# Greenfields Community Housing Headquarters

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|---|---|
| **Innovate UK project number** | 450007 |
| **Project lead and author** | Studio Partington |
| **Report date** | 2014 |
| **InnovateUK Evaluator** | Tom Kordel (Contact via www.bpe-specialists.org.uk) |

| **Building sector** | **Location** | **Form of contract** | **Opened** |
|---|---|---|---|
| Office | Braintree | Traditional (2-stage) | 2009 |
| **Floor area (GIA)** | **Storeys** | **EPC / DEC** | **BREEAM rating** |
| 2180 $m^2$ | 3 | B / N/A | Very good |

**Purpose of evaluation**

The BPE study was carried out in order to determine actual performance compared to its design intention, evaluating specific individual components as well as the integration of the system as a whole. It also looked at the experience of the people interacting with the building, both the staff and the facilities manager responsible for the operation of the building and its services.

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

The building is all-electric, using a ground-source heat pump(GSHP) for heating. Electricity consumption for power and heating was estimated at 192.6 kWh/m² per annum. The energy consumption and carbon dioxide emissions were higher than intended at design stage. Some energy was was attributed to a lack of optimisation the services, such as electric lighting and circulating pumps left on out of hours, while others were the result of changes made after the building was occupied. The sub-meters did not have a pulsed output (contrary to the specification), and therefore current transformer clamps were installed on the sub-meters. These problems prevented the disaggregation of GSHP electrical energy for heating and cooling.

| **Occupant survey** | **Survey sample** | **Response rate** |
|---|---|---|
| BUS, paper-based | 100 | 89% |

Surveys and interviews with staff revealed some dissatisfaction with the internal conditions of the open-plan offices. The survey also revealed a lack of understanding among staff on how to use features within their control as opposed to those the BMS controlled. The low-level windows were intended to be controlled by the staff in the open-plan offices, however there appeared to be confusion about how their use affected the effectiveness of the high-level hoppers that were controlled by the BMS in very warm weather and for night purge ventilation.

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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.**

# Executive Summary


The Greenfields Community Housing (GCH) Headquarters building in Braintree, Essex is a bespoke office building providing open plan and cellular offices supporting Greenfields' employees, and community facilities providing an interface for Greenfields' tenants. It was awarded a BREEAM Very Good rating. This office brings together staff from several departments that were previously housed in separate locations.

The brief from the client to was maximise the energy efficiency whilst keeping in mind the comfort and experience of its users, both staff and visitors. In response to this, the design team combined passive design techniques including a shallow plan to maximise daylight and facilitate natural ventilation with low carbon technologies including ground source heat pumps to meet the entire space-heating load.

The tender for the main contract followed a two-stage process, one of the reasons for which was to allow the design team to try and address all value-engineering suggestions proposed by the contractors at an early stage, prior to the appointment of the sub-contractors. This was to ensure that all implications of the proposed changes were considered so that the integrity of the proposed building and energy strategy was not compromised.

A mechanical and electrical sub-contractor was appointed for the project with further specialist sub-contractors appointed for the ground source heat pump installation and Building Management System.

This BPE study was carried out in order to determine actual performance compared to its design intention - evaluating specific individual components as well as the integration of the system as a whole. It also looked at the experience of the people interacting with the building, both the staff and the facilities manager responsible for the operation of the building and its services.

While the design strategy was relatively simple, it relied on the coming together and interaction of a number of active and passive systems as well as on the understanding and interaction of the staff with these.

The layers between the design team and specialist contractors and installers meant that the number of layers between the installers for some of the specialist equipment and the principal contractor also affected the communication and coordination amongst the sub-contractors and with the design team.

The programme of the project was set by a fixed date by which the other offices had to be vacated and delays to the project programme meant that the time that had been allocated for the commissioning and handover of the building to the users was compromised. This resulted in a lack of understanding of the facilities team and occupants on how to adjust the physical and mechanical features in the building to achieve comfort in daily use.

The study also revealed a higher than intended use of energy and consequently $CO_2$ emissions than what had been intended at design stage. While some of this could be attributed to a lack of optimisation of use of the services, like the electric lighting and central plant circulating pumps being left on out of hours, others were the result of changes made after the building had been occupied, without a completed understanding of their implications. These included the installation of an air curtain over the main entrance to the reception and the incorporation of solar control film on the large windows facing south to limit glare.

The BMS setup at the time of the research did not monitor critical parameters that would allow a more accurate diagnostic and interpretation of system operation. One of the factors that caused significant delays to the research project programme was the lack of sub-meters capable of a pulsed output that could be recorded by the BMS. Significant upgrades were also made to the interface by the building owners to enable the collection and analysis of data to understand building performance.

Survey and interview with the staff revealed some dissatisfaction with the internal conditions of the open plan offices. However there was general appreciation for the quality and design of new headquarter building. It is however worth noting that the staff in this building are from a range of different departments with varying working patterns and schedules, some of who work part time and others that spend considerable amounts of time on the organisation's sites. This is therefore likely to have an impact on expectations from the building.

The survey however also revealed a lack of understanding amongst the staff on how to use the building and the features that were within their control as opposed to those that the BMS controlled. One key aspect was the ventilation of the building, the low level windows were intended to be controlled by the staff in the open plan offices, however there appeared to be confusion about how their use impacted, if at all, the effectiveness of the high level hoppers that were controlled by the BMS in very warm weather and for night purge ventilation, the building owners, who were made aware of the survey responses during this study, were working on informing their facilities team and staff to help address these issues.

A key learning from this project for the design professionals was that a one-size-fits-all approach may not be appropriate with some building services and as building services are becoming more complex due to the demands for energy efficiency and carbon reductions, a 'fit and forget' approach is not realistic either. It is also crucial to manage the expectation of users when designing a building that incorporates technology and systems that are new and may be unfamiliar to people.

The primary benefit of the study for the occupants however is a list of simple measures identified that, when implemented, would help save operational energy (and cost) and also help optimise its operation to achieve comfort conditions throughout the year.

It is possible that a building can be optimised to run as close to its intended performance level from the outset, but maintaining efficient performance requires effective management. Performance can easily deteriorate, potentially leading to poor environmental conditions and high energy use.

A long-term strategy should be considered for the maintenance of BMS where present, to adjust the controls algorithms for the building services to ensure the installed equipment is operating to its maximum potential and not in conflict with other systems. This could be achieved by training the facilities staff but also by seeking specialist advice, for instance as an extension to the maintenance contracts that may be in place for the BMS.

The building occupants have been engaged with and supportive of the research project and aware of the findings to date. As the lead organisation for this project was also the architects for the project, the learnings will be incorporated into their design practice in the future and also help provide any support to GCH as an outcome of this project.

# Contents

# 1 Introduction and overview

## 1.1 Introduction

The Greenfields Community Housing (GCH) Headquarters building in Braintree, Essex is a bespoke office building providing two distinct functions:

- open plan and cellular offices supporting Greenfields' employees, and
- community facilities providing an interface for Greenfields' tenants

The brief from the client was to maximise the energy efficiency of the building while keeping in mind the comfort and experience of its users, both staff and visitor members of the community.

The building was awarded a BREEAM Very Good rating and received funding from the BRE as part of Phase 2 of the Low Carbon Building Programme for one non-reversible heat pump that was part of a ground source installation.

The building has been designed to combine passive measures and low carbon technologies to achieve an energy efficient and comfortable environment. This BPE study was carried out in order to determine actual performance compared to its design intention - evaluating individual components as well as the integration of the system as a whole.

**Figure 1 South (front) facade of Greenfields Headquarter Office building, Braintree, Essex**

The BPE study seeks to evaluate key features of the design energy and environmental strategies of the project. The study is led by Richards Partington Architects, who designed the building and maintain an on-going relationship with the occupants providing support as and when needed and are also able to incorporate all learnings into their subsequent projects.

Some key members of the design and construction team, including the principal M&E consultants and electrical contractors have, since the completion of the project, left the organisation or gone into arbitration, impacting their involvement in this research project.

During the course of the study, some key features that were expected to be present in the building were found to not be functioning as anticipated, which led to a number of delays in the setting up of the monitoring. The building had been awarded a BREEAM 'Very Good' rating which included credits for a BMS system. While the system was in place, the interface unit which allowed for its effective adjustment and data recording had been value-engineered out. , It should be noted that, as a result of the BPE study plan, GCH realised the importance of these and they subsequently invested in re-instating (post-contract) them to support the research project, and also their own long-term monitoring and building management strategy.

## 1.2 Key areas of evaluation

The following features were focussed on in the Building Performance Evaluation study:

### 1.2.1. Ventilation

The plan of the building is narrow and long to maximise the potential for natural light and ventilation. The offices are primarily naturally ventilated in warmer months (single-sided and cross-plan) via a combination of openings; low- and mid-level windows operated by the occupants and high-level hoppers operated by the building management system (BMS) in response to internal temperatures.

During the winter, a mechanical displacement ventilation system is used, which draws fresh air through an externally located thermal labyrinth via the operation of an air-handling unit (AHU) in the basement plant room. The purpose of the labyrinth is to pre-temper the incoming air to reduce the amount of electric heating that would be needed to bring the air up to supply temperatures. By introducing pre-tempered air into the offices, the displacement ventilation system meets part of the space heating demand in the offices.

### 1.2.2. Ground Source Heat Pump

Mechanical components of a ground source heat pump (GSHP) installation are rated based on tests in controlled laboratory conditions. However, the design, installation and efficacy of the ground component are all key to the performance of the technology. Three heat pumps are installed in this office building: two of these capable of operating in a reversible cycle to provide comfort cooling as needed in the communal areas; the third providing only heating in the office spaces.

This study evaluates the ability of the heat pumps to meet the design loads, which were impacted by a combination of the sizing of the systems and the interaction of the controls.

### 1.2.3. Internal conditions and controls strategy

It is important in a building that combines a number of active and passive systems, and relies on a degree of user control that the occupants understand how the building is intended to operate. Controls should be simple to understand and to use otherwise occupants will tend not to use them. Poor interaction by building users will likely lead to user discomfort and increase the energy use in such buildings.

Some of the systems have the option of being controlled both by the BMS and manually. These include the ventilation system, where the high level hoppers are operated by the BMS on warm days (and also serve the night purge ventilation), and occupants can manually operate the low level windows.

Internal lighting luminaires in the open plan offices are installed with daylight sensors. These can also be controlled by the staff, complying with the requirement for occupant controls under BREEAM.

Staff understanding and interaction with these controls is therefore key to the success of the intended ventilation and lighting strategies.

During the occupant survey and the interviews it was noted that there was a lack of understanding amongst staff about the degree to which they should interact with the building and services, most noticeably, the opening of low level windows and its connection (or lack of) with the BMS.

Some issues were also reported with the ease of understanding of the controls, for instance, the electric lighting zones, where it was not clear how the zones were set out.

The main office layouts are large open-plan rooms and it is difficult to meet everyone's requirements at the same time. There was also a perception that the few staff members that complained the most were considered without consensus from the remaining. This highlighted the need to help manage the expectations of staff from open plan offices and a clearer explanation of the installed controls and systems.

### 1.2.4. Thermal mass

The lower two floors of the office building are constructed out of ins-situ concrete that is externally insulated and clad. The ceiling soffits in the open plan offices are exposed concrete to act as a thermal sink and help regulate extreme temperature modulations across the space in all weathers. The high level hoppers have been installed to couple with this exposed thermal mass and help make the night purge strategy more effective.

**Figure 2 Concrete slab with a soffit profile to maximise exposed surface area**

The top floor of this building is made of a lightweight steel frame structure. The main office areas on this floor are predominantly orientated towards the north and therefore were not expected to capture much of the solar gains.

The study looks at the internal conditions and effects of thermal mass and lag in the office spaces that have similar occupancy levels to understand the impact of the strategy.

### 1.2.5. Occupant perception

This headquarter building was built to bring together employees and departments previously accommodated in a number of other offices. In addition to engaging with members of the community at the design stage, an assessment of the specific requirements of the employees was made. The study looks at how the staff perceives the design, comfort and operation of the new building through responses to a structured survey and informal interviews.

## 1.3 Key project stages,

The first phase of applications for this project were submitted in June 2010

The project was shortlisted for the second phase and after a site visit by the research team and TSB evaluator a report was put together to inform the second phase application, submitted in October 2010.

Based on this the first contract duration was intended to be from April 2010 to April 2013, to allow for two years' worth of monitored data to be collected. This application was made on the assumption that the BMS had data recording capabilities and interface based on the specification and BREEAM report.

However it was found that the user interface had been 'value engineered' out of the installation and the research team eventually convinced the occupants to reinstall this into their building to be able to manage the building services in a more efficient manner.

It was also noted after the start of the project that the sub-meters did not have a pulsed output (contrary to the specification and BREEAM report) and, after agreement with TSB, it was agreed that CT clamps would be installed on the sub-meters to be able to log readings on the BMS. There were several delays in getting this work done, mainly due to the occupant's reservations around powering down the building and the work had to be coordinated with a power-down scheduled for installation of back up facilities in the building.

In addition to this, the building owners and occupiers requested that the work be carried out by Carrob Controls, who already had the management contract for the BMS system to prevent any future complications.

There were several delays on this process due to lack of clarity and understanding of the parameters that needed to be monitored and the frequency with which they needed to be logged. There was also confusing around the information that the BMS was able to extract and other data which it could not, due to which some of the initial aims of the project, like evaluating the operational COP of the heat pumps could not finally be met.

After several iterations with the data log, download and access arrangements ,which required assistance from the IT department at Greenfields, monitored data was available from July 2013 reducing the data recording and subsequently analysis from the intended period of 24 months to 12 months at the very most, keeping in mind the end date for the project being September 2014.

During the course of this project form the initial contract dates, the following two variations were made:

Variation 01 for the project to take place from February b 2012 to April 2014

Variation 02, extending the end date to September 2014.

Throughout the course of this project and all the delays the building occupants were given updates and their cooperation was sought to help facilitate the setting up of the sub-meters and subsequent data logging and access facilities.

Also, the BUS survey took place October 2012 along with the building walkthrough and interviews with key design team members and facilities manager. The report from the BUS survey was provided to and discussed with the building occupants.

## 1.4 Key observations from project set-up

Changes to monitoring programme

- Due to all the delays in the project, the overall duration was reduced and the following activities were removed from the programme due to time constraints:
- Detailed monitoring to take place in separate office zones during two summer and winter weeks was not carried out
- Spot checks looking at the internal conditions including within the thermal labyrinth were not carried out

Changes to budget

- Cost of installing CT clamps to the sub-meters and the setting up of the BMS to facilitate monitoring was not initially included in the project budget but had to be funded from within this sum
- Due to a reduction in the duration of the project, dissemination activities were reduced and the main route for this will be the final report. This is also to acknowledge that there were several changes in the initial design team, with some key changes in the main M&E sub-contractors' organisation due to which their involvement in the project and its findings have been very limited. The architects of the building will, as authors of this report, be in a position to disseminate key findings from this report within their practice.
- In order to add value to a reduced monitoring programme, a study of the thermal performance of the building was commissioned and a thermography report was prepared.

Changes to study focus

- Due to limitations within the BMS to record specific data the COP of the heat pumps could not be calculated and this is discussed in detail in sections 6 and 7 of this report
- In order to provide context and value to the analysis of data, fuel bills were used but these were not necessarily in sync with the duration for which monitored data was available. Information was assessed on a pro-rata basis to help overcome this.
- Spot checks and detailed monitoring over short durations of specific parameters such as indoor air quality, comparative thermal conditions with additional sensors and thermal labyrinth conditions could not be carried out in the building due to the reduction in time and cost of the project.

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

## 2.1 Introduction

The brief from Greenfields Community Housing was for a flexible head office that demonstrated and embodied the organisation's commitment to the environment. The response to this was a design that integrated the form and architecture of the building with the services systems that incorporated principals of energy efficiency from the outset. The ability of the building to be an interactive place for the community and staff was a key consideration through the process.

**Figure 3 Art installation in double height space connecting office and community interface area**

A working group comprised of Greenfields' residents, board members and staff was engaged with the design development and procurement stages for the project. The building also is home to artwork specifically created for the building that expresses the diversity and spirit of the community.

Representatives of GCH's tenants were invited to give their input on the general layout of the building, specifically areas which would be used by them and other members of public. The appearance of the building and the choice of finishing materials were also influenced though this engagement process.

**Figure 4 Reception area installation incorporating art contributed by members of the community**

In order to understand the performance of the building, in addition to carrying out interviews with the key design team members, a thermographic survey was carried out across an evening and following morning, to appraise the quality of construction after nearly three years of occupancy. Interviews with the financial officer and facilities manager for GCH were also carried out along with a general walkthrough and visual appraisal.

## 2.2 Design strategy

The building is located close to the Braintree Freeport rail station, on a previously undeveloped site next to a shopping centre that allowed the predominant facades to have a north-south orientation, a narrow plan and openable windows for natural ventilation.

The administration and housing centre was designed to be an efficient and welcoming space celebrating its community gateway status and, in line with the culture of the client organisation, incorporated tenant representation in the governance and decision-making processes.

The building is located on a narrow, steeply sloping plot and the building design needed to take account of these limitations. To some degree the width limitation dictated that the office had a narrow plan, which is suited to a natural ventilation strategy. This arrangement also allows the design to incorporate high levels of natural daylight. The orientation of the site, with the south elevation facing the open plan car park to the shopping complex, allowed the building to be optimally arranged to gain most benefit from passive solar design. Accordingly, tall windows to the south and west facades were incorporated to maximise daylight into the offices and provide effective natural ventilation. The smaller cellular offices and ancillary spaces were located along the north facing facades.

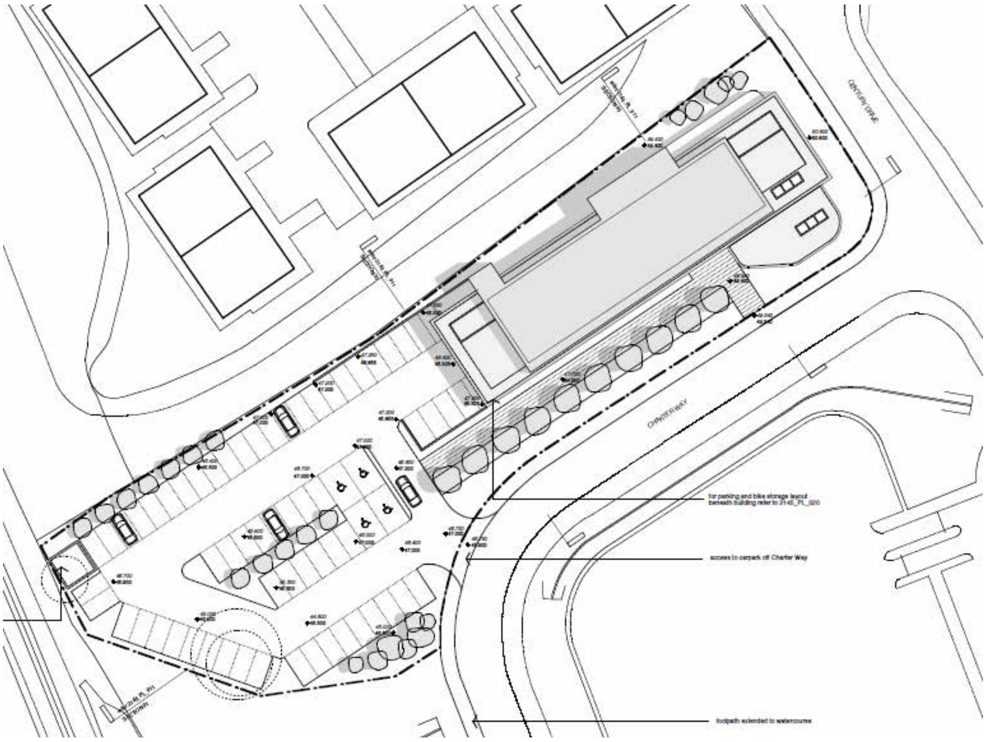


**Figure 5 Site plan**

The informal café 'green room' on the second floor faces south and opens out onto a terrace that is accessible by the staff.

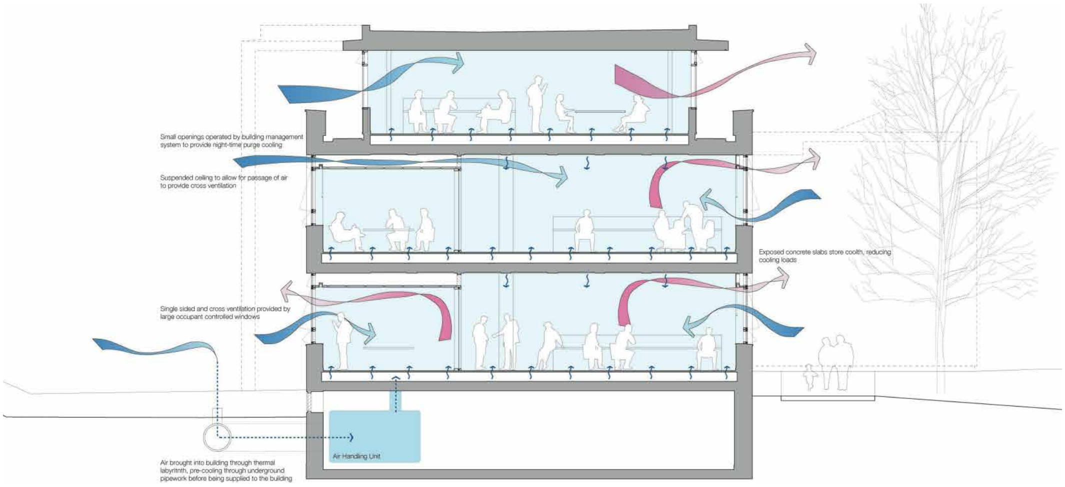



**Figure 6 Ventilation strategy diagram by design team**

Solar gains into the building were limited by designing in overhangs, solar control glazing and mature trees on the southern face of the building. The trees, however, were not successfully installed as part of the landscape along the south façade of the building, and have not been able to provide the intended shading from high sun in the summer months.

Occupants are provided means to control comfort levels within their environment, with the internal lighting zoned, windows provided with integral blinds and openable panes at lower levels. The main entrance area comprise of an open double height space leading off to the community facilities on one side, with a high level skylight controlled by actuators via the BMS.

## 2.3 Energy and environmental strategy

The building achieved a B rating EPC and was awarded a Very Good rating against the 2006 version of BREEAM for offices, achieved by a well-insulated airtight building fabric, high quality double-glazing with a low-e coating to minimize excessive solar gains and efficient building services incorporating low carbon technology.

The ventilation is mixed-mode with openable windows used through the summer and fresh air provided via displacement ventilation by drawing air through a thermal labyrinth at the rear of the building. It was intended that the length of the labyrinth would be maximized but this would have made the inlet too close to the street and car park and this had to be subsequently reduced to run along the edge of the building only.

Heating is provided to all the offices via trench heaters served by ground source heat pumps (GSHP). The GSHP employs boreholes as opposed to a trench type ground loop and the boreholes are spread beneath the car park. Some comfort cooling is also provided to the communal areas through two of the three ground source heat pumps, which are reversible.

The concrete used in the construction of the basement incorporates ground granulated blast-furnace slag (GGBS) to minimise the amount of Portland cements and the amount of energy use in production. Rainwater is collected from the roof surfaces and recycled for WC use and a large tank has been incorporated under the car park for this.

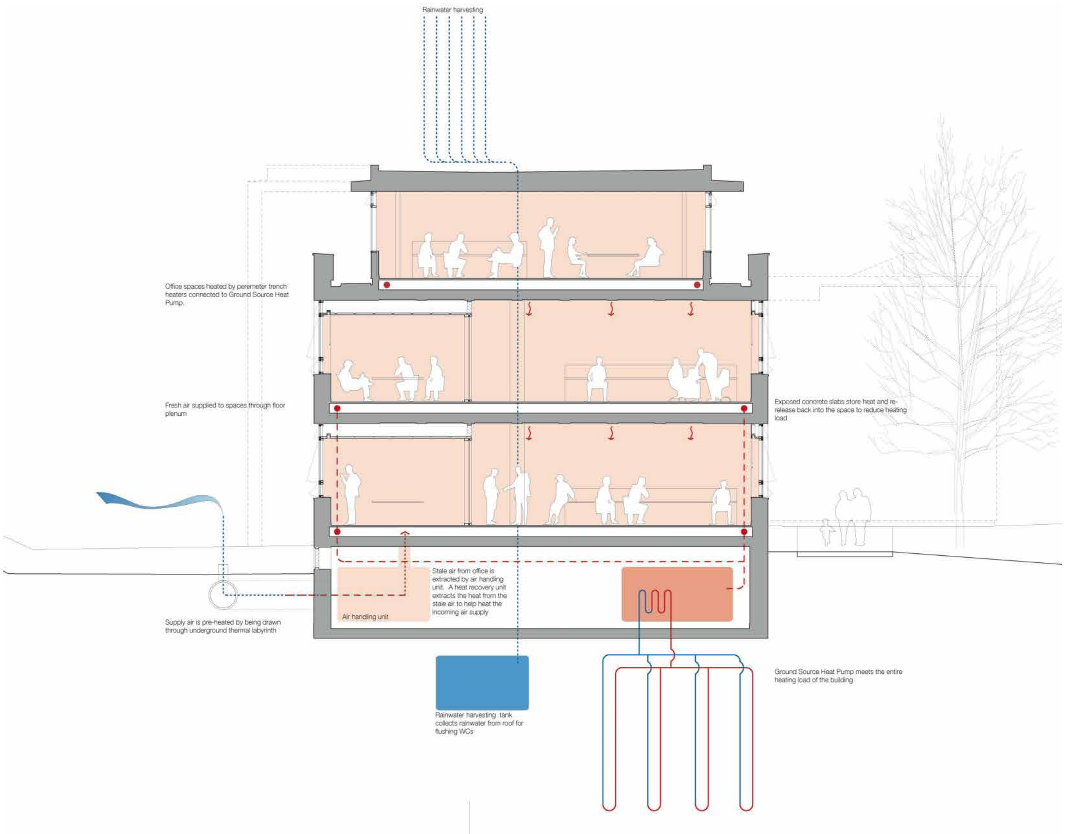



**Figure 7 Preliminary space heating strategy diagram (solar thermal panels not included in final design)**

## 2.4 Construction

The choice of construction system and materials used for this project was predominantly led by the recommendations made by the design team in response to the client's brief for an energy efficient building.

The building has been constructed from a cast in-situ concrete frame on the lower ground, ground and first floors with a steel framed second floor. The external finishes of the walls are a combination of brick, timber and metal cladding over rigid insulation boards.

