Graham Construction Head Office

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Innovate UK project number	450087
Project lead and author	GRAHAM Construction
Report date	2014
InnovateUK Evaluator	Unknown (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Offices	Hillsborough, NI	Design and build	2009
Floor area (TFA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
3106.5 m^2	3	A / C (unofficial)	Excellent

Purpose of evaluation

The project aimed to determine the energy consumption of the building and how it compared to industry benchmarks and other office buildings in the UK. Other aspects studied were: the performance of the biomass system, the performance of the building fabric compared to design defaults, variation in airtightness performance compared to as-built results, and the performance of the building services compared to design defaults and industry benchmarks. The study also reviewed the lessons learned from the building's design, procurement and construction, and how they affected energy performance and occupant satisfaction.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
Partial	Yes	yes

Electricity was measured at 71 kWh/m² per annum, and thermal (fossil fuel) at 98.8 kWh/m² per annum. Although the building was designed and constructed with a 'low energy, sustainability' ethos this didn't wholly filter through to the operation and management of the building. The study found that the building could benefit from a formal energy policy and energy management plan with clear targets. It was a challenge to collect and analyse energy consumption data. However, the biomass boiler was a success and resulted in substantial carbon emissions reductions and cost savings. When compared to *ECON 19* benchmarks for a naturally-ventilated open-plan office the building performed better than typical practice.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	181 of 245	74%

The Building Use Studies survey results were predominately positive. Overall a high number of the issues raised in the survey scored better than the benchmark and scale midpoint with a few issues scoring between the benchmark and the scale midpoint. The following issues scored poorer than the benchmark and scale midpoint: variable temperatures in winter and draughty air in winter, poor control over environmental conditions, glare, and too much daylight and noise from colleagues.

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About this document:

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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.

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Executive Summary

Following a successful application to the Technology Strategy Board's Building Performance Evaluation Programme, GRAHAM Construction has been monitoring the performance of their Headquarters Building in Hillsborough, Northern Ireland over a 2 year period. The following is a summary of the key findings.

Building Fabric and Daylighting Performance

- U-value testing results can be summarised as follows:-

	North Wall U-value $Wm^{-2}K^{-1}$	Curtain Wall U-value $Wm^{-2}K^{-1}$	Roof U-value $Wm^{-2}K^{-1}$
In situ u-value	0.295	1.12*	0.34**
Design Values	0.29	1.98	0.11

*** Values are for glazing only **Potential issue with testing – see full report for more information**

- Air tightness test results were slightly better than they were at building handover. (4.63 m3.h-1.m-2 @ 50 Pa during the BPE study and 4.98 m3/hr/m2 at building handover). This is significantly below the building standards minimum level of 10 m3/hr/m2 (current at the time of building handover).
- The smoke test was able to show that drafts are an issue in some areas of the building particularly around the entrance foyer, the atrium, the lift and the area to the right of reception on the ground floor.
- Thermal Imaging highlighted potential areas of heat loss from entrance doors, curtain walling, building service grilles, 3rd floor north facing office and some areas of solid wall on the north fascade between the narrow windows on the 1st and 2nd floors.
- The results from the daylight survey were largely positive and good levels of daylighting and uniformity were present throughout.

Occupant Survey

- The Building User Survey (BUS) results were predominately positive. The response rate was high (73%) and the overall survey results put GRAHAM in the top 5th percentile from a sample of 50 buildings from the 2011 benchmarks. These benchmarks were held static for the BPE programme in order for all buildings over the programme to be compared to an unmoving benchmark.
- Overall a high number of the issues raised in the survey scored better than the benchmark and scale midpoint with a few issues scoring between the benchmark and the scale midpoint. The following issues scored poorer than the benchmark and scale midpoint : - variable temperatures in winter and draughty air in winter, poor control over environmental conditions (this is the design/strategy for most areas so this was expected), glare and too much daylight and noise from colleagues.
- Feedback gathered from walkrounds and interviews suggests that staff overall are very impressed with the new building and enjoy the high levels of natural daylighting and attractive communal areas/break out spaces. Lack of document storage areas, noise from colleagues, draughts and complaints over small numbers of gents toilets

are issues which have been raised as concerns amongst staff. Section 5 contains a full explanation of the results and issues raised from occupant feedback.

Aftercare, Operation, Maintenance and Management

- Although the building was designed and constructed with a very clear 'low energy, sustainability' ethos there is evidence that this hasn't always filtered through to the operation and management of the building. The building could benefit from a formal energy policy and energy management plan with clear targets.
- The building is well maintained and managed overall scoring well in the BUS survey under this category and with a dedicated onsite facilities manager supported by security, cleaning staff and specialist sub-contractors.
- A comprehensive Building Management System has been installed and offers a high level of control to the facilities manager. Some functionality of the BMS is underused with the sub-metering in need of maintenance at the beginning of the BPE project. In addition there was no energy management interface with the BMS originally and this was added to enable closer monitoring as part of the BPE project.
- Issues associated with aftercare, operation, maintenance and management are discussed fully in Section 6 with technical issues summarised in Section 9.

Energy Use

- One of the key challenges in the BPE project has been collecting and analysing energy consumption data. The list of individual issues associated with recording and retrieving data can be found in Section 7.5 and also throughout Section 6.0.
- Two years of energy data was collected and a full analysis of this is provided in Section 7.0.
- The use of the Biomass boiler has been a success and has resulted in substantial carbon emissions and cost savings.
- When compared to ECON 19 benchmarks the building performs better than typical practice (for a naturally ventilated open plan office) but is still some way off achieving best practice.
- A DEC assessment was commissioned as part of the BPE project and the building achieved a C1 rating.
- A third of the electricity usage can be attributed to the IT server room and electricity used to provide power to areas external to the main building. This usage is not included in the DEC assessment or in the TM22 analysis.
- TM22 analysis of Year 1 identified a large amount of out of hours electricity usage for small power and lighting with 50% of electricity for small power and 40% for lighting consumed out with office hours.

Environmental Data

- The building maintains stable indoor temperatures throughout the working day and overnight and at weekends/holidays. This stability indicates that the high levels of thermal mass in the concrete pillars and ceilings is having a positive effect on maintaining comfortable temperatures. There is evidence of some overheating on the 2nd floor but not for prolonged periods.
- Levels of CO_2 within the building are higher during winter possibly due to windows and vents being closed in winter (maximum 1600 ppm in winter and 800ppm summer). However levels of CO2 are not high enough to be of serious concern nor are they for prolonged periods. The building appears to be well ventilated for most of the year.

Contents

1 Introduction and overview

GRAHAM are a Construction, Asset Management and Property Investment company with over 1500 employees in regional offices across the UK and Ireland. GRAHAM have a commitment to constructing and managing high quality buildings and demonstrating best practice in energy and environmental performance wherever possible. When GRAHAM decided to construct their new company headquarters building in Hillsborough, Northern Ireland, there was a major focus on creating a productive, inspiring working environment with as low an environmental impact as possible.

Since completion in November 2009, the building has won a number of high profile awards including the RICS 'Sustainability Award 2011', '2011 Corporate Workplace Award' from the British Council of Offices and Northern Ireland's 'Most Sustainable Building of the Year 2010'. The building has an impressive level of achievement at design stage with an air tightness result of 4.98 m3 hr/m2, an EPC Rating of A and a BREEAM Excellent Rating achieved at Design Stage.

As well as achieving excellence in the design and construction of the Headquarters Building, GRAHAM is committed to maintaining and improving the performance of the building over its lifetime. This commitment has been demonstrated by their decision to apply for Technology Strategy Board funding to undertake a Building Performance Evaluation Study.

GRAHAM assembled a project team consisting of members of the original design team, local academia, external energy consultants, as well as members of GRAHAM's Facilities Management and Construction divisions. The GRAHAM management team are very committed to the TSB BPE programme and have provided support throughout the project. For a full list of project team members please see Appendix A.

The brief for non-domestic BPE studies is relatively flexible with a few key project outputs. The key components of the study include: -

- Commissioning Checks
- Purchase and Installation of Monitoring Equipment
- Air Tightness Testing
- Thermography
- In situ U-Value Measurements
- Daylight Survey
- Collation of Two Years of Energy Data
- Collation of Environmental Data
- TM22 Analysis
- Energy Walkarounds
- BUS Survey
- Focus Groups & Semi Structured Interviews
- University of Ulster Thermal Mannequin Study
- Data Analysis
- Interim and Final Reports
- Dissemination of Results

In addition to the findings from the mandatory TSB items, GRAHAM set out to find answers to the following questions which would have a particular relevence to the building both now and in the future: -

1. What is the overall energy consumption of the building and how does this compare to industry benchmarks and other office buildings in the UK and the BPE programme? How is the energy use broken down and how does this compare to known benchmarks?
2. What is the performance of the Biomass system?
3. How does the building fabric perform compared to design defaults?
4. How does the air tightness performance vary from as built results?
5. How do building services perform compared to design defaults and industry benchmarks? Will include lighting, heating, ventilation etc.
6. What are the levels of building occupant satisfaction? How can occupant satisfaction be improved? How can building occupants influence further reductions in energy consumption?
7. What would be required to make this building a zero carbon building? How far away is the building from zero carbon status? What perceived impacts would this have on occupant satisfaction?
8. What results would a Post Construction Review BREEAM Assessment provide? Would the Design rating of 79% be retained or have items committed to during the design stage been lost during construction?
9. What lessons can be learned from the design, procurement and construction of this building? How has this affected the energy performance and occupant satisfaction of the building?
10. What were the additional costs incurred in building a Low Carbon BREEAM Excellent Building?

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

The GRAHAM Head Office is located on a semi-rural site close to the town of Hillsborough, 12 miles from Belfast. The three storey building was completed in November 2009 at a capital cost of £10m and was designed and built to be a sustainable low energy building. The client was involved throughout the entire process of the design and was also the main contractor for the project. The floor area is 3200m2 with approx. 180 permanent members of staff on site (this has increased to 250 since monitoring began). The building has an A rated EPC rating and scored a design stage BREEAM Excellent rating. The accommodation consists mainly of open plan office space with a mix of cellular offices and meeting rooms.

GRAHAM chose the design team and procured the building using a GMP Design & Build contract. This project is slightly unique in that GRAHAM was the client and the contractor. The project was completed on budget and on time.

Working closely with sustainability advisers and architects BDP and local M&E Engineers, Caldwell Consulting, GRAHAM established four main objectives:

- To provide a comfortable and inspiring work environment for staff.
- To make the building as sustainable as possible.
- To make it affordable.
- To be able to use it as a ‘good practice’ demonstration case study.

Building Design

The design team aimed to provide generous and comfortable occupant space with a fully flexible open plan environment with breakout areas and touchdown points linked to reprographic and refreshment facilities to encourage interaction between employees and provide the opportunity for informal, unplanned meetings and conversations. The finishes of the building were designed to be of a high quality to present a professional image to visitors and clients, whilst providing an uplifting and visually stimulating workplace for staff. Choices that reflect this commitment were the addition of a glass lift, attention to signage and a generous reception area.

The designers decided to adopt a ‘passive design’ approach which involved making the most use of natural resources such as solar radiation to reduce energy consumption of the building. By paying careful attention to the orientation of the building the design engineer estimates that the company will save on heating bills as the building will now be able to take advantage of solar gains.

The building faces south east to take advantage of morning sun in winter to passively heat the building. The south east facade is highly glazed to maximise useful solar gain with the north facing façade having minimum glazing where possible. While solar gain is encouraged during the winter, in summertime it is blocked from the main facade by solar shading to prevent overheating and reduce occupant exposure to glare.

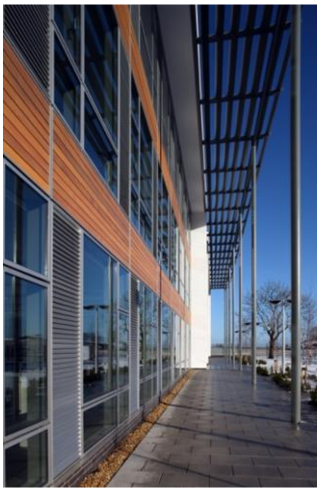


Figure 1.1: South East Facade with Solar Shading

Figure 1.2: 3 storey South East facing glazed facade

Areas such as open plan office workspace are located along the South East side of the building to optimise the use of natural light and reduce the need for electric lighting during daylight hours. Storage facilities and toilets and are located on the North West side as they do not require as much natural daylight. A glass roof and atrium running through the centre of the building facilitates the use of natural daylight and ventilation as illustrated in the picture below.

Figure 1.3: 3rd Floor Atrium

The building was designed to achieve high levels of natural daylighting and uses occupancy detection sensors to minimize electrical lighting loads.

Building Fabric

The building fabric for the walls is predominantly glazed curtain walling and partial fill cavity block with render. The curtain walling has a design u-value of 1.98 W/m2K and the walls 0.28 W/m2K. The roof and upper floors are in-situ concrete. The roof has a design u-value of 0.11 W/m2K.

The air tightness test at building handover yielded results of 4.98 m3/hr/m2. This is a significant improvement over building regulations (10 m3/hr/m2).

Ventilation

The building is predominantly naturally ventilated using floor to ceiling motorized louvres and manually openable windows. The large central atrium creates a stack effect for the ventilation and cooling of the building. Exposed concrete ceilings and openable louvres allow for night-time cooling as well as providing thermal mass to regulate the buildings internal temperature. During the day, if an area of the office becomes too hot or stuffy and staff have not opened their windows, the automatic louvres take over and gradually open. As the louvres are fully controlled by the BMS, they are designed to open to the right proportion in order to prevent unwanted draughts. The louvres respond to readings from temperature and CO_2 sensors. This improves air quality within the office areas as well as maintaining comfortable temperatures. Mechanical ventilation has also been provided and there is an Air Handling Unit on the roof of the building. If temperatures are too low to open the louvres the mechanical ventilation will supply fresh air to the building.

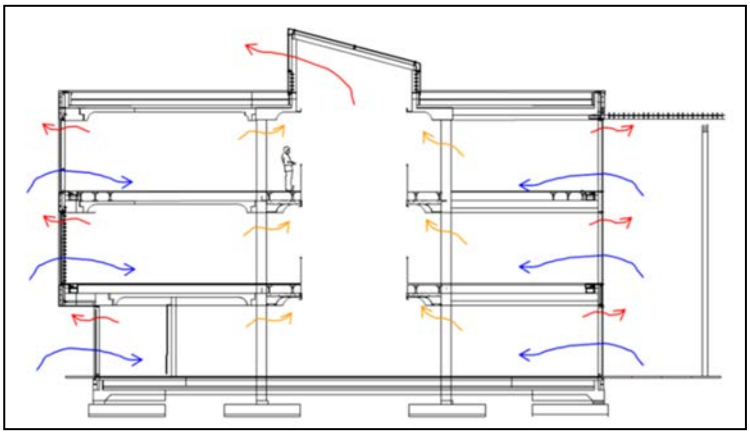


Figure1. 4: Passive stack ventilation

Figure 1.5: Automatic Louvres

The use of air conditioning has been minimised with local units installed in the boardroom, two of the conference rooms and the server room. The server room is predominantly naturally ventilated with the intermittent use of air conditioning when required.

The building is heated using a biomass wood pellet boiler with an oil boiler as a backup. The building is located in an area with no access to a gas network therefore biomass was the most cost effective, low carbon option available.

A BMS system has been installed to control heating and ventilation and monitor water and energy consumption. There is a high amount of energy sub-metering in the building as well as individual controls for each louvre. There is a full time facilities manager located on site who is employed by GRAHAM FM and who is responsible for the operation of the BMS.

Water

Rainwater Harvesting has been used for WCs and water efficient fittings have been installed throughout the building to minimise water consumption. Water sub-metering has been provided and is connected to the BMS.

Materials

The site of the new head office was formerly a disused fertiliser factory. In keeping with the sustainable ethos of the project, the existing derelict structures were crushed and used as building materials for the new building. Where a need for new concrete arose, it contained 50% ground granulated blast-furnace slag (GGBS) to reduce its carbon impact. Building materials were selected with reference to the BRE 'Green Guide to Specification' in order to ensure their environmental integrity and low embodied energy materials were chosen.

It was ensured that any timber used for the building process, along with that used for construction activities, was certified as being sourced from an ethical source. Long life building components were used, and consideration was also given to the dismantling and recycling of materials at the end of the building's useful life.

High recycled content carpets were specified and chairs and acoustic walling is made of natural wool and nettle fibre that can biodegrade in 3 months. Desk furniture is made from recycled wood pulp, again, from sustainable sources.

Transport

The building is located close to a main transport node, minimising travelling distances to the various sites where the company work. The building also includes bicycle storage facilities along with showers and changing rooms for staff wishing to cycle to work.

Biodiversity

A qualified ecologist was employed to advise the design team on the best form of landscaping to support local wildlife. In addition to planting, a bat-friendly security lighting system was used.

Design Team Review

The design brief emerged following design team meetings which GRAHAM representatives attended. GRAHAM Construction wanted a showcase building for their new headquarters. BREEAM Excellent was set as the performance standard for Sustainability. The design team were told to achieve 'best in class' for energy and water consumption however there were no specific performance targets incorporated into the design brief for energy efficiency and the design was started before the introduction of Energy Performance Certificates. The building did achieve an A rated EPC on completion though.

The client was represented on the design team throughout. Members from GRAHAM Construction as well as GRAHAM Facilities Management were present on the design team. The procurement of this building was unique in that GRAHAM were the Client, Developer, Occupier and Main Contractor. Therefore there were no incentives or retention clauses in place.

GRAHAM staff were engaged in the design via monthly meetings and a website was set up to enable queries and questions on the new building to be answered. The project architect supplied mock up suites to illustrate the new desks and office layouts that would be in place.

It was commented on that three options for building design were presented to GRAHAM and the most energy efficient option was selected. It is assumed that Facilities Management issues were given due consideration as GRAHAM's FM Manager was present at design team meetings. It should be pointed out though that the current on site Facilities Management staff had not yet been appointed and therefore were not present at design team meetings.

Throughout the project, feedback on the building design has been collated from structured and non-structured interviews with staff, original design team members, and client representatives from original design team and facilities management. Specific staff feedback on the building is largely positive as can be seen from the Building User Survey (BUS) and Semi Structured Interviews (See Sections 5 & 6 of this report). Issues that have been raised as part of the design review include: -

- **Natural ventilation strategy** appears to be working and has resulted in a minimum use of air conditioning and mechanical ventilation
- The inclusion of exposed **thermal mass** seems to be working as designed as the temperatures within the building are relatively steady without large fluctuations
- The **natural ventilation strategy** seems to work well in most areas (not all see later issues on drafts in the ground floor). Natural ventilation has not worked so well in cellular offices and some of the meeting rooms. Additional mechanical ventilation has been retrofitted to Meeting Rooms 3 & 4 on the ground floor. There are still some complaints about overheating and poor ventilation in this space. As there is always a demand for more cellular office space (mainly from senior management and departments who require more privacy), servicing these areas may require further retrofitting of air conditioning and/or mechanical ventilation. The decision to have mechanical ventilation installed as a back up means that retrofitting will not be as expensive as it might have been had no mechanical ventilation been installed at all.
- Occupation of the building is at maximum levels now and some areas of the building are showing strain. The number of **gent's toilets** in the building is an issue for staff and in hindsight more gent's toilets could have been installed at design stage.
- **Increase in staff numbers** have meant that portacabins have been added to the rear of the building to accommodate more staff that have joined GRAHAM since the building was completed. These portacabins are not as efficient as the main building and have an effect on energy consumption.

- **Storage space** is also cited as an issue for the building and for facilities management staff. There is no dedicated storage area (apart from filing cabinets) for documents in the building. This has resulted in outside portacabins being used for storage of documents which staff might need access to at short notice. Other documents are being stored offsite with a dedicated storage contractor which was the plan for all paperwork at design stage. However it is not practical to send some documents off site. This has had effects on energy consumption (electric heaters used to heat document storage areas). In addition FM have had some issues with storage of supplies and equipment.
- The **BMS system** was designed to afford the user a high level of control with features including boiler optimisation, night time cooling, energy and water management. Feedback from the original M&E engineer is that a lot of the functionality of the BMS system is not being used and that the system is over-specified for the facilities management team in charge of the building. There was evidence of this in other elements of the BPE study.
- The GRAHAM HQ building is a high specification office building and it is clear to see some **areas where additional spend has resulted in an improved aesthetic environment**. The glass lift in the centre of the atrium, material finishes and attractive furnishings, a generous reception area and visitor waiting area and an attractive staff canteen. Staff also have ample cycling and shower facilities adjacent to the building and an attractive landscaping area with ample parking.
- **Some areas where cost savings have been made** at design stage include: the decision to have an electronic sliding door at reception instead of a revolving door. This has had some repercussions, particularly areas on the ground floor where draughts are an issue.
- U-values in the building fabric could have been to a higher standard but costs made this prohibitive.
- Daylight sensors for the lighting were discussed at design stage but were omitted due to cost implications.
- The Building Management System included connection to a high number of sub-meters. However as a Building Energy Management System was not specified (due to cost savings), the data from the meters was only collected for 12 days before it was erased from the system. Spreadsheets from the system could be exported every 12 days; however this relies on someone interpolating the data from the spreadsheets for reporting. A BEMS front end enables easier monitoring and targeting of energy to take place. It can be an essential part of energy management but was not included in the building's original design.

Figure 2.1 Design Features in GRAHAM HQ

3 Review of building services and energy systems.

Building Services

This section of the report contains a description of the key building services and energy consuming equipment in the GRAHAM HQ building.

Heating
The buildings main heat source is a 240kW Hoval biomass boiler sized to meet the space heating and hot water demand of the building. As there is no gas network nearby a backup oil boiler has also been installed – a 291kW Hoval Cosmo. The specification of the oil boiler allows the biomass boiler to be switched off during summer months when demand is minimal. The biomass boiler is inefficient if run for small loads therefore it makes economic sense to have an oil boiler that can run efficiently at times of reduced load. In addition the specification of the oil boiler allowed the design team to specify a smaller biomass boiler which made significant capital cost savings during construction.

Figure 3.1: Biomass Boiler and Oil Boiler

Figure 3.2 Pumps for Heating System

The boilers are located in an external boiler house along with the hot water storage cylinder. Heat is transferred via LTHW pipework to the main building. It is then distributed around the building via trench fan coils and some radiators. The heating is sub-metered into three zones, south, north and core and not on a floor by floor basis. The BMS allows for further zoning control of the heating system. There are approximately 24 heating zones in the buildings and temperatures can be adjusted for each of these zones via the BMS.

Temperature and timer setpoints are controlled via the BMS using a boiler optimisation programme. The BMS switches on the boilers in response to the time and temperature setpoints input into the system by GRAHAM FM. The Biomass boiler is manually switched off in summer and manually switched on again in autumn.

Figure 3.3 Heating Distribution

Ventilation
The building is predominately naturally ventilated via manually openable windows and automatically opening vents in the external facade and central atrium. The louvres are controlled by the BMS using temperature/CO_2 sensors. The vents will respond automatically to CO_2 and temperature readings to achieve comfortable internal conditions. Each vent can be operated individually and if occupants request the vent to be closed permanently, this can be done using the BMS. Manually openable windows allow occupants to have some additional control over ventilation and air quality. There is an additional mixed mode ventilation system that will supply fresh air to the building during winter months when temperatures will limit the opening of the vents. This is supplied via grilles located on the floor and is extracted via openable vents in the atrium. Meeting Room 4 on the ground floor is an internal room space with mechanical ventilation only and no external vents. This is an exception as approx 95% of the building has access to natural ventilation.

