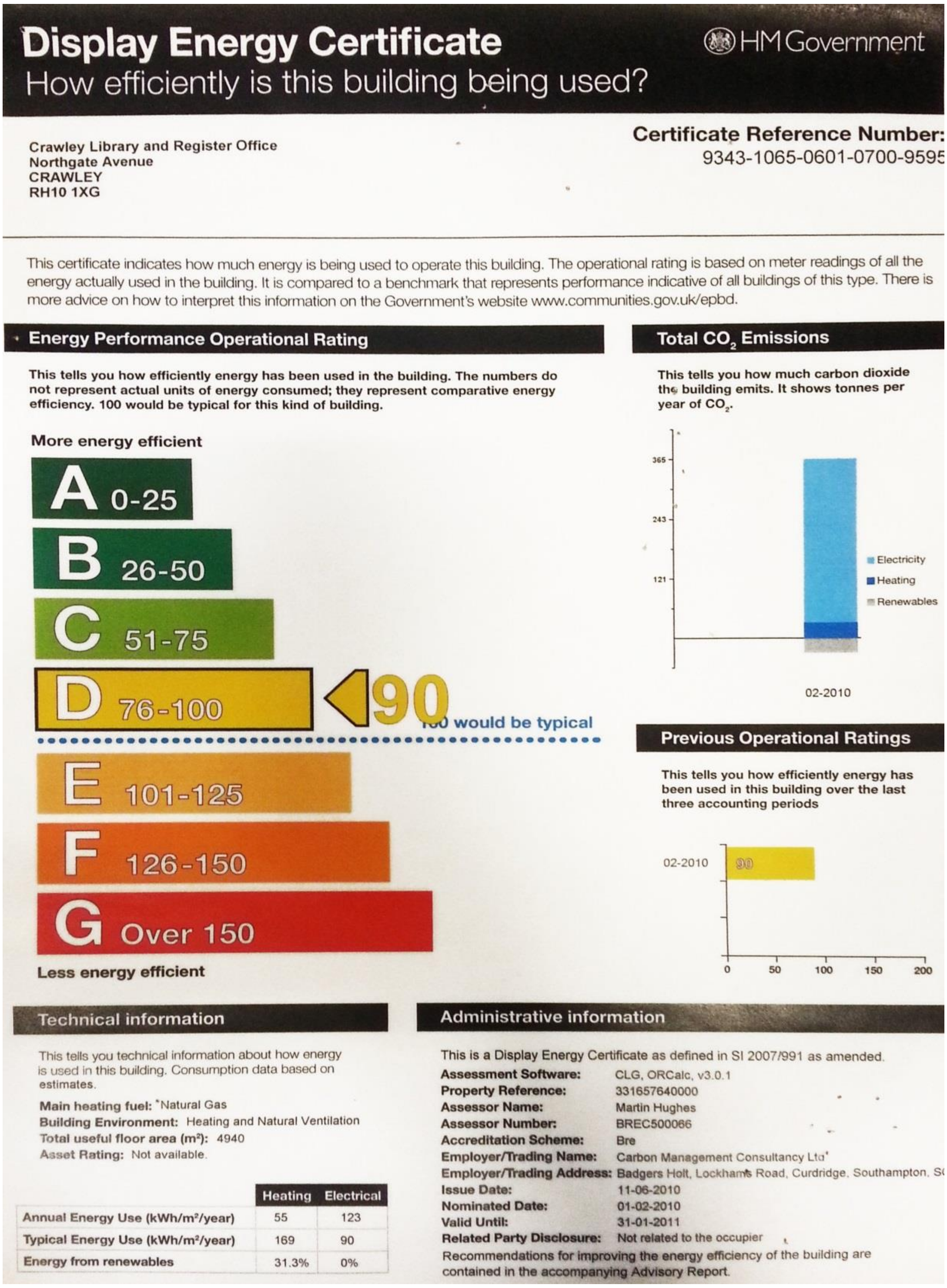
Roof light blinds

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

Comments

The roof lights are operated by a remote control. The remote operates all the blinds at once but different blind positions can be achieved for different windows. There is no fixed place for the remote so it might be hard to find in the room if previous user hides it away. Additionally, the purpose of the remote is not clear as there is no indication on it that it is for operating the blinds. As a result users might think that they cannot open/close the blinds.

10.9 Display Energy Certificate



Display Energy Certificate

How efficiently is this building being used?

HM Government

Crawley Library and Register Office
Northgate Avenue
CRAWLEY
RH10 1XG

Certificate Reference Number:
9343-1065-0601-0700-9595

This certificate indicates how much energy is being used to operate this building. The operational rating is based on meter readings of all the energy actually used in the building. It is compared to a benchmark that represents performance indicative of all buildings of this type. There is more advice on how to interpret this information on the Government's website www.communities.gov.uk/epbd.

Energy Performance Operational Rating

This tells you how efficiently energy has been used in the building. The numbers do not represent actual units of energy consumed; they represent comparative energy efficiency. 100 would be typical for this kind of building.

Total CO_2 Emissions

This tells you how much carbon dioxide the building emits. It shows tonnes per year of CO_2.

Previous Operational Ratings

This tells you how efficiently energy has been used in this building over the last three accounting periods

Technical information

This tells you technical information about how energy is used in this building. Consumption data based on estimates.

Main heating fuel: Natural Gas
Building Environment: Heating and Natural Ventilation
Total useful floor area (m²): 4940
Asset Rating: Not available.

	Heating	Electrical
Annual Energy Use (kWh/m²/year)	55	123
Typical Energy Use (kWh/m²/year)	169	90
Energy from renewables	31.3%	0%

Administrative information

This is a Display Energy Certificate as defined in SI 2007/991 as amended.

Assessment Software: CLG, ORCalc, v3.0.1
Property Reference: 331657640000
Assessor Name: Martin Hughes
Assessor Number: BREC500066
Accreditation Scheme: Bre
Employer/Trading Name: Carbon Management Consultancy Ltd
Employer/Trading Address: Badgers Holt, Lockhams Road, Curdridge, Southampton, S
Issue Date: 11-06-2010
Nominated Date: 01-02-2010
Valid Until: 31-01-2011
Related Party Disclosure: Not related to the occupier

Recommendations for improving the energy efficiency of the building are contained in the accompanying Advisory Report.