The ground and intermediate floors are constructed of cast in-situ concrete and the top floor roof is a lightweight metal-decked structure. The windows are double-glazed Velfac units with a low-e coating to limit overheating in the structure and a U-value of 1.8W/m$^2$K.

**Figure 8 View of entrance with timber frame and brick finishes**

## 2.5 Contract and project management

### Tender process

The tender for the main contract followed a two-stage process, which was recommended by the project's Quantity Surveyor. One of the functions of the two-stage process was to deal with value-engineering suggestions proposed by the contractors at an early stage. The client's design team believed that it would be important to ensure that a successful contractor, along with their chosen design team and sub-contractors, understood the building and the associated strategies at an early stage. In doing so, the contractors could propose value-engineering suggestions and their implications considered and then accepted or dismissed, prior to their appointment.

This process did yield some savings by changing, e.g. finishes and partition specifications. However, some of the proposed savings for the building services were not acceptable to the design team, and were not carried forward, e.g. an alternative to heat pumps. In the end the two-stage process proved to be burdensome and provided little value to the client.

### Contract

The procurement followed a traditional approach, with the project architect acting as Contract Administrator (CA). The successful main contractor was appointed via the CA shortly after the tenders were evaluated.

### Project management

The programme for the construction was largely driven by a non-moveable completion date. The client needed to vacate their other office buildings by November 2009, and co-ordination of the migration of more than 100 staff coming together under one roof needed careful planning in order to minimise operation disruption.

The main contractor appointed a mechanical and electrical sub-contractor, who became responsible for all services in the project. This included their appointment of further specialist sub-contractors for systems, such as the GSHP installations and the BMS. In taking this approach, the main contractor relied, almost completely, on the ability of their M+E sub-contractor to meet the programme. A services design co-ordinator did form part of the main contractor's team to liaise with the sub-contractor, but there was little communication between the co-ordinator and the design team.

The reliance on a chain of sub-contractors resulted in the main contractor being less able to co-ordinate activities. This resulted in programming issues, which due to the non-moveable completion date, had an adverse effect on the commissioning programme. The programmed commissioning period did not take place as many trades were still incomplete during this time. Each sub-contractor was primarily concerned about the commissioning of their particular systems. They were not necessarily considering the operational requirements of the building and how each system needed to co-operate, or integrate with others. An example of this is the GSHP installation, which is controlled via the BMS. The GSHP internal controls were originally conflicting with commands given by the BMS.

## 2.6 Thermography

The thermographic survey of the building was carried out at the end of March in cold conditions (there was snow on the roof at the time of the survey) and during an overcast spell of weather. The $\Delta t$ (difference between internal and external temperatures) was nearly 20°C and the heating system in the building were still in operation. The main findings from the survey are summarised here and a complete report has been appended.

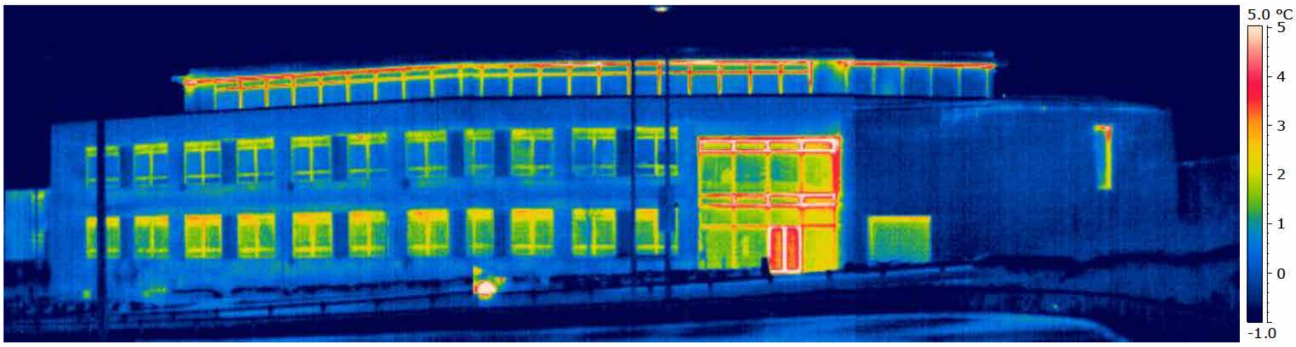



**Figure 9 Thermal image of south facing facade of building**

The walls of the building appeared to be well insulated with relatively uniform heat loss through these. Some additional heat loss was however noted at the second floor level, in particular with the flashing connection between the roof and the head of the curtain wall glazing system, and through the main reception doors. It is unclear whether this was due to lower thermal performance of the units or due to air infiltration through these units.

There were significant amounts of potential air leakage detected during the internal survey: behind the plasterboard of the walls on the main stair core and in the sections between the windows in the open plan offices.

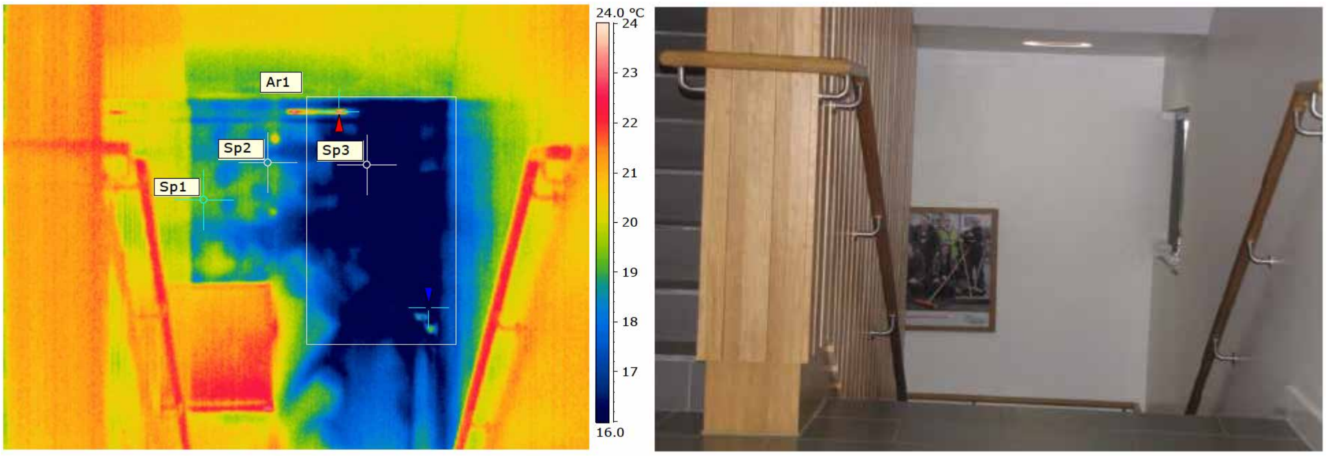



**Figure 10 Potential thermal bypass behind plasterboard - main stair core**

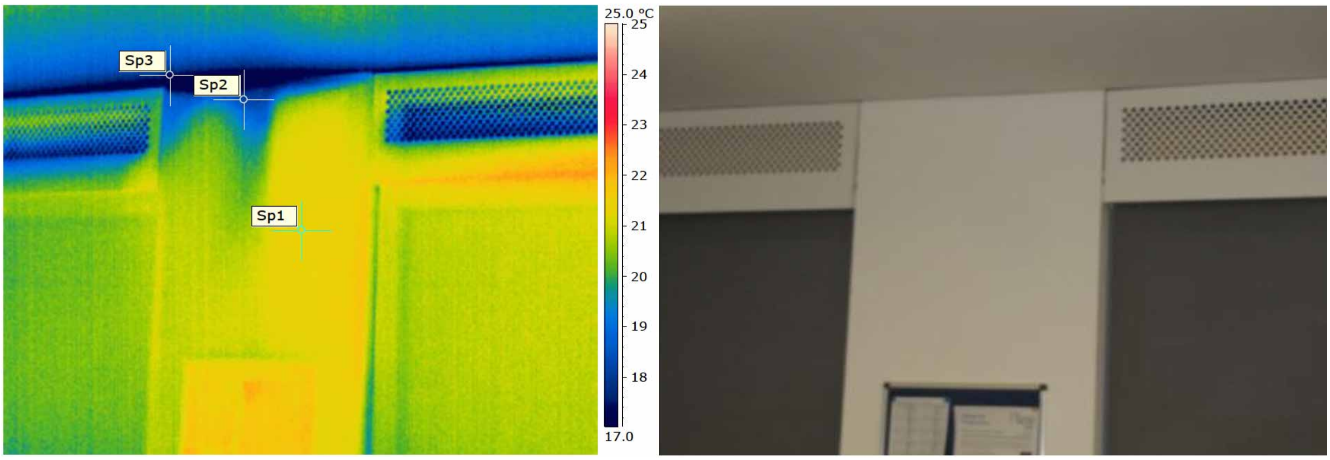



**Figure 11 Potential thermal bypass behind plasterboard - windows in open plan office**

The heat loss from thermal bridging through the frame is higher than would be expected across the building and the specification of the glazing and curtain-glazing units should be checked to see whether the specified units were installed and whether any damage has taken place (due to shrinkage etc) over the time the building has been occupied.

## 2.7 Conclusions and key findings for this section

The design, construction and energy strategy were predominantly led by the brief from the client for an energy efficient building. However, albeit a traditional form of contract was used, the general feeling with the client team was that the main contractor did not sufficiently manage the services installations. This led to a reduced commissioning programme, which had consequences for the successful operation of the building at hand over and beyond.

Some features such as the thermal labyrinth were incorporated as low carbon passive measures to minimize the mechanical heating load. The effectiveness of these however may be undermined by limitations on site due to which the length of the labyrinth was reduced to the edge of the building rather than extending along the length of the site.

Some of the instances of thermal bridging identified in the appended full thermography report should be investigated, in particular where these occur with water ingress. Of particular concern is the high heat loss noted behind the plasterboard in the main stairwell, which could contribute significantly to the space heating load. Once investigate, measures could be suggested to rectify the problem, however it is accepted that there may be limited scope to do so without some disruption to the normal use of the building.

The cast in-situ concrete construction appeared to have a relatively robust thermal performance, however areas of concern were noted with the window units, which are meant to have their thermal performance tested and certified during manufacture.

Some strategies of passive design may require for a number of features to function together in order to be successful and it is important for all components to be integrated properly. A significant part of the solar shading strategy along the south façade depended on a row of trees planted along the outside. The integration of these was not successful as the trees were not planted well and subsequently died. While these were replanted by Greenfields, they have not been able to provide the foliage cover as expected, affecting comfort for the staff, both in terms of glare and overheating.

# 3 Review of building services and energy systems.

## 3.1 Introduction

The building services strategy for this office building was determined mainly by the client's brief for a low carbon solution. The building is designed to operate using passive and mixed-mode systems, with space heating provided via trench heaters and displacement ventilation in the winter, and ambient temperatures achieved by natural ventilation in the summer.

Cooling is provided to the server room and only to some of the intermittently used office and communal spaces where the density of occupancy was difficult to determine and was assumed to be high.

Detailed evaluation of the aspects covered in this section and also the specific controls interfaces can be found in Appendix D of this document.

## 3.2 Mechanical Ventilation (AHU)

Displacement mechanical ventilation supplies air into raised floor plenums and through grilles set within the floor tiles. Mechanical extract is served, typically by a single extract point adjacent to the riser cupboards. A supply and extract air handling unit is located in the basement plant room, which draws air in via an engineered concrete labyrinth set beneath the building, which is intended to temper the incoming air.

The air-handling unit also comprises a thermal wheel heat recovery unit and these can be switched off when heat dumping is required during summer. This however is not likely to be used since the displacement ventilation system is intended to be used only in the winter when the windows would not be opened (and during the heating season). However, it was noted that the AHU was operating throughout the year and this is discussed in more detail in the sections dealing with the monitored data.

The toilet areas are ventilated using a conventional twin extract arrangement. There are no user controls and the fans run according to BMS time clock settings.

## 3.3 Natural ventilation

The automated high level hoppers are controlled by the BMS and operate the openings in response to sensors for external temperature, wind speed, rain and time control, along with a manual override (via BMS). The design intention is that the actuators will open the vents when the space temperature reaches 21deg C in summer and that it provides night time cooling as long as the external temperature is lower than the internal. While the ventilation conditions are reportedly regularly monitored by the building manager, overheating issues are known to happen during the heating season on mild days, during which time, the night time cooling is disabled. This is generally addressed by the building manager overriding the vent opening controls on the BMS and is possibly the most pragmatic approach during these periods.

There was a general lack of understanding noted amongst staff about how to use windows, which some stating they had been instructed (by management) not to open the lower windows for additional ventilation as by doing so they 'would confuse the system'. This was contradicted in the interviews with the building manager and that they had advised the staff that the windows should be opened according to need.

It was notable that during the course of this review, no documentation, be it specifications, O+M manuals, or otherwise include a comprehensive description of the ventilation system and how it should be operated and managed. For a mixed mode system that relies on some form of occupant understanding this is a significant omission from, what should be, part of the building manual.

The position of the rain sensor associated with the natural ventilation controls also revealed some issues – these needed to be physically dried with a towel after a period of rainfall as water pools on the head of the sensor falsely registers rainfall long after the rain has stopped. This interfered with the BMS controls for natural ventilation by closing the inlets for longer than would be necessary. In addition to this, physically drying the sensors was not a practical long term solution.

## 3.4 Ground source heat pumps

There are three ground source heat pumps installed, two with a reversible pump that can be used to provide cooling. The operation of these pumps is controlled by the BMS, with the heating set to come on at 0600hrs and switch off at 1700hrs during the week day, at the time that the walkthrough was conducted for this project. This operation schedule is varied by the on-site facilities manager, usually to extend heating on times, e.g. for evening meetings.

A review of the operation of the heat pumps revealed a conflict in the way that the three systems operate. While GSHP1 (heat only) appeared to operate correctly it was not clear how much GSHP2 (heat and reverse cycle cooling) contributed to GSHP1, although the expectation is that it would only 'top-up' output of the heating during particularly cold spells, or during heat-up periods from cold.

A conflict in the controls set up appeared to lower the confidence in the operation of GSHP3 (cooling only), which had been configured for reverse cycle only, for providing cooling. It appeared that the control system (believed to be the controller on GSHP2) would call upon GSHP3 to run in forward cycle, i.e. to deliver heat, due to which GSHP3 would overheat and go into fault mode. This would need manual resetting, only possible after a few hours when the system had sufficiently cooled down. Due to this the client has installed a separate and more conventional DX cooling system to the server room: an additional energy load that was not part of the initial design and predictions. This was installed without the input or consultation with the design team and other alternatives were not considered.

## 3.5 Lighting

The open plan offices on the ground and first floors are provided with pendant up/down light luminaires and those on the second floor via recessed modular luminaires set within the suspended ceiling grid. All lighting was installed with daylight sensors.

It appeared from the walkthrough that the installed lighting density on the ground and first floors was too high and may be influenced more by the layout of the luminaires than the required lux levels for the space. It is unclear whether the designed levels were achieved taking into account operation of the dimmers as the M&E consultants for the project were unavailable to comment.

The high levels of electric lighting was also noted to cause discomfort to the staff, and in response to complaints from the staff (in the east facing open plan office on the ground floor), the lighting levels were permanently reduced by simply removing two out of the four lamps in each fitting.

The problems with the artificial lighting levels have been exacerbated by the installation of a film on the windows due to which the lights are not dimming since the sensors detects low day light levels.

## 3.6 Server and IT equipment

A detailed asset register has been included in section 6.7 of this report, to support the TM22 analysis. The servers installed in the building are for the users of the building only and operate throughout the year.

## 3.7 Other energy loads

Hot water is provided via local electric water heaters, with typically 30 litre storage capacity serving toilet blocks and 15 litre capacity serving tea/coffee stations. These are not connected via timer controls which, if fitted, could be set to operate during office hours.

The tea/coffee stations are provided with water zip boilers and there is an electric shower on each floor. The zip boilers are fitted with an integral energy saving timer, but these do not appear to be set (i.e. 24hr operation).

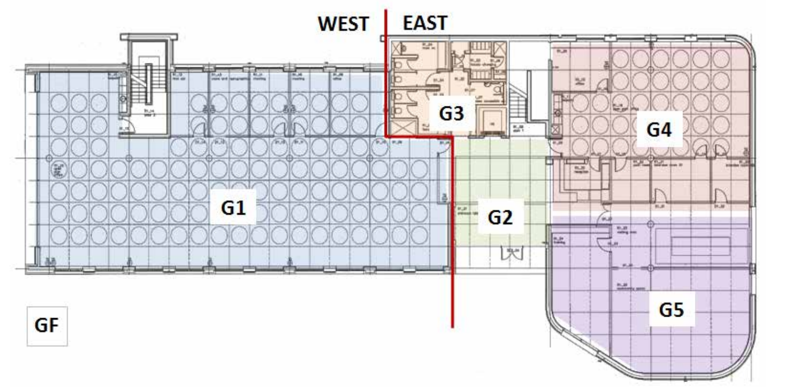
Local hot water heating was not the original strategy proposed by the designers. Originally a centralised hot water system comprising a 1200 litre calorifier, served by the heat pumps was specified. This was omitted as part of the value engineering process and replaced with the localised units. This may have offered a capital benefit, but the amount of local heaters (16) could potentially be more expensive to operate and maintain in the long term.

## 3.8 Metering and Controls

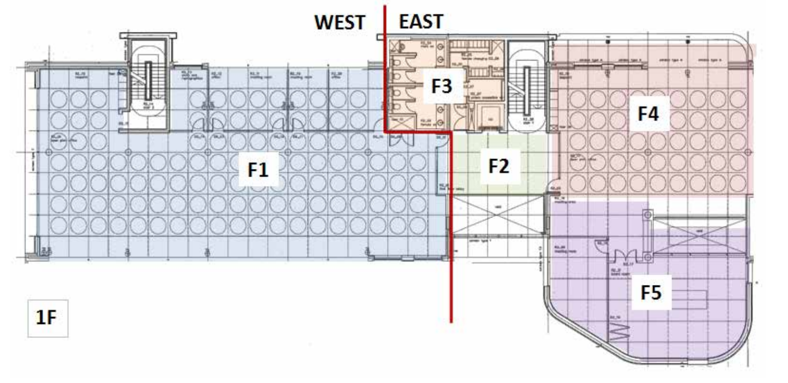
The GCH building is managed and controlled via a TREND BMS system installed in the basement plantroom. A review of the control strategy suggests a relatively simple control regime is in place to ensure occupant thermal comfort is met. The BMS manages the operations of the façade louvres based on a set of criteria, which are temperature and wind speed dependent. Space temperatures are also regulated through thermostatic radiator valve (TRV) controlled trench radiator heating and tempered fresh air supplied from the AHU through displacement vents. More details on the operating set points are included in the detailed walkthrough report appended to this document.

However, during the value engineering exercise, the BMS's client PC had been omitted. This required the building manager to physically go to the basement plantroom to carry out any adjustments to the building management through the interface panel on the BMS plant control panel.

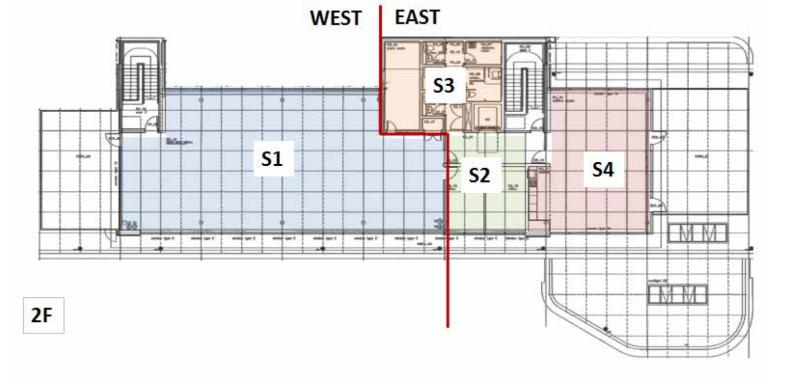
At the time of setting up the monitoring for this BPE study, it was also noted that the sub-metering installed in the building was not capable of sending out a pulsed output that could be logged onto the BMS. It was suggested by the M&E consultants that this may have been omitted by mistake but this could not be confirmed. The monitoring programme therefore had to rely on data being logged using current transformer (CT) clamps on the meters, which are not as reliable or robust as meters with an integral pulsed output.




| Zone | Activity |
|---|---|
| G1 | Open plan office |
| G2 | Core area |
| G3 | Toilet/WC |
| G4 | Open plan office, meeting rooms |
| G5 | Breakout/meeting rooms |




| Zone | Activity |
|---|---|
| F1 | Open plan office |
| F2 | Core area |
| F3 | Toilet/WC |
| F4 | Open plan office, meeting rooms |
| F5 | Breakout/meeting rooms |




| Zone | Activity |
|---|---|
| S1 | Open plan office |
| S2 | Core area |
| S3 | Toilet/WC |
| S4 | Common room/social area |

**Figure 12 Zone and area breakdown of the GCH building**

The building management has been set up based on a zonal configuration. The building has been split into 3 occupied zones and each floor is divided into West and East zones. Figure 12 summarises the breakdown of zone and areas in the building. The BMS centrally regulates the temperatures of the open plan office spaces, whilst cellular rooms are regulated via localised thermostats, which controls the operation of ceiling mounted fan coil units (FCUs).

The BMS also controls the operation of the GSHPs in conjunction with the operation of all other central plants – heating and cooling circuit, the AHU and circulation pumps. Figure 13 is a screenshot of the BMS graphical interface showing the heating and cooling system. It can be seen that there are three GSHPs connected in parallel to the secondary circuit, which is split into the heating and cooling circuit by regulating control valves.

Several irregularities have been identified in the BMS graphical interface in which there is ambiguous information and misrepresentation. One example is that the AHU only has heating coils to temper supply air to desired temperature before introduction into the office spaces;

however, the BMS graphics appears to show the AHU heating circuit connected to the cooling circuit.

Also, there is a label indicating that GSHP2 has been set to only run in heating mode; however, the BMS data analysed in Section 7 suggests that GSHP2 has also been running in cooling mode, albeit for short period of time, supposedly to supplement GSHP3. The review of the GSHP has established other technical issues, which have been detailed in Section 7.

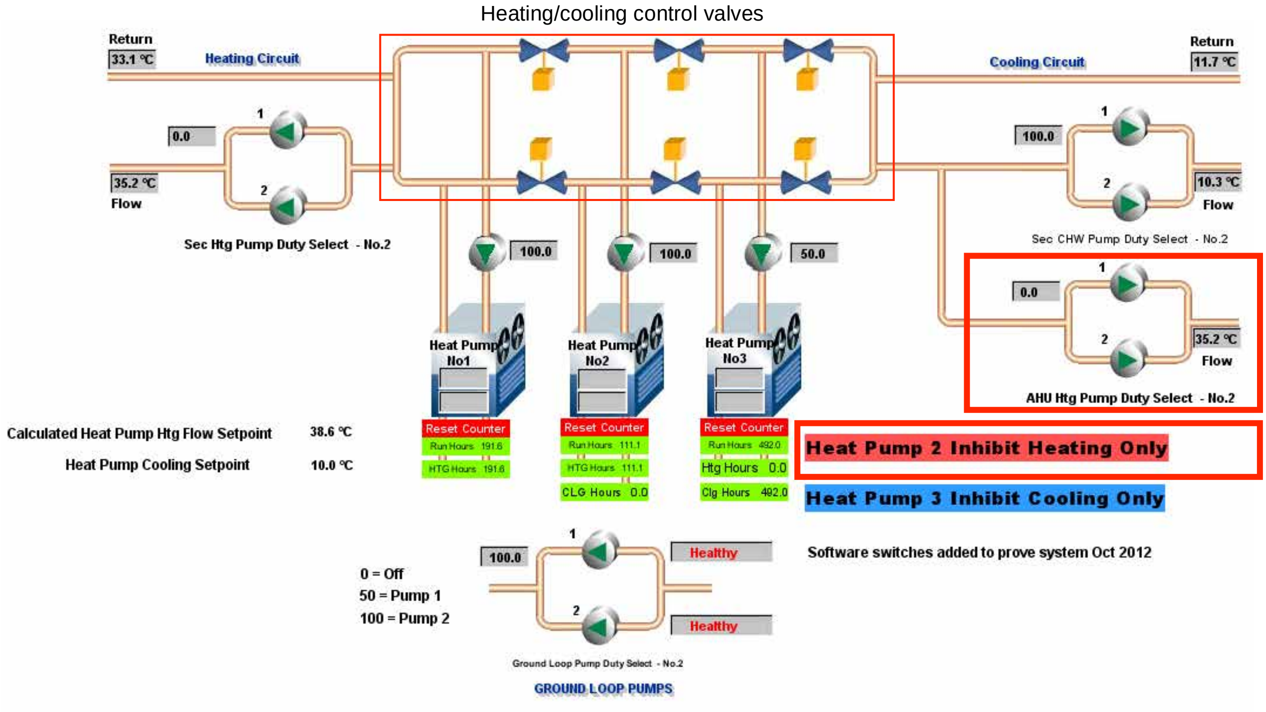



**Figure 13 Screenshot of the BMS graphical interface showing the heating and cooling system**

As part of the study, work has been carried out by a supplier to enable the BMS to record data for 53 parameters from 19th July 2013, and 13 more relating to energy use of the GSHPs started from 19th August 2013 as listed in Figure 13. All parameters were logged at 15-minute intervals.

| Start | | Parameter | Abbreviation | Start | | Parameter | Abbreviation |
|---|---|---|---|---|---|---|---|
| 19th July 2013 | 1 | Outside Air Temperature | OAT | 19th July 2013 | 34 | GSHP2 heating run hours | GSHP2 Htg RunHrs |
| | 2 | Wind direction | Wind Direction | | 35 | GSHP2 cooling run hours | GSHP2 Clg RunHrs |
| | 3 | GF space temperature WEST | GF SpcTemp Wst | | 36 | GSHP3 heating run hours | GSHP3 Htg RunHrs |
| | 4 | GF space temperature CENTRAL | GF SpcTemp Cnt | | 37 | GSHP3 cooling run hours | GSHP3 Clg RunHrs |
| | 5 | GF space temperature EAST | GF SpcTemp Est | | 38 | DB - Basement light | DB - BL |
| | 6 | GF fan coil unit operation | GF FCU | | 39 | DB - Basement power | DB - BP |
| | 7 | GF North Louvres | GF N Louvres | | 40 | DB - GF light | DB - GL |
| | 8 | GF South Louvres | GF S Louvres | | 41 | DB - GF power | DB - GP |
| | 9 | GF North East Louvres | GF NE Louvres | | 42 | DB - F1 light | DB - FL |
| | 10 | F1 space temperature WEST | F1 SpcTemp Wst | | 43 | DB - F1 power | DB - FP |
| | 11 | F1 space temperature CENTRAL | F1 SpcTemp Cnt | | 44 | DB - F2 light | DB - SL |
| | 12 | F1 space temperature EAST | F1 SpcTemp Est | | 45 | DB - F2 power | DB - SP |
| | 13 | F1 space temperature LOBBY | F1 SpcTemp Lobby | | 46 | DB - Common Area | DB - CA |
| | 14 | F1 fan coil unit operation | F1 FCU | | 47 | DB - CMR | DB - CMR |
| | 15 | F1 North Louvres | F1 N Louvres | | 48 | DB - Comms room | DB - Comms |
| | 16 | F1 South Louvres | F1 S Louvres | | 49 | DB - Main panel | DB - Main Panel |
| | 17 | F1 North East Louvres | F1 NE Louvres | | 50 | DB - UPS | DB - UPS |
| | 18 | F2 space temperature WEST | F2 SpcTemp Wst | | 51 | DB - External light | DB - Ext |
| | 19 | F2 space temperature CENTRAL | F2 SpcTemp Cnt | | 52 | DB - Main incomer | DB - Main |
| | 20 | F2 fan coil unit operation | F2 SpcTemp Est | | 53 | Timed start output | Timed start output |
| | 21 | F2 North Louvres | F2 N Louvres | 19th August 2013 | 54 | Wind speed | Wind Speed |
| | 22 | F2 South Louvres | F2 S Louvres | | 55 | GSHP No.1 L1 L2 L3 Total | GSHP1 Elect TOTAL |
| | 23 | AHU Heating pump | AHU Htg Pump | | 56 | GSHP No.1 L1 Total | GSHP1 Elect L1 |
| | 24 | GSHP 1 and 2 pump | GHP 1 and 2 pumps | | 57 | GSHP No.1 L2 Total | GSHP1 Elect L2 |
| | 25 | GSHP 3 pump | CHP 3 Pump | | 58 | GSHP No.1 L3 Total | GSHP1 Elect L3 |
| | 26 | Ground loop pump | Gnd Loop Pump | | 59 | GSHP No.2 L1 L2 L3 Total | GSHP2 Elect TOTAL |
| | 27 | Secondary chilled water pump | 2nd CHW pump | | 60 | GSHP No.2 L1 Total | GSHP2 Elect L1 |
| | 28 | Secondary hot water pump | 2nd Htg pump | | 61 | GSHP No.2 L2 Total | GSHP2 Elect L2 |
| | 29 | Ground source cooling flow temperature | GSHP Clg Flow Temp | | 62 | GSHP No.2 L3 Total | GSHP2 Elect L3 |
| | 30 | Ground source cooling return temperature | GSHP Clg Rtn Temp | | 63 | GSHP No.3 L1 L2 L3 Total | GSHP3 Elect TOTAL |
| | 31 | Ground source heating flow temperature | GSHP Htg Flow Temp | | 64 | GSHP No.3 L1 Total | GSHP3 Elect L1 |
| | 32 | Ground source heating return temperature | GSHP Htg Rtn Temp | | 65 | GSHP No.3 L2 Total | GSHP3 Elect L2 |
| | 33 | GSHP1 heating run hours | GSHP1 Htg RunHrs | | 66 | GSHP No.3 L3 Total | GSHP3 Elect L3 |

**Figure 14 List of BMS parameters being logged and downloaded for analysis (TN02)**

The BMS is also set up to control the automated natural vents over the window, opening them in increments based on space and external temperature, wind speed, rain and time control, along with an override (via BMS). The design intent was for the actuators to open the vents when the space temperature reaches 21°C in summer and provide night time cooling as long as the external temperature was lower than the internal.