Figure 3.4 Mechanical Ventilation

Figure 3.5 Natural Ventilation

Figure 3.6 Automatic Vents Inside and Out

Cooling
Air Conditioning is provided in the boardroom, meeting rooms 1 and 2 and the server room. The rest of the building relies on thermal mass, natural and mechanical ventilation to cool the building. Night time cooling can be utilised if necessary. Exposed concrete ceilings provide additional thermal mass and assist in regulating temperatures.

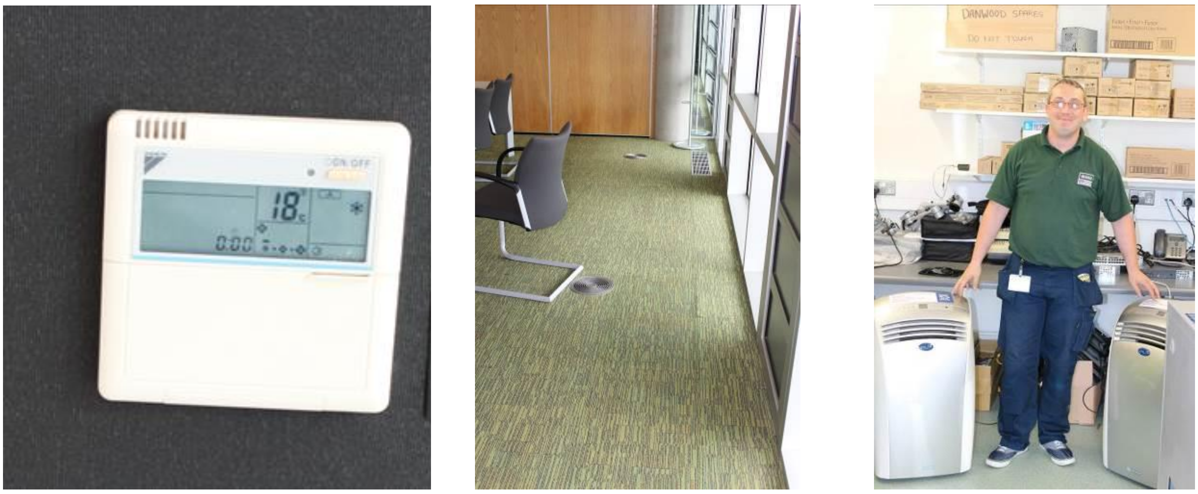


Figure 3.7 Air Conditioning controls, distribution and two portable air conditioning units in the IT workshop

Lighting
Internal Lighting
Lighting is mainly compact fluorescent T5s throughout. There are occupancy PIR sensors on all of the lighting in the open plan and cellular offices on the 1st, 2nd and 3rd floors. There is a manual switch for the lighting in the atrium which is controlled separately as emergency/essential lighting. Lighting in the stairwells is controlled manually and again is emergency/essential lighting. There is no manual override for the lighting in the office areas. The toilets and storage/plant rooms also have PIR detection. There is some LED lighting in the reception area for presentation purposes. The sign in the reception area is electrically lit by a CFL. CFL's are also installed in the stairwells, toilets and canteen areas. Daylight sensors could have been added in some areas however the budget did not extend to this measure.

Figure 3.8 Various lighting types in the offices, canteen and stairwell

External Lighting
There is external lighting in the car park and around the doors and pathways to the building. The external lighting is controlled via a time clock for useful hours of operation only. This is mainly 7-9am and 4-11pm. The lighting is controlled for daylight therefore in the months of the year when the lighting is not required due to high levels of daylight it does not operate.

Figure 3.9 External lighting in the car park

Server Room
The server room at GRAHAM HQ provides IT support to all GRAHAM employees of which there are over 1000. A number of GRAHAM employees are based on site or in regional offices in Scotland, England and Ireland. For this reason the server room and associated equipment is probably larger than what would normally be required for an office of this size. The server room has an air conditioning system but it also has access to natural ventilation through grilles on the external facade. It is located on the north west façade of the building to minimise cooling.

Figure 3.10 IT Server Room and IT workshop

Small Power
There is a large amount of office equipment including laptops, PCs, monitors, telephone chargers, printers, photocopiers, shredders and scanners. In addition there are 5 break out areas for staff. Each one of these has access to a Zip Hydrotap which can supply boiling water on demand for tea and coffee. In addition there is a fridge and dishwasher in each breakout area. All appliances are A-rated. There are two vending machines in the building and 5 plasma screen televisions. The conference rooms, meeting rooms and boardroom all have equipment including projectors, plasma screen televisions, teleconference and video conference facilities.

Figure 3.11 Small Power usage in the building

Canteen
The canteen is located on the 3rd floor and has all of the equipment you would expect to find in a small commercial kitchen. An equipment audit in the kitchen recorded the following items: - single oven, plasma television, radio, hot water boiler, mixer, grill, toaster, soup kettle, till, fryer, combi oven, hot plate & hot cupboard, dishwasher, microwave, drinks chiller, freezer, double fridge and a single fridge. There is also a large extract fan in the kitchen to take away warm air and cooking smells from the kitchen area.

Figure 3.12 Canteen

Access Control System
The access control system is the security system for the building. It includes CCTV cameras, card swipe system, door entry system and the burglar alarm.

Lift
There is one glass lift in the building and it is situated in the centre of the building. Most of the staff use the staircases to the north of the building or in the centre of the building.

Figure 3.13 Lift Area

Controls

The building has a high number of sensors and controls which operate and regulate the building services. Temperature and CO_2 meters provide information to the BMS which operates the mechanical ventilation and louvres, as well as the heating system to meet pre-programmed temperature and CO_2 set points. The BMS also controls the boilers via a boiler optimisation programme.

Sub-metering

There are approximately 30 electrical sub meters in the GRAHAM building and 6 heat meters as well as meters for Biomass and Oil. The main electricity meter is connected to the BMS also. All of these meters can be viewed as part of the TREND Energy Manager system which was purchased as part of the BPE project. Issues with the sub metering have been recorded separately in Sections 6 & 7 of this report.

BMS

The BMS is a TREND system and controls most of the building services except the lighting. Heating and ventilation are the main systems under the control of the BMS. It also monitors temperature and CO_2. The BMS also monitors the sub metering but only holds the data for 11 days before it is overwritten.

External Areas

In addition to the main building there are a number of external areas that are supplied by electricity from the main meter. These are as follows: -

- **Boiler House** – houses the Biomass and Oil Boiler for the building as well as pumps for the heating and hot water system, rainwater harvesting pump and controls, meters and controls for heating and hot water.
- **IT workshop** – an external workshop area for IT equipment. Being used more towards the end of the monitoring period. Servers being added to the building. Previously only a few PCs, a fax machine and some telecoms equipment here. Lighting and heating same as the main building. A portable air conditioning unit has been added in the last 6 months at the same time the servers were added.

Figure 3.14 IT Workshop

- **Cyclist Toilet and Shower Area**. There are three showers, fed from the central hot water tank, located in this area. Heating is provided from the central boilers distributed via radiators.

Figure 3.15 Cyclist changing and shower area

- **Portacabins for Staff.** Portacabins were added to the rear carpark of the GRAHAM HQ building in January 2014. These portacabins have their own oil boiler but the electricity is supplied from the sub-meter 'Future Workshop'.

Figure 3.16 Portacabins for staff external areas

- **Portacabins for Document Storage.** These portacabins are located in the empty warehouses behind the building and are used for document storage. They are heated by on peak electric heaters. The electricity for these portacabins is sub-metered from the 'Future Workshops' sub-meter.

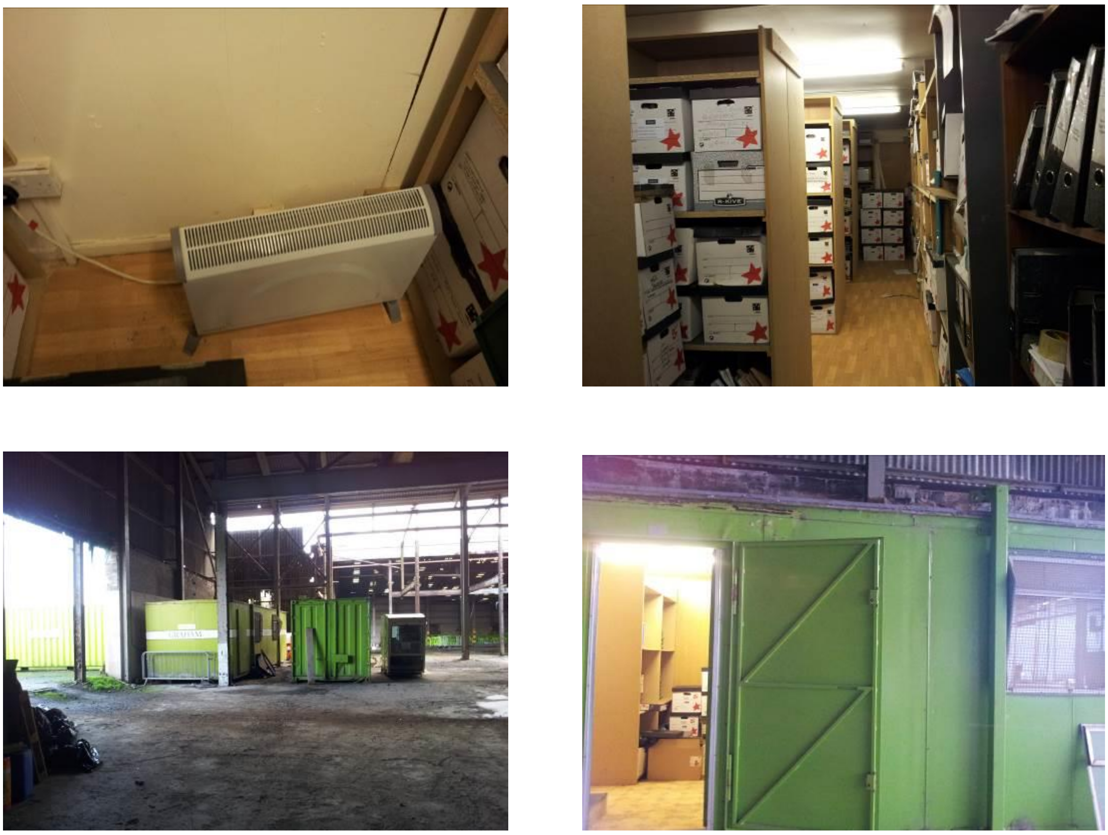


Figure 3.17 Portacabins for document storage and electric heaters

4 Building Fabric and Daylighting Performance

Building Fabric Performance

University of Ulster were contracted to undertake u-value measurements and thermography services on the GRAHAM HQ Building. A full report is available in Appendix B. A summary of the key results from this report can be found below.

In Situ U-Values

The in-situ U-value tests duration was approximately 14 days and was conducted between December 20th 2012 and January 5th 2013. An office located on the top floor of the building as can be seen in figures 4.1 and 4.2 was considered the most appropriate location which enabled measurements on the north wall, curtain wall and roof element to be taken from a single location which optimised the location of dataloggers and simplified the setup arrangements.

In order to achieve confidence in the test data two heat flux sensors were attached to each of the three building elements. The heat flux sensors were wired directly into the Datataker datalogger.

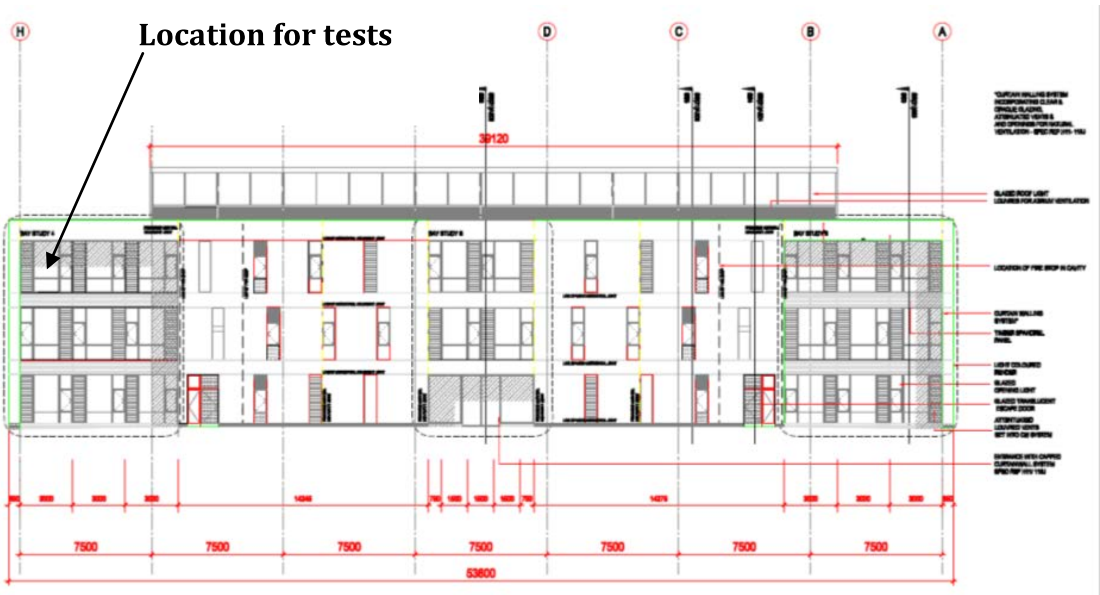


Figure 4.1 North West elevation of building

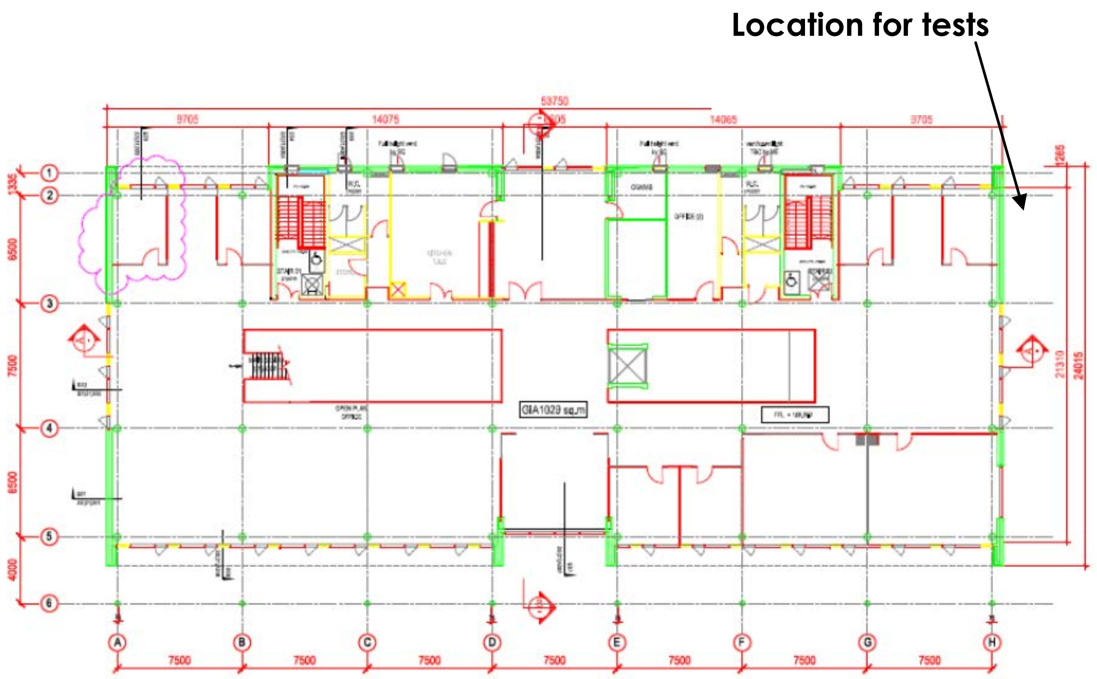


Figure 4.2 Plan of building

Table 4.1 Results for in-situ u-value measurements

	North Wall U-value $Wm^{-2}K^{-1}$	Curtain Wall U-value $Wm^{-2}K^{-1}$	Roof U-value $Wm^{-2}K^{-1}$
Sensor 1	0.34	1.02*	0.25
Sensor 2	0.25	1.22*	0.43
Design Values	**0.29**	**1.98**	**0.11**

***** Values are for glazing only

It can be seen that the measured in-situ U-value results for the ceiling/roof element are widely divergent from those determined by the design calculations. The variance is not easily explained as the values for both the curtain walling/glazing and the north wall are typically in the same region as the design calculations with some inter-element variance likely due to variations in the room test conditions and sensitivity/error of the test equipment. The variation in the design and measured U-values for the curtain wall could also be a result of the measured U-value being only for the glazing element whereas the design U-value is for the entire curtain walling system including the framing system which would have a much higher U-value than the glazing.

The experimentally measured U-values of 0.25 $Wm^{-2}K^{-1}$ for Sensor 1 and 0.43 $Wm^{-2}K^{-1}$ for Sensor 2 taken from the internal heat flux sensors mounted on the ceiling element compared with a calculated value of 0.11 $Wm^{-2}K^{-1}$ are divergent by a considerable degree. This could be attributed to a number of potential reasons:

- **Thermal Bridging at the Sensor Location:** Thermal bridging may have been caused by disruptions to the insulation layer above the roof slab/screed which may be due service channels or conduits that connect the lighting fittings, smoke detectors etc. If the sensor was placed in the vicinity of these thermal bridges this would have a significant impact on the heat flux data and subsequent U-values.

- **Thermal Contact Resistance:** If the heat flux sensor does not make good thermal contact with the wall, curtain wall (glazing) or ceiling/roof element it is measuring, the sensor will cause a local hot spot to form (or a cold spot in the case where heat flux is negative). This hot spot will alter thermal gradients and change the convective and conductive heat transfer coefficients serving to skew the readings. Where possible the heat flux sensors were bonded to the surface (glazing) or a support rod arrangement as shown in Figures 3.5 and 3.7 was used to apply a constant pressure to minimise effects of contact resistance.

- **Internal Temperature Stability**. The internal room temperature over the test period was analysed along with the difference in internal and external surface temperatures for each of the building elements. The results of this can be illustrated in Figure 4.1. This clearly shows a significant variation in room temperature with a daily temperature swing of over 5°C common with a consequential temperature variation in surface temperatures. In addition to these fluctuations there was a significant continual drop in room temperature on the 29th and 30th of December which resulted in a significant variation in internal surface temperatures. Closer examination of Figure 4.5 shows that the ambient and surface temperatures were also lower at the very start of the test period i.e. on the 22nd and the 23rd of December. These dates are for Saturday and Sunday as are the 29th and 30th therefore it would appear that the BMS reduces the internal set-point temperature of the building over the weekend period to when the building is generally unoccupied. This however could have a negative impact on the results of the in-situ testing as a constant internal temperature is desirable.

To examine the impact of this on the measured in-situ U-values a daily U-value was determined for each building element. The results of this are illustrated in Figures 4.6, 4.7 and 4.8 of the main report (Appendix B). The continual drop in internal temperature on the 29th and 30th can be seen to significantly impact on the measured U-value for these days thereby influencing the overall U-value which is further discussed in point 4 below.

- **Thermal Mass of Building Element.** The thermal inertia of the roof element could significantly affect the in-situ U-value particularly with the temperature fluctuations discussed in point 3 previously. With the internal ambient temperature reaching 21°C the temperature of the building elements would increase accordingly. As the ambient temperature in room subsequently dropped to approximately 16°C the thermal energy stored in the floor slabs and north wall meant that there was a greatly reduced heat flux through these elements and indeed there was a heat flux from the roof slab back into the room thereby significantly affecting the U-values calculated from the measured data. Therefore the combination of thermal inertia and temperature swing in the room had an effect on the measure U-values. This is evident in Figures 4.7 and 4.8 in the main report which show the measured U-values each day for the north wall and roof respectively. As the curtain walling system has a low thermal mass the effect of thermal inertia and temperature variation is less pronounced.

- **Low Temperature Difference (inside v outside).** With the continual variation and drop in internal temperature there were instances when the temperature difference between the internal and external surfaces was no more than 5°C. This would result in a small heat flux through the element therefore significantly increasing the error in the measured values particularly for heavyweight building elements.

- **Duration of the test.** The length of the test period can have an impact on the accuracy of the measured U-values particularly for heavyweight construction elements. The tests undertaken in this study lasted for 13 days; however the internal temperature fluctuations which occurred in the middle of the test could be a cause of the errors in the measured results particularly in the building elements with higher thermal mass. In Figures 4.7 and 4.8 in the main U-value report (Appendix B) the U-value is seen to start to stabilise between the 24th and the 27th of December. However this is then disrupted by the internal temperature fluctuations which effectively reset the test. A longer test period is therefore required where the internal temperature can be accurately controlled preferably at an elevated set-point to ensure a good temperature difference between the internal and external environments

In reality, the reason for the discrepancy between in-situ U-value figures for the roof element and the design values is likely to be some combination of the highlighted reasons above.

It is also worth reporting that there is a fundamental incompatibility of the calculating method to produce figures for unknown roof element build-ups due to additional services i.e. disruption to insulation layers caused by conduit runs and electrical gear which are not accounted for in the software. Inversely, the calculated figure for U-value for the wall and curtain walling/glazing element tends to correspond more closely with the in-situ figures when more information is known about the build-up of that particular element. Therefore, due to the inherent difficulties of defining the precise properties of the roofing element due to post construction services an in-situ figure may be more representative of thermal performance than a calculated one. (This phenomenon is supported by findings of a separate report on in-situ U-values by Society for the Protection Ancient Buildings 2011 – SPAB).

Thermography

The thermal imaging survey for this project was undertaken on Wednesday 30th January 2013 and commenced at 7.15am. The weather conditions were ideal for thermal imaging with the external temperature in the range 1°C to 3°C, the wind speed was light, it was not raining and the external surface of the building was dry, and low cloud cover minimised any effects of solar radiation from the sun on the building. The internal ambient temperature of approximately 20°C was maintained by the Building Management System which runs continuously therefore minimising any effects of the thermal inertia of the structure. A full copy of the results can be found in Appendix 2 of this report.

Thermal Imaging highlighted potential areas of heat loss from entrance doors, curtain walling, building service grilles, 3rd floor north facing office and some areas of solid wall on the north fascade between the narrow windows on the 1st and 2nd floors. Some examples are shown below.

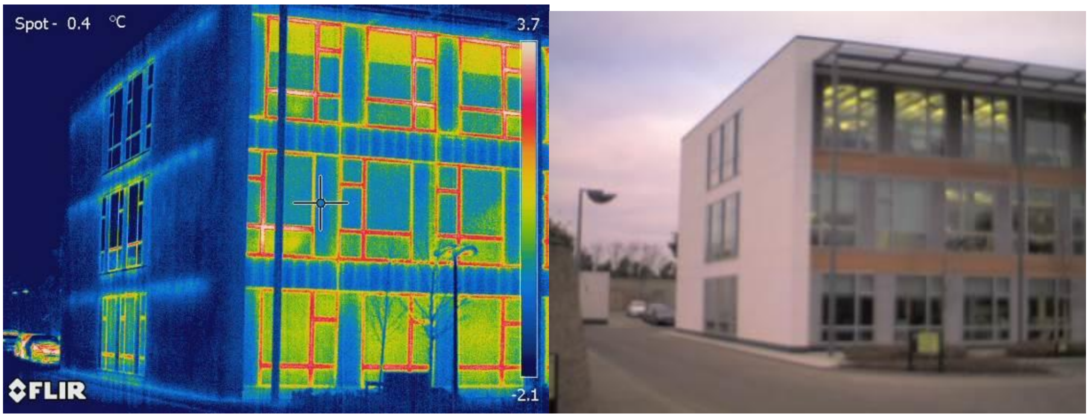


Figure 4.3 Thermal image of external left side gable end elevation and location photograph

Figure 4.3 illustrates a reasonably consistent and uniform heat loss profile for the left side gable wall of the building. There is evidence of thermal bridging where the floor slabs meet the gable wall and this contributes to marginal heat loss which spans across the gable as evidenced by the 'fingers' or 'line' of lighter colour heat loss patterns in the image tracking the floor slabs across all levels. Again the surface temperature of the ground floor cladding is higher than the middle and upper floors.