The overheating perceived in the office spaces, even on mild winter days is likely to be because the night time cooling is disabled for that season. In order to purge the building in the morning, the high level vents are often opened by the building as a temporary intervention. From an energy viewpoint however, it would be preferable to optimize the heating controls to help mitigate this problem. This should also take into account the heating supplied by the pre-tempered air via the displacement ventilation system in the winter months.

## 3.9 Conclusions and key findings for this section

The design and specification of services that will have a visual impact on the aesthetics of the building and spaces must be informed by adequate analysis. While it was clear to see that the lighting layout was coordinated with the roof soffit profile which in turn was designed to maximise exposed thermal mass for supporting the night-purge ventilation strategy, it was noted from the walkthrough (and some of the survey responses) that the internal light levels were considered to be too bright.

The ground source heat pumps were incorporated in response to the client’s preference for low carbon technology. The operational implications of the system may have however not been highlighted adequately from an early stage.

The high levels of electric lighting combined with the control strategy no longer being effective due to the installation of the film is likely to have a significant impact on both operational energy use and occupant dissatisfaction (due to perceived discomfort and lack of ability to control the service). A review of the installation and controls and recalibration of the installation should be considered.

It is common practice for the main M&E consultants to sub-contract specialist services to several sub-contractors. While this may be a way of ensuring the correct expertise is available, the specification and coordination of and between the systems becomes significantly more crucial.

Communication must be ensured not just within the services team but all changes must be communicated back to the main design team as well. A services coordinator was appointed as part of the services team but little communication was reported with the design team.

For a building that is regarded to be relatively 'low-tech', with a mixed-mode ventilation system and comfort cooling only, the importance of how controls are set up is higher than in a fully serviced solution. This is because there is a level of control and interaction of the users with the building that is essential to achieving comfort and must not be in conflict with the way the automatic controls are set up.

The setting up of the BMS is crucial when multiple systems capable of multiple operations come together. For instance, mechanical supply ventilation is capable of being coupled with cooling and heating, but in the case of this building was only designed to provide pre-warmed air in the winter and not be connected to the cooling cycle of the heat pump at all.

# 4 Key findings from occupant survey

## 4.1 Introduction

The Building User Satisfaction (BUS) survey was carried out as part of the requirements of this research project, on the 10th of October 2012 An email informing the nature and purpose of the survey was circulated to Greenfield employees a week prior to the survey and on the day.

The standardised questionnaire was handed out to all the staff present in the building, with some additional forms left on the desks of people not present in office at the time.

Around 100 survey forms were distributed out of which 87 responses were collected on the same day and 2 were returned by post at the end of the same week.

Semi-structured interviews were carried out with key occupants, the facilities manager and the finance director of the organization, who was also able to provide information on the handover and initial occupancy stages. Their input has been incorporated in the relevant commentary throughout this report.

The feedback on the survey forms was processed by ARUP and plotted against the response from several other buildings of a non-domestic use. This included buildings of different uses and also with varied building services strategies, which would impact the expectations of the users from the buildings and also the degree of interaction of the users with the building to achieve comfort levels. All the buildings within the dataset are represented with the unfilled circles in the graph below and the Greenfields office building is marked with the filled circle.

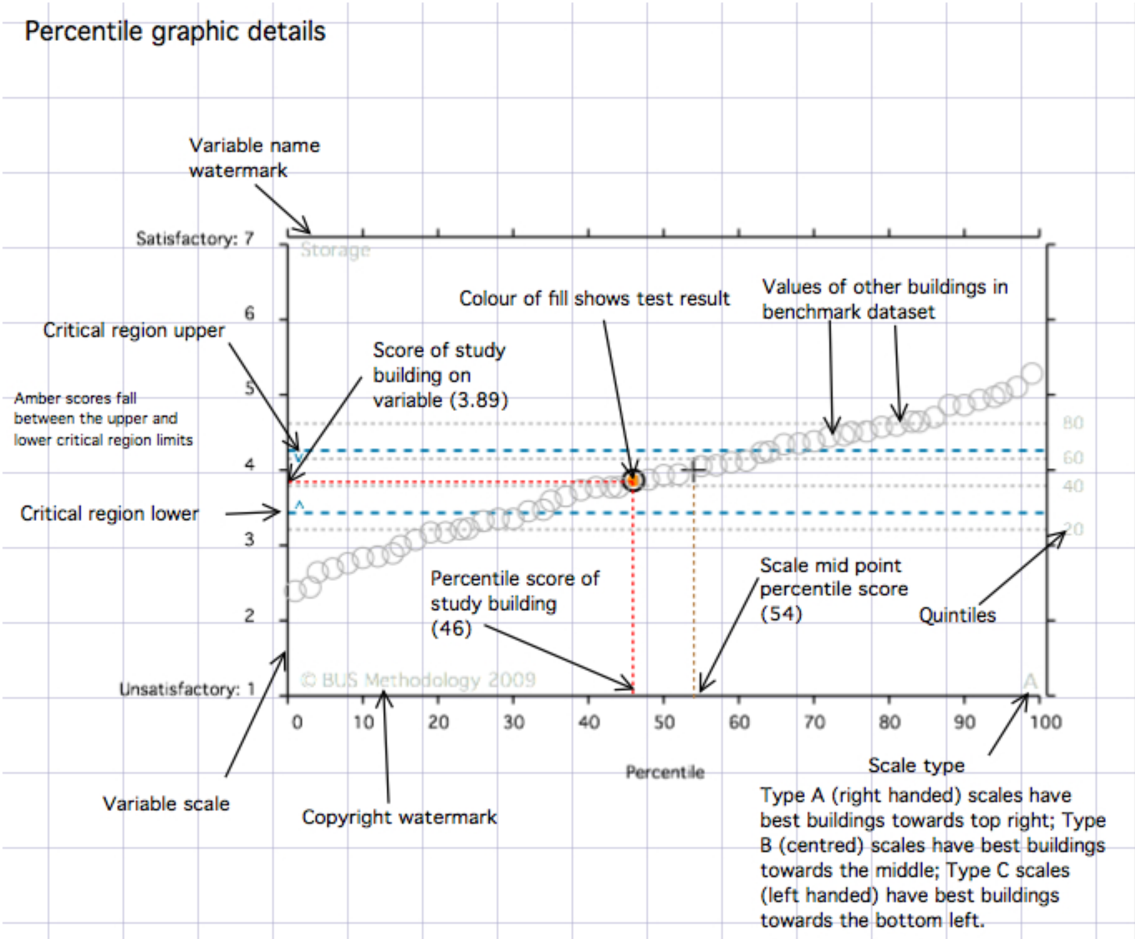
## 4.2 Interpreting survey responses and graphs

The BUS survey result evaluates the experience of the users on a scale of 1 to 7 against a list of criteria. The results are also placed within the context of results of the same survey conducted for similar buildings (other offices in this case), which are used to set benchmarks.

The results expressed below in graphs and charts follow a ‘traffic signal’ convention, with scores significantly higher than the benchmark indicated in [green], those within the critical regions shown as [amber] and averages falling below the benchmark critical range in [red]. An appendix of all the graph types and their interpretations is included at the end of this report

**Percentiles:**

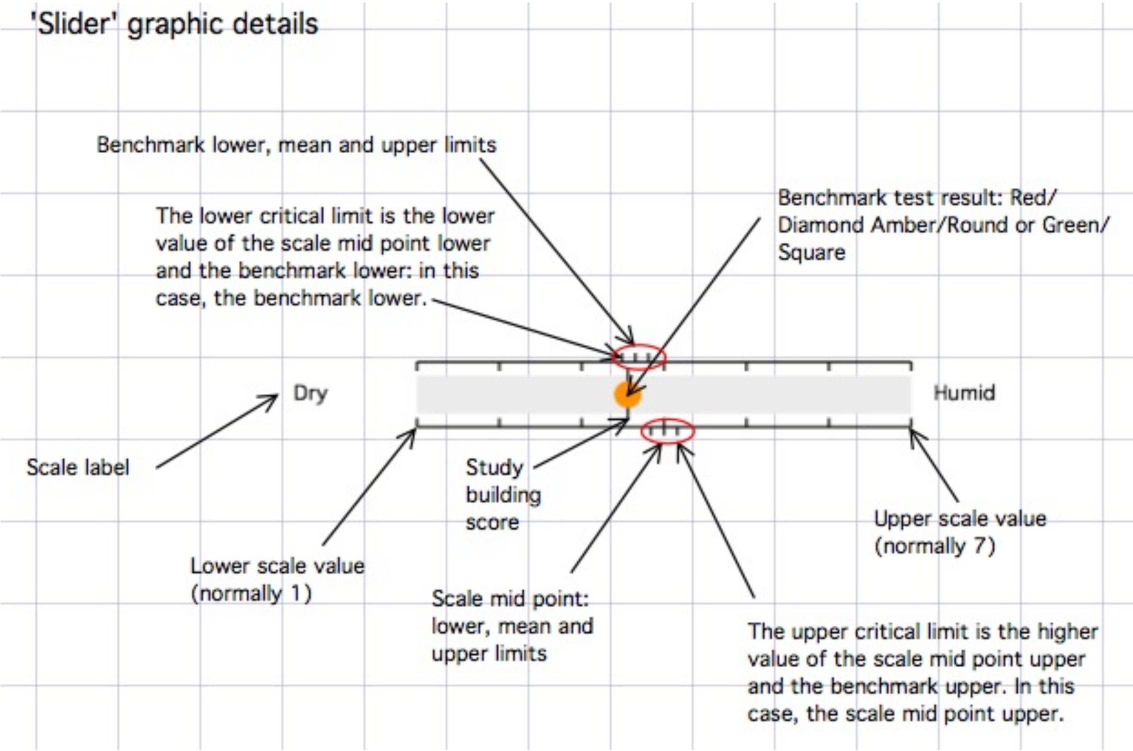
These show the score of the studied building represented by the filled in black circle, placing it in context of other non-domestic buildings, which includes other offices, schools, hospitals, museums etc. with different heating, cooling and ventilation strategies. The black cross in the graphs represents a hypothetical building achieving an average (mid) score within the context of all the other studied non-domestic projects.




**Horizontal sliders:**

These are marked with the 'critical' range, which is defined between the scale mid-point and the benchmark mid-point values. The scores lying within this range are marked as orange, with higher scores marked as green and lower ones indicated in red.

It should be noted that this provides a comparison of the score of the building survey with the average of responses of surveys from other buildings. These do not by themselves represent 'good', 'average' or 'poor' conditions for the specific category.




## 4.3 Overall Comfort

The overall scores were positive, however some issues were highlighted through this exercise.

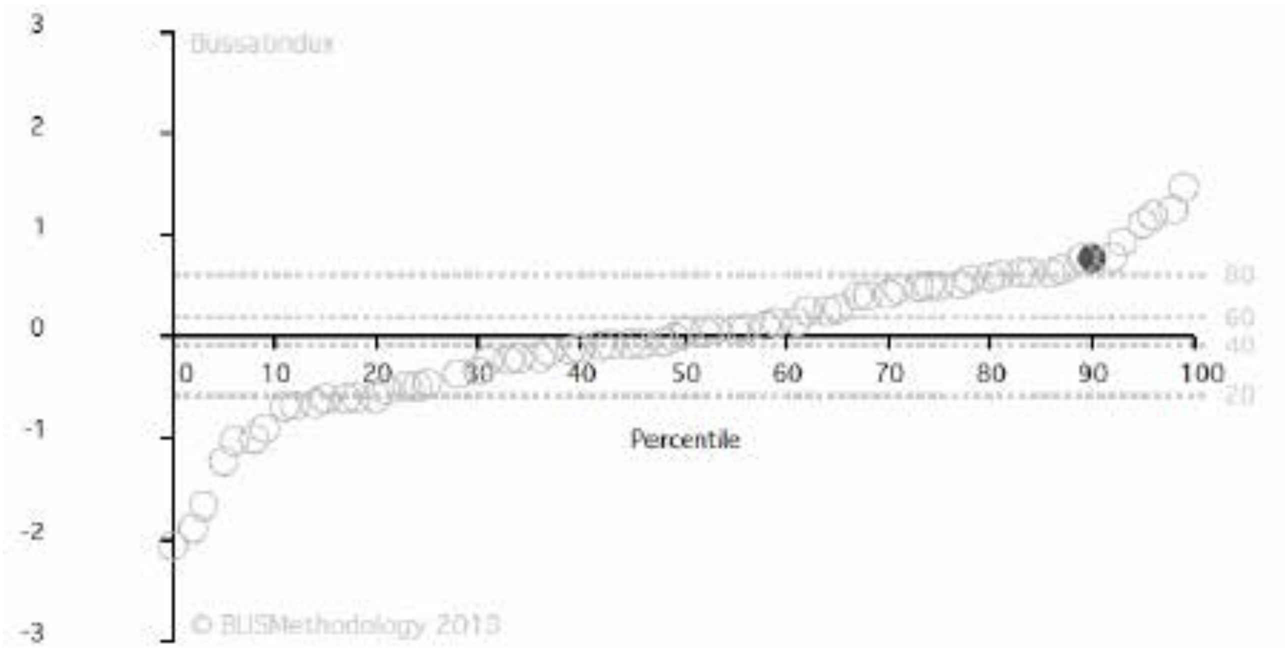



Figure 15 Overall satisfaction evaluation

## 4.4 Design

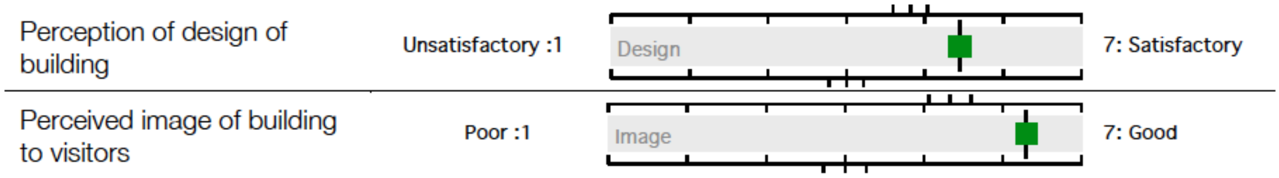



**Figure 16 Summary of responses on Spatial Characteristics of building**

The overall score for the design of the building was high, as was the forgiveness index, with the opinion split between people's high expectations from a new bespoke office building, and the appreciation for the range of activities and facilities incorporated in the building.

The score from the building marked above tends to be towards the positive end of the graph and the green marker represents that it performs better than the range of responses from within the wider dataset. Red markers on this scale represent responses that have fallen below the standard set of responses and yellow circles represent where the responses for the studied building fall within this critical range.

***'Nice ideas but does not take into account individuals and their preferences'***

***'Large office - easy communication with the team. Fact that more teams based within one building helps. Break-out area and kitchen point work well - efficient.'***

The modern appearance of the building and its standard of finish and facilities are perceived as largely positive aspects. However, the expectations for comfort from a new building is not being met in its daily operation.

***'The building itself is an amazing one, however the heat and lack of ventilation tarnish it.'***

***'Lack of toilets when they don't work, which is often due to system of harvesting water. Don't expect to use a bucket to slop water down the toilet or walk to Freeport in this day and age.'***

## 4.5 Comfort

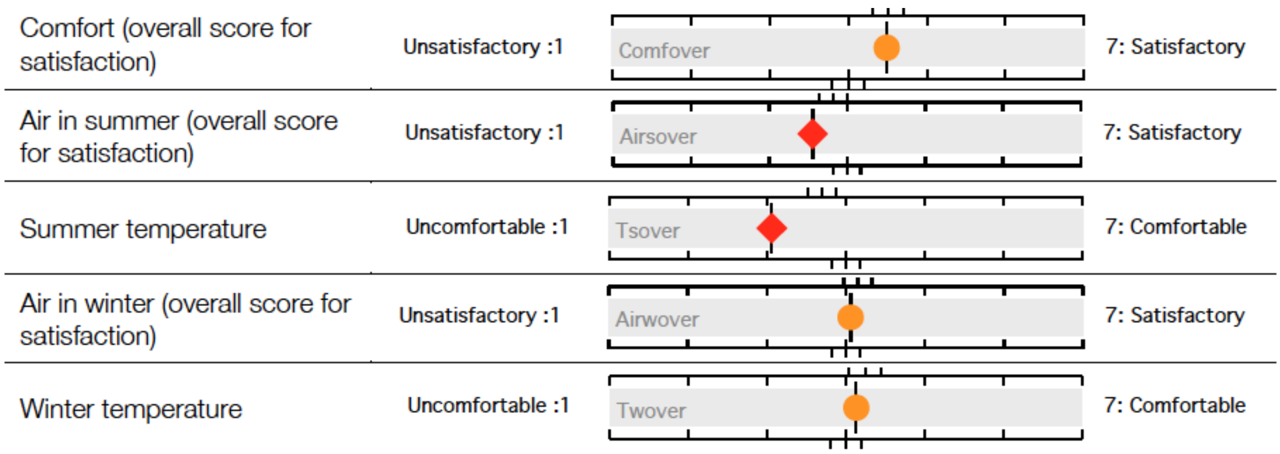



**Figure 17 Summary of responses on Internal Conditions**

There was generally dissatisfaction with the internal comfort conditions in the building, with the office areas perceived as being too warm, both in the summer and in the winter. While the winter conditions were designed to be controlled by managing the heating system via the BMS, the summer conditions were intended to be controlled by night purge ventilation via the BMS and largely by occupants operating windows as required.

***'Very hot and stuffy even in colder months. Temperature similar to 'Green room' would be perfect.'***

The 'green room' is an informal space located on the top floor of the building with vending machines and tables for staff to use during breaks and lunch, and leads on to a terrace. It is likely that due to the informal nature of this room, the user find it easier to control the light and ventilation and also have a wider range of comfort in a non-work environment.

There was however significant dissatisfaction with the summer temperatures in particular and some responses highlighted this as a health concern.

***'Due to lack of air etc. causes lethargy and headaches. An environment to spread germs. Concern over toilets as during damp/wet weather there is s very often a smell of sewerage.'***

***'I have no doubts that the heat levels have a negative impact on every sense of well being, possibly health and do have an impact on my productivity (negative).'***

On the said day of the survey, most of the windows were closed, this was due to a combination of some of the staff being unsure that they were meant to operate these and due to the general problem of achieving comfort for all people in an open plan office space. The research team encouraged the staff to open windows during the walkthrough and the space felt noticeably cooler later in the day.

## 4.6 Facilities management

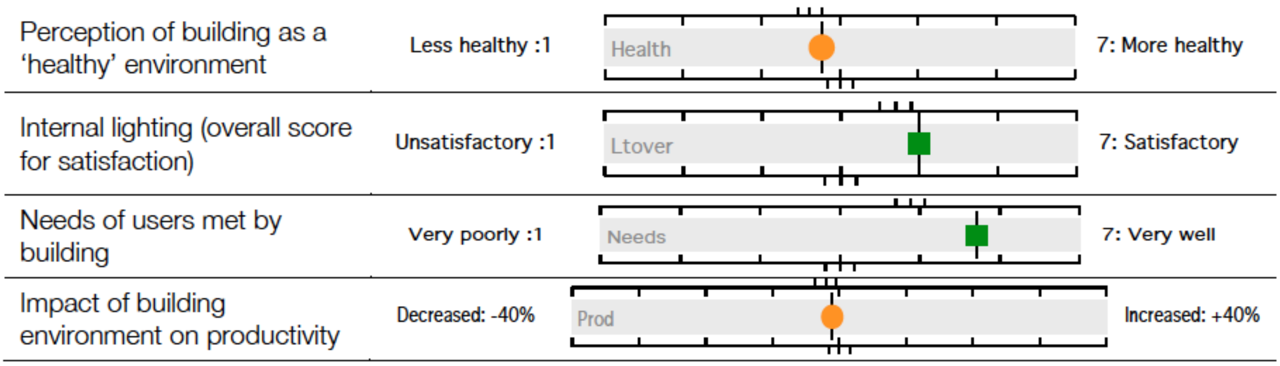
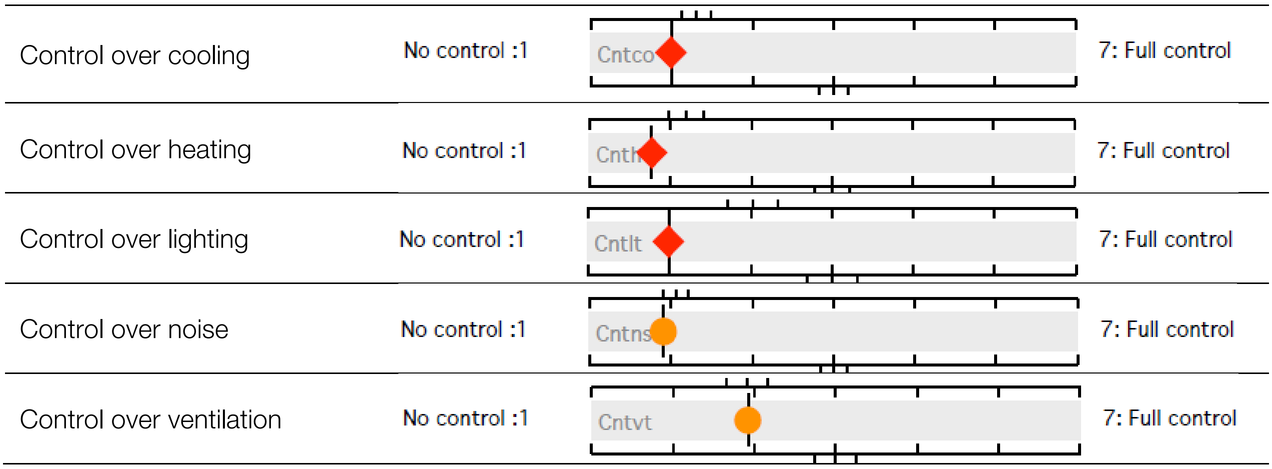



**Figure 18Summary of responses appraising the Work Environment**

There appeared to be considerable uncertainty amongst the staff on the degree of control they had on the services and their environment, which impacted the level of satisfaction felt with the operation and conditions within the building and also with the facilities management team.



***'Building gets too hot. Apparently windows only open on temperature outside. Crazy!'***

***'Gets so hot - but windows slam shut. Lights always breaking. Taps always breaking.'***

***'Cannot adjust lights. Too hot in summer - windows barely open, no fresh air/oxygen.***

## 4.7 Recommendations

In order to address some of the ambiguity on how the staff must interact with the building in order to be comfortable, additional information should be provided. This may be in the form of simple manuals or reminder notices posted in the office or as a series of open discussions.

While it is accepted that it is difficult to find a 'one-size fits all' comfort level in office spaces that are shared by occupants with varying preferences who also interact with the spaces for varying durations, it is important for staff to have a regular route to communicating feedback to the facilities team rather than feel that only a few people that complain disproportionately are heard. This would also help people appreciate the varying perceptions of comfort and expectations from the same work space.

A repetitive comment from the surveys was the perceived discomfort in summer. The ventilation in the building was designed to be via low level windows in the summer which were meant to be controlled by the occupants, in addition to the high level hoppers that were on actuators connected to the BMS. It needs to be acknowledged that the trees that were part of the shading strategy along the southern facade were not incorporated successfully, which would impact the initial design strategy appraisal. While the installed solar film has helped partially with reducing glare within the open plan offices, it appears to have reduced the ability of the electric lighting dimmers to work properly due to which there is now glare perceived from artificial lighting. The offices also have blinds and their use does not appear to be compatible with the other measures for limiting solar gains and glare. It would also mean that discomfort in the summer is not unexpected and more support must be provided to deal with this, including managing the opening of both high and low level windows. The BMS logs temperatures within the separate offices and this can be used to help with the exercise.

The building was designed to accommodate different departments of the organisation within one building, which is generally appreciated by the staff. Issues arising from the resulting building configuration, such as noise due to visitors etc. may be addressed for example, by managing access times and staff expectations.

The building's environmental services strategy relies on a combination of a managed Building Management System (BMS) and a level of occupant control. It would appear that the staff needs to understand the underlying environmental strategy for the building with guidance as to how they can control their environment. The operation of the BMS will need to be managed and should be evaluated periodically to ensure that it is being used efficiently. Anecdotal evidence suggests that people have a higher threshold of tolerance in buildings that are naturally ventilated if they feel they have adequate control on their environment.

## 4.8 Conclusions and key findings for this section

There is a generally positive response to the design and appearance of the building, with the staff being appreciative of the modern standard and facilities and also of the bespoke nature of the office that incorporates provisions for different activities.

The environmental strategy for the building was based on the staff engaging with different features of the building to achieve comfort within their working environment, including lights, heating controls and windows. While provisions for facilitating these controls have been made, the staff generally does not understand the environmental provisions or interact with these features.

Some design strategies should be reviewed by both the client body and the design team, including the balance between window sizing for daylight and shading measures including the landscape strategy incorporating trees and occupant controlled internal blinds.

# 5 Details of aftercare, operation, maintenance & management

## 5.1 Aftercare

Delays during construction (due in-part to a cold winter in 2008), in conjunction with a non-movable construction end date, impacted the programme for the commissioning of the building and services. Procedures for handing over the building were rushed and coincided at a time when the client was focused on the logistics of relocation, rather than understanding how to use the new headquarters. Consequently, the building was handed over without being fully commissioned, particularly the BMS, and the new owners had limited knowledge of its operation and services.

Neither operation and maintenance manuals, nor a building log book were available at handover. Not only did this hinder the ability to learn about the building, but their omission has been cited as a reason for a delay in setting up necessary maintenance contracts for key plant and services in the building. The O&M that is currently available for the project provides detailed manuals for the individual components but little by means of the algorithm to which the BMS has been set up.

The main contractor dealt with emerging snagging issues in the immediate 12 month defects period following hand over, but limited training and hand over guidance had been offered. GCH appointed key staff members to set up a planned maintenance programme with the assistance of the design team and the contractor's site manager. However, all of this was done after hand over, and after the client became aware of the many tasks involved with managing the heating and ventilation in the building as they were entering winter.

## 5.2 Maintenance

Many of the operational procedures have been discussed elsewhere in this report and in detail in the walkthrough report. This section details some of the maintenance issues encountered by the building's facilities team. There have been a number of reliability issues related to the heat pumps, server room cooling, and in particular the lighting and controls in the open plan offices.

### Space heating

The heat pump installation was one of the first to have planned maintenance contracts set up by the client. The company appointed to maintain the system is the original installation company, which is understandable. One legacy of the initial operational problems with the heat pumps (due to inadequate commissioning of the controls for GSHP 2 and 3) is that the engineer deals mostly with fault clearances to ensure reliability of service. It would be recommended to have a full strategic review of the controls and associated response times of the heating system and to have the heating system, as a whole, re-commissioned accordingly.

### Lighting

The office areas fitted with the pendant lights have been subject to numerous complaints by staff. Complaints received are mostly to do with the offices being too bright, but some are to do with lack of control. The fitting of the window film has likely had a role in increasing the lumen output from the luminaires to compensate. This could be improved with the re-commissioning of the sensors, which would reduce both lighting levels and energy use. The installed capacity of lighting should be reviewed for future projects. The amount of luminaires seems excessive and either the lumen output should be reduced (smaller number of lamps and/or lower lamp output), but preferably the number of luminaires should be reduced. In the east office, the staff have requested that 50% of the lamps are removed (two lamps out of four per fitting) and this has reduced the lighting to a satisfactory level. The amount of installed pendant fittings is a maintenance burden to the facilities team which has proved to be costly and time consuming for carrying out global lamp changes. This has been exacerbated by the high degree of control gear failures, which has resulted in higher than expected maintenance costs.

Controls for the office area lighting are poorly understood by all staff. It is not clear how they are zoned and each open plan area has only a single non-retractive switch at the entrance, which does not appear to have any function. At the time of the walkthrough there was no means to switch the lighting off at all. Clearly this is an issue that needs to be urgently addressed. However, due to the amount of problems encountered by the client, it is not possible to determine if the problem is a latent commissioning defect, or caused through post-handover maintenance procedures.

The second floor open plan offices and other remaining areas of the building have no reported problems with the lighting, both in terms of operation and maintenance. Further details can be found in the walkthrough report.

**BMS**

Controls - It is expected that the simple user interface at the BMS panel located in the basement plantroom being the only accessible means to managing the BMS impedes good building management practices.

Prior to study, omission of client PC due to 'value engineering' must have an impact on how well the building operation was being monitored and run. However, in order to support the research project, the building occupants installed the PC interface. The sub-meters in the building were subsequently connected to the BMS via CT clamps and while this is not a robust installation, it is unclear whether the building occupants intend to use this data to inform their facilities management and energy use optimisation.

## 5.3 Management

The strategy for managing the comfort conditions in the building relies both on a successful understanding and operation of the BMS, and on the building users to control their immediate environments. However, in reality, the building managers received numerous complaints from staff in the early stages, post hand over, many of which were related to inadequate commissioning and poor user understanding (inadequate hand over procedures). Common complaints included:

- Headaches from solar glare
- Overheating (both summer and winter)
- Too bright (artificial lighting)
- Sewage smells

These user complaints are explored in detail in the walkthrough report, but the remainder of this section summarises some of the management responses to these issues along with a discussion for the longer-term maintenance implications and impact on energy and comfort performance.

## Overheating and glare

In response to the complaints about overheating and glare, the building owners had solar film fitted to the windows. This was carried out without consulting the design team, who were not aware of the complaints. Since fitting the window film, the complaints have almost gone. However, the fitting of the film has reduced the amount of available daylight slightly, which means the lighting sensors are signalling the luminaires to remain on throughout the day. While this may have helped reduce passive solar gains (temperature data for before and after installation was not available) the increased use of electric lighting along with a lack of understanding of use of the openable windows is likely to have countered this effect.

The design team had specified solar control blinds as part of the contract, but from information provided by the main contractors they appear to have been value-engineered out. Staff also complain that the blinds flap in the wind when closed (and windows opened). This could be improved if the specified blinds were captive type, but the exposure of the south elevation (where many of the complaints come from) would benefit from some sheltering, as was intended with the trees in the landscaping scheme.

Many staff members were also of the opinion that they were not supposed to open windows as they had been told by the facilities manager that the building was fully automated by the BMS. They believed that opening the windows in summer would confuse the system and could signal the heating to come on. This illustrates the importance of user understanding and the communication of the intended strategies.

The BMS automatically opens the natural inlet vents when internal temperatures reach 21°C in summer. For some staff, this temperature may be set too low and make a complaint to the facilities manager. Based possibly on one complaint, the facilities manager will override the BMS and close the ventilation inlets to the entire building. The override facility should only be used in extreme circumstances, and it is possible that the vents remain closed until the following day when the system resets. It is recommended that the set point temperatures are reviewed to allow the actuators to open, possibly at a slightly higher temperature.

## Energy implications

- The fitting of window film will possibly offer some comfort benefit in summer. There is no active cooling in the main office areas (where the window film is fitted) so there will be no energy benefit.
- The window film may have the effect of reducing useful winter gains into the building. The characteristics of the film could not be verified, but many solar films have a solar energy rejection value >50% and up to 85%. This could have a negative impact in winter by increasing reliance on the heat pumps to maintain comfort conditions, hence increasing the energy cost of the building significantly above design targets.
- The reduced daylight available inside the offices results in the lighting being on for longer than necessary, possibly at full brightness (not dimmed to synchronize with daylight levels). Re-commissioning of the lighting sensors to calibrate them to lower light levels would reduce the amount of energy use.

### Rainwater and soil services

Harvested rainwater is used to serve the toilet flushing in the building. However, poor electrical installation practice led to the toilets being closed for a period after hand over. Water ingress into a pump wiring terminal box resulted in a complete failure of the pump. The failure was difficult to trace as it was concealed within a manhole chamber under the car park. This has been resolved, but as a contingency to prevent future similar events, the disabled toilets on each floor have been connected into the mains water.

Poor workmanship on the above ground soil drainage resulted in numerous complaints about sewage smells, which occurred around the same time as the rainwater pump failure. The cause of the smell was traced to incompatible connectors between the above ground and below ground systems. Sewage gases were able to escape at these interfaces and into the office spaces.

These issues should have been reported as latent defects. However, these situations needed to be addressed urgently and it is understandable, given the declining relationship between client and the main contractor, that these were independently resolved by the facilities team.

### Facilities Management

The facilities management team consists of two people, including the facilities manager. They are employed full time by GCH and work in the office building. Their knowledge of the systems and services are based upon tacit knowledge and they have developed a reasonable level of understanding about the individual systems and their quirks. Neither have had any formal training in Facilities Management, nor specific training on installed plant and systems, including the BMS. It is understandable, therefore, that other than co-ordinating engineer attendance for the planned maintenance contracts, their roles are more reactionary and often include dealing with staff complaints.

## 5.4 Recommendations

It is understood that due to pressures of an inflexible date for the staff to move into the building, the handover process was compromised. It is recommended that appropriate training is now provided to the facilities manager on the intended strategy for the building, operation the use of the installed system

A mixed-mode building requires a certain amount of interaction between the users and various features in order to be a comfortable space. It is recommended that a process of collecting structured feedback from the staff is put in place, which will help with regular appraisals and adjustments of the way the BMS is set up in regular intervals

Due to changes in the amount of daylight entering the open plan offices, (due to lack of trees along the south facade and the additional film added to the windows) the lighting levels that the controls were designed for have changed. It is recommended that the internal lighting and controls strategy is reviewed.

## 5.5 Conclusions and key findings for this section

The end date of the project programme was inflexible since the staff had to move out of other premises. Due to delays in the programme, commissioning had to be accommodated within the period allocated to handing over. The implications of this were not fully appreciated by the occupants who have since then had problems with the operation of the building.

Some of the repeated complaints about the building including smell from the toilets would have been more effectively addressed pre-occupation but the opportunity for this was undermined.

There appeared to be no clear log and maintenance reports that were provided to the research team. This would have been an effective instrument in enabling the facilities managers to observe use trends and optimise the heat curve setting for maximum system efficiency.

The displacement ventilation system appears to be non-obtrusive with no specific comments or complaints about disturbance from its air flow and temperature.

It is unclear how the labyrinth is maintained. If unwanted plant growth takes place within the duct, it may impede air flow and present resistant to the AHU operation, which will increase energy use. There is no data to ascertain this as the analysis on the AHU was not carried out.

The high level hoppers can be opened during the day in very warm weather but it was reported that the actuators also respond to rain and may not open the windows even after it has stopped raining if water is detected on these. The location of these and their slope may need to be checked and changed if needed.

According to the BMS, there is a common operation flag for all FCU units for the respective floors, which are adjusted via thermostats in each room. The interface for these allows occupants to increase and decrease the temperature in the space relative to the supply temperature by a certain amount. This is not a very informative control and an alternative may be considered.

# 6 Energy use by source

## 6.1 Introduction

This section reviews the energy use by the building over the monitoring period. During this time, the building was fully occupied. It is presumed that any initial transitional period is over and the energy use is reflective of longer-term occupation.

The building energy use data is recorded by the building management system (BMS) and is used in the analysis in this section. This data source has been added to the BMS as a retrofit activity during the course of the study. Issues associated with its installation are summarised in Section 7.

This section summarises the energy break-down by end-use and highlights issues of excessive energy use through an energy reconciliation exercise using the CIBSE TM22 methodology and via comparison against corresponding benchmarks.

## 6.2 Building energy use

The energy assessment is based on billed and metered energy data provided by GCH for the period 1st January 2013 to 31st March 2014. The building is an all-electric building and hence there is no metered gas. The building principally uses ground source heat pumps (GSHP) for its provision of space heating and cooling. Domestic hot water (DHW) for taps and showers is generated via direct standalone point-of-use electric systems.

The electricity provision to the building has changed between several suppliers and tariffs. However, all consumption reporting are consistent and good quality billing data could be obtained for this analysis. **Error! Reference source not found.**18 shows the billed energy consumption for 1st January 2012 to 31st March 2014, broken down into day and night consumption. Included in the graph are the corresponding local heating and cooling degree-days based on a base temperature of 15.5°C.

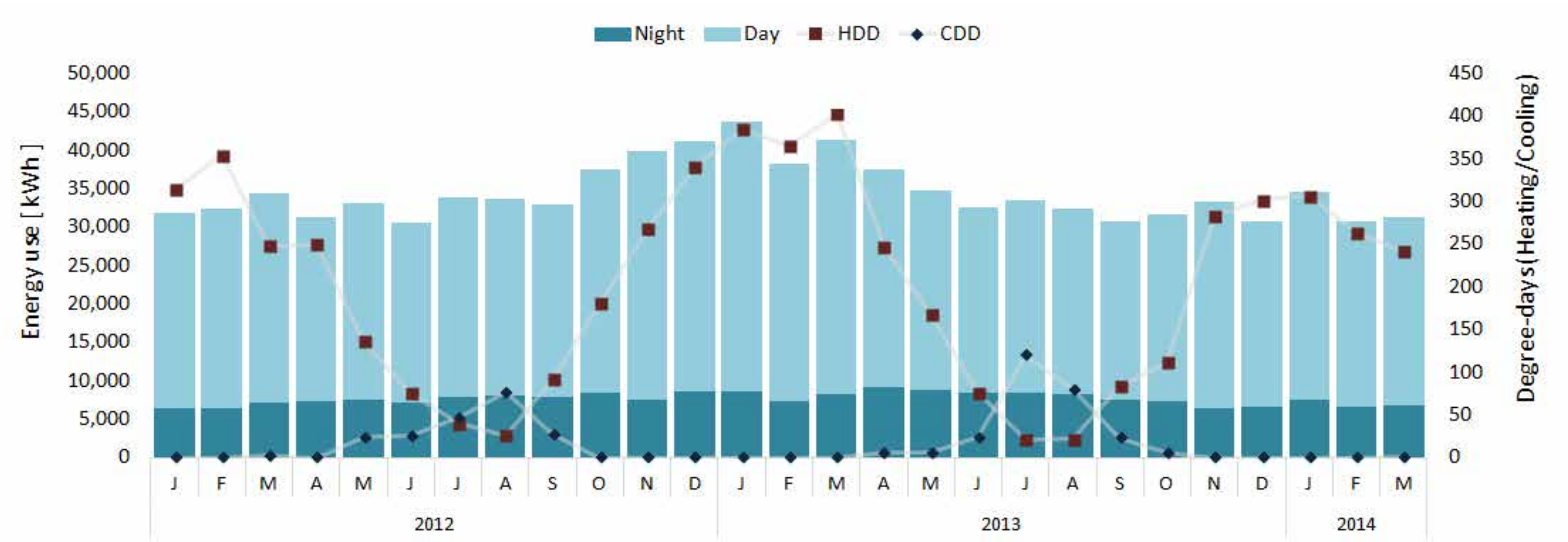



**Figure 19 The GCH building billed electricity consumption for the period January to December 2013, including the corresponding local Heating and Cooling Degree-Days**

The metered energy data from GCH's energy bills shows the highest energy consumption occurred during the 2012/2013 winter period which corresponds to the highest prolonged heating degree day data. However, with the exception of this peak, in general the energy consumption during the rest of the monitoring period is similar. An explanation for this is that heating (and cooling) is a relatively small proportion of the energy use in the building which is more dominated by other uses such as the server room, the AHU, pumps, lighting and small power use. This is demonstrated later in this section – see Figure 28.

The night (midnight to 7am) energy consumption appears to be fairly constant throughout the monitoring period. Subsequent analysis of BMS sub-meter data in this Section highlights this is principally due to out-of-hours use of lighting and the continuous operation of the IT/comms room and plant equipment.  This is seen in data presented in **Error! Reference source not found.** and **Error! Reference source not found.** (details of sub-meters are described in Section 6.3). The average monthly metered night time energy consumption recorded by the BMS is approximately 7700 kWh, which is consistent with the average billed consumption.

## 6.3 BMS metered energy use

The building has 15 physical meters at the distribution boards in its basement plantroom, comprising of 14 electricity sub-meters and 1 building-side main meter, as illustrated in **Error! Reference source not found.**. Based on the O&M manual, there are some energy uses that appear to be un-metered, which include the lift in the core area. There may be other appliances not sub-metered but these have not been identified. The *main panel* circuit is where most of the building central plant is connected, including the GSHPs, AHU, extract fans and circulation pumps. The FCUs are powered on the respective floors' small power circuits.

During the study, a retrofit installation has been carried out to enable the BMS to record the building energy use provided by the physical meters. In addition, 3 CT clamps were also installed to include measurement of energy use by the respective GSHPs onto the BMS. Official BMS energy data is available from 19th July 2013 to 31st March 2014.

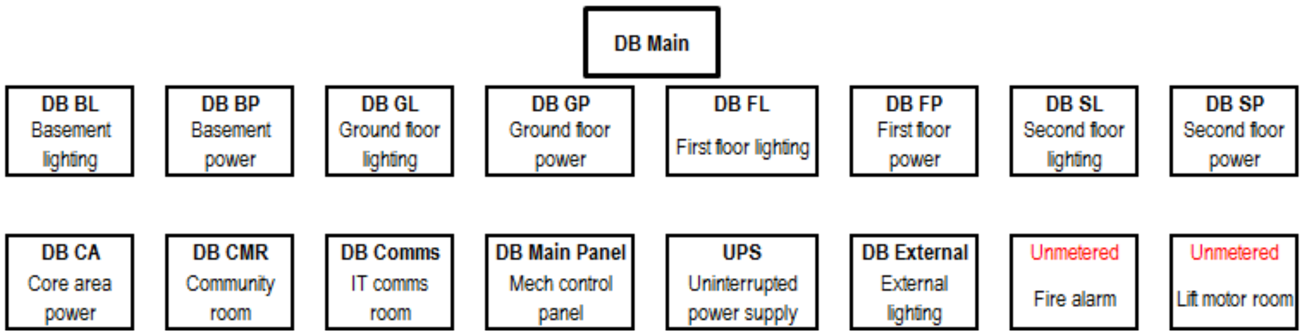
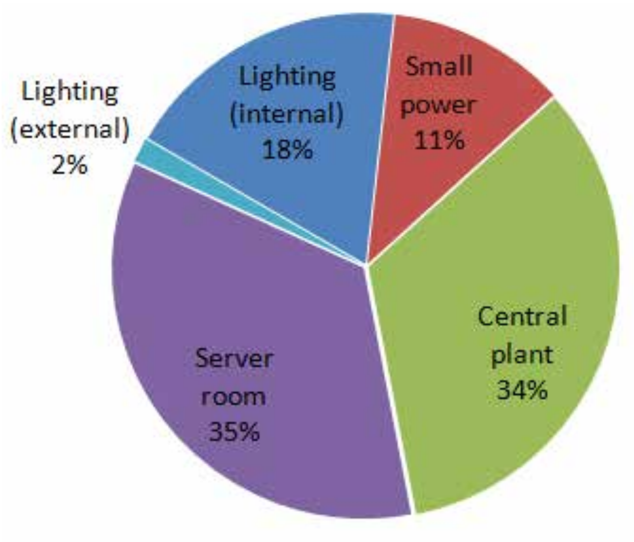



**Figure 20 The metering arrangement for the GCH building**

Figure 21 shows the proportion of the respective end-use energy consumption over the building annual total. Included is the tabulated annual consumption for the end-use energy categories rationalised to the building total floor area of $2180m^2$.




| End use category | Sub-meter |
|---|---|
| Lighting (internal) | DB BL, DB FL, DB SL |
| Small power | DB BP, DB FP, DB SP |
| Central plant | DB CA, DB CMR, DB CA, DB Main Panel |
| Server room | DB Comms, DB UPS |
| Lighting (external) | DB Ext |

| End-use energy | kWh/m2 |
|---|---|
| Lighting (internal) | 30 |
| Small power | 19 |
| Central plant | 54 |
| Server room | 56 |
| Lighting (external) | 2 |

**Figure 21 proportion of building total energy consumption based on end-use category**

## 6.4 Energy by end-use: Lighting

**Error! Reference source not found.** shows the sub-metered lighting energy use for all floors in the building. All the floors exhibit approximately consistent lighting energy use throughout the monitoring period. The exception was the ground floor where the lighting energy was observed to reduce from October 2013. This occurred for both weekdays and weekends energy use, being most pronounced for the latter. This may be due to an improvement of lighting management during out-of-office hours. We have not been able to identify through discussions with the building manager why this change occurred.

It appears that some lights are left switched on, on the ground floor and similarly on the first floor, on weekends as well as over the Christmas-New Year period. This may be for security purposes, otherwise it presents an opportunity for energy saving.

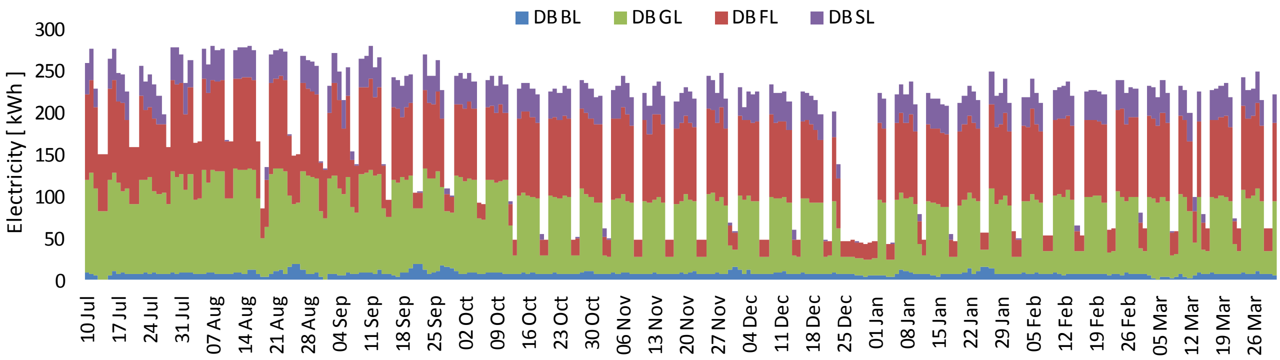



**Figure 22 Daily lighting sub-meter readings (stacked) between 10th July 2013 and 31st March 2014**

**Error! Reference source not found.** shows the monthly lighting energy consumption for the respective floors, where the ground and first floor are consistently higher throughout the monitoring period, due to higher levels of occupancy, hence the utilisation of work space and the relatively larger office floor areas. The second floor as shown earlier in Figure 12, is significantly smaller in floor area due to a proportion of the floor being used as an outdoor terrace. Furthermore, the office space is significantly reduced by a breakout area in the east wing of the second floor. This is reflected in the lower lighting energy use on the second floor. Out-of-hours use, shown in **Error! Reference source not found.**, also contributed to an overall higher consumption on the ground and first floors.

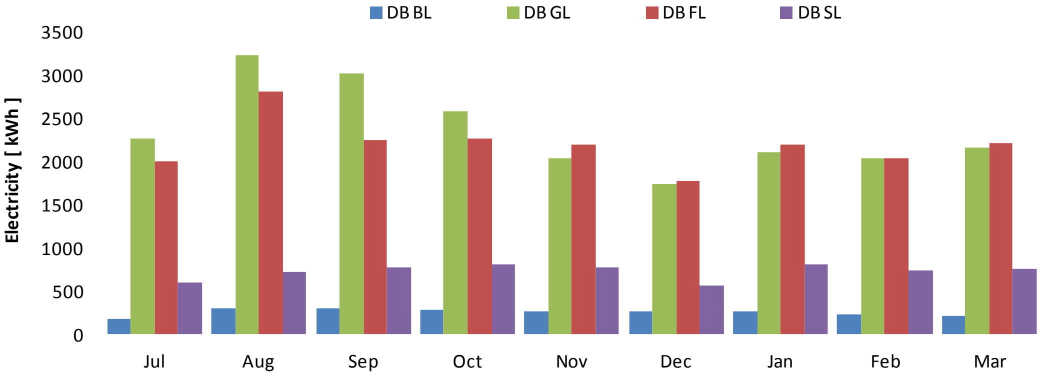



**Figure 23 Monthly lighting energy use between 10th July 2013 and 31st March 2014 (July total not for a full month)**

## 6.5 Energy by end-use: Small power

In general, small power consumption was consistent throughout the year on each floor, with the exception of significant variations on the second floor over the monitoring period as shown in **Error! Reference source not found.**. This could be due to the relatively small office space on the floor and a more variable occupancy compared to the other floors. It is anticipated that the breakout area on the second floor would naturally have a very diverse level of usage on a daily basis.

The low consumption over the weekends confirms both limited occupancy (the building manager has pointed out that there were occasions when the building was opened on some Saturdays with low level of occupancy) and good management of turning off small power appliances.

There is effectively no significant small power use in the building around the Christmas-New Year break weeks, which again implies good building management that ensured, as far as possible, unnecessary small power loading was switched off when the building was closed.