Figure 4.4, (others in main report) illustrates the heat loss for the front door area of the building and the central front façade. The automatic doors in the centre of the image exhibit a higher degree of heat loss than the surrounding glazed area due in part to the intermittent opening and closing of the doors to facilitate entry to the lobby space. Note the hot spots which represent the down/up lighters mounted on the wall. The surface temperature pattern for the door region is generally consistent with what would be expected with no anomalies in heat loss detected.

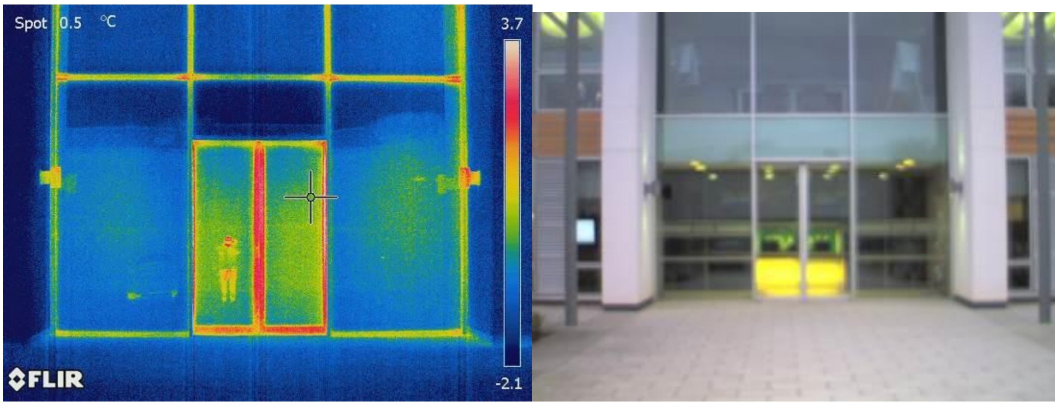


Figure 4.4 Thermal image of external front door (with reflection) and location photograph

The thermograph in Figure 4.5 illustrates a number of anomalies. The elevated surface temperature pattern represented in red which is apparent in the top left of the thermal image where the curtain walling meets the junction with the roof slab and the standard masonry walling, (as shown in the location photo), would indicate increased heat loss in this region.

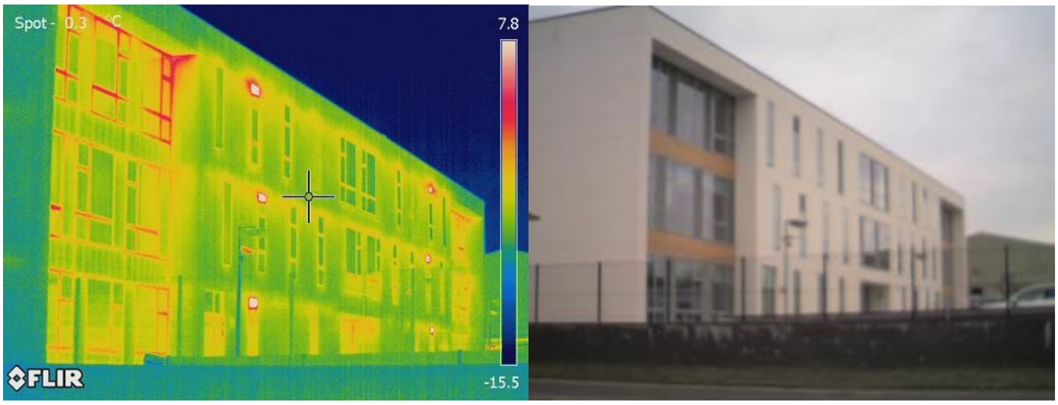


Figure 4.5 Thermal Image of rear elevation and location photograph

This may be a result of missing/voids in insulation, damp ingress or air leakage or a combination of all three. It could also be due in part to localised internal temperature variations as a result of the location of the inlet grills for the buildings' heating system. The inlet grills are spaced around the periphery of the building and the warm air may be travelling up the internal face of the curtain walling system causing an increased temperature in the region. The six hot spots at the top of the windows are as a result of extractor flues or fans for the toilets. The extractors are linked to the lights in the toilets so when someone enters the toilet the lights come on which activates the extractor fans. The fans are on over-run timers which automatically switch off after a predetermined time has elapsed.

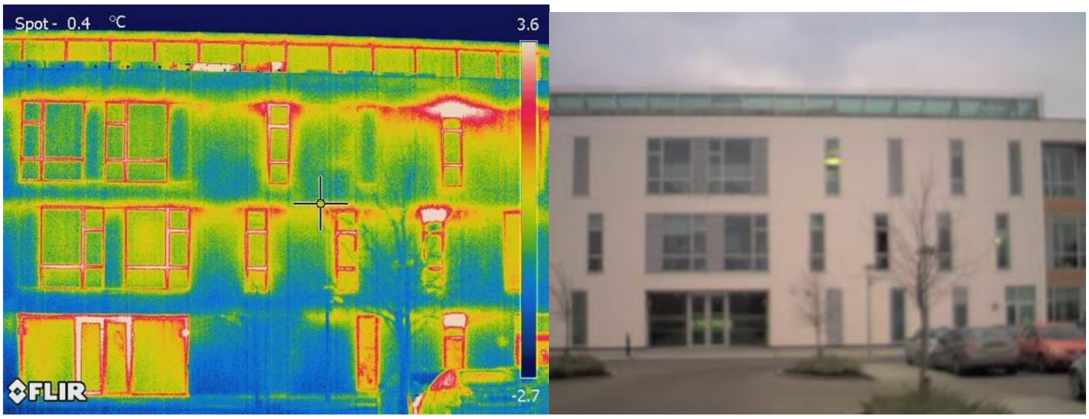


Figure 4.6 Thermal Image of external rear elevation (showing hot spots) and location photograph

The thermal images shown in Figure 4.6 also shows evidence of elevated temperatures at the very top of the building. This represents the air handling plant on the building roof which is generating heat. The hot spots at the top of the windows as discussed previously are clearly evident in these images.

Figure 4.7 shows some evidence of increased heat loss between the narrow windows particularly on the first and second floors. This is most evident at the top of the windows which may be a result of thermal bridging due to the window lintels, heat escaping from the top of the window or due to an elevated internal temperature as the warm air rises to the top of each floor. There is also evidence of some increased heat loss around the door however continual opening may be the primary cause for this.

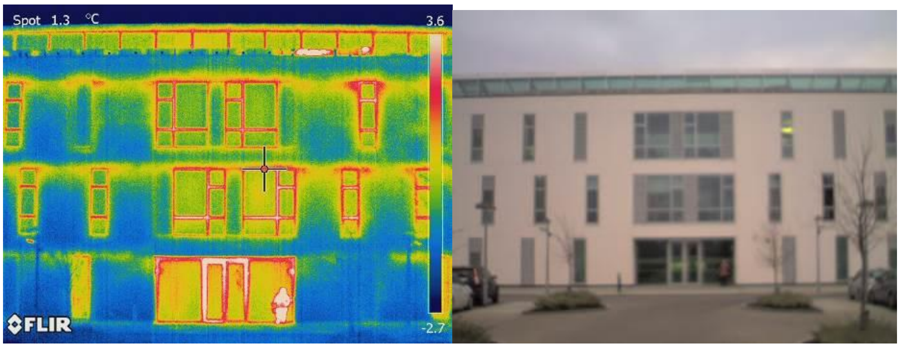


Figure 4.7 Thermal Image of external central rear façade (showing person) and location photograph

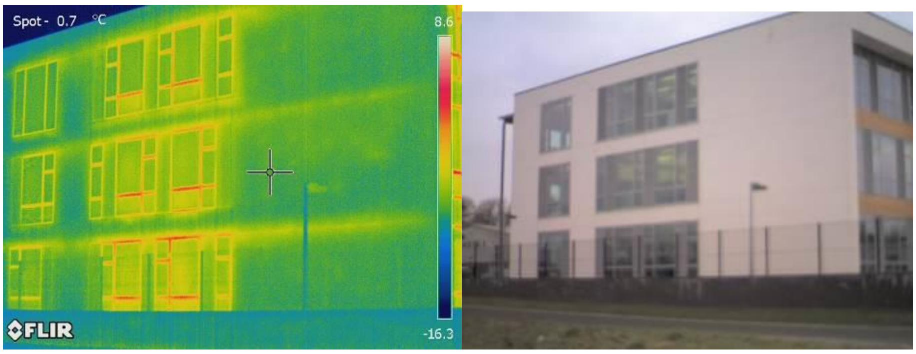


Figure 4.8 Thermal image of external right side gable and location photograph

The thermal image in Figure 4.8 illustrates a consistent and uniform heat loss profile for the right side gable wall of the building. Like the left gable there is evidence of thermal bridging where the floor slabs meet the external wall and this contributes to marginal heat loss which spans across the gable as evidenced by the 'fingers' or 'line' of lighter colour heat loss patterns in the image tracking the floor slabs across all levels.

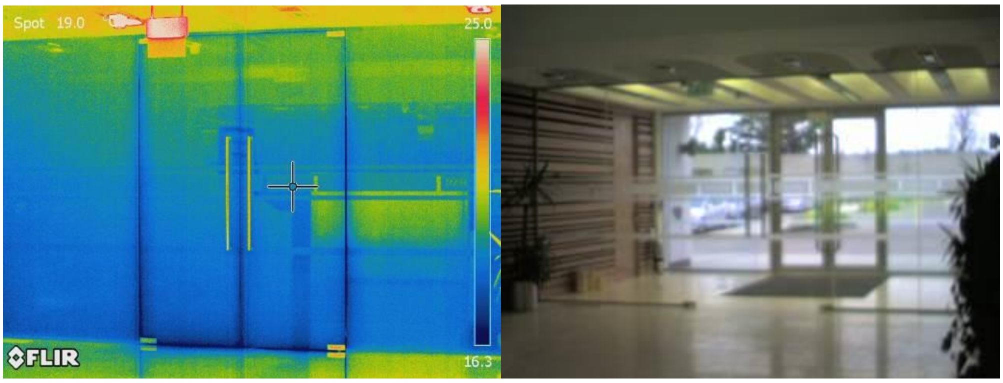


Figure 4.9 Thermal image of internal rear access door exiting to rear car park

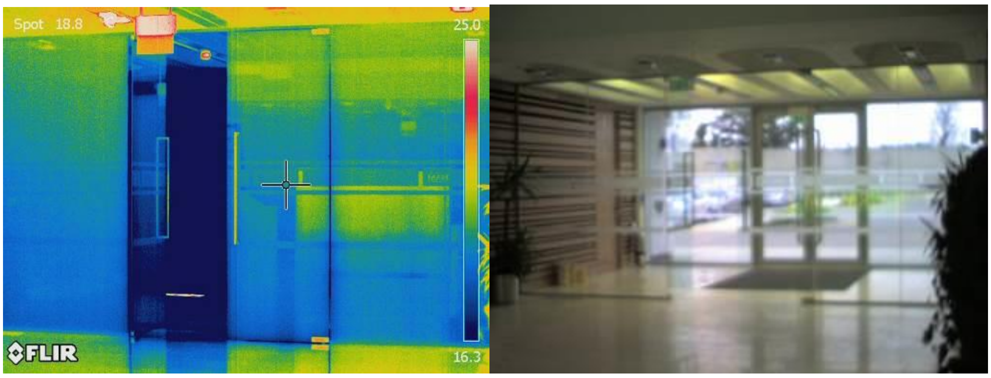


Figure 4.10 Thermal Image of internal rear access door (door ajar) exiting to rear car park

The thermal images in Figures 4.9 and 4.10 illustrate the effect of the lobby space on the surface temperatures around the door. In general the doors are effective at minimising heat loss with a small temperature decrease at the bottom of the door which is a result of increased heat loss to the cooler lobby area. The cooler lobby air is clearly illustrated by the open door in figure 4.10 which is typical across all buildings of this nature.

Air Tightness and Smoke Testing

The building's air permeability was determined by means of a depressurisation test carried out by Stromal on the 21st November 2013. The initial normalised air flow at a pressure differential of 50 Pascals (*Q50*) was established in accordance with the required test methodology of ATTMA TS1. The result attained from this test was:-

Air Permeability, *AP50*: 4.63 m3.h-1.m-2 @ 50 Pa

This is below the target level of 5.0 m3.h-1.m2 at 50 Pa specified. Thus the building complies with this part of the requirements. Appendix C contains a copy of the test data and graph generated from the test software, together with a certificate of compliance.

The air tightness test produced a result which is a small improvement on the original test of 4.98 m3/hr/m2. The building has maintained high levels of air tightness post construction. Following the air tightness test Stroma carried out a smoke test. Results from this have been recorded and a short video clip produced. This has been submitted to TSB. The main findings of the smoke test indicated that there was a draught from the main door when it was closed. The draft was following a curve around to the north west side of the building and rising up beside the lift. This draught intensified significantly when the front door was open. It was recommended that new brushes be installed on the outside door and further draught proofing measures installed on the inner door. Stroma commented that if the main door was properly sealed the air tightness results could have been improved. Possibly a revolving door would have been more air tight but the remedial measures should improve performance.

Figure 4.11Sliding doors at the front reception area

Daylight Survey

A daylight survey study was carried out by Caldwell Consulting Engineers to undertake measurements within selected key areas of the building and establish daylight factors and uniformity.

The study was undertaken on Saturday 20th October 2012 between 09:00 and 15:00 hrs. The conditions at the start of the day were overcast but became brighter later in the day. Only readings taken at the start of the day have been included in this study.
BREEAM Criteria HEA1 Daylight was the target that was set for this building. The building achieved this at design stage. In BREEAM 2006 Hea 1 daylight factor of 2% or above is considered good with above 5% excellent. Uniformity of 0.4 or a minimum of 0.8% is considered good.

A full copy of the report can be found in Appendix D

Room Guide

Room No	Description
00A	Ground Floor, front of the building, left of reception, facing South East, Open Plan Office
00B	Ground floor, right hand side, rear of the building, facing North West, Cellular Office
00C	Ground Floor, right hand side, front of building, open plan office
01D	1st floor, right hand side, rear of the building, cellular office, facing north west
01F	1st floor, centre, above reception, front of the building, conference room 1, facing south east
02H	2nd floor, front of the building, left of reception, facing south east, open plan office
02F	2nd floor, area directly underneath the atrium, staircase, communal seating and lift area
02G	2nd floor, conference room 2, right hand side, front of the building south east facing

Summary Results

	Room 00A	Room 00B	Room 00C	Room 01D	Room 01F	Room 02H	Room 02F	Room 02G
Average Daylight Factor	6.68%	6.95%	4.07%	4.31%	10.71%	6.31%	37.88%	2.56%
Minimum Daylight Factor	1.20%	2.86%	1.25%	2.64%	3.93%	1.53%	18.58%	0.85%
Uniformity	0.18	0.41	0.31	0.61	0.37	0.24	0.49	0.33
BREEAM Criteria pass	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 4.12 Daylight Factor and Uniformity

	Room 00A	Room 00B	Room 00C	Room 01D	Room 01F	Room 02H	Room 02F	Room 02G
Average Lux level	1300	1012	2116	857	1735	1347	12033	938
Minimum Lux level	316	409	631	493	643	297	6500	473

Figure 4.13 Lux Levels

Daylight Survey Conclusions

The analysis of the results indicates that the daylight for the building is considered good when compared against BREEAM Criteria. The values where generally high very close to the window and failing further away from the window. The second floor areas which benefit from the atrium some have higher daylight levels in the rear as well as the front. However the overall daylight factor is similar to the comparable area on the first floor. Room 02F is considerably higher than the other rooms as it is a communal area situated directly underneath the central atrium in the central floor space. This is currently used for the staircase, communal seating/breakout area and lift area.

The average and minimum lux levels showed very good results. The minimum office level is 300 lux2 and on measurements all showed close or above these values. This indicates that there is a strong possibility that internal electric lighting would not be required for larger portions of the year. Further study into this could lead to saving in cost, energy and carbon emissions.

Conclusions and Key Findings for this section

U values

In-situ thermal transmittance U-value tests and thermal imaging have been used to examine the as built performance of GRAHAM's headquarters in relation to the design specification. This included an in-situ U-value measurement of the curtain walling (glass element only), the north wall (standard masonry construction) and the roof using heat flux sensors and associated temperature sensors.
The results of the study indicated that the measured in-situ performance of both the curtain walling and the north wall were in very close agreement with the design specification however there was a deviation in the measured u-value for the roof with the design specification.
The average measured U-value for the curtain walling 1.12 Wm-2K-1. While the design specification value for the curtain walling is 1.98 Wm-2K-1, this figure is for the entire system of glass and frame and the design specification U-value for the glass element is 1.1 Wm-2K-1. The measured U-value for the north wall was 0.295 Wm-2K-1 while the design specification was 0.29 Wm-2K-1. The measured value for the roof was 0.34 Wm-2K-1 however the design value was 0.11 Wm-2K-1. A number of possible reasons for this deviation have been identified and discussed in section 4.

Thermal Imaging

The thermal imaging study of the building showed that in general the main facades were consistent with what would be expected from a building of this type of construction. There was evidence of some thermal bridging on the two gable walls at the floor/wall junctions. This was minimal. There was however a few areas which require further investigation. This includes an area at the curtain walling/masonry wall junction on the top floor at the rear of the building.

Air Tightness

Air tightness results are slightly better than they were at building handover. This means that there have been no significant changes to the building fabric performance since handover. The smoke test was able to show that drafts are an issue in the building particularly around the entrance foyer, the atrium, the lift and the area to the right of reception on the ground floor. New brushes have been fitted to the exterior door, however the sliding door at the main entrance will still cause increased air flow when it is in use.

Daylight Survey

The results from the daylight survey were largely positive and good levels of daylighting and uniformity were present throughout. However, the electric lighting strategy is not complementing this as much as it could be. Daylight sensor controls could have provided further reductions in electrical lighting consumption. As the office lights are controlled mainly by presence detection sensors, most of the lights are on throughout the day regardless of the level of natural lighting within the building.

5 Key findings from occupant survey

Summary of BUS Survey Results

The BUS survey was undertaken on the 14th June 2013 at the GRAHAM Head Office. Independent energy consultants Easlár administered the BUS surveys to staff with the assistance of the GRAHAM Sustainability Manager.

An email was sent out to all staff from the Chief Executive of GRAHAM one week before the survey took place and again on the day before the survey. These emails asked for everyone's co-operation with the study and demonstrated the support of GRAHAM's management team to the TSB project.

Surveys were handed out to all staff at their desks in the morning and collected just after lunch. 245 surveys were handed out on the day and 181 were completed. This is a response rate of 73% which is above the 40% required by Arup. GRAHAM is satisfied with the response rate and the quality of responses received on the day. The completed forms were collected in sealed boxes and removed from the site by the independent energy consultant. Individual responses are confidential and staff were assured of this prior to the survey. The data from the surveys was input into the BUS response template provided by Arup and was emailed to them for analysis. Full results can be viewed on the following webpage: -

http://portal.busmethodology.org.uk/Upload/Analysis/gz4gm0aj.msx/index.html

Copies of the reports can be found in Appendix E.

GRAHAM Building User Profile Summary

- 31% of building users surveyed were under 30 and 68% were over 30.
- Only 1% of respondents were outside contractors.
- 90% of respondents used the headquarters building as their normal work base
- 64% were male and 35% were female (1% didn't say)
- 42% had worked at their present desk for more than one year and 57% had worked there for less than 1 year
- 70% had worked in the building for more than 1 year and 29% had worked there less than 1 year
- 71% share a work area with more than 3 people

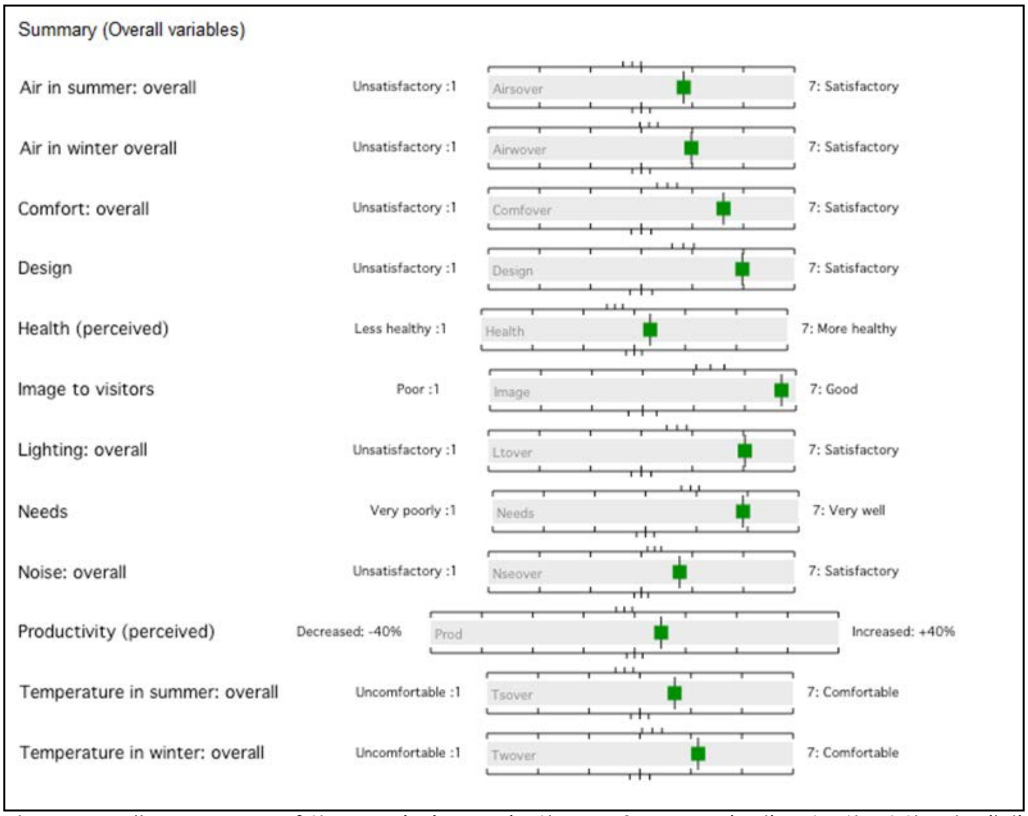
The results have been split into the following categories: -

- Issues scoring better than benchmark and scale midpoint (Green Square)
- Issues scoring between the benchmark and the scale midpoint (Amber Circle)
- Issues scoring poorer than benchmark and scale midpoint (Red Diamond)

The benchmark used by the BUS survey is taken from a sample of 50 buildings from the 2011 benchmarks. These benchmarks are held static for the BPE programme in order for all buildings over the programme to be compared to an unmoving benchmark. Therefore the 2011 benchmark buildings use for comparison are not from the BPE programme but all buildings in the BPE programme use the same benchmark.