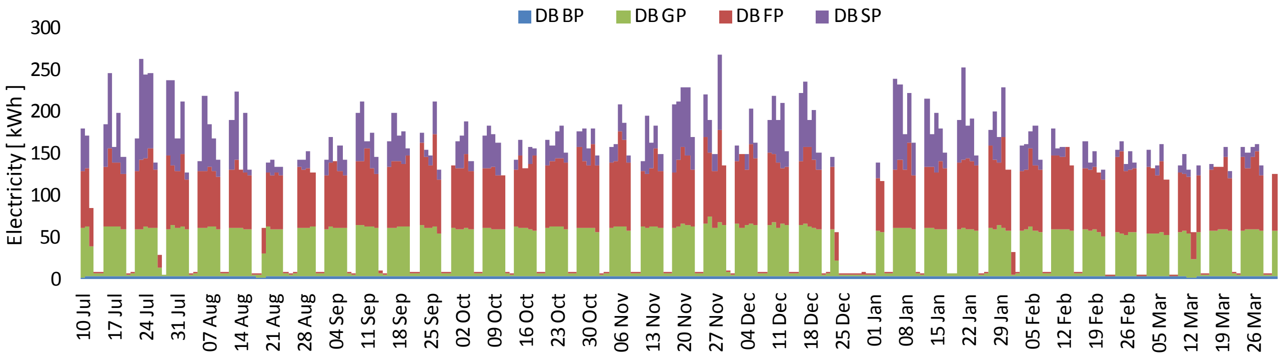


**Figure 24 Daily Floor small power sub-meter readings (stacked) between 10th July 2013 and 31st March 2014**

Similar to the lighting energy, the monthly small power consumptions are generally higher throughout the monitoring period for the ground and first floor as shown in **Error! Reference source not found.**, corresponding to higher levels of occupancy.

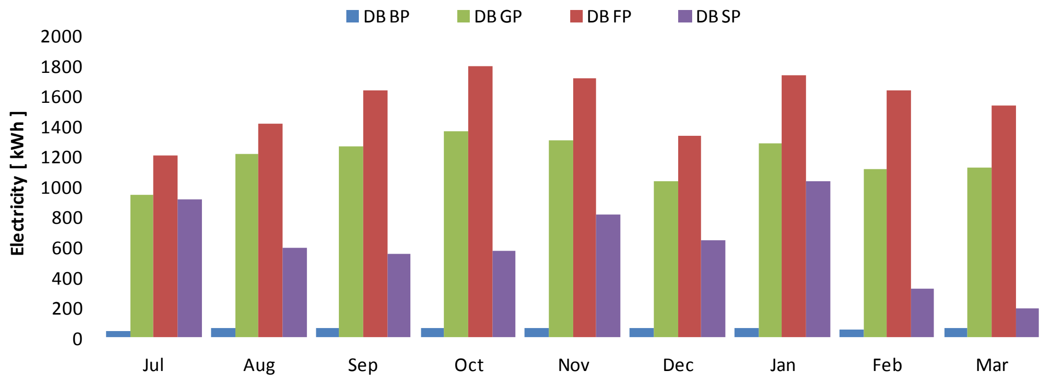



**Figure 25 Monthly small power energy use between 10th July 2013 and 31st March 2014 (July total not for a full month)**

## 6.6 Energy by end-use: Central plant and other areas

**Error! Reference source not found.** shows the energy use in other areas and by the building central plant and IT/comms room, including that for external lighting, core area (atrium circulation and reception) and the community room.

The *DB Main Panel* circuit includes the building services plants such as the GSHPs, AHU, extract fans and circulation pumps. There is a slight increase in energy use on the *DB Main Panel* circuit from November 2013 onwards, which corresponds to the onset of the heating operation, which appeared to have been accompanied by an increase in the cooling operation (see **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). However, it is not entirely clear from the data whether the simultaneous cooling and heating was due to coincidental demands from different parts of the building or to heating-cooling conflict as a result of mismanagement or poor BMS setup. It must be noted that the open plan office spaces are not mechanically cooled, but only the cellular spaces (meeting rooms and small offices).

The *DB Main Panel* sub-meter also shows a significant and constant use of energy over the weekends. **Error! Reference source not found.** shows the operation of the heating and cooling circulation pumps, the ground loop pump and the circulation pumps for the GSHPs as recorded by the BMS. It is inferred, through the operation flags, that the cooling circulation, ground loop and GHSP circulation pumps were being operated continuously, which may be the cause for the observed weekend consumption. This represents a potential area of energy wastage, which should be addressed by the building owners and facilities manager.

Other aspects of central plant energy use appear to be consistent and as expected throughout the monitoring period, with significant reductions over the weekends indicating plant turn-down during out-of-office hours, as can be seen with the heating circulation pump shown in **Error! Reference source not found.**, the AHU as shown in **Error! Reference source not found.** and the FCUs in **Error! Reference source not found.**.

The energy use sub-metered on the *DB Comms* and *UPS* circuits, which serve the data centre, are as expected, continuous and fairly consistent over the monitoring period. The slight reductions in the UPS energy use correspond to reduced computation demand during out-of-office hours and over the weekends and Christmas-New Year period.

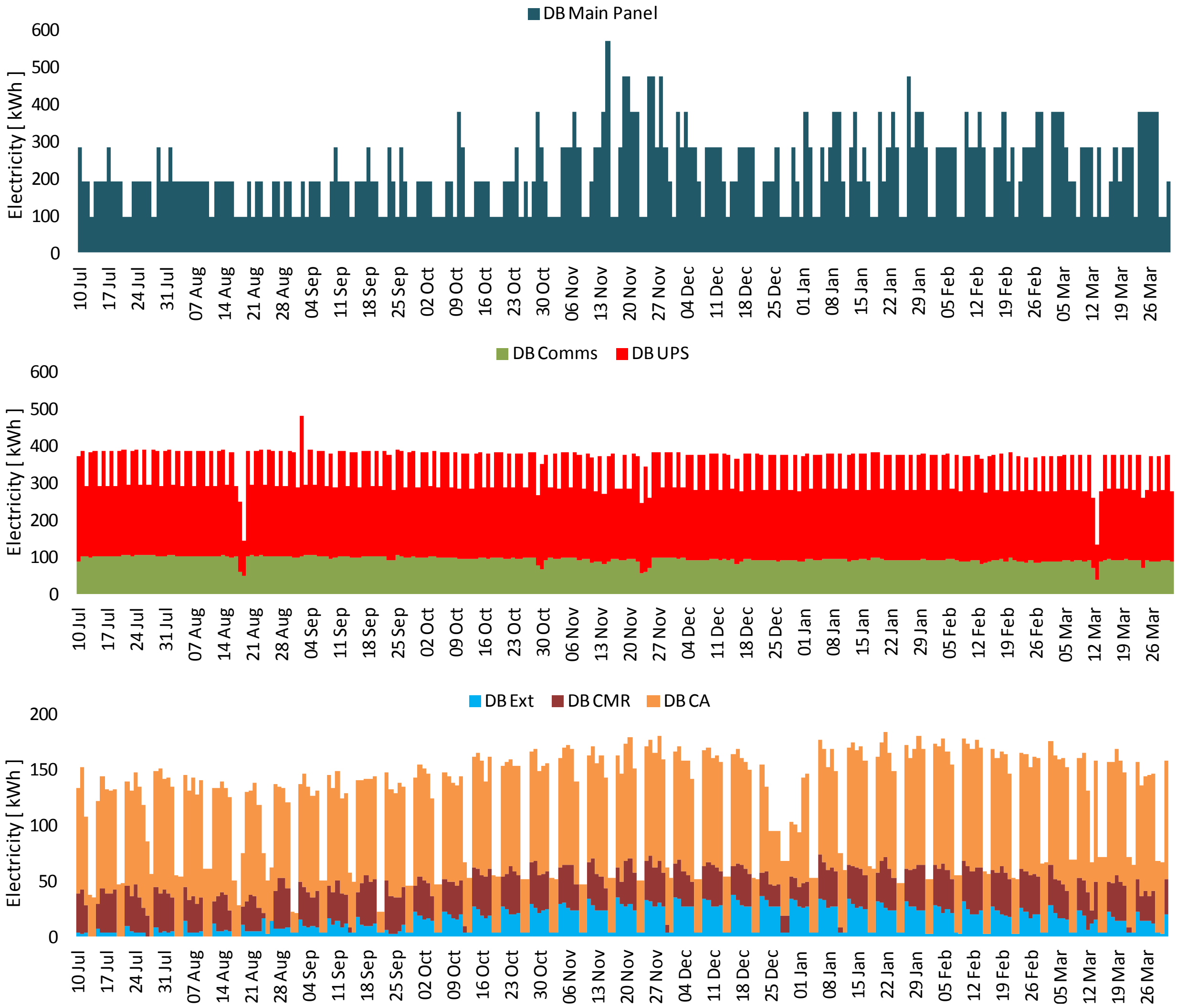



**Figure 26 Central plant sub-meter readings (stacked) between 10th July and 31st March 2014**

One notable observation is that the external lighting (*DB Ext*) appears to only come on during weekdays and turn down over the weekends. A closer look at the hourly energy use in Figure 27 shows a small continous energy use, which increases during out of office hours. In particular, each weekday shows an evening peak and most weekdays show a peak between around 5 and 7 am. The design information shows that the lightings types used are for general illumination and not security purposes, the latter which may have presence detection fitted. Therefore the cause of the variation cannot be fully ascertained.

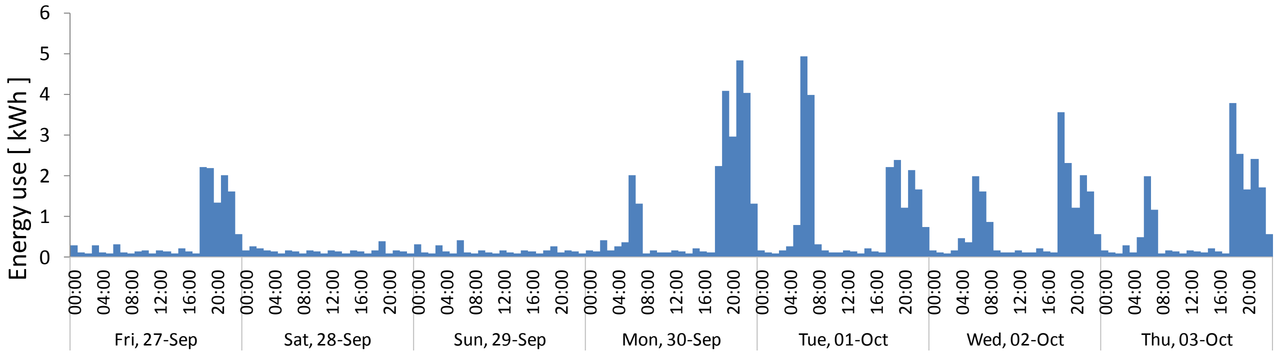



**Figure 27 Hourly data of external lighting energy consumption**

The *DB CMR* sub-meter, which is for the community room, appears as expected with energy use over the weekdays and none on the weekends, except for the Christmas-New Year period, for which the cause cannot be fully substantiate without additional data. Similar observation applies to energy use the core area of the building (entrance foyer, stairwells, lift lobby, circulation and reception area) sub-metered on *DB CA,* where although reduced energy use can be seen over the weekends, is still substantial. Without additional information, it is unclear the cause for such base-load on this circuit. One possible cause could be the continuous use of trace heating in the toilets (see Section 6.7); however, further investigation by the building manager would be required. The operation of the air curtain, which was retrofitted due to complaints of cold draught at the reception, may also be the cause of additional energy use.

**Error! Reference source not found.** shows the main energy consumers in the building are the central plant - the IT comms/server room on *DB Comms*, UPS (*DB UPS*) and building services plants such as the GSHPs, AHU, extract fans and circulation pumps, which are connected to *DB* Main *Panel*.

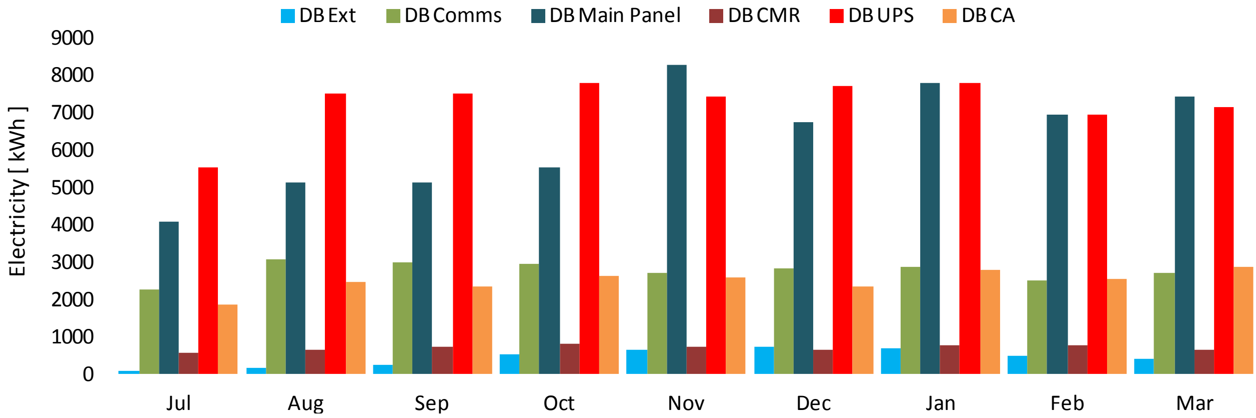



**Figure 28 Monthly central plant energy use in the building between 10th July 2013 and 31st March 2014 (July total not for a full month)**

## Benchmark comparison

Figure 30 shows the comparison between the GCH building's metered energy use against the equivalent ECON19 benchmark and that predicted via the Part L (as-build) assessment. The GCH building is expected to exhibit better overall energy performance, being a newer building, compared to the ECON 19 benchmark figures based on an older building stock. For a fairer comparison, the Good Practice benchmark figures ECON 19 were used.

The GCH building is equivalent to a Type 2 office building with the addition of mechanical ventilation. Hence, for this comparison, the Type 2 office building benchmarks were used for space heating and cooling and the Type 3 benchmarks for fans, pumps and control.

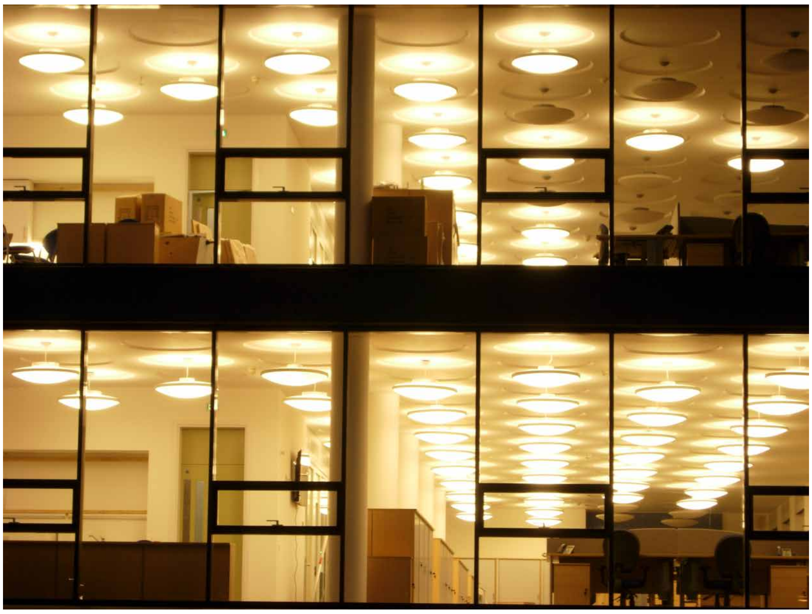


**Figure 29 Ground floor open plan office indicating density and patters on internal electric lighting**

**Error! Reference source not found.** shows the comparison of the lighting (internal), small power and central mechanical plant (fan, pumps and control) of the GCH against the ECON 19 benchmark figures.

- The GCH building consumed 35% more energy in lighting than the benchmark. This may be partly explained by the use of lighting during out-of-office hours (see Section 6.4)
- The GCH building had similar small power energy use to the benchmark.
- The GCH building consumed approximately 50% more in auxiliary energy (fans, pumps and controls) than its ECON 19 benchmark. This may be explained by plant operations (see Section 7.5).
- The GCH building is significantly lower in energy use for the provision of space heating. This may be attributed to the better building fabric for the new GCH building and the use of high efficiency GSHPs as opposed to gas boilers in the ECON19 benchmark.

In terms of comparison with the GCH building's Part L energy predictions, it can be seen that whilst the GCH building energy use for lighting is in-line with Part L, it consumed significantly less energy for small power. Whilst small power energy use is difficult to predict at design and is largely determined by how the building users ultimately use the building, it would be expected that the central plant performance would be more closely aligned with prediction. Furthermore, it would be expected that there will be opportunities to optimise the building performance and subsequently reduce its energy consumption and $CO_2$ emissions.

Of probably most significance, the GCH building consumed significantly more energy than its Part L prediction for central plant (combination of heating, cooling, auxiliary plant). The breakdown in central plant energy suggests potential energy waste in the constant provision of mechanical ventilation in the building, which the building manager is strongly advised to investigate. The TM22 detailed assessment, which is described next, will help identify potential area of energy waste as such relevant energy saving opportunities can be subsequently recommended through the review of the building installation and commissioning documents.

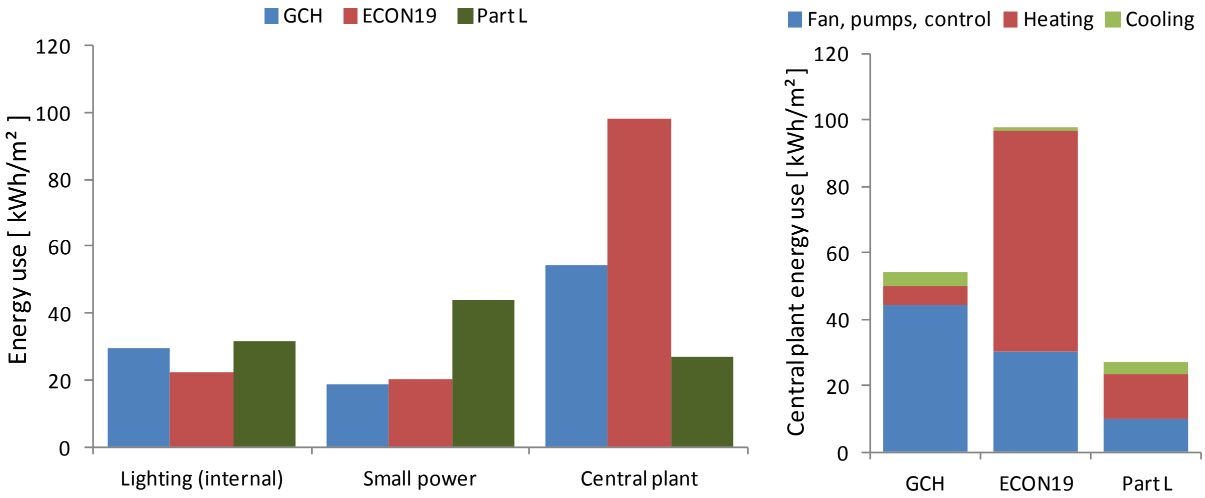



**Figure 30 Comparison between GCH building actual metered energy use, ECON19 benchmarks and that predicted via the Part L (as-build) assessment, including the breakdown of the central plant energy use**
"Note: The GSHP ground-loop, which should be part of the heating and cooling plant energy use, is embedded within the total energy use for "fan, pumps and control" recorded on the DB Main Panel sub-meter. It has not been possible to accurately extract the ground-loop energy use from the sub-metered data for reassignment under the heating and cooling plant energy use."

## 6.7 CIBSE TM22 assessment

The CIBSE TM22 assessment is an exercise that separates the energy use in the building by end-use category to help understand all the consumption within the building.

- A survey is conducted initially to compile an asset register which lists all energy consuming appliances and equipment associated with the building. This includes the quantity of each type, location, distribution board reference and rated wattage. The asset register compiled for the GCH building can be found in the appendices.
- The usage profile is then estimated for each appliance and item of plant in the building.
- The combination of usage profile and energy use for each energy consuming product allows a prediction of the energy consumption in the building.
- The prediction is compared out against the relevant actual sub-metered energy use.

This enables the identification of significant discrepancies between predicted and actual energy use in the building and potential sources of energy waste.

### CIBSE TM22: simple assessment

The CIBSE TM22 v17 spreadsheet was used to carry out a simple initial assessment on the total building energy use. The spreadsheet does not include degree-day adjustment in its calculations and the outputs presented are a direct representation of the data entered. **Error! Reference source not found.** shows the output for the simple assessment comparing the building's metered energy consumption against its equivalent CIBSE TM46 benchmark for a general office. Whilst the total energy use of the building is less than its TM46 benchmark, it exceeds the benchmark by approximately 40% in terms of $CO_2$ emissions due to its all-electricity energy source, which has a higher $CO_2$ intensity factor than natural gas.

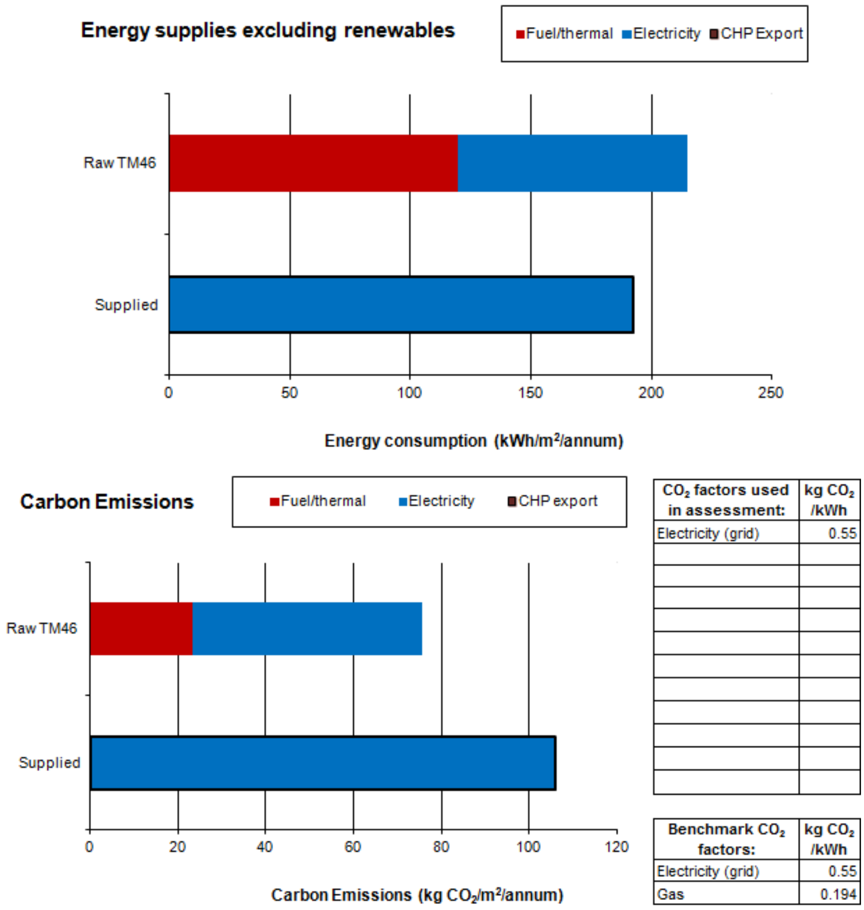



**Figure 31 TM22 output showing the GCH building equivalent $CO_2$ emissions against the TM46 benchmark**

To account for the influence of weather variation on the building energy use, the building's metered energy was then degree-day adjusted to normalise to the CIBSE TM46 benchmark figures relative to its local degree-day data. **Error! Reference source not found.** summarise the adjustment made.

**Table 1 Summary of degree-day adjustment to the metered energy consumption and $CO_2$ data**

| | Energy supplied (kWh) | | $CO_2$ emissions ($kgCO_2$) | | |
|---|---|---|---|---|---|
| | Fuel/thermal | Electricity | Fuel/thermal | Electricity | TOTAL |
| Metered use | - | 419,902 | - | 230,946 | 230,946 |
| DD adjusted use | - | 378,534 | - | 208,194 | 208,194 |

| Heating Degree-Days (HDD) | |
|---|---|
| GCH HDD | 2462 |
| CIBSE HDD | 2021 |

| Unit values | Energy supplied (kWh/m²) | | $CO_2$ emissions ($kgCO_2/m^2$) | | |
|---|---|---|---|---|---|
| | Fuel/thermal | Electricity | Fuel/thermal | Electricity | TOTAL |
| Supplied | - | 192.6 | - | 105.9 | 105.9 |
| Raw TM46 | 120.0 | 95.0 | 23.3 | 52.3 | 75.6 |
| DD adjusted GCH | - | 173.6 | - | 95.5 | 95.5 |

With the weather-normalisation adjustment, the building's energy consumption is lower than metered. This normalisation better illustrates its true energy performance relative to other equivalent buildings in the existing stock. The preferable normalisation methodology would be to degree-day adjust the CIBSE TM46 benchmark energy data instead; however, for the purpose of generating consistent charts on the TM22 spreadsheet the actual building's metered energy data has been adjusted and **Error! Reference source not found.** shows the corresponding outputs.

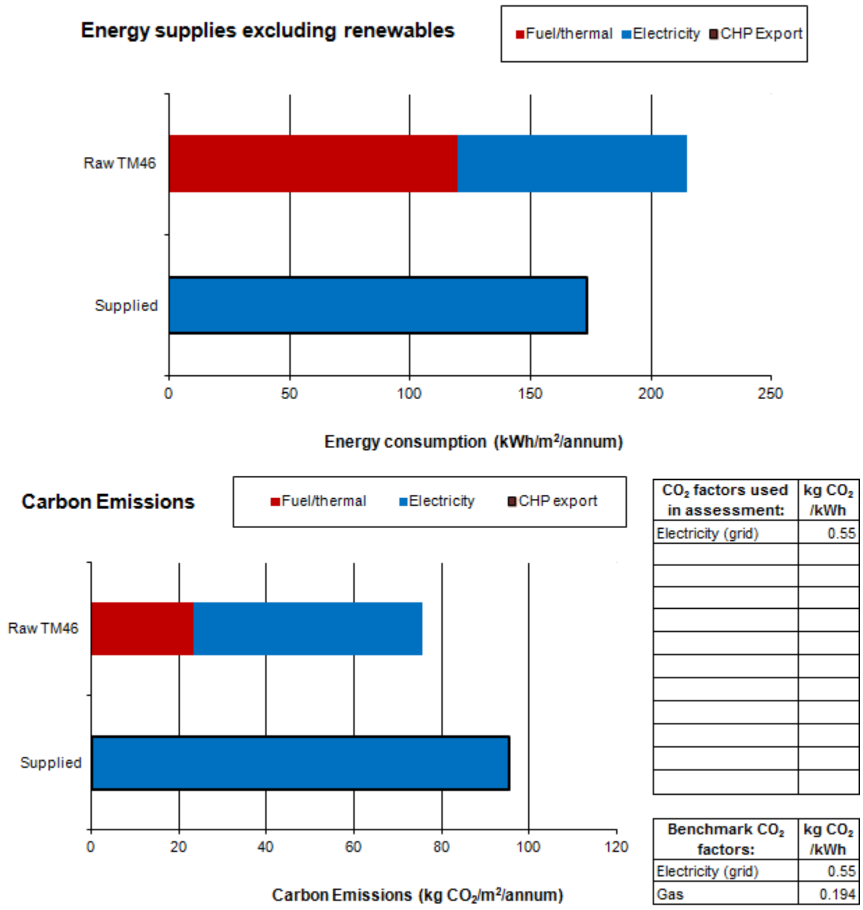



**Figure 32 Degree-day normalised TM22 output for the GCH building in-use $CO_2$ emissions against the TM46 benchmarks**

It can be seen that post-normalisation the building now emits 26% more $CO_2$ than the equivalent benchmark. This is largely due to GCH being an all-electricity building. Whilst the

GCH building consumes less energy than its equivalent benchmark, the higher $CO_2$ intensity of its electricity compared to gas in the benchmark building means the GCH building is worse in its environmental performance.