The following is a summary of the results from the BUS survey.

Summary (Overall variables)

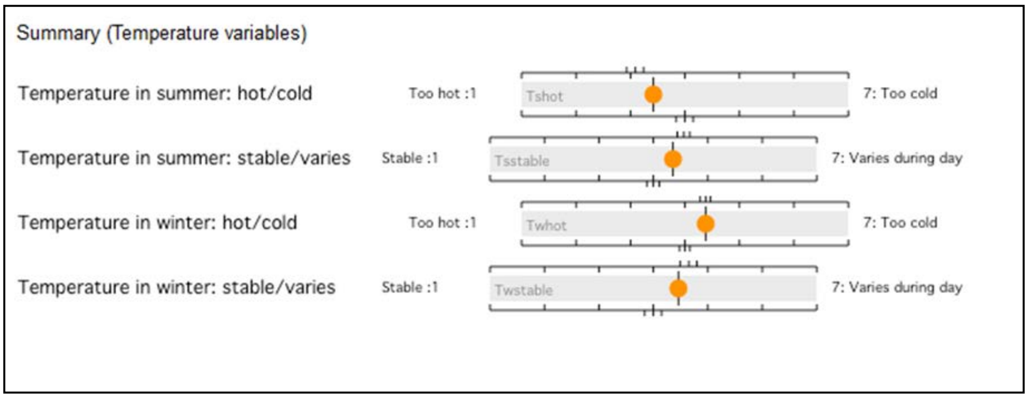


The overall summary of the main issues in the BUS survey indicate that the building is scoring well when compared to the benchmarks of other buildings and the scale midpoints. The image to visitors is particularly good which is in keeping with general comments from staff and visitors at the headquarters building.

Temperature
Although every benchmark in the above summary table is a green square, therefore indicating a good performance when compared to the benchmark and midpoint scale, this can sometimes mask individual issue with performance. The table below shows that although temperatures are better than the benchmark provided by other similar buildings that are indications that some users have provided feedback that suggests the following issues could be evident: -

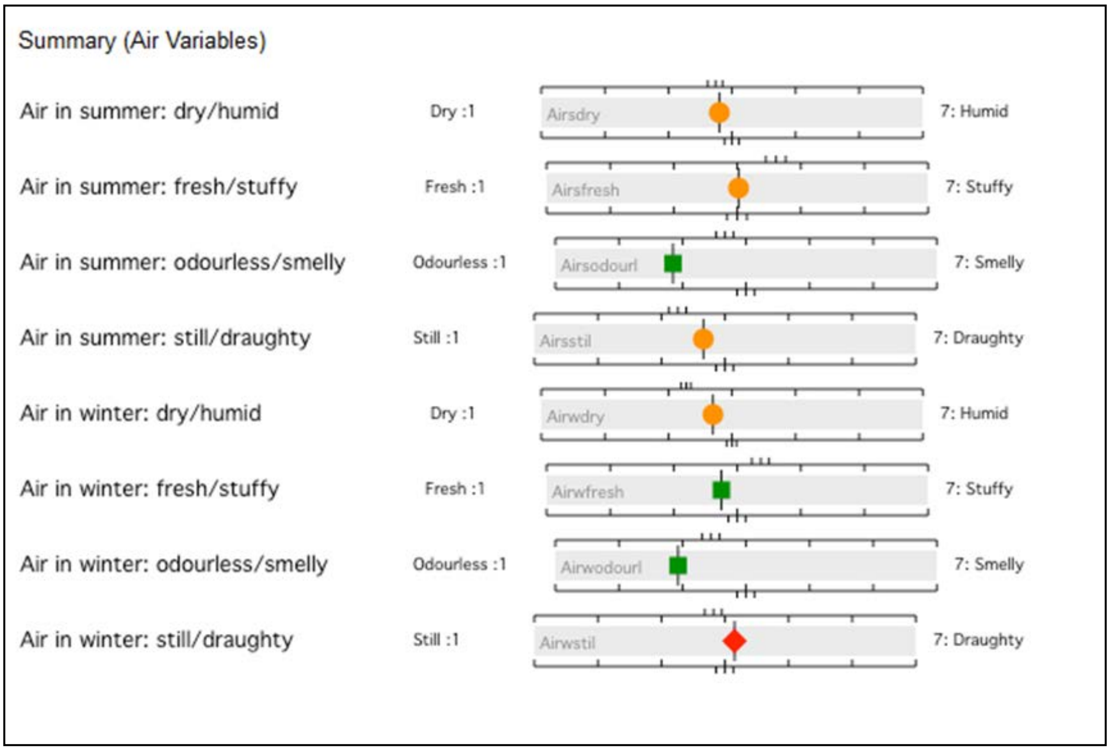
- Overheating in summer
- Variable summertime temperatures
- Too cold in winter
- Variable winter temperatures

This does not appear to be the feedback of the majority of building users; however it could be that these issues are evident in some areas of the building but not in others.



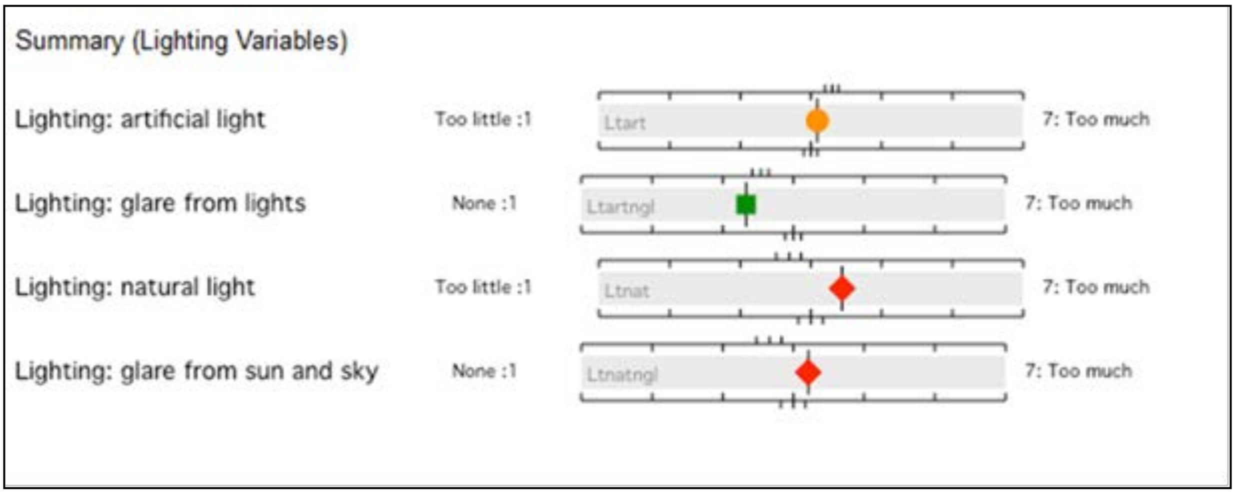
Air

The results of this table would indicate that the air in summer is slightly dry, slightly stuffy and slightly still. However these issues would appear to be reported by a handful of building users in certain parts of the building. There are no issues with odours in either winter or summer. This could be due to the canteen being in a separate area closed off from open plan offices. Hot food preparation is discouraged in breakout areas. Air is reported as fresh in winter and slightly dry. The main issue with air appears to be draughts in winter. This is in keeping with verbal feedback and results from air tightness and smoke tests. Overall users reported being largely satisfied with air related issues as can be seen in BUS Table 1.



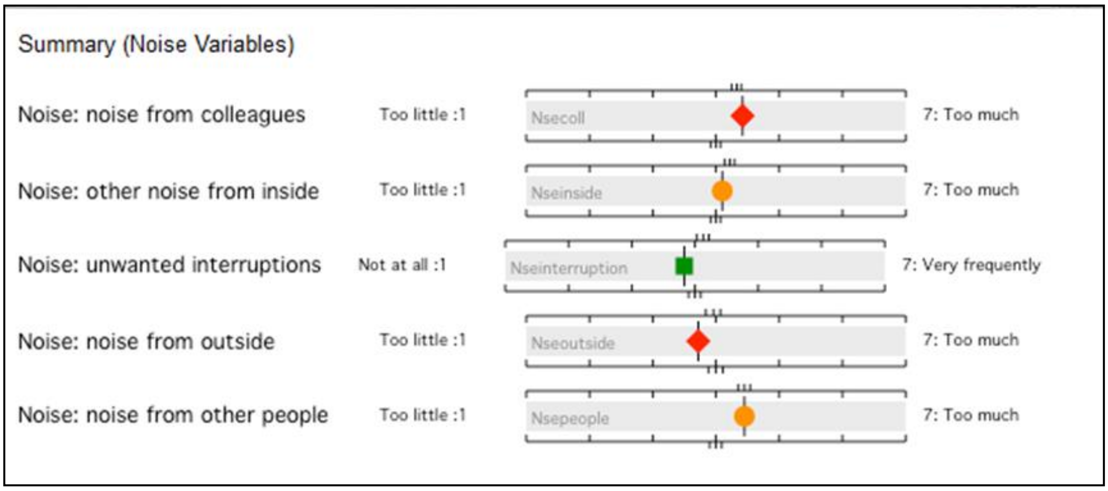
Lighting

Although BUS Table 1 indicates that most building users are satisfied with lighting overall, this masks some individual issues users have with lighting. It also indicates a high 'forgiveness' factor which is evident throughout the results. Users have individual issues but overall are satisfied. The main issues with lighting are that there is too much natural light and glare from the sun and sky. The design of the building allows for high levels of natural daylight and environmental measurements have shown high lux levels in some areas of the building. Notably underneath the atrium and the south/east facade.



Noise

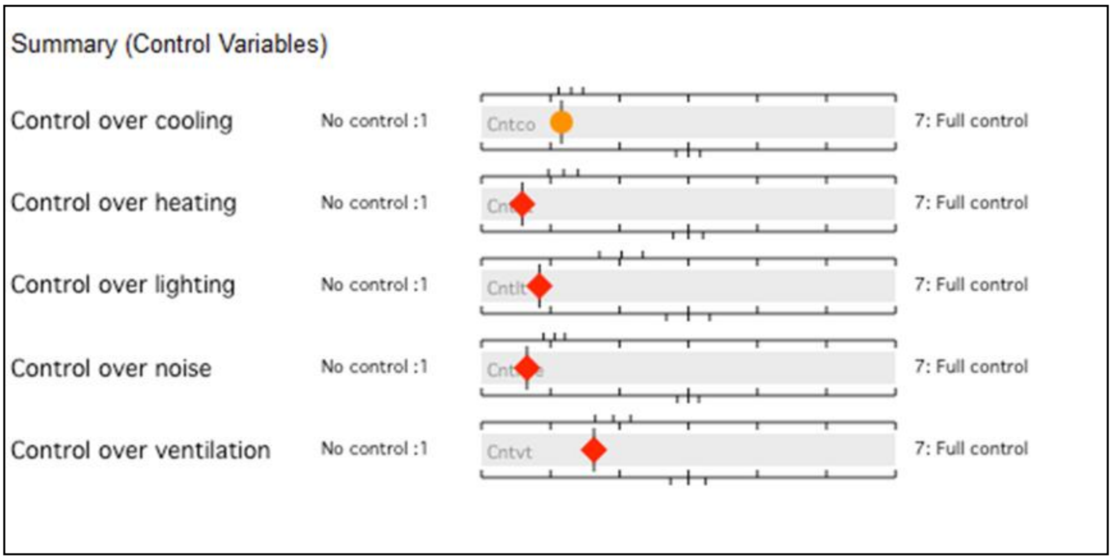
Again although most users are satisfied with 'Noise overall' as can be seen in BUS Table 1, there are some issues that have emerged when looking at individual sources of noise. Most notably users reported noise from colleagues as being too much. As the building is mostly open plan and is relatively busy and occupied during the working day this can be understood. However GRAHAM may wish to investigate ways to prevent this being an issue. Noise from outside has been reported as too little when compared to benchmarks. This is probably due to the rural location of the building.



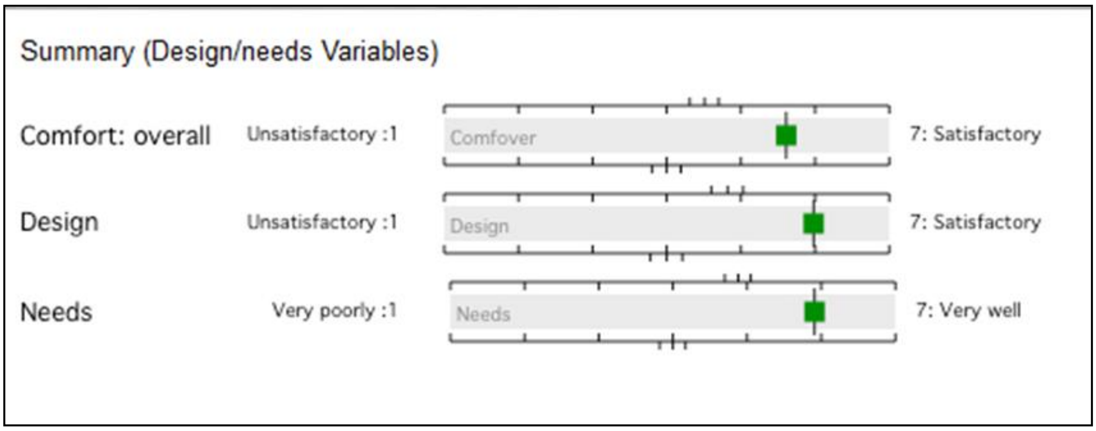
Control

This is the poorest scoring section of the BUS survey and it is no surprise as the building services have not been designed to provide occupants with individual levels of control. There is very little occupant control in the building. Control over cooling is slightly better as air conditioning is only present in meeting rooms and it can be locally controlled. There are also some openable windows in the building which might explain why the control over ventilation performs slightly better.

One interesting point to consider is that this lack of control does not seem to be impacting on user comfort as BUS Table 1 and BUS Table 7 report that this scores above the benchmark and midpoint scale. Effectiveness and speed of response of requests to changes scored highly which may also impact on user comfort. This indicates a good level of response from the FM team with regards to changes to building services.

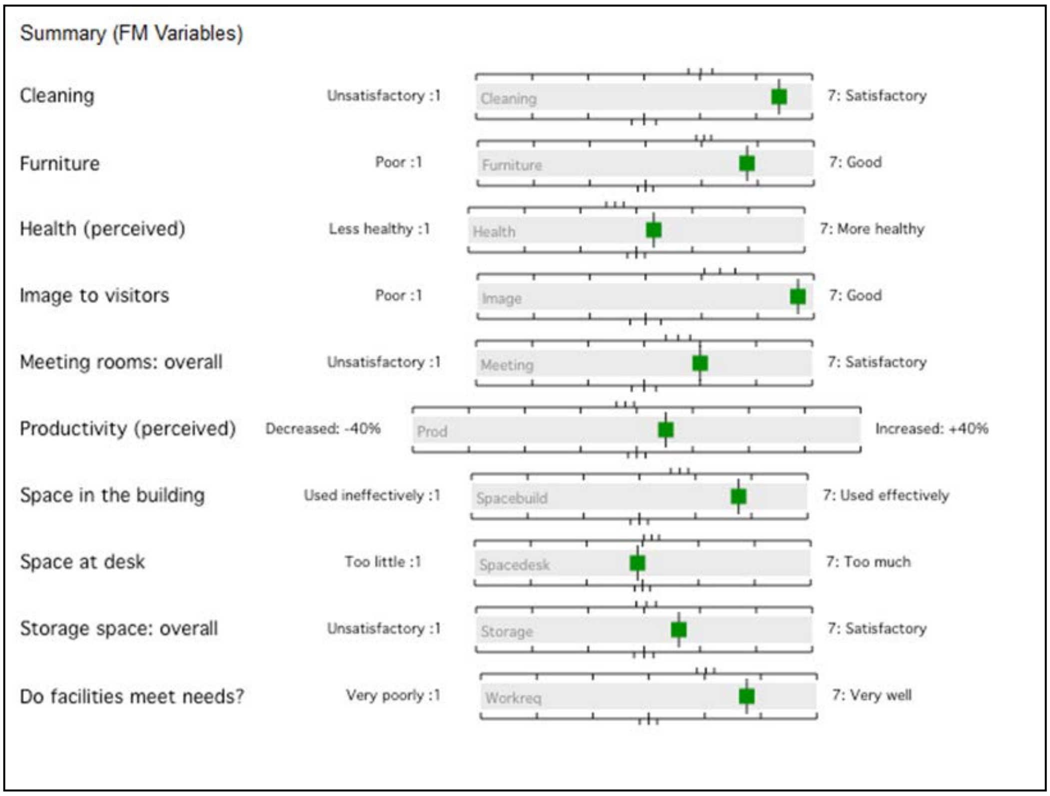


Design/Needs Variables
Overall comfort, building design and user needs all score highly with building occupants. This indicates that although there are individual issues in the building that overall satisfaction is high and the building is performing well in relation to meeting the needs of staff.



FM Variables

All of the FM variables scored highly with cleaning, furniture, image to visitors and user needs featuring particularly highly.



Summary of all results

Green Squares	**Amber Circles**	**Red Diamonds**
Issues scoring better than the benchmark and scale midpoint	Issues scoring between the benchmark and the scale midpoint	Issues scoring poorer than benchmark and scale midpoint
Air in summer: odourless/smelly Air in summer: overall Air in winter: fresh/stuffy Air in winter: odourless/smelly Air in winter overall Cleaning Comfort: overall Design Effectiveness of response to requests for changes Furniture Health (perceived) Image to visitors Lighting: glare from lights Lighting: overall Meeting rooms: overall Needs Noise: unwanted interruptions Noise: overall Productivity (perceived) Personal safety in building and its vicinity Space in the building Space at desk Speed of response to requests for changes Storage space: overall Temperature in summer: overall Temperature in winter: overall Do facilities meet user needs?	Air in summer: dry/humid Air in summer: fresh/stuffy Air in summer: still/draughty Air in winter: dry/humid Control over cooling Lighting: artificial light Noise: other noise from inside Noise: noise from other people Temperature in summer: hot/cold Temperature in summer: stable/varies Temperature in winter: hot/cold Temperature in winter: stable/varies	Air in winter: still/draughty Control over heating Control over lighting Control over noise Control over ventilation Noise: noise from colleagues Lighting: natural light Lighting: glare from sun and sky Noise: noise from outside

Figure 5.9 BUS Summary of all Results

The above table shows that the main issues highlighted in the Building User Survey are: -

- Draughts in winter
- Lack of User Control
- Too much noise from other colleagues and too little noise from outside
- Too much natural light and glare

Journey to work

An overwhelming majority of building users at GRAHAM make the journey to work by car. 84% of building users travel to work as the sole occupant of the car. 12% get a lift by car or car share. 3% of building users cycle. This could be largely due to the rural location of the GRAHAM head office. Although public transport links are available within walking distance of the office very few employees are using public transport.

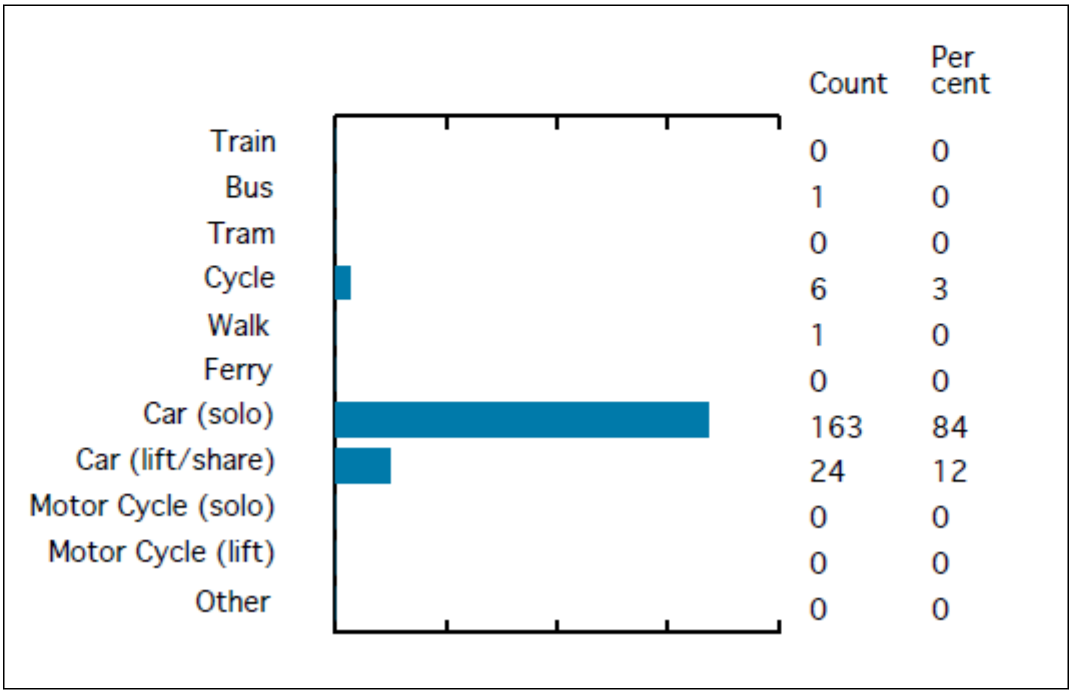


Figure 5.10 Travel Survey Results

Individual Feedback and Commentary

There are a large number of individual comments the full list can be found in Appendix E. The following is a summary of the comments made in the BUS report focusing on the most common comments rather than one off individual opinions: -

Things that work well

- IT facilities and equipment of a high standard
- Having all facilities, departments and staff in one place
- Good atmosphere and communication with other staff
- Canteen and break out areas
- Comfortable, bright well maintained building

Changed behaviour because of conditions in the building

- Lowering voices and minimising noise because of open plan environment
- Some users putting on extra clothing because they are cold
- Some users are too warm and suffer from headaches/drowsiness

Comfort Overall

- High number of positive comments (58% comments were positive)
- Some comments that the building is overcrowded at times
- Can be cold in winter and warm in summer
- Glare can cause discomfort
- Draughts reported as an issue for some
- Too few male toilets reported as a concern
- Noise can be an issue for some users also

Design

- High number of positive comments and general complimentary feedback (61%)
- Bright, airy and comfortable workspace
- Too much light and glare reported from atrium (however this was also viewed as a positive from other users).
- Not enough male staff toilets
- Too hot in summer and too cold in winter
- Can be noisy at times
- Lack of storage and small desk sizes (for those who need to look at A1 drawings)
- Draughts in winter
- Overcrowding and lack of privacy

Health (perceived)

- Quite difficult to summarise this section as there were 35 individual comments and most of them with negative comments were too personal to draw any real conclusions
- 14 of the comments were positive but for different reasons although a healthy bright environment was cited more than once
- Overheating, stuffiness and sneezing were all quoted as complaints but by a small number of individuals

Hinder (things that hinder)

- Availability of meeting rooms
- Noise and lack of privacy
- Desk space too small for reading large drawings
- Draughts and uncomfortable temperatures (too hot/too cold)
- Lack of reliable printers
- Lack of storage

Lighting

- Glare is the most reported lighting issue
- Positive feedback on high amount of natural lighting

Meeting Rooms

- General comments are around the lack of available meeting rooms and the difficulty in booking rooms at peak times
- Meeting rooms are generally of a high standard although the smaller ones have been reported to be poorly ventilated.

Needs

- Positive general feedback that all needs are being met
- More male staff toilets
- Request for microwaves and toasters in break out areas (or canteen area to be used for staff to heat own lunches)
- Requests for more meeting rooms
- Request for quiet area/library space for improved concentration

Noise

- Mobile phones and colleagues talking loudly on them seems to be the main source of noise complaints
- Interruptions from other staff also cited as a source of noise

Productivity (perceived)

- Being too warm or too cold were cited as reasons for reductions in productivity
- Noise was also commented as affecting productivity
- Significant number of positive general comments on productivity

Requests for changes

- Requests have been made to close vents because of draughts. Ventilation changes are the most requested changes on the survey feedback
- Requests for blinds to combat glare
- Changes in temperature – some to turn up heating, some to turn it down

Space at desk

- A significant number of respondents have commented on not having enough desk space. This seems largely in relation to viewing drawings.
- It was also commented on that desk size has decreased from previous desk sizes
- However other respondents commented that their desk size was sufficient for the work they do.
- One particular comment was ‘it’s like a car, does job, but wouldn't mind a bigger one’.

Storage

- Storage seems to be a problem for a large number of respondents.
- 56 respondents commented on the storage of documents – 54 of these comments cited not enough storage as the biggest issue

Journey to work

There were few comments on the journey to work however the comments made included: -

- Poor public transport links
- Traffic problems
- Length of journey
- Others commented that their journey was hassle free

- Some suggestions included more opportunities to work from home for those that live further away, and car sharing schemes would be beneficial

6 Details of aftercare, operation, maintenance & management

Building Handover

As the building was procured and constructed by GRAHAM directly the building handover was managed by GRAHAM staff, specialist sub-contractors and members of the original design team. Caldwell Consulting, who were the M&E design engineers on the project, were employed to oversee commissioning. This is a unique situation in that it is not often the case that a contractor is handing over a building to themselves.

GRAHAM FM (GFM) is in charge of the facilities management of the building. There is an onsite facilities manager who reports directly to a manager in GFM who is located offsite. The Contracts Manager at GFM has also been involved in the project although he is not involved in the day to day running of the building. The Planning Manager within GRAHAM Construction is very involved in the GRAHAM HQ building and was involved in the design, procurement and building handover of the project and still lends support to GFM on building operational matters when he is in the HQ offices.

Additionally the M&E engineer is still working with GRAHAM on other projects and is a frequent visitor to site. Often they are asked questions on the building and how the systems in the building work. Initially the M&E engineer was recording energy and water consumption for the building. However the onsite facilities manager now has that role. The aftercare of this building extended to two years and the original M&E engineer is still involved in assisting Facilities Management staff.

Plans for environmental logging and review were considered by the design team and the BMS has the capability to do this. However no one within the organisation was identified to do this pre-handover. This could be one of the reasons why the only figures reported for energy and water use pre-BPE study were manually collected from the main incoming meters. The BMS is not being used for this even though it was designed to provide this information. Training was given to building users on the BMS from ATC, the BMS company responsible for the system, however this was ½ day and most of the people trained pre-handover were not directly responsible for the Facilities Management of the building. Staff members who were trained at building handover have the responsibility to pass this training on to the current on-site facilities manager.

Fine tuning of the systems appears to still be on going. Most of the systems are now working as intended with a few exceptions. There are still some complaints regarding user comfort in some areas of the building which it is hoped the BPE study can help to resolve. A full set of O&M manuals are available on site. Although it has been noted some of this information was not accurate. Notably the equipment in the kitchen did not match that in the O&M manuals. However the majority of other information is accurate.

Existing staff were given induction training when they located to the building. New staff are also given induction training and a tour and explanation of the building. A Building User Guide for the Hillsborough Office is in use. It contains information on Open Plan Working, Team Locations, Using the Telephony System, Printing, Room Booking & Equipment, Post, Staff Restaurant, Fire Alarms, First Aid, Data Storage, Being Green, Corporate Branding and other GRAHAM Offices.

Although there is a section on 'Being Green' information on the building's design, building services, energy efficiency, water efficiency and green transport are not included. The user guide would not comply with BREEAM guidelines either. This highlights that some of the BREEAM commitments made at design stages were not followed through as the building did not undertake a Post Construction Review. More information is available on this in Section 10. In the meantime recommendations on how to improve the user guide have been provided.

Operation, Management and Maintenance

GRAHAM FM is responsible for the day to day running of the building. There is an onsite facilities manager and there are three part time cleaners as well as a security guard who report directly to the onsite FM manager. The cleaners work in the morning and late afternoon to early evening. The security guard is on duty early in the morning and again in the evening until 7pm when the building is closed.

Operation

The FM manager is responsible for the operation of the building services and has full access to the BMS. This building has very little direct occupant control therefore adjustments have to be made via the BMS when users report issues. Common issues include the following: -

- Opening/Closing external louvres (this can be done for each individual louvre in the office)
- Increasing/decreasing temperatures in zones
- Making adjustments to mechanical ventilation system when it is in use

FM have reported that it is difficult to please everyone in an open plan shared workspace. There are areas in the building which generally receive more complaints than others. Areas where complaints have been noted are Conference Room 1, Meeting Rooms 3&4, Ground Floor West and Ground Floor Reception. The main issues for complaints in these areas are around temperature control and ventilation. Drafts have been reported in the ground floor reception area. This has been proven in the smoke tests carried out by Stroma and in the BUS survey results. Some of the areas on the 2nd floor south facing side of the building have reported overheating. In each of these cases it is possible to adjust set points on the BMS to try to achieve comfort for these users. The overheating is compensated by allowing vents to remain open for additional cooling. The ground floor issues of drafts are on-going however additional radiators were installed on the ground floor to compensate for the heating and new brushes have been installed on external doors. This has proved effective in some ways but will continue to be monitored.

The complaints in Meeting Rooms 3&4 were around poor ventilation. As these spaces are internal rooms, ventilation had to be improved mechanically. Overheating in this room is also an issue. The mechanical ventilation supplies fresh air from outside and does not pre-heat or pre-cool air. If complaints persist in this area air conditioning may be considered.

Heating Operation

GRAHAM staff are mainly between the ages of 20 and 60and there are no vulnerable user groups identified. Therefore it is reasonable to assume that temperature settings of between 18 and 21 degrees will be suitable for most occupants. However these setpoints have been altered particularly in areas where draughts have been reported. Temperatures have been increased and two additional radiators have been installed on the ground floor. These temps are approx. 23 degrees. Environmental monitoring results can be found in Section 8 of this report.

Thermostats are set via the BMS and temperature sensors are in zones throughout the building. Occupants do not have direct control over temperature. Occupants can ask the facilities manager to change the temperature in their zone and he will do this via the BMS. There are approximately 20 temperature sensors on each floor. Each floor has approximately 5 zones. Each of the zones is controlled by one temperature sensor or an average from a combination depending on the size of the zone. Temperature sensors seem to be reading sensibly on the BMS and were correlated during spot checks taken at the commissioning exercise. In addition environmental monitoring data suggests no extreme issues with temperature fluctuation (see section 8.0).

Heating is set at 25 degrees on the ground floor – mainly in response to complaints from users about it being too cold. The rest of the building has a heating setpoint of 22 degrees. The ventilation system is also automated in the building and will automatically open louvres in a given zone when the temperature goes above 23 degrees (26 for ground floor) to provide cooling and it will also operate when the ppm of CO_2 go above 1500 ppm. In winter time if the temperature outside is below 15 degrees the mechanical ventilation will kick in to ventilate the building instead of the louvres. Vents can be turned off individually and overridden if a user does not want them to open automatically. This seems to have been requested often. There are also manually openable windows for building users to operate. There is a lockdown mode for the vents at night to prevent them opening automatically.

Problem areas for underheating and overheating include Conference Room 1 and Meeting Rooms 3 & 4. These rooms have intermittent occupancy and therefore it can be difficult to have the set points adjusted for the appropriate occupancy levels. Conference Room 1 is often reported to be either too hot (at which point AC is manually switched on) or too cold (occupants have left the room without switching off AC) and the next occupants are too cold. The BMS does not control the AC. Meeting rooms 3 and 4 are reported to be too warm and ventilation is poor. There is no natural ventilation strategy in these rooms as they are internal spaces.

Lighting Operation

Lighting controls are automated in all of the office areas both open plan and individual offices. There is a high level of daylighting in this building and it is thought that if more daylight sensors could have been installed then the lights would be switched off in certain areas more often. Motion sensors are the main control strategy in the building.

Some areas of the building suffer from glare. The reception area has had tinted film retrofitted. Also the area immediately below the atrium has a high amount of glare in the middle of the day in the summer. However the desks located here are hot desks and aren't used very often. Most of the desks have been well positioned to avoid glare and brise soleil on the east and south facade minimise the glare.

Lights in the central atrium are left on permanently to light the stairs. These lights can be manually switched on and off but only by the facilities manager with a key. They are almost always on but this is mostly due to a safety precaution. Levels of lighting are very good under the atrium so it probably isn't necessary to have these lights on during the day.

The security guard is responsible for switching the atrium and reception lights off at the end of the day (7pm). He cannot switch off the PIR controlled lights as there is no manual override. There have been issues in the past with over sensitive PIR sensors coming on at night (thought to be activated by birds or shadows from cars outside) however this has since been fixed. The security guard has reported that sometimes these lights come on when there is no one in the building. Apart from being slightly spooky (though the security guard said he does not get scared) this could be causing unnecessary energy usage out of hours.

BMS Operation

FM have commented that there is a lot of information and functionality on the BMS and that it is probably not being used to its full capacity. As such there may be issues with controls and sensors which have never been picked up. There is a night cooling strategy within the BMS that has never been used. The BMS is being used in a reactive way rather than pro-active. The BMS does not have a summer/winter setting. This means when the seasons change adjustments have to be made manually. Weather conditions dictate the changes that need to be made to the BMS. However the BMS has a good amount of individual control. Every motorised vent in the building can be individually adjusted using the BMS. There are approximately 24 heating zones in the buildings so temperatures can be adjusted to suit small user groups. FM would have preferred more control of individual heaters rather than controlling zones. Overall the BMS is perhaps a bit complicated for the end user. The engineer involved at design stages was responsible for the BMS specification and the current facilities management staff were not involved in the design although other members of GRAHAM Construction and FM were.

The BMS alarms have not been set up properly or have been overridden. The only alarms currently set up are the AHU Filter replacement and security alerts. The user interface is ok and fairly straightforward if you know what you're looking for. Once when the FM site manager was not available one of the cleaners had to make an adjustment to the vents in a meeting room. The FM manager was able to talk them through this process over the phone.

The BMS optimises the use of the boilers which mean they come on at 3 am (Biomass and Oil) to ensure the space is heated to 22 degrees for 7am in the morning. At the beginning of the project the BMS was switching boilers on in the middle of a Saturday night. There was no reason for this – it was never in the original setup. This has now been fixed. The BMS goes into 'lockdown' mode at 7pm every evening when everyone should have left the building. -The biomass boiler is switched off in the summer time when heating is not required. This is manually carried out by FM. The hot water during summer is heated by the oil boiler.

Main issues currently reported with the BMS are CO_2 sensors not reading accurately, inaccurate sub-meter readings and wind speed sensor not working. These issues have caused some operational issues within the building including vents opening when they shouldn't (because the BMS thinks CO_2 levels are high when they aren't). In addition the atrium windows are supposed to close when wind speeds are high. There was one instance during a storm when this became an issue. As the wind speed sensor was broken the windows did not close, this caused the motor to break, causing rain to pour into the 2nd floor office space as the window remained permanently open. This has now been repaired. A manual override for the windows could have prevented this.

Overall the building is operating well and the feedback on facilities management from building occupants in the BUS survey was higher than benchmarks and one of the areas that the building scored highest.

Maintenance

Maintenance is carried out using a PPM Planner which is a planned preventative maintenance system used by GRAHAM. All servicing and maintenance of systems is recorded here. It can also flag up when maintenance is scheduled and who the maintenance suppliers are for individual systems. Regular maintenance is carried out on the building with most systems being serviced bi-annually or annually.
GRAHAM has maintenance contracts in place for many of the systems in the building. These contracts were in place for other buildings and thus were able to be extended to the new building. Some systems such as the BMS and the automatic louvres required specialist maintenance contractors.

The Rainwater Harvesting is working however the filters on the system need changed more often than recommended by manufacturer's guidelines. The pressure vessels on the RWH also needed replaced not long after handover. These issues are possibly due to dirt on the roof or leaves and debris from surrounding countryside and some demolition work that has now completed. The RWH tank is cleaned out every year. This uses a lot of water. Another issue with the RWH occurred when a cable caught on the main pump and the toilets wouldn't flush. The RWH tank is difficult to access as it is under the carpark. It is required to be cleaned out fully every 5 years- this hasn't been done yet and FM are sceptical that this can be carried out as there is a lack of space to reach the tank.

Air Handling Units have the filters changed every 6 months. The alarm on the BMS sounds when this is required. An engineer comes to service the AHU every 3 months. There have been some issues with the motors on the automatic vents. Some of the fuses on the motors blew and had to be replaced. This work is ongoing. By switching all of the vents to the open/closed position on the BMS can check which ones have motors that need replaced. In addition the motors for the atrium vents were originally wrongly sized for the size of vents and they blew and had to be replaced immediately. Apart from the motors the vents don't require any maintenance. There were some issues at handover with commissioning as the supplier is located in England and was not always available for on-site commissioning activities.

When accessing the plant on the roof and the vents /windows of the atrium, harnesses are required and two people must be together at all times. The atrium requires scaffolding to change lights and cleaning of the atrium windows may not be accessible for cleaning (hasn't been done yet). The motors on the louvres for the atrium vents are not easy to access when they require changing.

Birds have been known to sit on the brise soleil and leave a mess on the windows and shading louvres that is difficult to clean.

Another comment from FM was that the outside portacabins are difficult to monitor and heat. The electricity for these portacabins comes from the main electricity meter. Electric heaters and small power can be left on by staff and it may take FM a few weeks to discover the issue and intervene.

The biomass boiler needs to be cleaned out every two weeks – this is not a problem and has been added to FM Duties. The oil boiler is serviced twice a year therefore there is no maintenance for FM – this is outsourced. The biomass boiler has only broken down once and this was caused by pellets trapped in the auger.

Fig 6.1 Biomass Boiler Maintenance

Energy Management

There is no official energy policy for the GRAHAM HQ building and there are currently no targets for energy saving or energy management. Overall energy consumption is reported to management however it is unclear what is done with these figures. FM are currently not undertaking monitoring & targeting.

The metering and monitoring part of the BMS was not used by GRAHAM before the TSB project. There are many issues with the metering and it is thought that these issues were never picked up at handover. The TREND BMS system was not set up to continuously log energy and water consumption (the data was overwritten every 11 days). GRAHAM was under the impression this data was being collected when it was not. As part of the TSB project a Trend Energy Management (TEM) system has been installed. This is an AMR front end to the TREND BMS. This will allow future M&T activities to take place however Energy Management responsibilities will have to be delegated to a suitable member of staff or external third party.

Overall the BMS and metering issues have been the biggest challenges of the project so far. Other issues that relate to the metering include: -

- No labelling on the sub-meters
- Sub-meters set up incorrectly on the BMS (names didn't match physical meter numbers)
- Meters stopped recording on BMS
- Meters recording inaccurate readings
- Poor information on what meters are actually measuring
- Main meter for electricity not connected to the BMS
- DHW meter faulty and had to be fixed as part of the project
- Site mains water meter not set up properly on BMS
- Sub-metering for fans and pumps not powered up on site
- Lack of physical readings to compare BMS readings with
- Poor service from BMS provider (lack of interest and long response time to fix issues)

Water monitoring
Accurate data on the site mains water consumption is still not available for the building even though the issue was raised at the beginning of the BPE project. Although sub-metering is in place and connected to the BMS and TEM systems, the readings do not make sense. The site mains water meter is reading less than the water consumed from the entire site. The site mains water meter is located under the external car park and it is difficult to access to take physical readings. A harness and other safety equipment would be required to access it.

Fig 6.2 Site Mains Water Meter

Building Walkthroughs

Information from the building walkthroughs and semi-structured interviews have contributed throughout this report. Issues and observations that were discovered and haven't been raised elsewhere in this report have been summarised below: -

- Automated control works while the building is occupied however more manual switches for turning things off at the end of the day and at the weekend would be beneficial.
- The company and number of staff at GRAHAM HQ is expanding rapidly (180 at the beginning of the project, upwards of 250 now not counting staff in portacabins outside). There does not seem to be enough space for storage and future expansion and the number of male staff toilets appears to be an issue in the building.
- The building is an office that contains all of the spaces required for an office building. Since the last walkthrough about 60-70 new staff have joined GRAHAMs. This has resulted in new desk spaces being created. Cellular offices were removed to accommodate this. Due to lightweight partitions in the offices this was not a major task. Therefore opportunities for expansion were considered at design stage. However FM have raised concerns about any future expansion and how to accommodate this.
- Also since the last walkaround portacabins with electrical heaters have been located at the back of the car park causing a large electrical load. The portacabins are used for storing documents and highlight a lack of storage in the main building. FM would have preferred a basement for storage as they are using every available

cupboard and plant room to store cleaning and maintenance supplies. An example of this impacting energy usage was when the boiler house had to be used to store new printers. The Biomass boiler could not be switched on due to concerns over dust contaminating the printers. This had impacts on Year 2 energy monitoring results. See Section 7.0 for more information.

- Draughts reported on the Ground Floor at the main door. This was evident on the walkthroughs and seemed to be coming from the doors. Gaps in the inside door were causing drafts. This was noticeably worse when the electric doors opened on the front of the building.

- Glare appeared to be an issue from anyone working directly under the atrium. This was only two desks which are currently used for hot desking. Brise Soleil does offer some glare protection on the east and south fascades. Brise soleil does have some issues as bird like to sit on the shading louvres and make a mess on the windows and exterior.

- Overheating was noted on the 2nd floor south facade but it was not deemed excessive when temperature measurements were taken.

- The building is suitable as an office space. Shared spaces are located for convenience and to give work stations maximum access to daylight and natural ventilation. A canteen area is provided and is closed off to the rest of the office space to ensure smells and privacy are not an issue.

- There are no visible issues of condensation or mould growth. The building is almost three years old and looks very much like a new building. It is well maintained.

- Overall most building users and visitors are very impressed by the building. The BUS survey is in agreement with this. The building looks impressive and some attention has been given to visual appeal including installing a glass lift instead of a solid one which gives nice views over the floors of the building and to the countryside beyond. Nice views are also visible from exterior fascades. There is also some interesting furniture in communal areas and sound baffling in bright colours. This gives the communal areas visual appeal.

- The building has a nice open plan feel to it. Staircases are located in the central atrium so most of the spaces can be seen clearly from here. There are no hidden corridors or dark passage ways – everything is located centrally. The building is not especially large but it is well laid out.

- Security is appropriate to requirements. There is additional security for staff via the door entry system. FM have access to all areas. Plant rooms, server rooms and roof voids are off limits to staff but there is no real need for them to go into these areas. Visitors sign in at the front desk. The building is in a rural location therefore it is unlikely to attract strangers or accidental visitors. Security of the building is appropriate to building needs.

- GRAHAM designed and installed for a very high spec BMS and monitoring system however because the metering was never checked or reported issues with the system were never reported back to the BMS installer. The building is nearly three years old and some of these issues are still being addressed. This is largely due to how time consuming it is to check all of the systems and capabilities of the BMS at commissioning stages. No one has had direct responsibility for monitoring energy and therefore this has not been picked up.

7 Energy use by source

Overall Energy Data for Year 1 and Year 2

One of the key challenges in the BPE project so far has been collecting and analysing energy consumption data. The list of individual issues associated with recording and retrieving data can be found in Section 7.5 and also throughout Section 6.0.

The most accurate data available for the building has been sourced from physical meter readings, BMS meter readings and utility bills. The energy data was collected from the period September 2012 until August 2014. The data for both these years can be summarised as follows: -

Table 7.1 Annual Energy Consumption Years 1 & 2

Utility	Usage kWh		Cost		CO_2 Emissions	
Year	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year2**
Electricity	376,330	396,049	£45,060.48	£47,525.91	197 tonnes	207.7 tonnes
Oil	151,142	170,602	£8,895.00	£10,227.18	40 tonnes	45.6 tonnes
Biomass	256,515	136,368	£6,154.45	£4,925.66	10 tonnes	5.3 tonnes
Total	783,161	703,019	£60,109.93	£62,678.75	247 tonnes	258.6 tonnes

Costs based on Electric 12p/per kWh, Oil 68p/per litre, Biomass Pellets £115/tonne in Year 1 and £168/tonne in Year 2 going up to £176/tonne in Feb 14. CO_2 Emissions Factors based on Electricity at 0.5246kgCO_2/kWh, Heating Oil at 0.2674 kgCO_2/kWh and Biomass Pellets at 0.039 kgCO_2/kWh. Year 1 is September 2012-August2013 and Year 2 September 2013-August 2014.

Annual Energy Usage Headline Figures

- Electricity usage has increased by almost 5% between Year 1 and Year 2. This is explored further in the next section of the report. However reasons for this include additional IT server room equipment.

- Oil usage has increased by 12% in Year 2 although this was mainly due to the oil boiler being used as the primary boiler in November/December 2013 as the Biomass boiler was not in use during these months. The Biomass was not in use as the boiler house was being used for storage of IT equipment (printers etc.) and there were concerns that the dust from the Biomass boiler could damage this equipment. As Biomass was used for a shorter heating season in Year 2 its usage was down by 88% in Year 2. Overall though fossil fuel usage (Biomass and Oil combined) was down 32% in Year 2. The reasons for this are probably a combination of a milder winter in Year 2 (2603

Degree Days in Year 1 as opposed to 2114 in Year 2) and more efficient operation of the boiler optimisation programme on the BMS.

- Although fossil fuel consumption was down 32% in Year 2, costs actually went up in Year 2 by 4.28%. This is largely due to the low price of Biomass pellets per tonne that GRAHAM had negotiated with their supplier which made it far more economical to run in the heating season than the oil boiler. As the Biomass boiler was used less in Year 2 and the oil and electricity consumption both increased, this resulted in costs increasing. The price of Biomass also increased during Year 2 which would also account for some of the increased cost. During the monitoring period electricity and oil costs have largely stayed the same however the Biomass cost has increased from £115/tonne to £168/tonne to £176/tonne.

- Carbon emissions per tonne increased by 4.36% which is surprising as energy usage had decreased in Year 2. However as Biomass has a very low carbon dioxide emissions factor in relation to electricity and oil, this meant that the energy consumption savings made were not transferred to the amount of carbon dioxide generated.