## CIBSE TM22: detailed assessment

The TM22 detailed assessment is a process to account for all elements of energy use in the building based on the asset register shown in the Appendices**Error! Reference source not found.**. The list comprises of office appliances (ranging from desktop computers, monitors to printers), hot water dispensers and electric shower, internal and external lightings and plant equipment such as pumps and fans. The power wattages and usage profiles were compiled for input into the TM22 spreadsheet in the effort to reconcile energy use registered by the sub-meters over the assessment period. Adjustments to the power wattage, which are often the rated power of the appliances, are adjusted in the assessment via the load factor to obtain the power consumption at typical operation conditions.

In order to carry out the assessment, a full calendar year's energy data is required. For this, the 2013 annual metered energy consumption is used based on the fuel bills provided for the building. The relevant sub-metered energy data from the BMS is only available from 19th July 2013 to 31st December 2013. Therefore, the sub-metered data was pro-rated to a full year, accounting for variation in degree-days where appropriate before entry into the TM22 spreadsheet.

One of the TM22 detailed assessment outputs is presented in **Error! Reference source not found.**, which shows consumption in (kWh/$m^2$) categorised by end-use. The "Raw TM46", "Good Practice" and "Typical" are benchmark figures. The "Design" energy use was derived from the input data of plant and appliances power wattages and usage profile, which were estimated based on site survey and product and design information. The "In-use" energy use was retrospectively derived by adjustments made in order to reconcile the "Design" energy use against the sub-metered energy. The adjustments were made to the usage factors for the respective items of plant and appliances in the building to account for difference in the duration of operation.

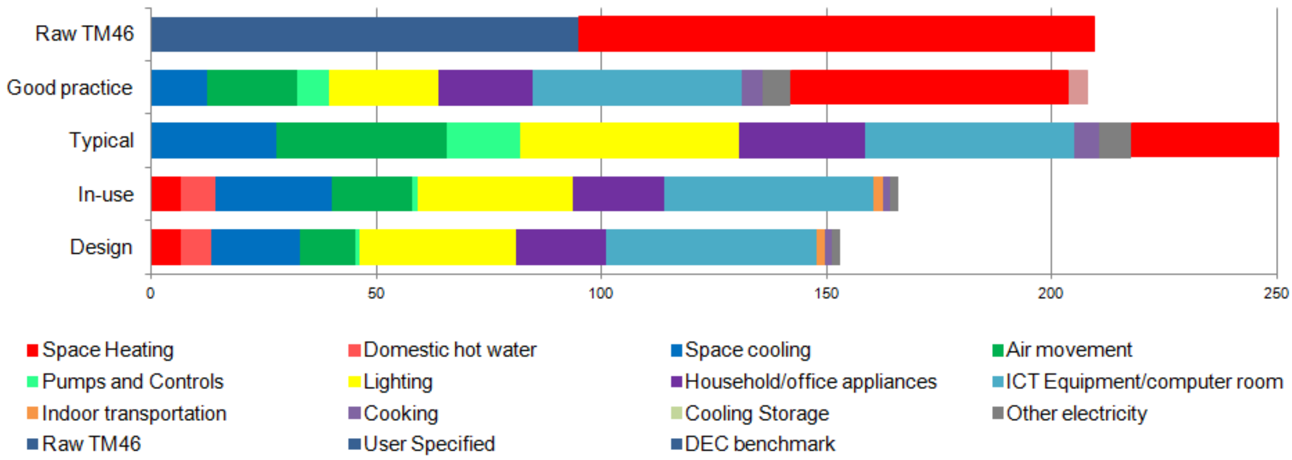



**Figure 33 TM22 detailed assessment output showing electrical and thermal energy use in kWh/$m^2$ by end-use categories for the building against available benchmarks**

It can be seen from **Error! Reference source not found.** that the "Design" total energy use is significantly less than any of the benchmarks presented. However, as tabulated in **Error! Reference source not found.** which **Error! Reference source not found.**summarises the outcome of the TM22 reconciliation exercise between all the sub-metered data and the "Design" energy estimation, there are significant discrepancies highlighted on the DB SP, DB CA and DB Main panel sub-meters.

| Sub-meter | Description | Metered | Design | Total | In-use (reconciled) | Total |
|---|---|---|---|---|---|---|
| E01 | DB BL | 3,127 | 3,197 | 2% | 3,197 | 2% |
| E02 | DB BP | 700 | 704 | 1% | 704 | 1% |
| E03 | DB GL | 31,617 | 31,676 | 0% | 31,676 | 0% |
| E04 | DB GP | 15,690 | 16,006 | 2% | 16,006 | 2% |
| E05 | DB FL | 27,940 | 27,677 | -1% | 27,677 | -1% |
| E06 | DB FP | 19,651 | 19,539 | -1% | 19,539 | -1% |
| E07 | DB SL | 8,657 | 8,646 | 0% | 8,646 | 0% |
| E08 | DB SP | 9,008 | 9,693 | 8% | 9,693 | 8% |
| E09 | DB CA | 29,470 | 27,484 | -7% | 29,771 | 1% |
| E10 | DB CMR | 8,416 | 8,349 | -1% | 8,349 | -1% |
| E11 | DB Comms | 33,288 | 33,758 | 1% | 33,758 | 1% |
| E12 | DB Main panel | 73,807 | 46,113 | -38% | 72,124 | -2% |
| E13 | DB UPS | 92,045 | 91,980 | 0% | 91,980 | 0% |
| E14 | DB Ext | 4,520 | 4,466 | -1% | 4,466 | -1% |

**Table 1 Summary of discrepancy between metered data against "Design" and "In-use" data in kWh**

These discrepancies imply that the plant and appliances in the GCH building were operated in manners not intended or expected as such to result in the increase in energy use. It must be noted however, that these discrepancies could also be caused when certain appliances are used more frequently than anticipated by the users. After all, usage profiles are design stage as mere prediction of actual use. In this case, this does not present energy waste but rather highlight the lapse in the understanding of how the building might ultimately be used.

In order to derive the "in-use" energy use, the process in the TM22 detailed assessment has particularly highlighted the following:

- Despite significant effort made to derive the best-estimate of appliance and equipment usage, it has not been straight-forward due to uncertainty of both the actual wattage consumption during the various operations of the appliances, as well as the frequency and the duration in which these appliances were being used. Unless spot measurements are carried out, it would almost be improbable an accurate estimate could be made.
- Some discrepancies remained between the DB SP sub-meter and the "In-use" values. Most prominent is the second floor power sub-meter at 8% discrepancy, for which the cause is not immediately apparent. Without any use of spot energy monitoring of the concerned appliances, we were not able to accurately ascertain the cause for this discrepancy. Based on **Error! Reference source not found.**, it can be seen that the small power use on the second floor is very diverse, which makes it difficult to accurately estimate via the TM22 route.
- To reconcile the DB CA sub-meter with the "In-use" value, we had to increase the utilisation of trace heating, and electric showers resulting in increased energy use

- To reconcile the DB Main panel sub-meter, with the "In-use" value, we had to increase the operating hours of the AHU, extract fans and the GSHPs in cooling mode, resulting in increase in energy use

It had been the intention to investigate the operation of the AHU and the performance of the labyrinth as part of the study. In particular, this would be helpful to better understand why actual AHU energy use is significantly higher than predicted by Part L. However, the study was reduced in scope and such intended measurements were not carried out.

## 6.8 Conclusions and key findings for this section

The following are the key findings and conclusion for this section:

- There is limited variation in the building total energy use over the period from January 2012 to March 2014. Heating (and cooling) is a relatively small proportion of the energy use in the building which is more dominated by other less weather-dependant energy uses such as the server room, the AHU, pumps, lighting and small power use. Furthermore, the heating energy use is significantly lower than the Econ 19 benchmark. This may demonstrate the good thermal performance of the fabric (see Section 2) and the passive solar gain strategy.
- There appear to be good management in terms of turning off most of small power use during out–of-office hours. However, a significant proportion of the lighting was left switched on within the ground and first floor during out–of-office hours. It is possible that the lighting was left on for security reasons. This should be further investigated as an opportunity for improved energy management.
- There appears to be some form of continuous use of energy in the core area, possibly linked to the use of trace heating, retrofit air curtain and more frequent use of the shower facilities. This should be further investigated as an opportunity for improved energy management.
- Overall, the building consumes similar energy to its Part L predictions. The building has similar level of lighting energy use and lower levels of both heating and small power energy use than predicted. However, the actual building consumes significantly more energy than predicted for mechanical ventilation. This study has been curtailed early and it has not been possible to investigate it in more detail.
- Overall, the building consumes less energy than the ECON 19 and TM46 benchmarks. However, it exceeds the benchmarks in terms of $CO_2$ emissions due to its all-electric setup, whereas the benchmarks assume gas use for heating.
- The CIBSE TM22 detailed assessment has helped to identify key areas of potential energy waste in the building, which should be investigated:
  - Use of lighting on the ground and first floor during out-of-office hours
  - Continuous operation of plants during out-of-office hours – circulation pumps, AHU and extract fan
  - Potential conflict between the provision of heating and cooling by the GSHPs
  - Potential excessive use of trace heating and retrofit air curtain
- However, further analysis of the BMS data is required to validate observations made in this section, which will be discussed in more detail in the next section.

# 7 Technical Issues

## 7.1 Introduction

During the course of the study, various technical issues have been identified, which are either independent or associated with other issues in the building. This section highlights the main issues in the GCH building that impact on occupant comfort and energy use.

## 7.2 Lighting

Some lighting issues have already been covered in Section 3. No BMS data is logged for lighting controls; however, metered lighting energy data for the respective floors has provided some insight into how lighting is generally used in the building. Prior to the monitoring period, there were issues with faulty lighting control sensors, which were subsequently replaced. At the time of the faults, the building manager reported not being able to switch the lights off. As the faults have been resolved, the building manager reported that no manual overrides are being implemented on any of the lighting circuits and lights should be switching off during out-of-office hours. However, sub-metered lighting energy use for the ground and first floor demonstrates consumption during out-of-office hours (see **Error! Reference source not found.**), which may require investigation by the building manager.

## 7.3 Ground source heat pumps and space conditioning

Three 50kW GSHPs have been set up to operate on different regimes – GSHP1 for heating only, GSHP 2 catering for both heating or cooling, whilst GSHP3 provides cooling only. Whilst the BMS interface suggests that GSHP2 only supplies 'top-up' heating (see Section 3.7), the recorded BMS data shows GSHP2 was also providing cooling, albeit to a very limited extent.

It has not been possible to determine the operational efficiency of the GSHPs within this study due to the lack of the necessary data. The BMS does track the heating and cooling circuit flow and return temperatures, but upon analysis there appear to be instances of peculiar temperatures being recorded for the cooling circuit (see **Error! Reference source not found.**). Furthermore, there is no available data on the circuit flow rates.

The retrofit of CT clamps on the GSHPs has enabled the energy consumption of the GSHPs to be recorded. Figure 34(a) shows the sub-metered energy use of the GSHPs throughout the monitoring period ($19^{th}$ August 2013 to 31 March 2014). The outside air temperature provides reference to the local external condition. An interesting feature is that throughout the heating period, cooling was provided in the building, either exclusively or in conjunction with heating provision.

(a)

(b)

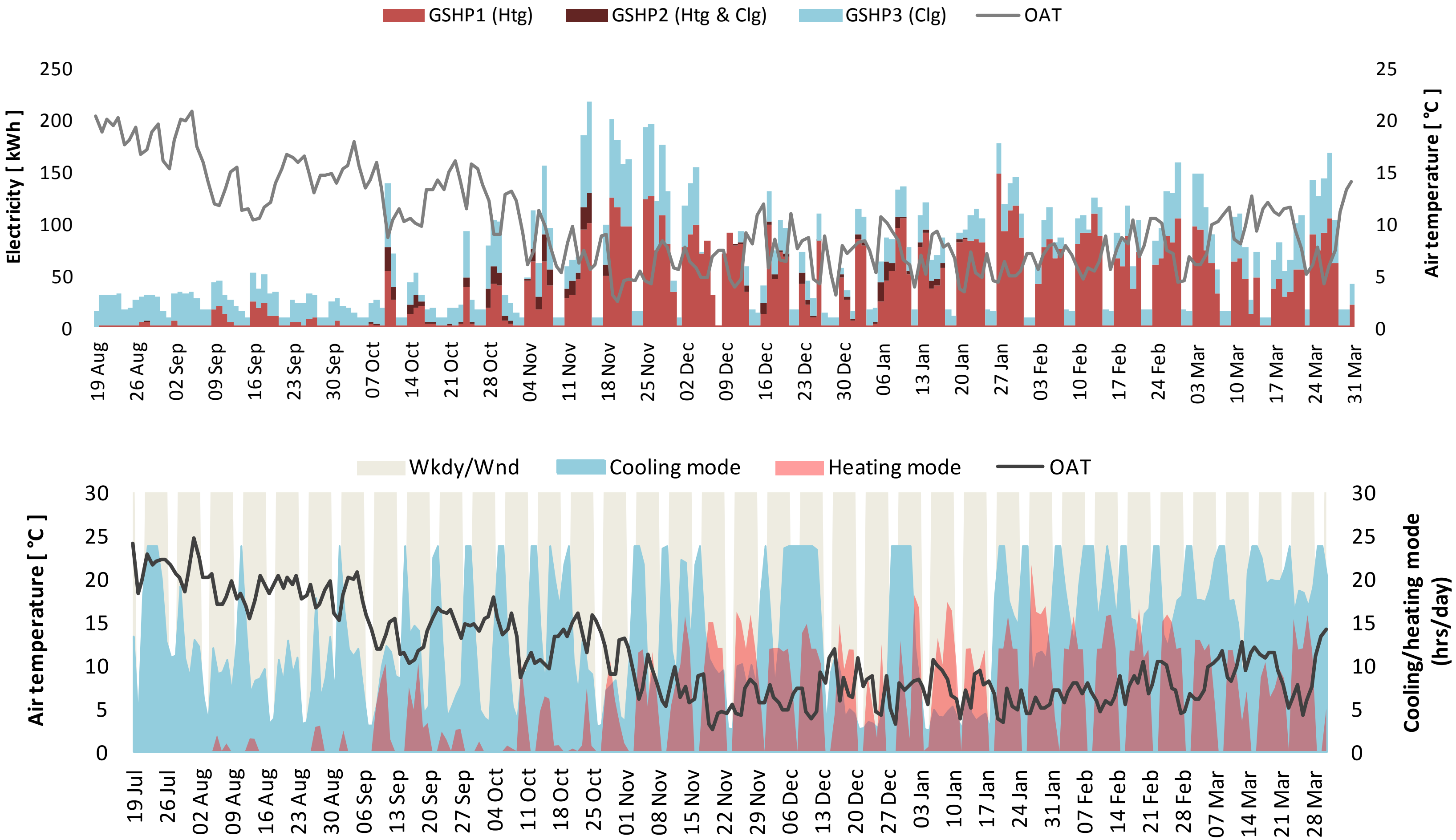



**Figure 34 (a) Stacked daily electricity consumption of the respective GSHPs (b) Overall building heating and cooling mode run hours (both graphs between 19th July 2013 and 31st March 2014)**

Figure 34 (b) shows the daily external air temperature and heating and cooling daily run hours for the whole building. It appears that the cooling run hours increase in conjunction with the onset of heating during the cold periods. This could be coincidental; there could be simultaneous heating and cooling demand in different parts of the building. The building manager has confirmed that some cooling is required to condition meeting rooms on occasions during the winter months. (It was also pointed out that during some summer days, the small ground floor offices, which do not receive any solar gain, might require some heating whilst other parts of the office might overheat at the same time).

However, these events of simultaneous heating and cooling demand in different parts of the building cannot fully account for the extent of increase in cooling run hours recorded for the heating period in comparison to during the summer period, more so when the majority of the building floor area, i.e. the open plan office spaces, is not mechanically cooled. It may be that there is a deficiency in the control setup, such that heating and cooling operations were in conflict. However, it has not been possible to confirm this possibility without additional BMS data or control setup information being available to the study.

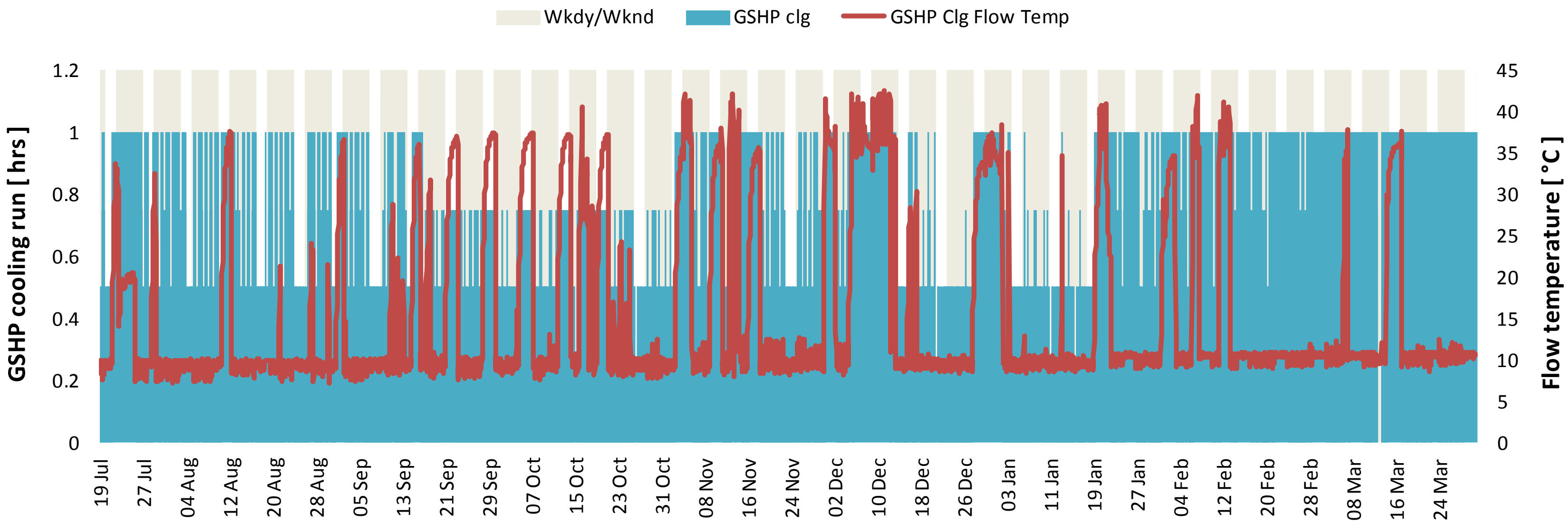
**Error! Reference source not found.**(a) shows the relationship between the GSHP's cooling operation and the cooling circuit flow temperature. The hourly data highlighted several peculiarities:

- Spikes of temperature increase up to ranges of 30-40°C. These temperature spikes are unexpected in a cooling circuit
- GSHP3 appears to be operating on most weekends, corresponding to the temperature spikes in the cooling circuit (see Figure 34) during which there was no heating demand
- Apparent increase in GSHP cooling operation during part of the heating season (end of Jan to Mar 2014), which may further support the suspicion of heating-cooling conflict in the buildings

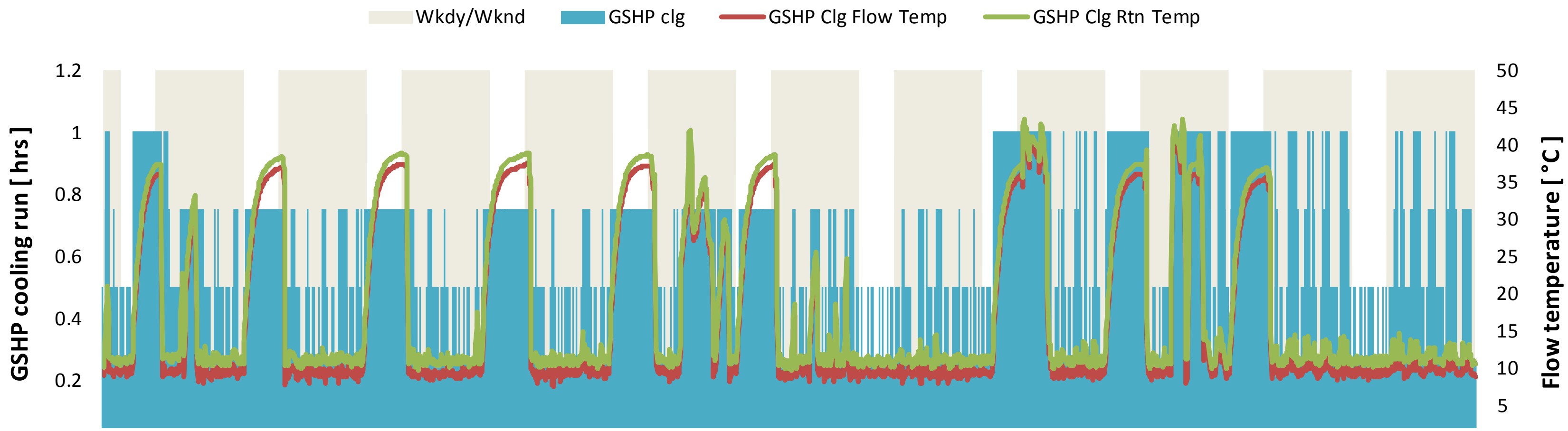
The GSHPs no longer serve the IT comms/server room with cooling as dedicated DX units were retrofitted for this purpose before the monitoring period started. It has been reported in Section 3.3 that there are apparent issues with the GSHP controls, which caused faults in GSHP3. Therefore, this observation of the anomalies in the cooling circuit temperature may be an evidential consequence, which led to these reported faults.

A closer look at the data as shown in **Error! Reference source not found.**(b) suggests a few possible causes:

- Poor GSHP control setup
- GSHP3 failing – heating circuit fluid taken through GSHP3 but GSHP3 was not cooling the fluid, such that the warm fluid then eventually heated the cooling circuit
- Control valves (shown in **Error! Reference source not found.**) faults or poor setup may have allowed heating circuit fluid to bleed into the cooling circuit, which in turn invoked cooling operation
- At the FCUs, both heating and cooling coils were enabled leading to conflicts and artificial loading, which, although possible, this is expected to be unlikely


Wkdy/Wknd
GSHP clg
GSHP Clg Flow Temp
GSHP cooling run [ hrs ]
Flow temperature [ °C ]
1.2
1
0.8
0.6
0.4
0.2
0
45
40
35
30
25
20
15
10
5
0
19 Jul
27 Jul
04 Aug
12 Aug
20 Aug
28 Aug
05 Sep
13 Sep
21 Sep
29 Sep
07 Oct
15 Oct
23 Oct
31 Oct
08 Nov
16 Nov
24 Nov
02 Dec
10 Dec
18 Dec
26 Dec
03 Jan
11 Jan
19 Jan
27 Jan
04 Feb
12 Feb
20 Feb
28 Feb
08 Mar
16 Mar
24 Mar

(a)


Wkdy/Wknd
GSHP clg
GSHP Clg Flow Temp
GSHP Clg Rtn Temp
GSHP cooling run [ hrs ]
Flow temperature [ °C ]
1.2
1
0.8
0.6
0.4
0.2
50
45
40
35
30
25
20
15
10
5

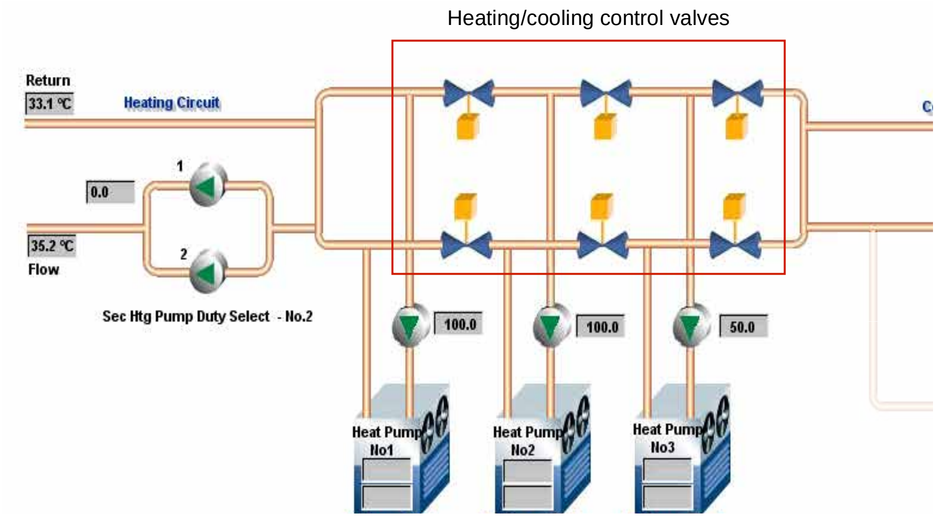
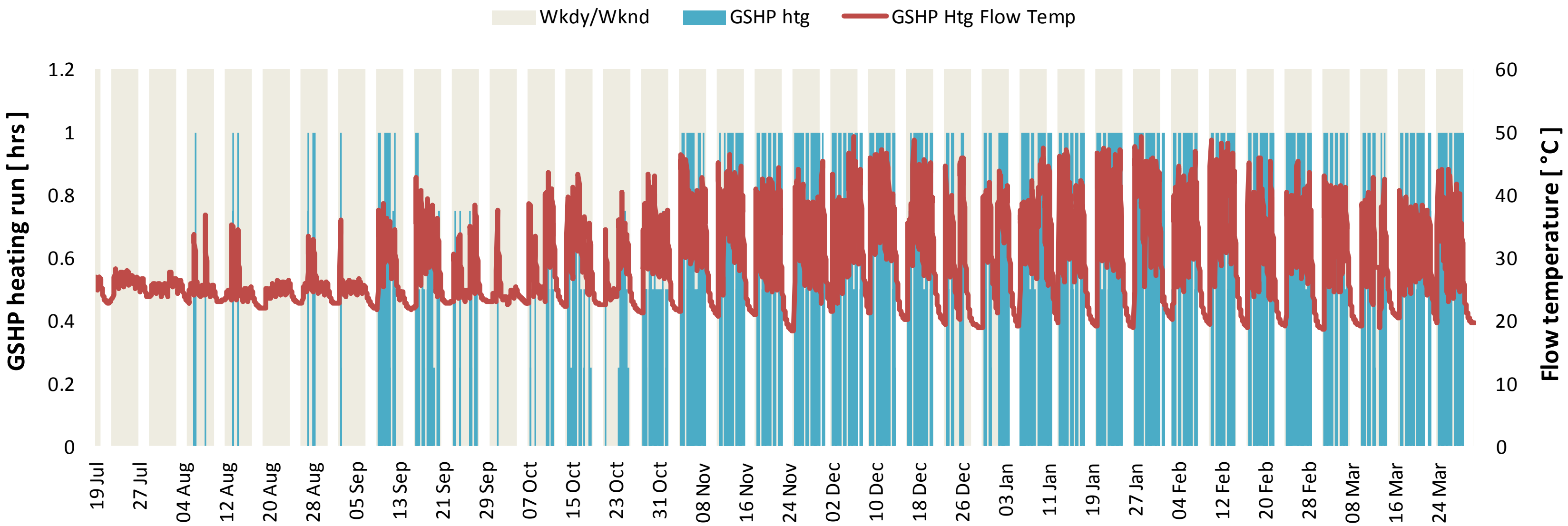