Table 7.2 Overall annual energy consumption against benchmarks

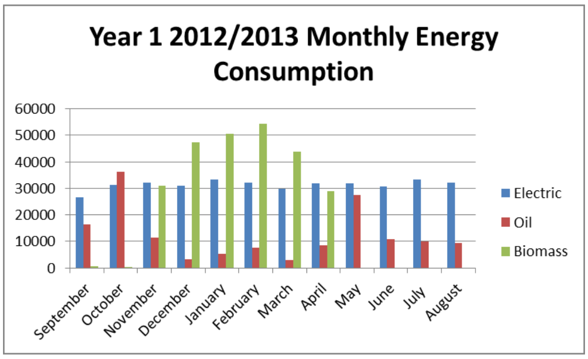
Monitoring Period	Electricity kWh/m2/ annum	Fossil Fuel kWh/m2/ annum	ECON 19 Natural Vent Open Plan		ECON 19 Air Con Open Plan	
			Electric	Fossil Fuel	Electric	Fossil Fuel
Design Benchmark (EPC)	36	82	**54-85**	**79-151**	**128-226**	**97-178**
Year 1 (All Energy)	120.88	130.86				
Year2 (All Energy)	127.49	98.81				
Year 1 (minus separables)	79	130.86				
Year 2 (minus separables)	71	98.81				

**Area is based on treated floor area of 3106.5 m2*

The above table shows how the building is performing in relation to the design benchmark from energy modelling and the EPC and ECON 19 benchmarks. The figures have been split into benchmarks showing the building's entire energy 'All Energy' and benchmarks showing energy usage minus allowable separables. Econ 19, TM22, TM46 and the DEC methodology allow you to exclude separables such as IT server rooms and external buildings. The design calculations do not include any electrical equipment in the benchmark.

Looking at the performance against benchmarks the 'All Energy' electricity consumption is closer to that of a fully Air Conditioned building. However once the separables are removed the electricity performance for Years 1 and 2 is closer to the benchmarks for a naturally ventilated open plan office. Although not quite best practice, the building does seem to be performing within the range between good practice and typical. The fossil fuel benchmarks are within the range of good practice and typical for a naturally ventilated open plan office, with Year 2 performing significantly better than Year 1. From the figures above it can be seen that Econ 19 does not account for energy from server rooms. This is becoming an ever increasing energy user in buildings. Benchmarks for this would be useful for measuring performance. Also, there have been calls for Econ 19 to be updated to take into account increased use of small power and ICT equipment. The performance against the design benchmark is closer to Year 2 for fossil fuel but the electrical benchmark is quite far away from the actual consumption. This is not surprising as the design benchmarks do not include for out of hours usage or unregulated energy loads like small power equipment or server rooms.

Overall Monthly Energy Consumption Year 1 and Year 2



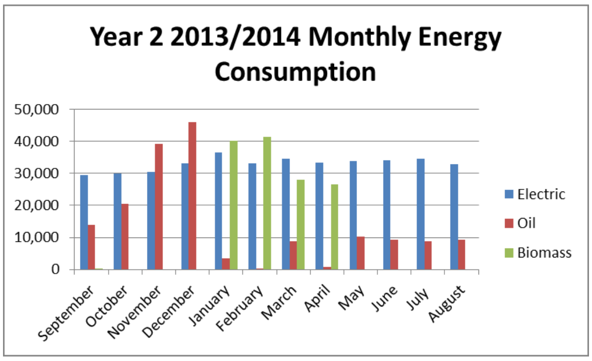
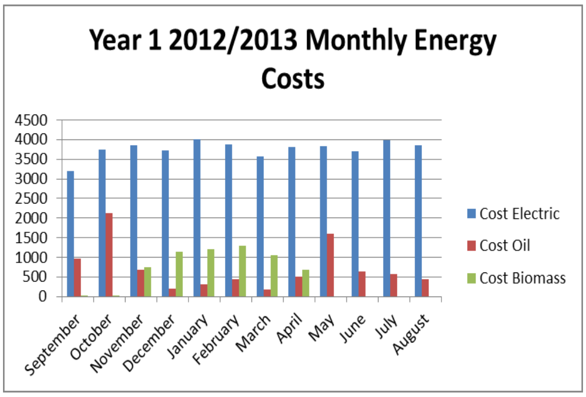


Figure 7.1 Monthly Consumption Comparison kWh Year 1 **Figure 7.2** Monthly Consumption Comparison kWh Year 2

Monthly trends from both years show clearly that Biomass was in use in November and December of Year 1 but not in Year 2. Oil usage is normally minimised during the heating season when the Biomass boiler takes over. Oil usage in summer time can be largely attributed to hot water usage. Electricity consumption is largely constant throughout the year although increases can be seen in Year 2 when compared to Year 1. This could be partly due to occupant numbers of the building increasing from 180 at the beginning of the project to 250 at the end of the project.

Overall Monthly Energy Costs Year 1 and Year 2



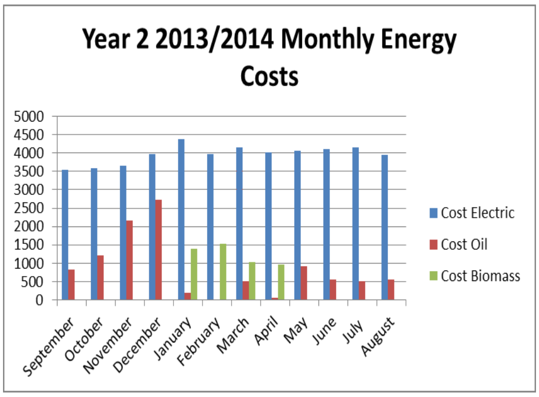


Figure 7.3 Monthly Energy Costs Year 1 Figure 7.4 Monthly Energy Costs

The Graphs show the energy costs for Biomass are significantly lower than the cost of oil. Electricity makes up the majority of annual and monthly energy costs and does not vary very considerably over the seasons.

Overall Monthly CO_2 Emissions Year 1 and Year 2

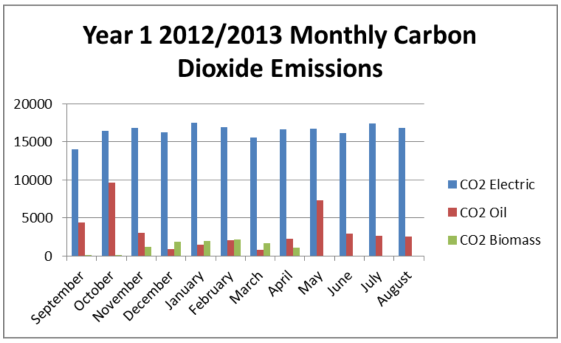


Figure 7.5 Monthly CO_2 Emissions Year 1

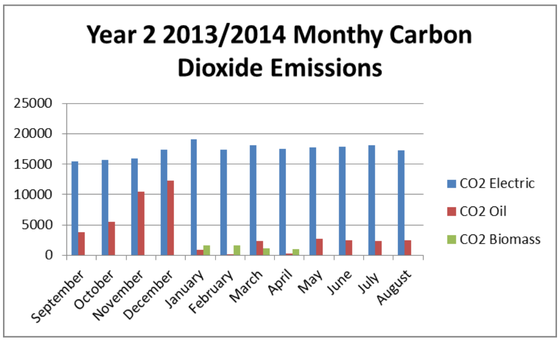


Figure 7.6 Monthly CO_2 Emissions Year 2

Biomass has the lowest carbon emissions per kWh and this can be seen clearly from the graphs above. During the seasons when the kWh for fossil fuel usage where are their highest, carbon emissions where still low (on a par with summer emission) due to the use of the Biomass boiler. Electricity is the most carbon intensive fuel type and is steady throughout the year.

Energy consumption by end use

Electricity Consumption by End Use Year 1 and Year 2

The following pie charts show the electricity use distribution over both years. Electricity consumption over both years is very similar with only marginal differences between both years.

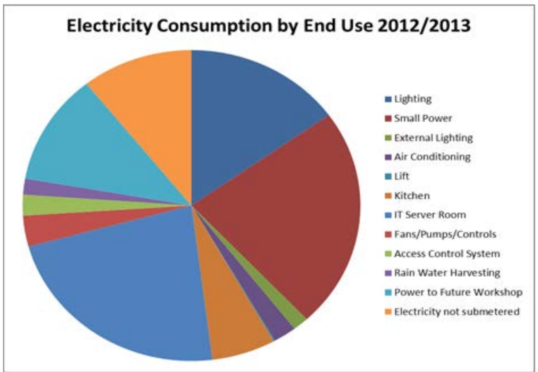


Figure 7.7 Electricity by end use 2012/2013

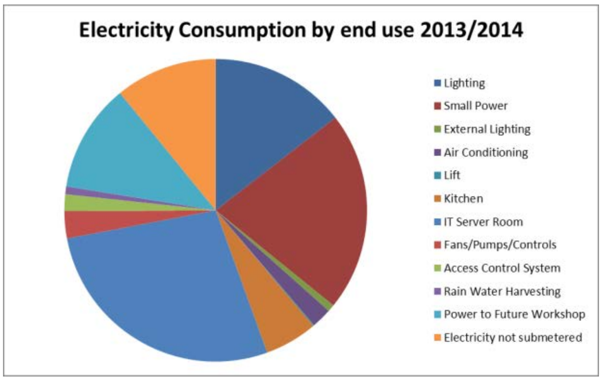


Figure 7.8 Electricity by end use 2013/2014

The largest noticeable difference is the increase in IT Server Room consumption. Some items have been reduced due to faults being fixed. Table 7.3 shows the comparison between Year 1 and Year 2 and highlights the percentage differences between the years.

Table 7.3 Year 1 and Year 2 Electricity End Uses

Electrical Breakdown	Total Year 1	Total Year 2	% Difference
Lighting	57801	57603	-0.34%
Small Power	87437	84504	-3.35%
External Lighting	5741	3001	-47.73%
Air Conditioning	7674	8522	11.05%
Lift	491	454	-7.62%
Kitchen	23383	22321	-4.54%
IT Server Room	86394	109265	26.47%
Fans/Pumps/Controls	12272	11493	-6.35%
Access Control System	7299	7121	-2.44%
Rain Water Harvesting	6339	3256	-48.64%
Power to Future Workshop	44231	45955	3.90%
Electricity not submetered	40506	43202	6.66%

Electricity consumption by end use is discussed under the separate headings below.

Lighting

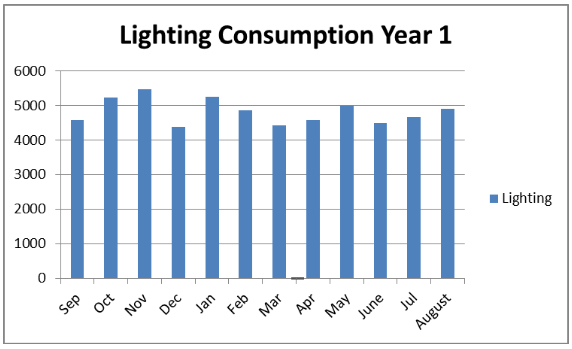


Figure 7.9 Lighting Consumption Year 1

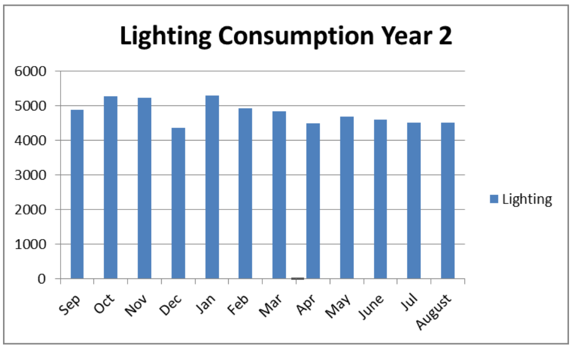


Figure 7.10 Lighting Consumption Year 2

Lighting consumption for Year 1 and Year 2 is almost identical. The consumption does not alter significantly on a seasonal basis apart from reducing slightly in some summer months and increasing slightly in some winter months. Lighting is metered in a floor by floor basis with an additional meter for Essential Lighting. See Table 7.4 below for individual sub-meter performance.

ECON 19 Benchmark Good Practice Naturally Ventilated Open Plan Office
 - ***22 kWh/m2/annum***
Design Benchmark **– *28 kWh/m2/annum***
GRAHAM Performance Year 1 – ***18.6 kWh/m2/annum***
GRAHAM Performance Year 2 – ***18.54 kWh/m2/annum***

Performance against benchmarks is better than Econ 19 good practice benchmarks and the design benchmark.

There are four sub-meters for internal lighting in the building. The meters are named on the TEM system and physical meters and are shown in Table 7.4. TM22 was completed for Year 1 of the study and it highlighted out of hours usage for evenings and weekends. TM22 calculated that the out of hours usage for all of the lighting sub-meters combined is 22,980 kWh. This equates to approx 40% of the total consumption of the lighting. This is an area where improvements could be made in energy consumption. Section 3 highlights the operation of the building's lighting system. One recommendation for improving the lighting would be a master switch to control all of the lighting that currently has PIR control only. This would enable all lighting to be switched off at the end of the day and at weekends and also prevent lighting coming on when there is no one in the building (as detailed in Section 5.0 of the report.

Table 7.4 Lighting Sub-Meters

	Sub-Meter	Annual Consumption Year 1	Out of Hours Usage TM22 Year 1	Annual Consumption Year 2
EM2	EM2 Gnd Floor Lighting	17277	6129	17979
EM3	EM3 1st Floor Lighting	19990	7174	19209
EM4	EM4 2nd Floor Lighting	15390	6998	15520
EM5	EM5 Essential Lighting	5053	2678	4896

External Lighting

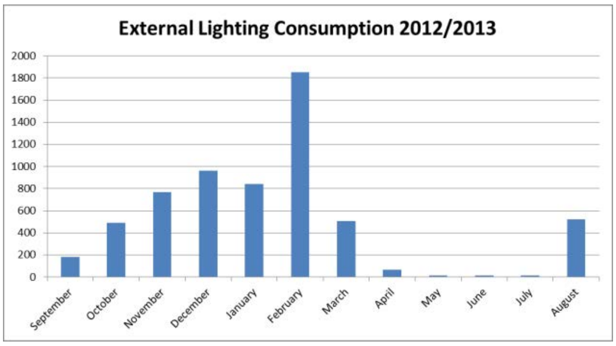


Figure 7.11 External Lighting Consumption Year 1

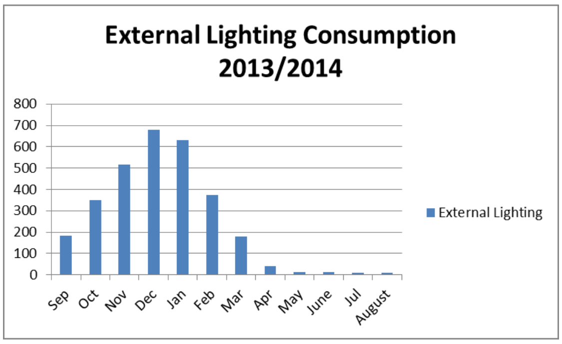


Figure 7.12 Lighting Consumption Year 2

External Lighting consumption has reduced by 48% from Year 1 to Year 2. The higher consumption in Year 1 was due to a fault with the timer in February 2013. This was repaired in March 2013 and consumption has continued to stay low since then. External lighting load profiles can be viewed on the TEM system and show optimum operating hours in use and seasonal variances.

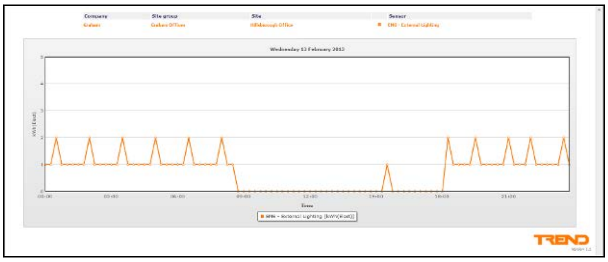


Figure 7.13 February 2013 –Lights on all night –fault in timer

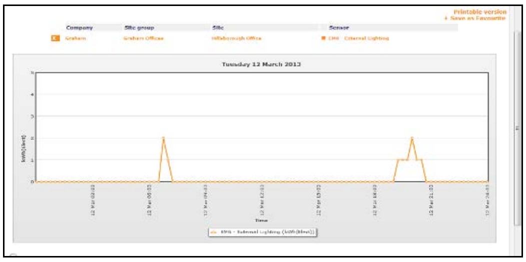


Figure 7.14 March 2013 – timer repaired

Small Power

Small Power consumption has decreased slightly from Year 1 to Year 2. This is quite surprising given that the occupant numbers of the building have gone from 180 at the beginning of the project to 250 at the end of the project. The IT workshop submeter which was previously added to the Small Power load has now become an overflow server room and as such its load has been added to the server room load since May 2014. Small power is metered on a floor by floor basis. See Table 7.5 for individual sub-meter performance.

ECON 19 Benchmark Good Practice Naturally Ventilated Open Plan Office
 - ***20–27 kWh/m2/annum***
GRAHAM Performance Year 1 – ***28.1 kWh/m2/annum***
GRAHAM Performance Year 2 – ***27.2 kWh/m2/annum***

Small power is closer to the Econ 19 benchmark for typical practice than good practice. This could mean that there is room for improvement in small power usage or it could mean that Econ 19 is out of date with regards to the level of small power equipment that is now to be found in office buildings compared to when the benchmarks were calculated.

There are seven sub-meters for small power in the building. The meters are named on the TEM system and physical meters and are shown in Table 7.5. TM22 was completed for Year 1 of the study and it highlighted out of hours usage for evenings and weekends. TM22 calculated that the out of hours usage for all of the small power sub-meters combined is 43303 kWh. This equates to almost 50% of the total consumption of the small power. Average daily load profiles can be viewed on the TM22 Half hourly data module. Most of the sub-meters have similar usage for Year 1 and Year 2 with the exception of Board N Essential Power which decreased in usage and the IT workshop which has gradually been converted to an overflow server room. Loads from this meter have now been added to server room loads as this is the main end use.

Table 7.5 Small Power Sub Meters

	Sub-Meter	Annual Consumption Year 1	Out of Hours Usage TM22 Year 1	Annual Consumption Year 2
EM7	Gnd Floor Power Dist Board B	14382	5993	14889
EM8	Gnd Floor Power Dist Board C	10820	5258	11406
EM10	1st Floor Power Dist Board E	15503	8330	15804

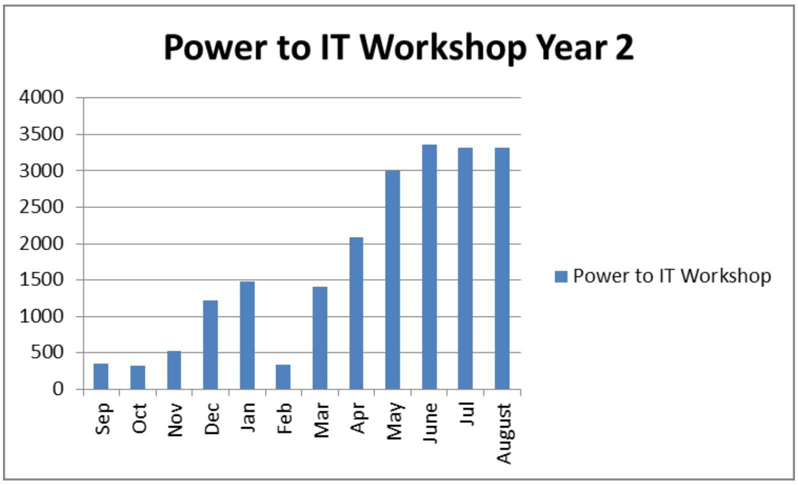
EM11	Power to Dist Board N	12616	6654	10440
EM12	Power 2nd Floor Dist Board H	10465	4352	10126
EM13	Power 2nd Floor Dist Board J	15928	9664	14099
EM16	Power to IT Workshop Lighting and Power*	4201	3051	7739

** Note this was only included in small power until May 2014 when it became an overflow server room. From May 2014 it was included in the Server Room loads*

Small Power is the 2nd largest electricity user in the building and there is potential to make savings here through good housekeeping and energy saving procurement measures. IT has provided an update in relation to energy usage and IT equipment as they are hoping to address some of this high energy usage through the introduction of energy saving measures. This has been included in Section 9.0 of this report

Server Room and IT Workshop

The Server Room has recorded the biggest increase from Year 1 to Year 2 of any other electrical end use and is the biggest single user of electricity at GRAHAM Head Office, accounting for over a quarter of the total electricity usage. The server room electricity usage has increased by 26.47% from Year 1 to Year 2. The server room has a 24 hour load profile and is an essential part of GRAHAM's business. The server room at the Hillsborough office is the main server room for all GRAHAM offices and companies. As the business is growing steadily so is the IT capacity. Since May 2014 the IT workshop located outside of the main building has also been used as a server room. This has been added to the server room loads for Year 2. IT has provided some operational information on the server room and their progress in terms of saving energy. However with a rapidly expanding business and the requirement for ICT equipment that this brings it is difficult to see where immediate savings can be made. The benchmark in Econ 19 for Server Rooms is between 11-13.3 kWh/m2/annum. The server room at GRAHAM HQ is 35.17kWh/m2/annum. This perhaps shows that some of the benchmarks in Econ 19 are out of date and also that a per m2 benchmark for a company wide server room is not appropriate in this instance.



Kitchen

The Kitchen at GRAHAM HQ is busy and well utilised by staff and visitors. As well as providing breakfasts and lunches, the kitchen supplies catering for meetings and events held in the building. All of the equipment in the kitchen has been listed in Section 3.0 and in the equipment audit section of TM22.

The electricity consumption of the kitchen was down almost 4.5% in Year 2 of the BPE study. Results of this can be shown below.

Annual Consumption Year 1 – 23,278 kWh (7.49 kWh/m2/annum)

Annual Consumption Year 2 – 22,321 kWh (7.18 kWh/m2/annum)

Out of Hours Usage (TM22) - 8390 kWh

Econ 19 Benchmarks – 3-5 kWh/m2/annum

The Econ 19 benchmarks are lower than the energy performance achieved at GRAHAM HQ. This could be because of the type of catering being provided in different offices. The canteen at GRAHAM offers hot meals and doubles as a shop for drinks and snacks. The out of hours usage reported by TM22 is approx. 36% of the total energy consumption however there will be equipment such as freezers and fridges which cannot be turned off overnight and therefore some of this out of hours usage will be justified. The kitchen makes up approx 6% of the overall electricity usage. Savings may be made with better housekeeping practices but overall it is not a substantial energy user for the level of service provided.

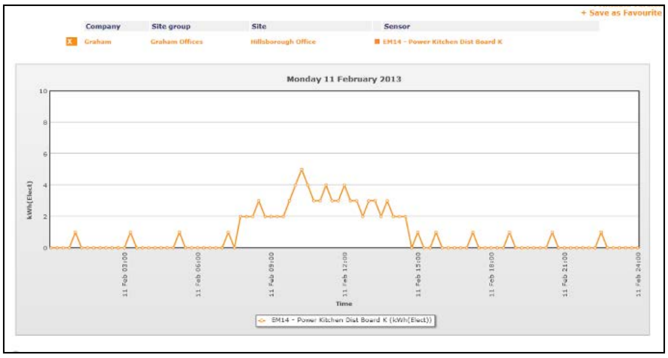


Figure 7.16 Typical 24 Hour Usage Kitchen Consumption

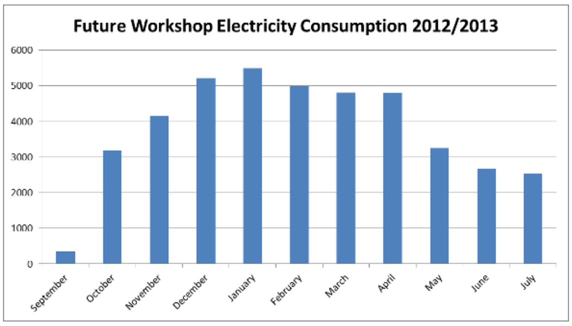
Power to Future Workshop

The ‘Power to Future Workshop’ sub meter measures usage from outside of the main GRAHAM building. In winter time this was found to be electric heaters with no time or temperature controls which were being used to heat portacabins being used for document storage. A new office portacabin was installed in the rear carpark/warehousing area and the power for this is metered by the ‘Future Workshop’ meter. This is an additional load to the heaters in the portacabins. The electricity consumption for this sub-meter is significant at approx. 11.7% of the total electiricty consumption. Consumption for this sub-meter increased by 3.9% in Year 2. TM22 half hourly data module identified that this load uses approx 71% of its energy out of hours. This is not surprising given that the main energy user in the future workshop is electric heaters which are on 24 hours a day in winter. Improvements could definitely be made here. This energy consumption could have been avoided if more storage area in the building was available. If storage area cannot be made available then a more efficient heating solution should be investigated. This electricity is not included in the DEC or TM22 methodologies.

Annual Consumption Year 1 – 43,956 kWh

Annual Consumption Year 2 – 45955 kWh

Out of Hours Usage (TM22) - 31,288 kWh



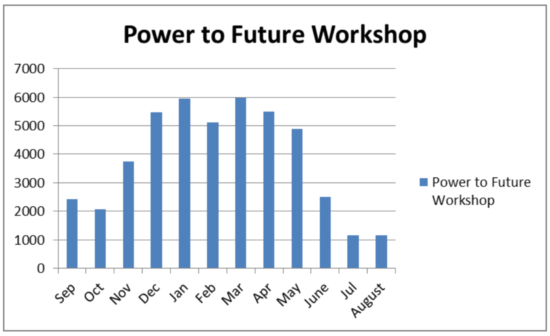


Figure 7.17 Year 1 Consumption Future Workshop

Figure 7.18 Year 2 Future Workshop Energy Consumption

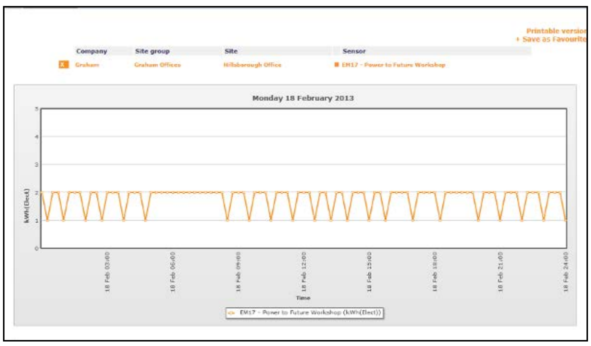


Figure 7.19 Daily Consumption Future Workshop

Figure 7.20 24 Consumption Future Workshop

Air Conditioning

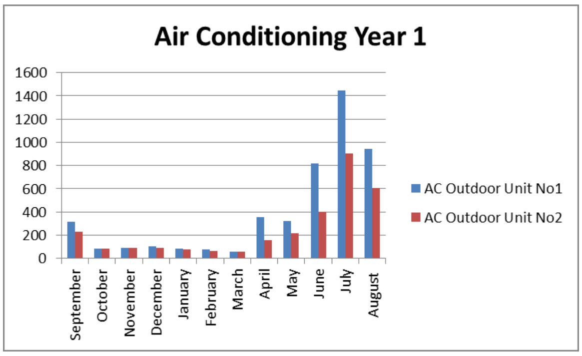
Air conditioning in the building is limited to the areas mentioned in Section 3.0 mainly the IT server room and Meeting/Conference Rooms. Therefore Air Conditioning is not a major energy user in the building (2.1% of total electricity load). However electricity usage of the Air Conditioning system has increased by 11.05% in Year 2. This could be attributed to higher external temperatures for Year 2 although Year 1 had a particularly warm summer. Air conditioning usage is more common in the summer months as can be seen from the graphs below. There seems to be some issues around control and air conditioning operating out of hours as can be seen from the TM22 out of hours figures. Almost 65% of energy consumption was recorded out of office hours. This is probably due to a controls issue where the air con is being manually switched on by occupants but not being switched off again as per control strategy.

In addition to the two meters recording air conditioning usage it was found in the latter stages of the project that the server room air conditioning is operating from the Access Control panel and sub-meter and not from either of the two Air Conditioning panels or sub-meters. As the air conditioning for the server room is not the only plant item on the access control panel it has been difficult to attribute what the energy use for this is.

Annual Consumption Year 1 – 7,674 kWh

Annual Consumption Year 2 – 8,522 kWh

Out of Hours Usage (TM22) – 4985 kWh



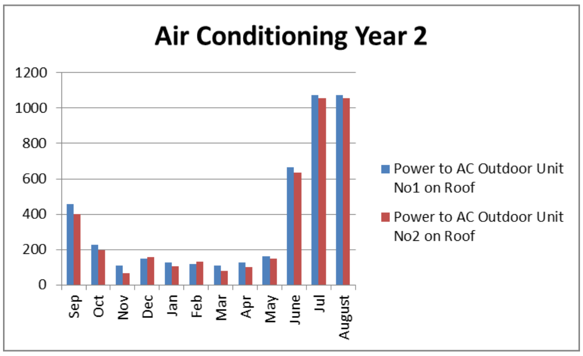


Figure 7.21 Air ConAnnual Consumption Year 1

Figure 7.22 Air ConAnnual Consumption Year 2

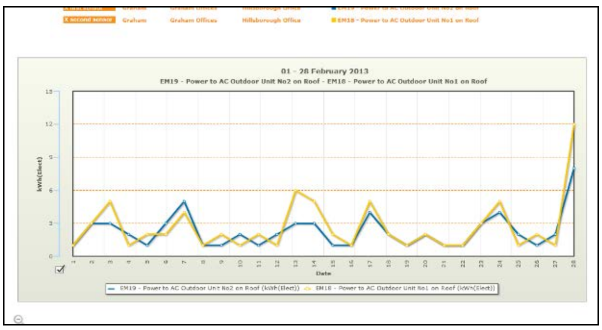


Figure 7.23 Daily Air Conditioning Consumption February

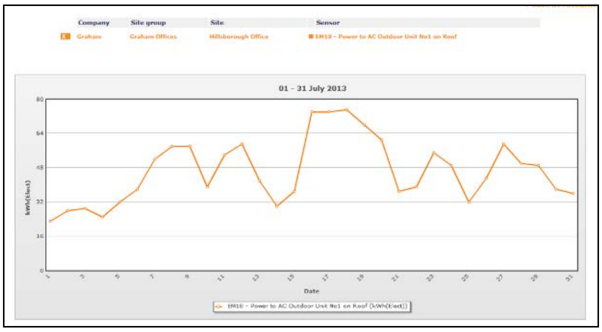


Figure 7.24 Daily Air Conditioning Consumption July 2013

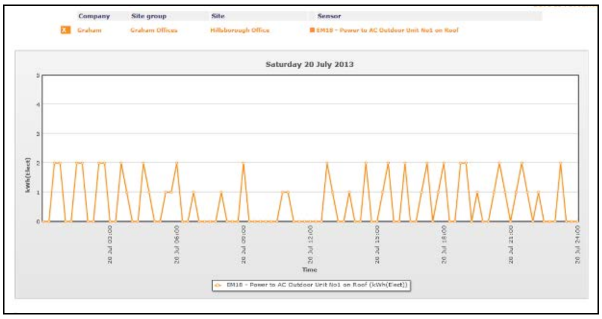


Figure 7.25 Out of Hours Usage Air Conditioning

Fans/Pumps/Controls

Fans, pumps and controls are used throughout the GRAHAM HQ building for the operation of the heating and ventilation systems. The use of fans, pumps and controls is not particularly excessive for a building of this type with a large amount of automated controls for heating and ventilation. Electricity usage is 2.9% of the total electricity consumption for Year 2. However some items that should be in this category are actually in the 'Electricity not sub metered' category. This is because they were not sub-metered within the electrical control panels. CP5 and CP6 contained some of these items but as these sub-meters were never connected the power loads for these items is not currently being sub metered. These items can be found in TM22 and include Heating Trench Modulation Control (Fans in Heating System), Supply Air Control (Mech Vent), Toilet Extract Fans, Louvre Control Motors CP6CP5, Dampers CP6CP5, Sensors (Temp/Control) CP5CP6, Kitchen Extract Fan and the two Air Handling Units located on the roof. These items are expected to contribute a significant load to the building therefore this benchmark is not reliable enough to account for all fans/pumps and controls. TM22 may have a more accurate benchmark for this end use. TM22 Outputs can be found in the next section of this report.

For the items currently being sub metered on these meters the consumption decreased by 6.35% in Year 2 from Year 1. Econ 19 benchmarks indicate that 4 kWh/m2/annum is Good Practice for a naturally ventilated open plan building. If all fans/pumps and controls were on these sub-meters the building would be achieving slightly better than this at 3.95 kWh/m2/annum. However as there are a number of high energy users which would fall into this category but are not sub-metered appropriately it would be unfair to quote this benchmark.

Annual Consumption Year 1– 12,279 kWh

Annual Consumption Year 2 – 11,493 kWh

There are five sub-meters for measuring fans, pumps and controls in the building. Most of the consumption on the individual sub meters is similar from Year 1 to Year 2 with some notable savings made on CP1 which is the control panel in the boiler house. This may be due to decreases in usage of the main boilers in line with decreased fossil fuel usage. The meters are named on the TEM system and physical meters as follows: -

Meter Number	Meter Name	Annual Consumption Year 1	% Out of Hours Usage TM22	Annual Consumption Year 2
EM20	Power to Control Panel CP1	7423	4948	6872
EM21	Power to BMS Control Panel CP2 in Pump Room	1361	632	1070
EM22	Power to BMS Control Panel CP3 in Stairwell to roof	1578	1047	1484
EM23	Power to BMS Control Panel CP4 in Stairwell to roof	1170	749	1201
EM28	Power to Pumping Station	898	584	866

Table 7.6 Fans/Pumps/Controls Annual Consumption

There is a high amount of out of hours usage however a lot of the controllers would be in operation 24 hours a day and the boiler optimisation programme fires up the boilers at about 3am in the heating season. This means controls and pumps for the heating would have considerable out of hours usage.

Power to Rainwater System

The power to the rainwater harvesting system includes the pump and the controller. Energy consumption was approximately 1.7% in Year 1 and 0.8% in Year 2 of the total electricity consumption. Consumption in year 2 fell by almost 48% of year 1 consumption.

Annual Consumption Year 1 – 6,339 kWh

Annual Consumption Year 2 – 3256 kWh

Total Amount of Water from RWH Year 1 – 513,474 litres*

Total Amount of Water from RWH Year 2 – 414,198 litres*

**Note these figures are based on data in the TEM and have not been checked with the same rigour as the energy data.*

The annual energy consumption graphs below for the Rainwater Harvesting pumps show that there was a fault in the pump in May 2013. This fault was causing the pump to run continuously. Facilities management arranged for this to be repaired and normal operation resumed in June 2013. This fault caused consumption to be almost 8 times greater in May 2013 than it would be in a normal month. This can account for some of the increased energy consumption in Year 1. The graph below shows the fault beginning in April 2013 with no change to the amount of rainwater collected.

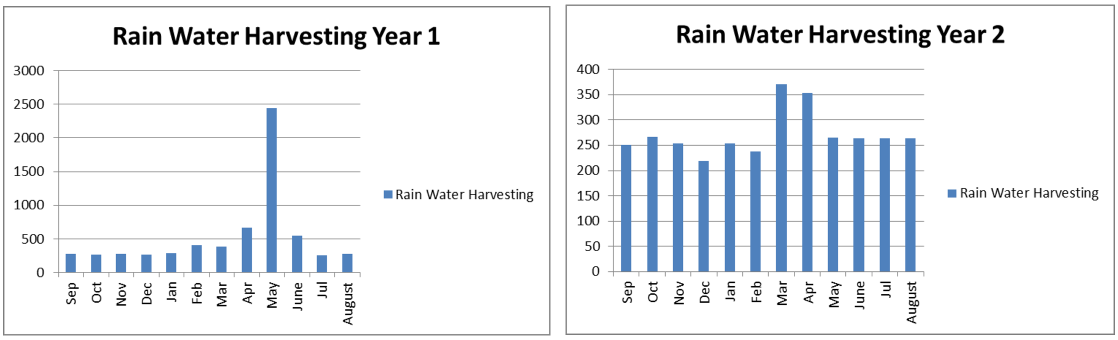


Figure 7.26 Annual Consumption Rainwater Harvesting Year 1 and Year 2

Figure 7.27 April Consumption RWH Pump

Lift

The energy consumption of the lift is very low at approx. 0.13% of the total electricity load for the building. The lift is very rarely used as all staff are encouraged to use the staircases. As the lift is glass and located in the centre of the building, its usage can be monitored and perhaps staff members are more reluctant to use it. It is mostly used for transporting supplies by FM or by those that have a genuine reason for using the lift.

Annual Consumption Year 1 – 492 kWh

Annual Consumption Year 2 – 454 kWh

Power to Access Control Panel

Annual Consumption Year 1: - 7,299 kWh

Annual Consumption Year 2: - 7,121 kWh

The Access Control System provided some issues with regards to TM22 and in predicting/reconciling loads for sub-meter readings. It was originally thought that the meter was only measuring electricity from the access control system that staff use to gain entry to the building and additionally the security system/cameras etc. However the readings from the sub-meter were quite erratic particularly over the summer months.

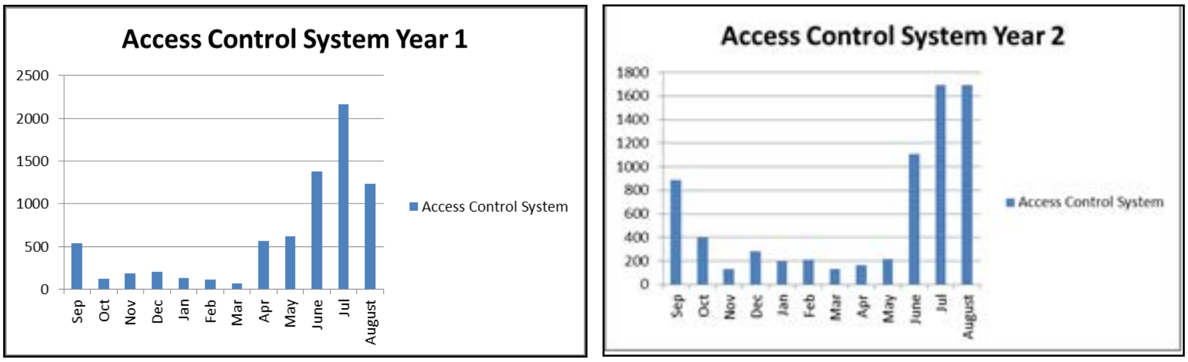


Figure 7.28 Annual Consumption Access Control Panel Year 1 and Year 2

From the above graphs it is clear that consumption was increasing over the summer months and decreasing again in winter.

After checking the TEM the following graph was generated:-

Figure 7.29 Load Profile of Access Control Panel and Air Conditioning Units

From the graph above the green line shows the load profile of the Access Control Panel sub-meter and the blue and yellow lines show the Air Conditioning sub-meters. The load profiles are so similar that air conditioning was suspected to be the additional load on the Access Control Panel sub-meter. Following on from this and after further inspections in the plant room a piece of duct tape had been used to cover over the access control panel switch.

Figure 7.30 Images of A/C indoor duct tape notice over Access Control Label.

It was deduced from this that the Air Conditioning in the server room is metered from this sub-meter. This was not in the design drawings and is not written down anywhere except for on this piece of duct tape. The load for the Access Control system should probably be added to the Air Conditioning consumption however it is difficult to do this as the Access Control panel has other loads linked to it. The TM22 analysis should be able to pick this up.

Unmetered Electricity Consumption

Unmetered electricity consumption includes loads which are not accounted for in any other sub meters. There are two sub-meters at GRAHAM HQ which were never connected to a power supply due to an oversight at handover/commissioning stages. These meters are known as CP5 and CP6. They predominately measure fans and controls. These items have been entered into TM22 under EM1 Electricity not sub-metered.

Annual Consumption Year 1: - 40,506 kWh

Annual Consumption Year 2: - 43,202 kWh

Approximately just under 11% of the total electricity at GRAHAM HQ is not sub metered.

It is difficult to provide an insight into the patterns of usage from these loads as the TEM system does not provide half hourly data on loads not sub metered. This could potentially be set up as a virtual meter but has not been so far on the project. Alternatively loads could be examined by manipulating the half hourly data via excel spreadsheets. Unmetered energy loads appear to be increasing slightly over time therefore it is advisable that a sub-meter is set up on the TEM to monitor this and control it if necessary.

Fossil Fuel Consumption by End Use

The heating and hot water demand is met by a combination of Biomass and Oil Boilers. The graphs below show the monthly load profiles for Biomass and Oil.

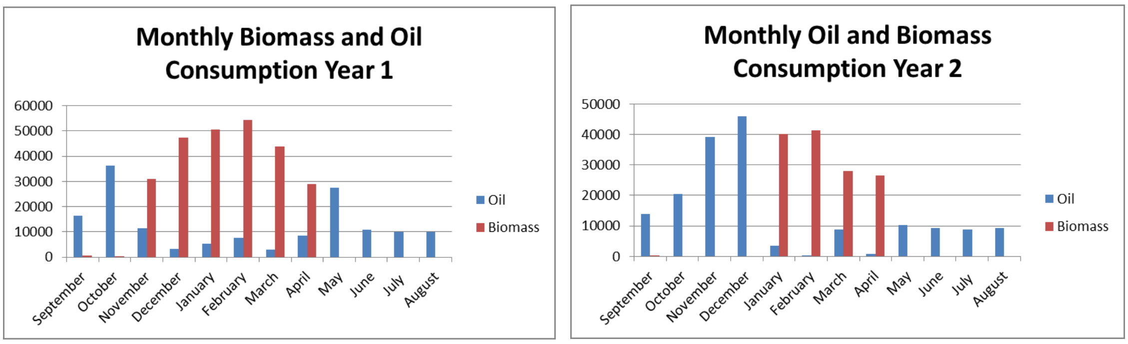


Figure 7.31 Monthly Biomass and Oil Consumption Year 1 & Year 2

As explained under overall energy consumption figures the Biomass boiler was in use for a shorter time in Year 2 than in Year 1 due to the boiler house being used for storage of IT equipment. Overall consumption figures were down in Year 2 probably due to increased external temperatures in winter and more efficient operation of the heating system.

Item	Energy Consumption Year 1	Energy Consumption Year 2	% difference
Total Fossil Fuel	406,526	306, 972	24.49%
Biomass	256,515	170,603	33.49%
Oil	151,142	136,369	9.77%
Total Heat	260,412	214,144	17.77%
Space Heating	228,700	179,709	21.42%
Hot Water	31,598	32,979	-4.37%
Core	37,348	15,621	58.17%
South	93,598	76,938	17.80%
North	57,641	48,173	16.43%

Table 7.7 Fossil Fuel and Heating Consumption Summary

All end uses for heating were reduced in Year 2 apart from hot water which increased slightly by 4.37%. The biggest savings were made in the Core area of the building which reduced 58% in Year 2. The core area in the building largely covers the atrium and communal areas of the building. The South heating zone of the building uses the most energy but this is the largest zone in the building by area and it is also the zone which has the most building occupants located within it.

Benchmarks

ECON 19 Fossil Fuel Benchmark – 79-151 kWh/m2/annum

Year 1 Fossil Fuel – 130 kWh/m2/annum

Year 2 Fossil Fuel – 98.81 kWh/m2/annum

Performance against Econ 19 benchmarks is in the mid range for heating. Although as Biomass supplies a significant portion of the building's heat demand the carbon dioxide emissions for heating are far lower than they would be if the system was completely reliant on oil.

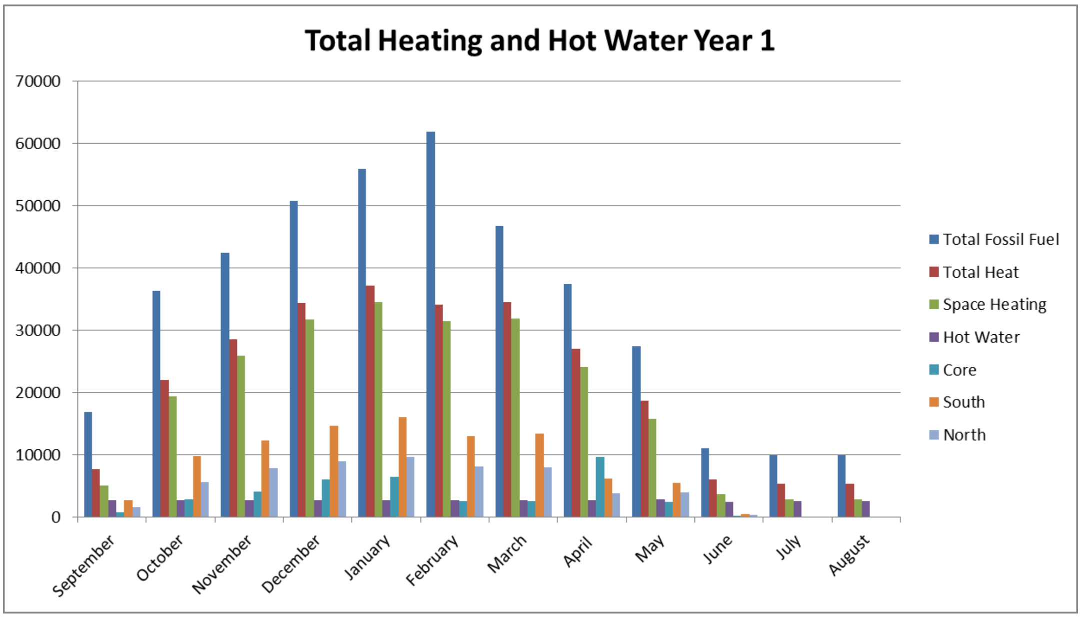


Figure 7.32 Monthly Heating and Hot Water Year 1

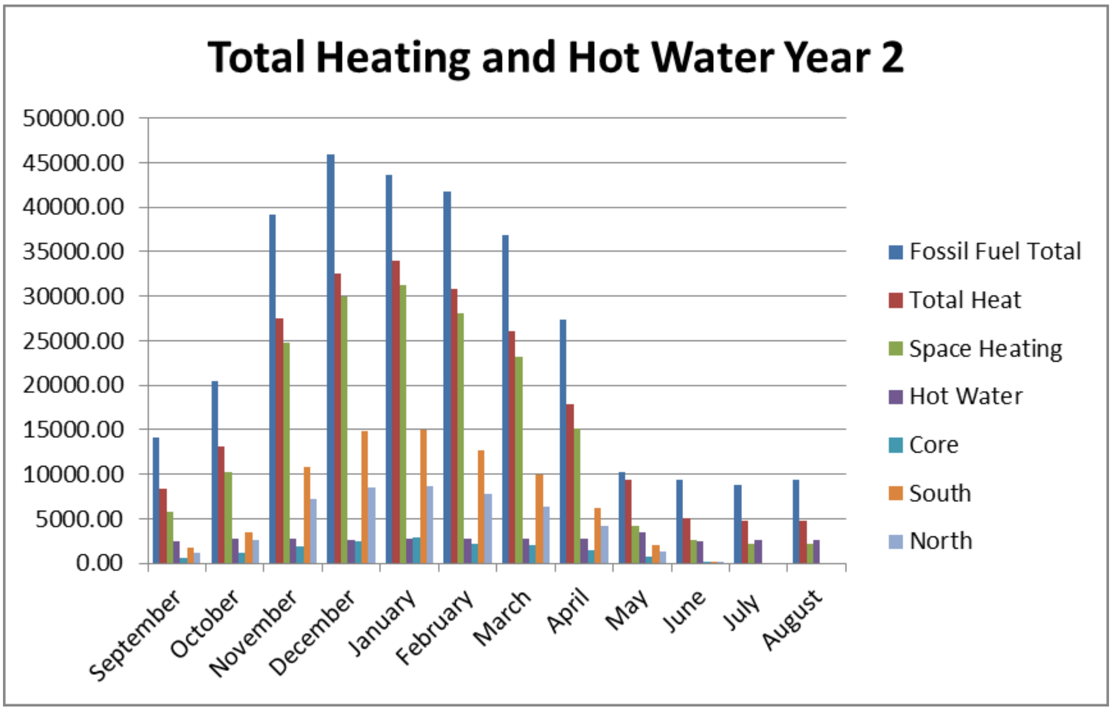


Figure 7.33 Monthly Heating and Hot Water Year 2

Monthly load profiles follow expected seasonal patterns with heat loads highest during the winter months November, December, January, February and March. Degree day data sourced for the site concurs with the seasonal patterns of the heating demand. The following linear regression analysis shows the degree day data plotted against the total heat demand from September 2012 until July 2014.