**Figure 36 Screenshot of the BMS graphical interface showing the heating and cooling**

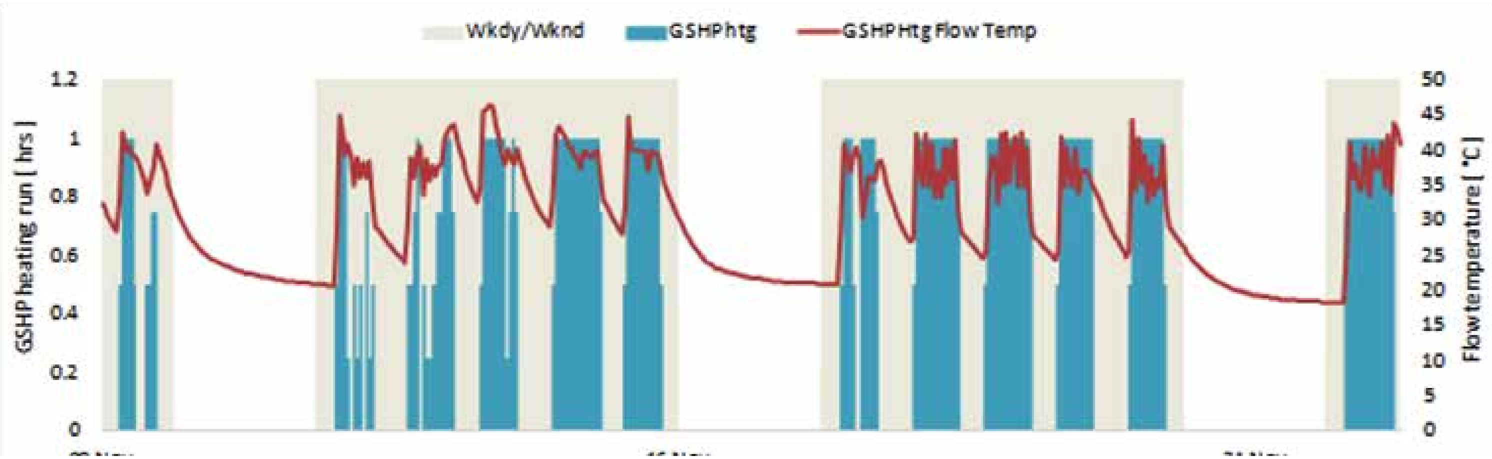
Ultimately, there are several aspects of the system setup that remain unk which render the investigation inconclusive. These are:

- Locations that the temperature data is measured which, if inapprop misleading diagnostics of system operation and condition
- No information is available on control valve operation and setup
- The condition of the control valves, whether they shut properly bleeding between the heating and cooling circuits
- The actual status of GSHP3, whether earlier faults (prior to the stuc resolved

The GSHPs operation in heating appears more in-line with expectation a **Reference source not found.**, where higher demand of heating operation heating season. Heating appears to turn down during the weekends and af 5pm and 6am. The heating circuit flow temperature is also shown to cycle operational temperatures.


Wkdy/Wknd
GSHP htg
GSHP Htg Flow Temp
GSHP heating run [ hrs ]
1.2
1
0.8
0.6
0.4
0.2
0
Flow temperature [ °C ]
60
50
40
30
20
10
0
19 Jul
27 Jul
04 Aug
12 Aug
20 Aug
28 Aug
05 Sep
13 Sep
21 Sep
29 Sep
07 Oct
15 Oct
23 Oct
31 Oct
08 Nov
16 Nov
24 Nov
02 Dec
10 Dec
18 Dec
26 Dec
03 Jan
11 Jan
19 Jan
27 Jan
04 Feb
12 Feb
20 Feb
28 Feb
08 Mar
16 Mar
24 Mar

(a)


Wkdy/Wknd
GSHP htg
GSHP Htg Flow Temp
GSHP heating run [ hrs ]
1.2
1
0.8
0.6
0.4
0.2
0
Flow temperature [ °C ]
50
45
40
35
30
25
20
15
10
5
0

## 7.4 Ventilation systems

The general ventilation in the building is mechanically provided by an AHU located in the basement plantroom. Fresh air is drawn through an earth duct, intended to slightly temper incoming air prior to further tempering in the AHU. Fresh air is not mechanically cooled in the summer to supplement space cooling.

Supplementary ventilation in the building is naturally provided through the use of mechanised façade louvres lining both the north and south aspects of the building, which, along with the narrow form of the building, help promote cross-ventilation and effectively provide cooling during the warm periods. These will generally cease to operate during the heating season. Openable windows supplement the access to ventilation via manual occupant intervention as required. The atrium on the East side of the building has an openable rooflight for stack ventilation, which is temperature controlled with overrides from rain sensors.

According to the *Descriptions of Installation* for the control strategy of the building, the mechanised louvre operations depend on the following parameters:

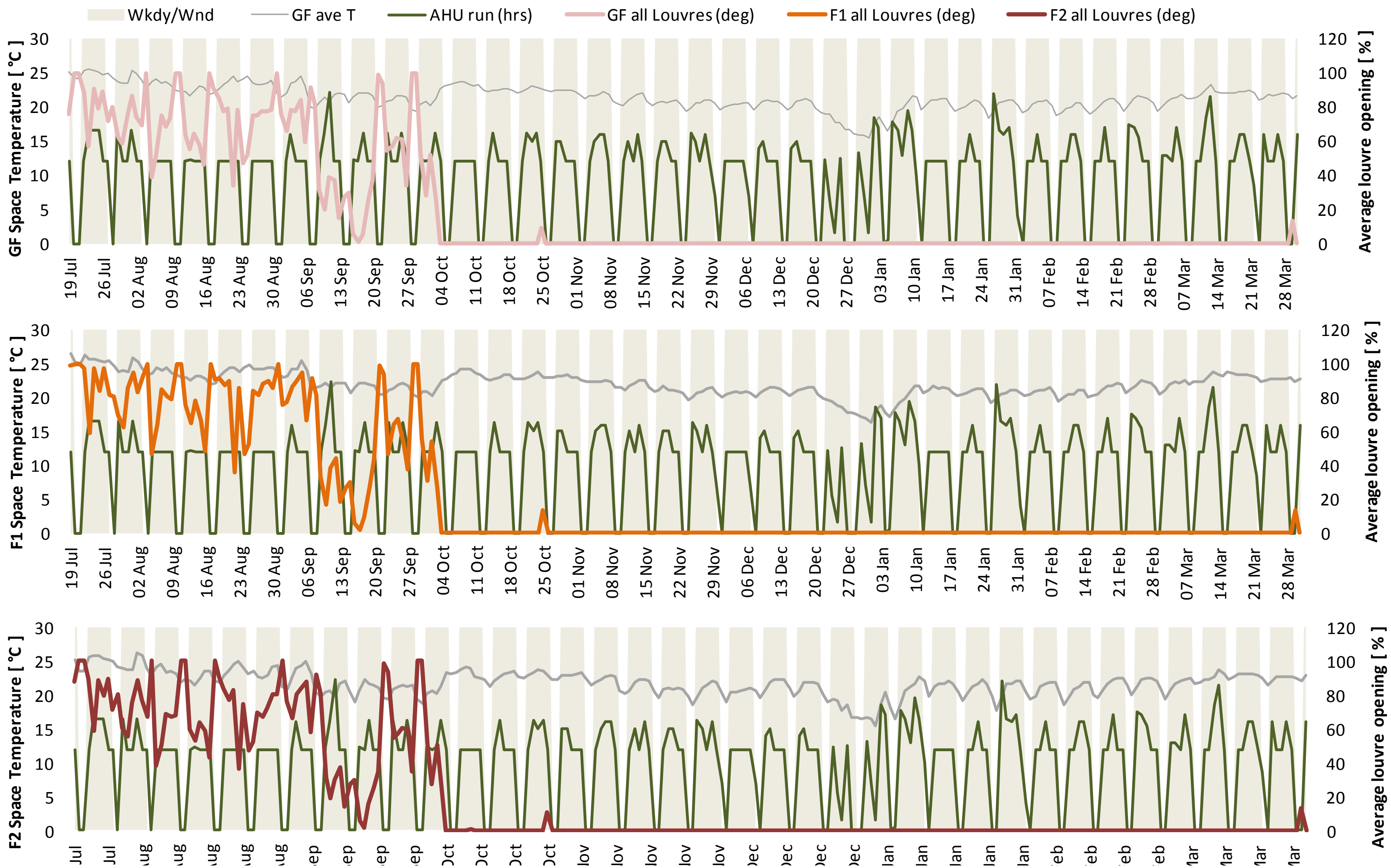
- Wind and speed control
- Rain Detection
- Time clock enable
- Window override
- Summer/winter operation
- Auto control

The BMS records data on the façade louvres operation in the number of degrees that the louvres are open. No data is available for the openable rooflight. It must be noted that the BMS data for the AHU and FCUs are only on-off operation flags and do not represent the intensity at which these plants were operating in terms of flow rates or heating/cooling capacity.

**Error! Reference source not found.** show the building response to external conditions for the ground, first and second floors respectively. It shows daily average internal air temperatures in the open plan office spaces and the corresponding AHU operation and façade louvres. In general, the AHU operated for 12 hours daily with some exceptions of 16 hours per day. The AHU appears to be switched off during the weekends and part of the Christmas period as expected.

It can be seen that there was active use of the façade louvres to regulate natural ventilation in the building from July 2013 up to around the end of September. From October, the louvres were effectively shut as the heating season sets in. It is interesting to note that during the summer period, there was no reduced AHU operation. This implies that the purpose of façade louvres is principally for the purpose of providing cooling. Potentially, there could be a more optimum mixed-mode controlled strategy, balancing natural ventilation capacity with reduction in AHU rates. In doing this, it is important to ensure thermal comfort as the AHU is providing the main cooling to the office space as there is no cooling of these spaces from the GSHPs.

The internal air temperatures were generally within comfort limits with no observable overheating or low temperatures during the monitoring period. The sudden drop in space temperature around end of December corresponds to the Christmas-New Year break, presumably when the building was partially occupied and then fully shut and unoccupied over several days.


Wkdy/Wnd
GF ave T
AHU run (hrs)
GF all Louvres (deg)
F1 all Louvres (deg)
F2 all Louvres (deg)
GF Space Temperature [ °C ]
F1 Space Temperature [ °C ]
F2 Space Temperature [ °C ]
Average louvre opening [ % ]
19 Jul
26 Jul
02 Aug
09 Aug
16 Aug
23 Aug
30 Aug
06 Sep
13 Sep
20 Sep
27 Sep
04 Oct
11 Oct
18 Oct
25 Oct
01 Nov
08 Nov
15 Nov
22 Nov
29 Nov
06 Dec
13 Dec
20 Dec
27 Dec
03 Jan
10 Jan
17 Jan
24 Jan
31 Jan
07 Feb
14 Feb
21 Feb
28 Feb
07 Mar
14 Mar
21 Mar
28 Mar

(a)

(b)

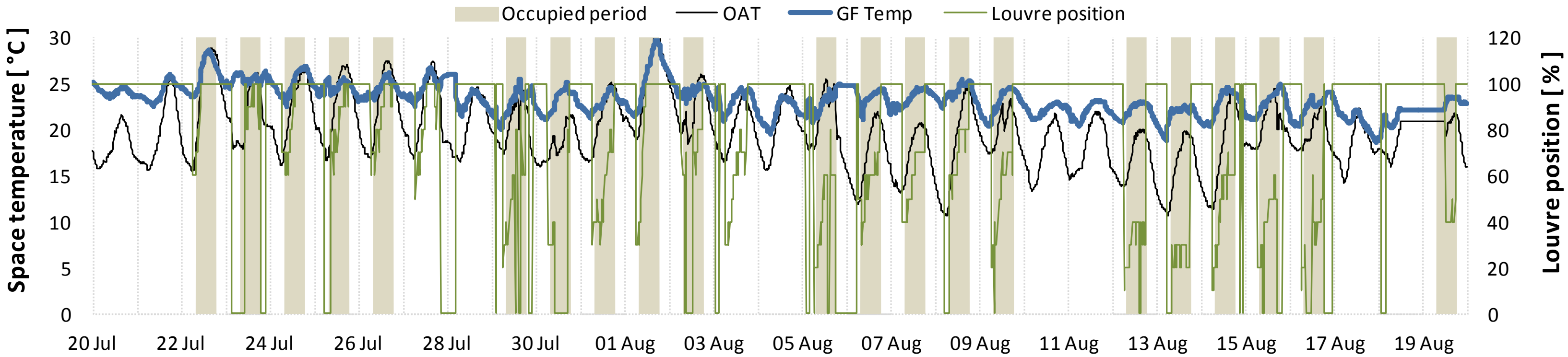
**Error! Reference source not found.**(a) presents, at greater time resolution, the hourly plot of the ground floor open plan space temperature with corresponding external air temperature and façade louvre position between 20th July and 20th August 2013. The figure shows how the louvre position was adjusted for a typical day and how this correlated to the external and internal space temperatures.

It can be seen that there were many instances whereby the louvres were fully opened throughout the day, over the weekend and out-of-office hours. We were not able to fully ascertain the louvre operational regime without any additional supporting data, as our interviews suggest that the louvre operation were manually overridden from autonomous BMS control. Nonetheless, it remains unclear as to why the façade louvre was open over the weekends. Additional investigation by corresponding physical witnessing against BMS data will be required to fully ascertain whether the louvre operation is as intended.

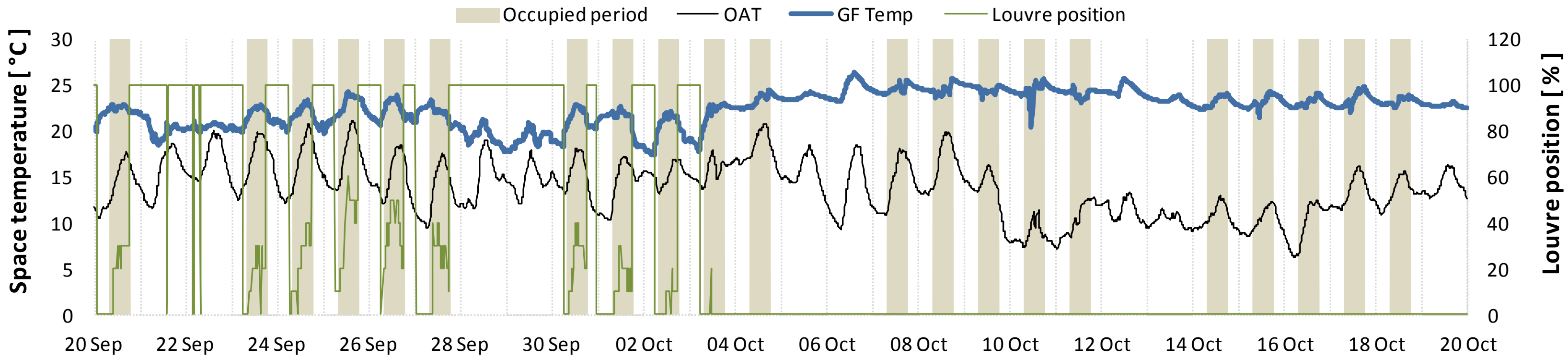
The collected data suggests that the natural ventilation strategy appears to be largely effective in maintaining a comfortable environment for the occupants, although there were instances where temperatures were much higher (22nd July and 1st August 2014). With the AHU appears also operating during these periods (see **Error! Reference source not found.**), the internal temperature remained high, suggesting that the ventilation strategy has not been effective on the extremes of conditions where the outside temperatures were also incidentally very high (above 28°C). Although this appears to be only small instances during the summer period, it may worsen in years to come, which the building owner may wish to monitor. Note that the internal temperatures in **Error! Reference source not found.** are daily average and therefore do not exhibit the high peaks shown in **Error! Reference source not found.**(a).

**Error! Reference source not found.**(b) shows a close-up of the beginning of the autumn season where the façade louvre stopped opening in conjunction with the gradual change in external temperatures. It has not been possible to establish whether the change in operating regime was sensory-based (temperature controlled) or temporal-based (change based automatically or manually based on time of the year).The FCUs in the building only serve cellular rooms – meeting rooms and cellular offices and are cluster-controlled on the respective floors in terms of operation flag. Their actual extent of operations would depend on the setting on the local thermostat controls, which is not being monitored on the BMS. The space temperatures in these rooms are also not being recorded by the BMS

In general, as shown in **Error! Reference source not found.**, the BMS operation flags suggested the FCUs operated (presumably at variable flow rates based on demand) for 12 hours daily with some exceptions of 16 hours per day. Again it must be iterated that the FCUs operation is inferred using the operation flag (i.e. the period that the FCU can operate), which is not able to indicate the actual demand (i.e. it is not known whether the FCU is actually needed and its flow rate). According to the operation flag, the FCUs appear to be turned off during the weekends and part of the Christmas period as expected. It can be seen that the second floor FCUs appear to have significantly reduced in operating hours to 5 hours daily from mid Jan 2014. There is no data available to ascertain the cause or reason for the sudden change in operation. No information was available from the building manager. As stated in Section 5, manual adjustments are constantly being made by the building manager on an ad hoc basis to the extent of operating times. It seems sensible that this reduction should continue unless occupants express dissatisfaction and other such opportunities to reduce energy should be explored (e.g. could a similar regime be applied to the other floors).




(a)




(b)

**Figure 39 Hourly external air temperature, ground floor space temperature and façade louvre position between 20th July and 20th August 2013 (b) Hourly external air temperature, ground floor space temperature and façade louvre position between 20th September and 20th October 2013**

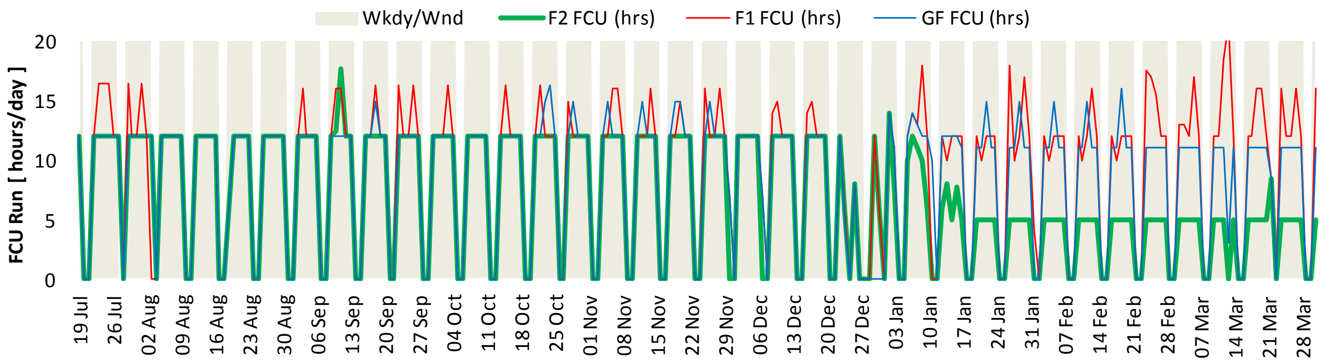



**Figure 40 Daily average FCU operating hours on the respective floors between 19th July 2013 and 31st March 2014**

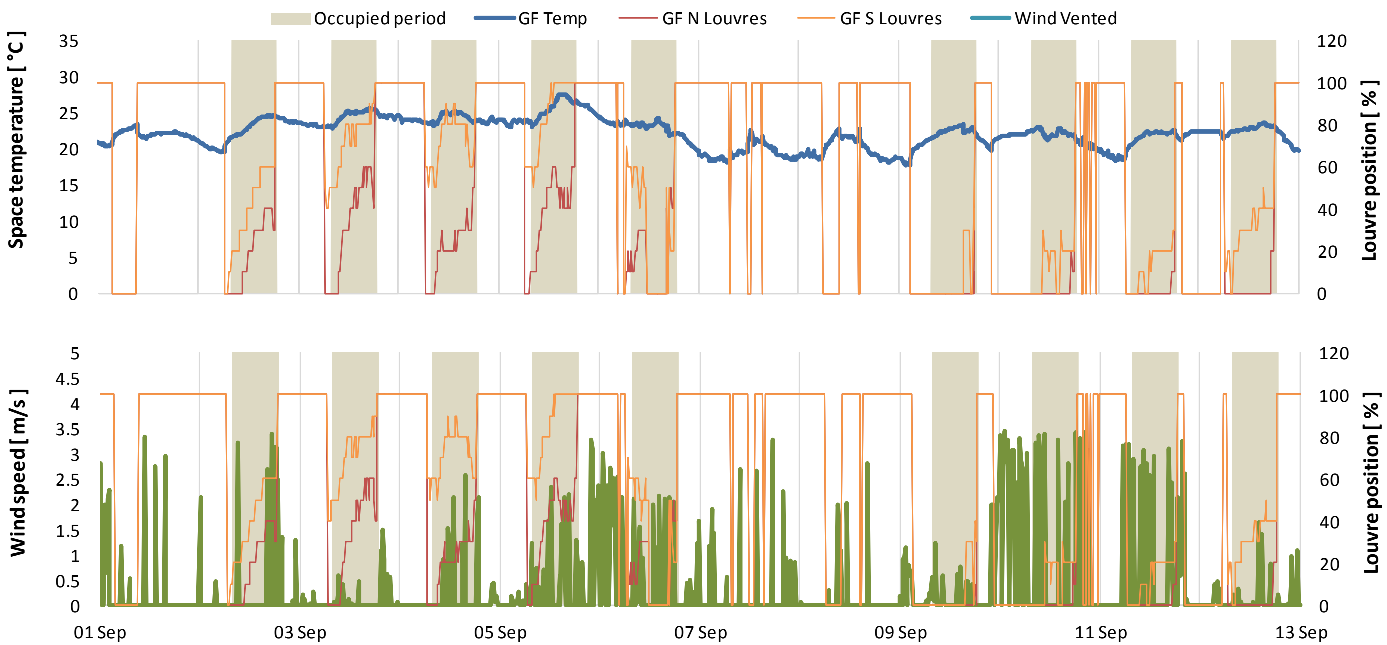



**Figure 41 Hourly ground floor average temperature against façade louvre position, GSHPs heating and cooling operation and relevant wind speed**

**Error! Reference source not found.** shows the ground floor hourly average temperature against corresponding façade louvre position. Also shown is the wind velocity for only when the wind direction promoted effective cross ventilation of the building, i.e. in the direction perpendicular to the long aspect ratio of the building.

It can be seen on the 10th to 12th September, the louvre position appears to be regulated in response to the magnitude of the wind speed, which when a user-controlled threshold was exceeded would fully shut the louvres.

It is interesting that, in a number of instances, there are a number of fluctuations between being in a fully closed and fully open position. For example, this can be seen on the 7th September and more prominently at the start of the 11th September. It is possible that this is correctly due to fluctuations in the environmental conditions. However, it does suggest further investigation of a refined control strategy to more smoothly control the louvre open position. This will allow better control of the internal environment and avoid un-necessary wear of the louvre actuators.

## 7.5 Central plant systems

**Error! Reference source not found.**(a) shows the daily operation flags for the secondary heating and cooling circuit pumps and ground loop pumps over the monitoring period. It appears that the heating circuit pump was operating in the summer period when, based on **Error! Reference source not found.**(b), there were days when no heating was required. It must be noted that DHW generation is direct point-of-use and not connected to the central heating system.

Also, there may be a possibility of further energy wastage where both the cooling circuit and ground loop pumps are shown to be running continuously. The similarity in the data for both these parameters may also suggest an issue with the logging of these data on the BMS, which are expected to operate in a similar trend as that of the heating circuit. As there was no validation carried out on the control supplier's work, be it during the original commissioning or the retrofit installation carried out in this study, it has not been possible to fully ascertain whether there is an error in the BMS setup or the similarity in data is due to intended operational setup. There is no further information in the building control strategy documentation to inform this observation. Recommendation for appropriate commissioning reports and handover documents will be highlighted to the building owner.

**Error! Reference source not found.**(b) shows the daily operation flags of the GSHPs circulation pumps. It appears that both sets of pumps were running continuously, regardless of the GSHPs operation or the extent of heating and cooling demands from the thermal stores. However, it must be noted that the operation of the GSHPs circulation pumps is inferred and the actual running of the pumps in terms of flow rates is unknown and not being monitored.

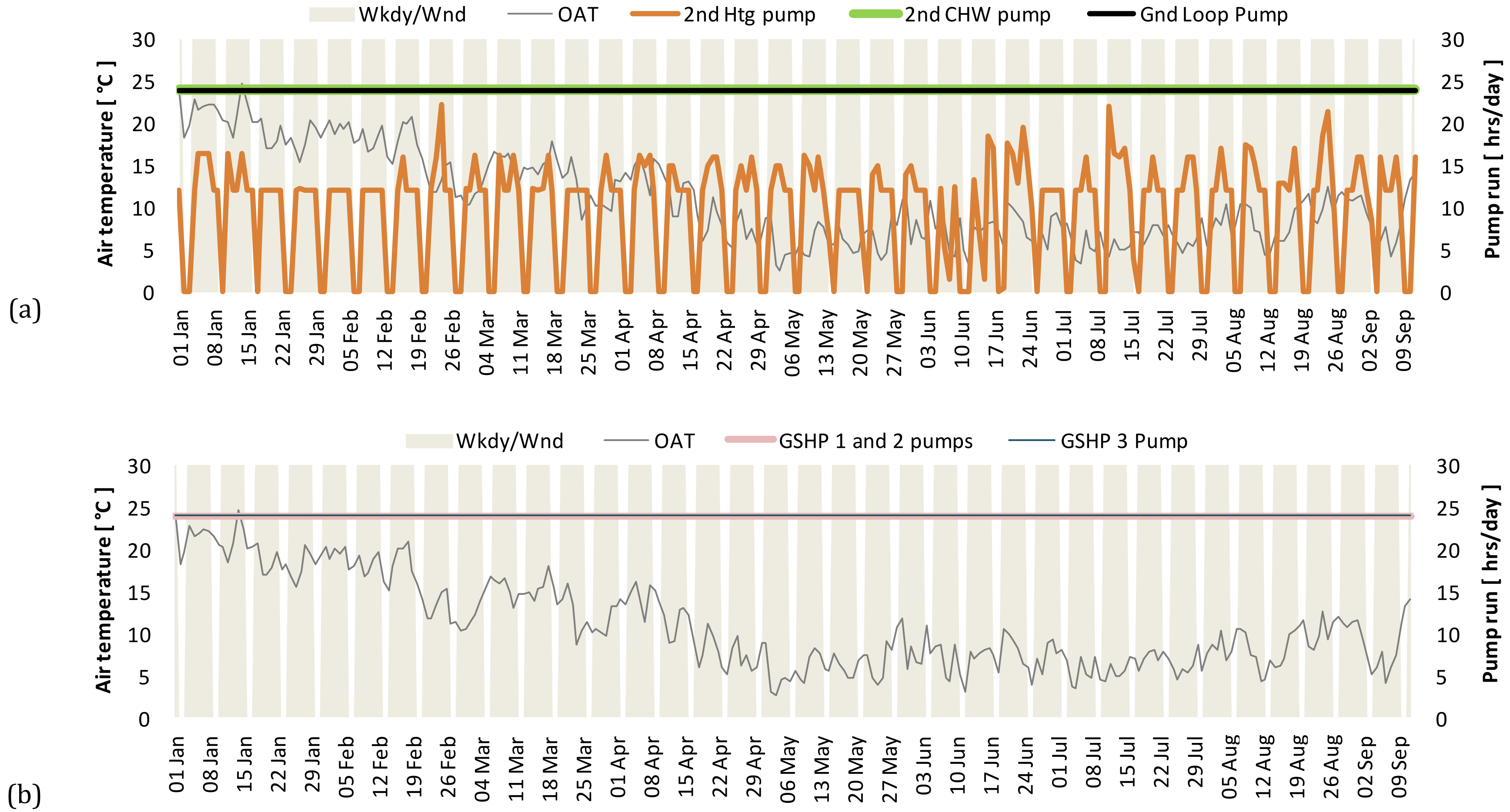



**Figure 42 (a) Daily average second floor space air temperature, building secondary circulation heating and cooling and ground loop pumps run hours between 19th July 2013 and 31st March 2014 (b) Daily average second floor space air temperature, GSHP1, 2 and 3 run hours between 19th July 2013 and**

## 7.6 BMS and interface

At the outset, a review of the BMS suggested a system, which is simple and sufficient to cater for the essential aspect of building control and management as summarised in Chapter 5. However, as a consequence of 'value engineering', the capability of remotely managing the BMS via a client PC has been omitted such that any adjustments and controls can only be made through a simplistic yet complex-to-use user interface panel on the BMS plant in the basement plantroom. This is expected to have caused inconvenience to the building manager and may have some impact on the promptness of control issues both being diagnosed and rectified. As a result of this study, the client PC has been re-instated and the building manager now has remote access to the BMS via an internet browser.

The capability of monitoring building energy use was retrofitted onto the BMS as part of this study. The retrofit work was carried out by an independent control supplier, a procurement which was influenced by the building owner. This is not the original supplier for the existing BMS.

It was made clear from the start of the appointment that due to various unknowns with the existing BMS, the project team was unable to provide a clear steer on the specific tasks to undertake, apart from a set of end objectives to be achieved and would have to rely on the supplier to provide further information about the system from which a more detailed and specific brief could be formulated. The study requires the BMS to collect data of all necessary parameters to support the analyses.

The retrofit work was carried out commencing February 2013, which was originally anticipated to take approximately several weeks. However, the time frame stretched to several months due to the availability of the technician at site and delayed delivery of components. It was difficult to properly validate the work completed by the supplier. When it was possible, errors and problems were identified which required a significant amount of remedial work.

No commissioning and testing have been carried out by the supplier, claimed to be outside the scope of work they originally tendered for. As a result, it has not been possible to verify whether the completed work, particularly the retrofit energy data streaming, was carried out to expected standards and the BMS is collecting good quality data. Official BMS data only became available from 19$^{th}$ July 2013 onwards. The next section highlights the issues identified as a direct impact of not being able to validate the supplier's work. The need for clearer brief that explicitly demand validation of work via commissioning and testing will be highlighted as a critical element when commissioning future works with any supplier. This includes making clear that payment will be withhold unless satisfactory commissioning and testing is undertaken.

## 7.7 Metering

A review of the BMS energy data has highlighted significant discrepancies between the sum of the sub-meter readings and the main meter. A key difference is that the monthly main meter consumption is two orders of magnitude less than the total sub-meter consumption – suggesting some problem in how the BMS data is output. Overall, this raises a concern over the metering in the building – which could relate to the metering itself or the set-up in the BMS – and suggests inadequate commissioning was carried out on the system. No evidence of commissioning has been provided by the control supplier who has suggested that it was outside their scope of works for any form of validation to be possible.

In order to retrospectively resolve the issue with discrepancies in the data, a data reconciliation procedure was formulated in the effort to better understand but ultimately to introduce correction factors that would enable the BMS collected energy data to be usable for the study.

## Energy data reconciliation process

The meter reconciliation process was split into three stages:

- Compare the main meter and sub-meters in the plantroom
- Validate sub-meter readings against utility bills for the same period
- Validate downloaded BMS energy data against manual meter readings

Compare main and sub-meters

To help ensure that all the meters were set-up correctly, manual readings were taken to compare the main meter with the summation of all the sub-meters for the same period. Note that the main meter is a building-side meter, which the BMS has connection access to, as oppose to the fiscal meter, which belongs to the utility company. It is the expectation that the main meter should have identical readings with the fiscal meter over the same period.

Comparison of manual readings between the main meter and the fiscal meter shows a discrepancy of several orders of magnitude. One suspicion is that the main meter was displaying energy reading for only one of three electrical phases, which could not be rectified despite attempts made. Therefore, an alternative approach was undertaken by comparing the fiscal meter against the corresponding manual readings of all the sub-meters.

The consumption manually read from the fiscal meter over the period between 13th Sept and 1st Oct corresponds with the total of the sub-meter readings. This suggests that the sub-meters should be correctly monitoring energy loads in the building.

Validate meters against utility bills

Utility bills have been obtained from the building manager for the corresponding periods when the fiscal meters were read by the utility company. The total monthly electricity consumption of the building recorded manually by the sub-meters approximately matches the readings registered on the utility bills. Some discrepancies were due to the difference in time when readings are recorded.

As an example of manual readings taken of the sub-meters between 13th Aug and 13th Sept 2013 is a total energy use of 31,601kWh, whilst the utility bills for 1st to 31st Aug 2013 is 32,304kWh. This again strongly suggests that the sub-meters are correctly monitoring the energy use in the building, certainly of the most significant energy loads.

Validate downloaded BMS data against manual meter readings

It was found that the energy use of some of the BMS recorded sub-meters differ significantly from the manual readings of the corresponding physical sub-meters. Also, the main meter energy use recorded by the BMS differed from manual readings from both the physical main and fiscal meters, as well as not matching the total of the BMS recorded sub-meters. As a result, BMS data for the main meter was discarded from further use and we looked to correct the BMS sub-meter data.

The labelling of ‘kWh’ or ‘MWh’ of the sub-meters in the BMS data appears to not always correspond with the physical meter readings. As no commissioning results were available from the supplier, it was not possible to validate whether the labelling inconsistency was intentional with appropriate adjustments implemented implicitly within the BMS embedded coding.

As part of the reconciliation process, a set of adjustment factors were derived and retrospectively applied to calibrate the BMS data so as to tally with the corresponding physical meter readings. The adjustment factors that were implemented are peculiar in that they are not of the expected order of magnitude to adjust for mislabelling between ‘kWh’ and ‘MWh’, but rather a reflection of un-calibrated sensors being used, coupled with unverifiable commissioning carried out for the installation and setup.

The cause for the discrepancies is further evidenced when the respective adjustment factors resulted in fluctuating degrees of matching when several repeat reconciliation exercises with physical meter readings were carried out in subsequent months. The project team was not able to verify the cause due to accessibility restriction and skills required to operate the BMS internal software interface. However, best approximations were made on the adjustment factors to tally total energy use between the respective BSM and manual meter readings.

The outcomes of the reconciliation process are presented in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.** for the various meters in the building. It can be seen, for example, that BMS and manual meter readings for circuits such as *DB GP* and *DB FP* in **Error! Reference source not found.** show some differences at the intermediate reading intervals; however, achieving good match for the respective total consumptions.

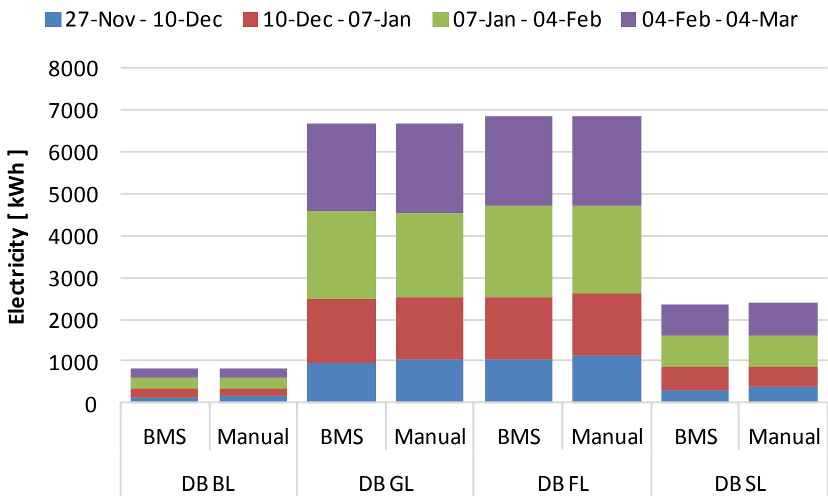



**Figure 43 Comparison of BMS and manual meter readings for corresponding periods on internal lighting circuits**

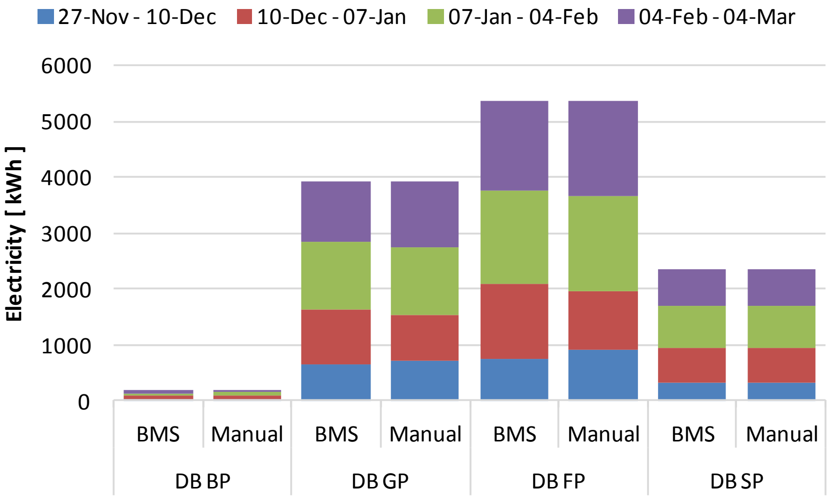



**Figure 44 Comparison of BMS and manual meter readings for corresponding periods on floor power circuits**

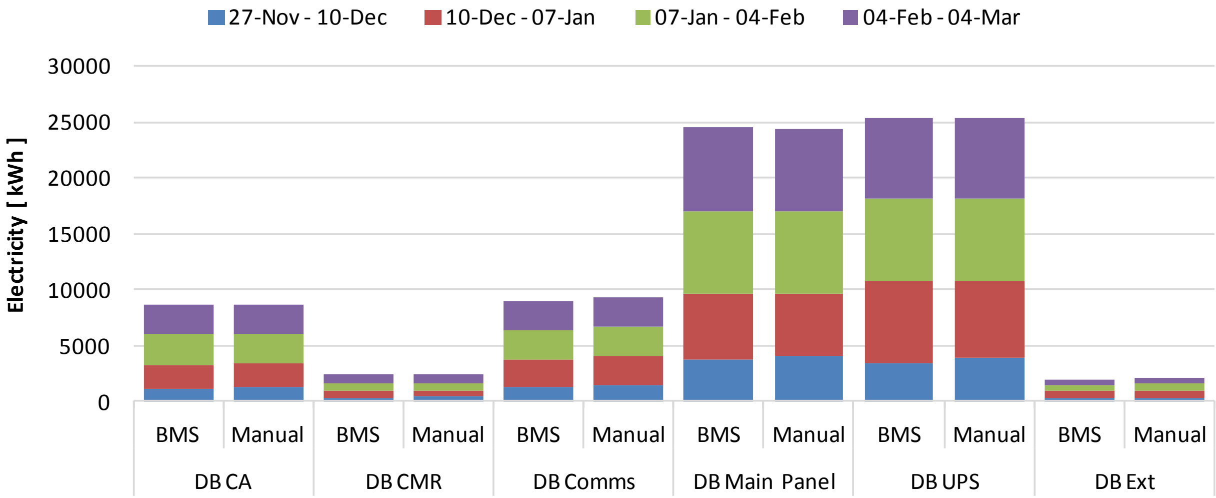



**Figure 45 Comparison of BMS and manual meter readings for corresponding periods on central plant circuits**

## 7.8 Conclusions and key findings for this section

The key findings and conclusions for this section are:

- Issues with setting up the energy metering capability on the BMS has led to complexity in carrying out analyses and have introduced ambiguities and inaccuracies in determining the breakdown in building energy use
- Some of the control parameters recorded in the BMS do not provide useful information on plant operation, which can be used for system diagnostics and evaluation of performance
- The BMS data highlighted some fundamental issues with the operation of the GSHPs, which require further investigation by expert suppliers outside this study

- The BMS data also highlighted several potential issues in the operation of circulation pumps in the building requiring further closer diagnostics, which transpire to be rectifiable problems, can alleviate energy wastage in the building.
- The procurement of suitable supplier is vital in ensuring work is completed to expectation and to time frame. To support this, it is essential that the scope of work is clear and specific. The ability to validate the work carried out is dependent of the commissioning evidence provided by the supplier, hence, this should be made explicit contractually.
- In combination with observation made on the BMS energy data in the previous section (Section 6), there are opportunities for energy savings identified in the study, some of which are straight-forward to implement, whilst some relating to the central plant will require further investigation and the services of plant experts for more in-depth system diagnostics and the necessary rectification work. This will be outside the scope of the current study. Opportunities for energy saving, which we would like to highlight are:
    a. Reduction in lighting energy use - the BMS data indicates ground and first floor lighting being left switched on out-of-hours
    b. Reduction in central plant energy use – the BMS data suggests circulation pumps operating at constant setting and at times unnecessarily when no heating or cooling was required in the building
    c. Reduction in GSHP energy use - if indeed there were incidences of heating-cooling conflict, then the implementation of better controls should reduce the associated energy wastage
    d. Reduction in AHU energy use – the BMS data and comparison with benchmark figures suggest that as a mixed-mode building, the GCH building is consuming significant amount of energy for mechanical ventilation. There were instances where mechanical ventilation appears to be operating unnecessarily. Further investigation would be required to better understand how improvements could be implemented to bring out energy reduction.
    e. Reduction in FCUs energy use - the BMS data suggests unnecessarily prolonged hours of operations, although the data is the operation flag, which does not give an indication of the flow rate or extent of actual FCUs running hours, therefore, actual savings may be marginal

# 8 Key messages for the client, owner and occupier

## 8.1 Key findings for design team

When incorporating low and zero carbon design features and technologies into a building, it is important to engage with the building users to manage expectations and also ensure adequate knowledge and skill is available within the user organisation to operate the building.

Communication across the design and construction team is essential, including all contractors and sub-contractors. This is to ensure not only that the original intentions are not compromised but also so that any knock-on effects beyond the specific scope of a particular expertise are understood and limited. An area where this was highlighted was in the specification of the sub-meters, which were meant to have a pulsed output integrated but this did not get translated to the specification of the units that were finally installed. This undermined the ability of the BMS to be able to provide useful data on energy use by sub-meter and the opportunity of effective analysis and use by the building facilities team.

There should be a realistic appraisal of the importance of and risks around effective handover of the building and this should be built into the project programme. While it is acknowledged that due to delays in the construction programme the building had to be occupied before it had been commissioned, an alternate plan should have been devised to ensure that the facilities team and staff understood how to operate the building.

In a mix-mode building it is important to ensure that the features that are to be controlled by the occupants are easily understood. While the low level windows in the open plan offices could be used as intended, some of the services controls, for instance the thermostat and open plan office lighting, did not have a very informative interface and therefore were not used effectively.

In designs where new or innovative systems are being trialled, for instance the thermal labyrinth, it would be good to incorporate methods by which the effectiveness of these is measured. This would help inform future projects, both for the design team members and also for any buildings the client may commission in the future.

Where landscape features such as trees along the southern façade are an integral part of achieving comfort by limiting solar glare, it is important to have a realistic appraisal of the factors that would contribute to the successful integration of the features and a possible mitigation strategy. The initial planting of trees was not successful and these were replanted but the size and foliage has not been able to successfully provide the intended benefits.

## 8.2 Key findings for facilities managers

The Greenfields head office building was designed to bring together staff that were previously housed in different buildings and with varied roles. It is likely that their nature of work and expectations from their office environments are different. Since achieving comfort in this building depends to a large degree on the staff's understanding and interaction with the building, the facilities managers can organise training and feedback sessions with the staff to ensure that they are able to understand the building services as well as possible.

Whilst the services installed in the building are relatively simple, in order for them to operate in the most energy efficient and effective manner, it is important to ensure that their controls and settings are not in conflict. The BMS interface allows for a number of parameters to be recorded and this resource can be utilised to optimise the operation of the services within the building. In addition to efficient operation that would ensure lower fuel bills and longevity of the equipment, this would also ensure higher levels of staff satisfaction.

Training on the use of the BMS and services should be provided to the facilities team at regular intervals. Clear documentation should be available on site for reference that is relevant to the actual installation. This would also give an opportunity to record any changes and adjustments made to the setting of the controls systems in response to feedback from staff and help track the performance of the services and systems.

A clear complaints and maintenance log must be maintained to ensure that any lessons learnt are recorded and are not lost due to changes in personnel.

The current BMS setup for the GCH building does not monitor critical parameters that allow more accurate diagnostic and interpretation of system operation. As demonstrated in the analysis carried out in this study, the use of operation flag to infer plant operation without additional parameters is evidently insufficient to provide conclusive diagnostic of how the building has been operating. For example the operation of FCU can be more clearly identified if the operation flag is also accompanied by data on the air supply or return temperatures. Therefore, in order to determine how a building is behaving and performing, appropriate monitoring of the correct parameters by the BMS will be very critical.

The central cooling system in the IT/comms room, which is no longer working has been scheduled to be de-commissioned due to leaks that have been identified as high risk to the operation of their servers. This situation has resulted in low confidence in the reliability of the reversible heat pump, which provides critical cooling to the server room, not just comfort cooling to meeting rooms, etc. Consequently, the client has installed a separate and more conventional DX cooling system to the server room: an additional energy load that would not have been accounted for in energy and $CO_2$ assessments used in BREEAM, or similar. It will also undermine any expectations of running costs that were made based on the design intent. It would be beneficial for further project to closely consider the suitability of the different types of system for optimum system performance and any corrective retrofit could be avoided.

A maintenance contract for the BMS system exists and it would make sense for the occupants to extend the scope of this to include an update on the current working of the building to help optimise the operation of all the services and occupant comfort.

## 8.3 Key messages for occupants

The building manager mentioned that the central cooling system in the IT/comms room is no longer working and has been scheduled to be de-commissioned due to leaks that have been identified as high risk to the operation of their servers. This situation has resulted in low confidence in the reliability of the reversible heat pump, which provides critical cooling to the server room, not just comfort cooling to meeting rooms, etc. Consequently, the client has installed a separate and more conventional DX cooling system to the server room: an additional energy load that would not have been accounted for in energy and $CO_2$ assessments used in BREEAM, or similar. It will also undermine any expectations of running costs that were made based on the design intent.

A maintenance contract for the BMS system exists and it would make sense for the occupants to extend the scope of this to include an update on the current working of the building to help optimise the operation of all the services and occupant comfort.

It is important to understand the interaction of any low carbon technologies with the building and its occupants when their use is commissioned. In addition to their operation needing to be properly managed, their capabilities and limitations need to be explained to the staff.

The occupants were generally appreciative of the new headquarter building in terms of its quality and design features. In order to help them maximise their comfort within the offices a more interactive approach, by means of group discussions and dissemination may be considered.

The commissioning and handover process for this building were rushed due to an inflexible date of occupancy. Due to this, there was limited opportunity to adjust the capabilities of the systems installed to address any complaints and changes were made, such as the installation of the window films and air curtain over the main entrance without consultation with the design team. While these may have addressed the immediate concerns of the occupants, these may have had the unintended consequence of undermining some of the other systems. It may be beneficial to consider other, potentially low impact, solutions to some of the concerns of the staff before commissioning upgrades or changes to the building fabric and services.

Energy management is not integral part of the building operation and the role of the facilities manager. This responsibility should be assigned to an employee’s role (possibly the facility manager). Importantly, the Board should be presented with monthly, quarterly and annual energy reports, preferably benchmarked against previous periods and/or good/best practice to allow top-down actions to be investigated and implemented.

# 9 Wider lessons

## 9.1 Lessons for design team

Recommendations for future procurement

- Be as specific as possible with the scope of work, highlighting critical elements and making sure the control supplier will be able to deliver to such requirement
- Request the BMS full list of system sensors, actuators and memory system for a full understanding of its capability and capacity to store data
- Request the control supplier to identify potential issues that might surface from the expected deliverables or the process to attain the required data
- Request for commissioning plan and validation of completed work carried out as part of the inclusive deliverables. This is expected in any building construction/refurbishment project, hence there should be no exception when it comes to retrofitting additional equipment.
- Provide time scale for deliverables and expect contractor to deliver to this time scale, including any retrospective remedial work from feedback, rather than to their timescale fitting in between other work.
- Require the control supplier to hand over all documentation and technical specification for any materials retrofitted, e.g. documentation for the newly installed CTs on the GSHP units.

Validation of commissioning and testing of installation should be carried out by the main contractor to ensure that the system controls are not set up to operate in conflict of one another. It is the responsibility of the design, contractor, and client teams to ensure that commissioning processes are not compromised. Where programmes are likely to overrun (for whatever reason or fault) contingencies must be made to ensure that the building is commissioned correctly, even if this means a managed amount of disruption for the client, or out of hours working for the contractor team. The consequences of dismissing the importance commissioning are all too important, as has been discovered in the study of this particular building.

Be prudent when procuring services of BMS and control supplier and ensure the supplier has the right skills and the ability in interpreting strategy documentation and translate information into implementation in practice is critical in ensuring the building controls work to design intent.

There is a duty of care on designers to not introduce unmanageable complexity: there must be provision in the design to facilitate management. It can be argued that the provision of the sub-metering system met the requirements of the Building Regulations, but this was insufficient for effective management to be exercised. The lack of any interface between the sub-meters and the BMS (or other AMR system) rendered the meter installation useless. In this instance it required the BPE team to arrange the interface and set up a reporting system so that the data could be collected for the monitoring project. It is hoped that this could continue to be used for managing the operation of the building's systems.

A one-size-fits-all approach may not be appropriate with some building services. Where low temperature cooling system like the comfort cooling via heat pumps is being installed, an alternative cooling strategy for specific and constant high loads like the server room, alternative cooling systems may be considered.

## 9.2 Lessons for building occupants

In shared office spaces it is expected that comfort for the maximum number of people will be achieved with outliers expected on either side of the scale. It is important to understand the capabilities of buildings so that expectations are set at a realistic level.

It is likely that if a higher degree of control is perceived by occupants on their surroundings, they may be more tolerant to extreme conditions. A recurring comment from the occupant survey was the perceived impression of overheating in some spaces, which was not completely corroborated by the monitored data.

## 9.3 Lessons for building owners

The building owner should be take a more considered approach to the application of value engineering in their future projects. This practice should be exercised with caution as such not to the extent that it would eventually compromise system operation and function either directly or indirectly by impeding the ability of the building users to interact and use the building as intended.

A good and thorough understanding of the overall building design philosophy and how its various systems function to deliver the desired performance would be vital such that implication of how each value engineering element may impact on the building performance could be better identified in the decision making process.

An important note for any building, particularly those that intend to have low energy characteristics (arguably all modern buildings), is that there is no such thing as 'fit and forget'. It is possible that a building can be optimised to run as close to its intended performance level from the outset, but maintaining efficient performance requires effective management. Performance can easily deteriorate, potentially leading to poor environmental conditions and high energy use. It is essential that energy management becomes integral to a building's operation.

## 9.4 Wider implications

Environmental performance rating such as the EPC and BREEAM are intended to acknowledge innovative designs, services and procedures within the building industry. It should be ensured that the underlying assumptions for these are not undermined, and, if these are so, these should be studied to make the process and guidance more robust.

The design team must remain available for consultation by the occupants and owners of the building to provide adequate support in the initial stages of occupancy.

Processes such as the 'Soft Landings' approach may be considered as a mandatory requirement for projects with complex or innovative technologies to ensure that the commissioning and handover are not compromised.

# 10 Appendices

Appendix A:  Building EPC

Appendix B:  Quarterly reports

Appendix C:  Thermography analysis

Appendix D:  Walkthrough report

Appendix E:  Semi-structured interviews report

Appendix F:  BUS report

Appendix G:  Asset register