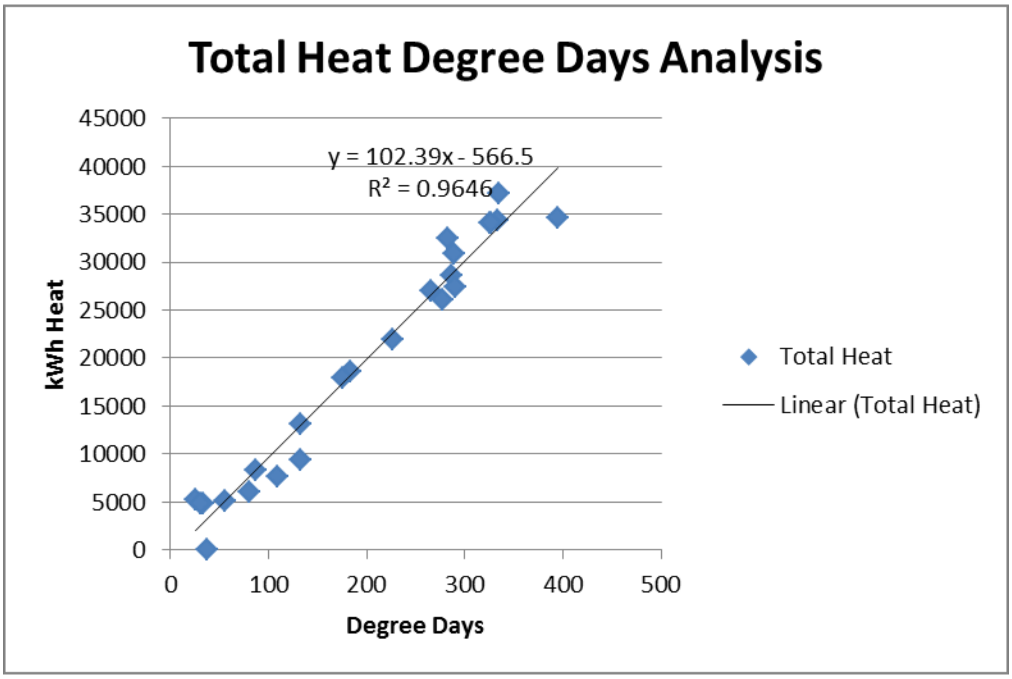


Figure 7.33a Total Heat Demand/Degree Days

What does the R2 show?

The R2 value is basically a measure of how good the correlation is. The closer the R2 value is to 1, the better the correlation. A good correlation between degree days and energy consumption indicates that the methodology is sound (the main pitfalls in degree-day analysis have been avoided or corrected for), and that the heating/cooling system is working well (the "control" of the system is good). In other words, the higher the R2, the better.

Generally speaking, an R2 of 0.75 indicates an reasonable correlation between energy consumption and degree days. 0.9 or above is very good. An R2 much below 0.7 or so is likely an indication that the heating control is either very poor, or that the analysis methodology needs to be improved (e.g. wrong base temperature, irregular building occupancy that hasn't been corrected for, heating/cooling metered together with other energy consumption that varies considerably throughout the year).

The above graph shows the correlation between heat demand and degree days to be good (0.96) which means that the heating is generally responding to fluctuating temperatures. It also explains that Year 2 has a lower heat demand due to less degree days and that the heating system is following this pattern.

Heat demand in the core, south and north zones of the main building are almost non-existent in the summertime months of June, July and August. However there is still a heat demand during the summer months and outwith the zones in the main building. The external changing room for cyclists contains radiators with low temperature hot water supplied by the main boiler. This is not sub-metered and would account for some of the additional load. Additionally the pipework used to carry the hot water from the boiler house to the main building will result in further losses. However savings might be possible and this should be investigated in more detail to ensure heat isn't being delivered to the building when it is not necessary.

Overall the % of fossil fuel converted to heat (as recorded on the heat meters) was 62% in Year 1 and 70% in Year 2. This figure would include efficiencies of both boilers, fuel efficiency and is dependent on the accuracy of the meter readings. Boiler efficiency is measured during annual service checks however this does not always account for seasonal efficiency when boilers are running at reduced loads. This area could warrant investigation as benchmarks indicate that improvements could be made in fossil fuel consumption. An interesting study would be the differences in performance between the oil and biomass boilers.

Hot Water

Hot Water usage is largely constant throughout the year and relatively low when compared to heating loads. Benchmarks from TM22 and Econ 19 indicate that 12-20 kWh/m2/annum is a good benchmark for hot water usage where catering and hand washing are the main hot water users in a building. The benchmarks assume a gas operated central cylinder so may not be exactly right for this building. The performance against benchmarks is as follows: -

Year 1 – 10.1 kWh/m2/annum

Year 2 – 10.61 kWh/m2/annum

Hot water performance is better than good practice.

Hours of operation and control

The biomass and oil boilers operate on a pre-programmed boiler optimisation programme which is controlled by the time and temperature targets for the main building programmed into the BMS. See below a graph from the TEM system showing an average 24 hour load profile for the boilers during January 2013. Both the Biomass and the Oil boiler were coming on at 3am in the morning to ensure the building was at an optimum temperature by 7am. Most building occupants arrive for work at 8.30am onwards. FM have been asked to trial moving the set points to see if optimum temperatures can be achieved by firing up the boiler later.

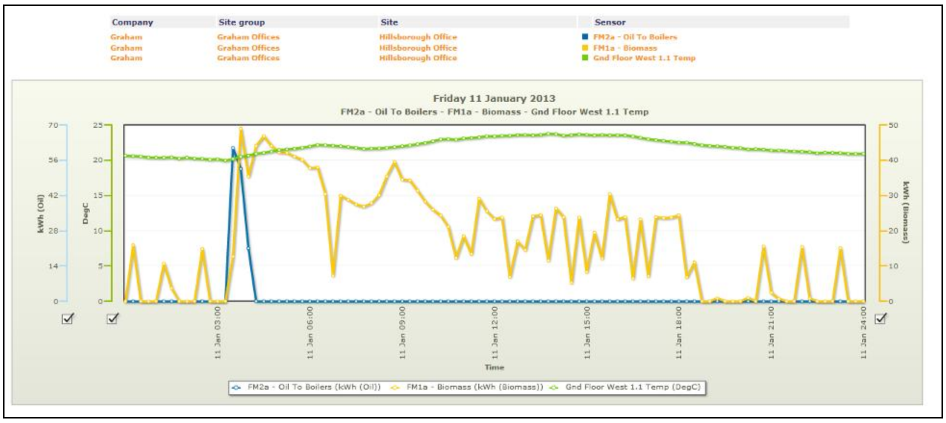


Figure 7.34 Boiler load profiles January 2013

In addition the oil boiler was coming on at the same time as the Biomass. This was decided as uneccesary and in Year 2 the BMS was programmed so that only the Biomass boiler would be switched on to provide heating. The graph below shows a typical Monday in January. Starting temperatures in the building are typically much lower on a Monday and as such the boiler optimiser could be justified for bringing the boiler on at 3am. However it does not seem efficient to be bringing the boilers on at the same time on other week days when internal temperatures do not require a substantial uplift. Recommend that FM review the boiler optimisiation programme to see if further savings can be made.

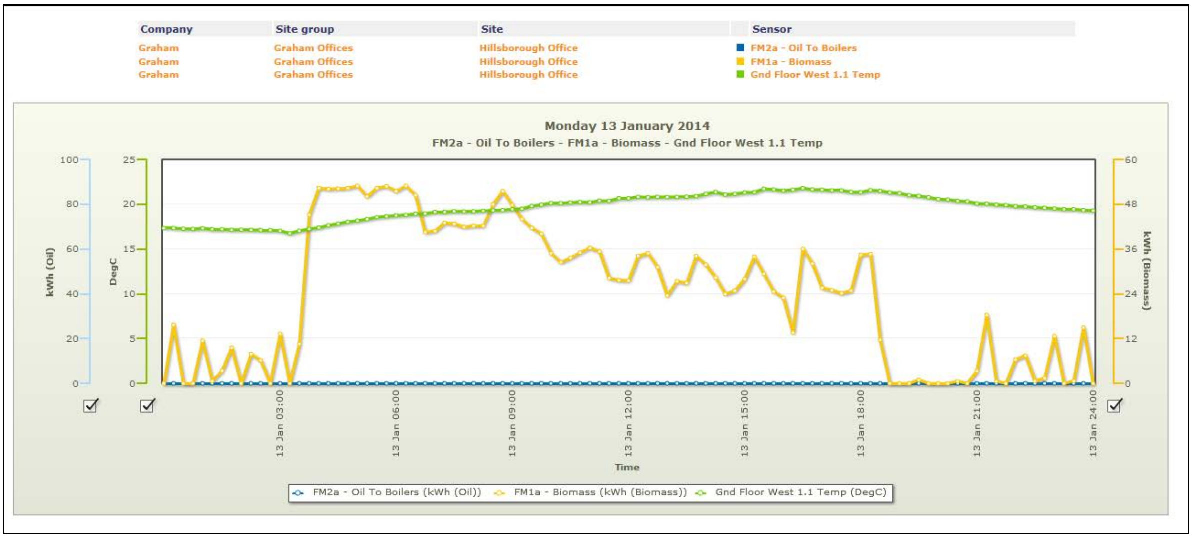


Figure 7.35 24 hour boiler profile January 2014

The graph below shows the biomass and oil boilers load profiles in November 2012. The boilers were coming on on Sundays when they shouldn't have been. This was changed for December 2012 and subsequent savings were made.

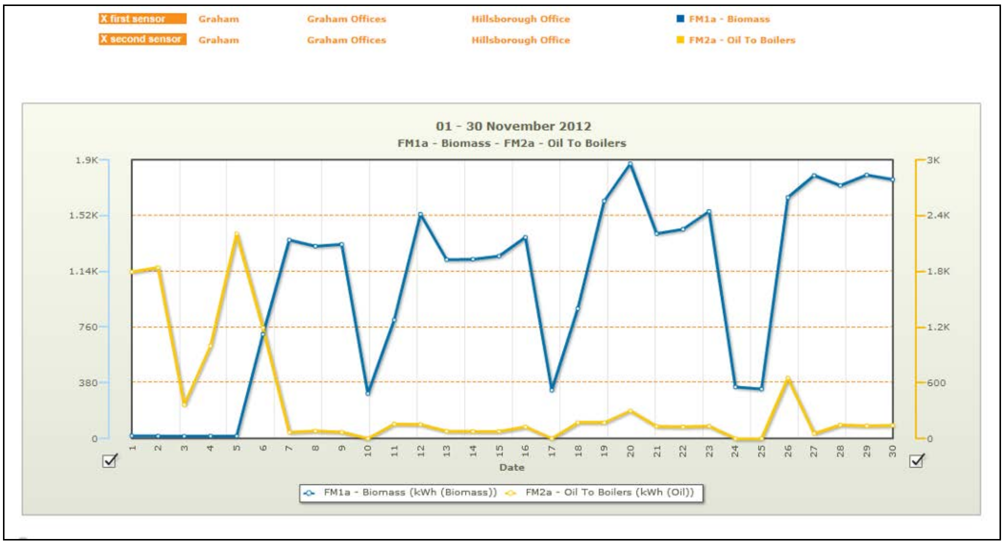


Figure 7.36 Boiler profile November 2012

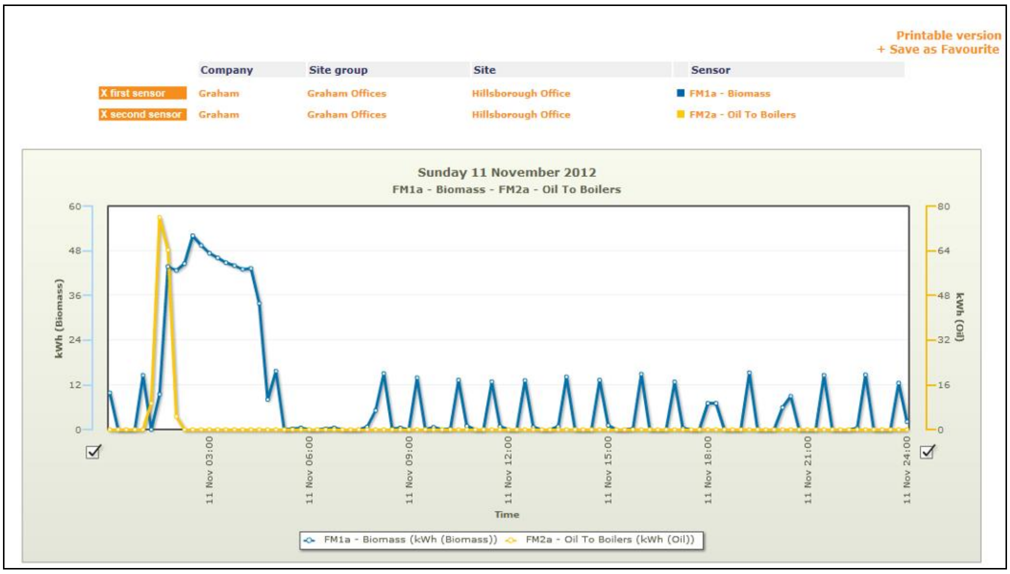


Figure 7.37 Boiler profile Sunday November 2012

TM22 Outputs

TM22 has been completed for one year of energy monitoring. The energy data used for TM22 is from September 2012 to August 2013 which is the Year 1 monitoring period.

BUILDING ENERGY SUMMARY				
Energy, carbon and cost summary	**Units**	**Electricity**	**Fuels**	**Thermal**
Non renewable fuel or electricity supplied to site	kWh/annum	333,929	150,373	0
Separable energy uses	kWh/annum	86,771	0	0
Renewable energy used on site	kWh/annum	0	255,975	0
Renewable energy exported	kWh/annum	0	0	0
Output from CHP used in building	kWh/annum	0		0
Exported CHP	kWh/annum	0		0

Fig 7.38 TM22 Summary Table for Total Energy Consumption of Year 1

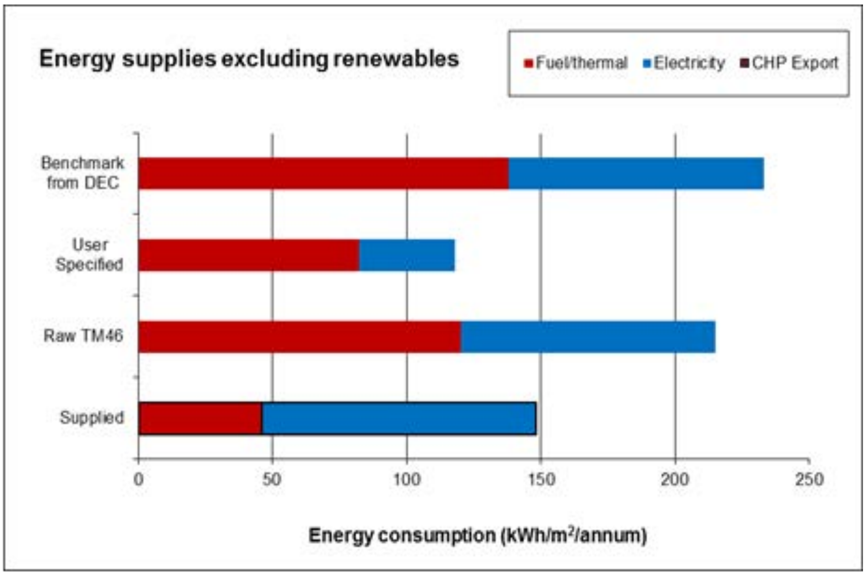
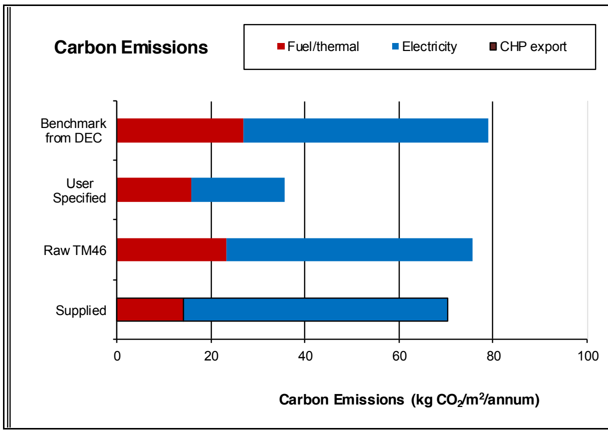


Fig 3.39 Total energy supplied excluding renewables

Fig 3.39 and Fig 3.40 shows the supplied energy against benchmarks. The User Specified Benchmark is the Benchmark for the building 'as designed'. This shows that fossil fuel for thermal purposes is lower than the benchmarks from the design calculations, DEC and CiBSE TM46. However this does not include energy used by the Biomass boiler. The electricity is greater than the benchmarks for the design calculations, DEC and TM46. The electrical benchmark for the design calculations does not include equipment therefore the benchmark is very low.



CO_2 factors used in assessment:	kg CO_2 /kWh
Electricity (grid)	0.55
Oil	0.265
Biofuels	0.025

Benchmark CO_2 factors:	kg CO_2 /kWh
Electricity (grid)	0.55
Gas	0.194

Fig 3.40 Carbon Emissions of supplied energy

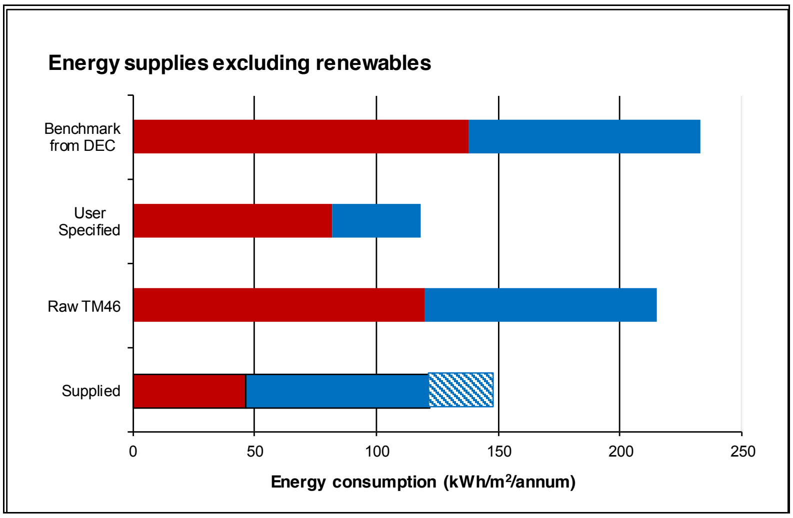


Fig 3.41 Energy supplies excluding renewables showing separables

Fig 3.41 shows the supplied energy excluding the contribution made from the Biomass boiler and showing the separables (IT server room and external buildings). When the separables are removed from the building's total it now shows the building performs better than the DEC and TM46 benchmarks for both fossil fuel and electricity. However the user specified design benchmarks are still much lower than the actual electricity used.

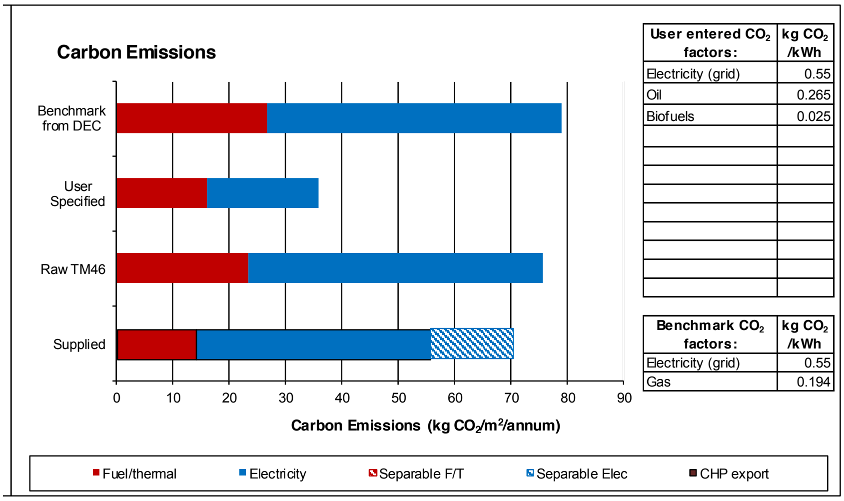


Fig 3.42 Carbon emissions for energy supplied excluding separables

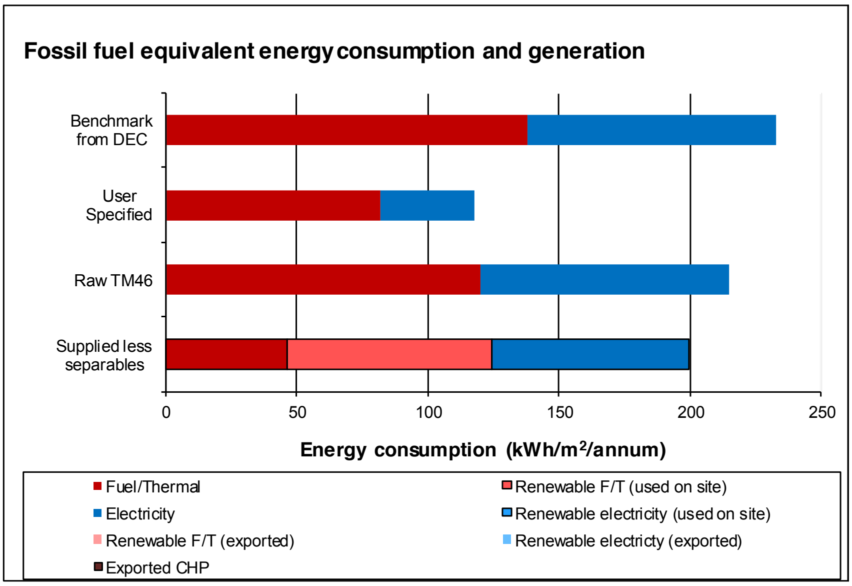


Fig 7.43 Energy consumption showing on site renewables

Fig 7.43 shows the energy consumed including on site renewables (from Biomass) but excluding electricity separables. This shows that the fossil fuel consumption is greater than the benchmark for TM46 and the design(user specified) benchmark but less than the DEC benchmark.

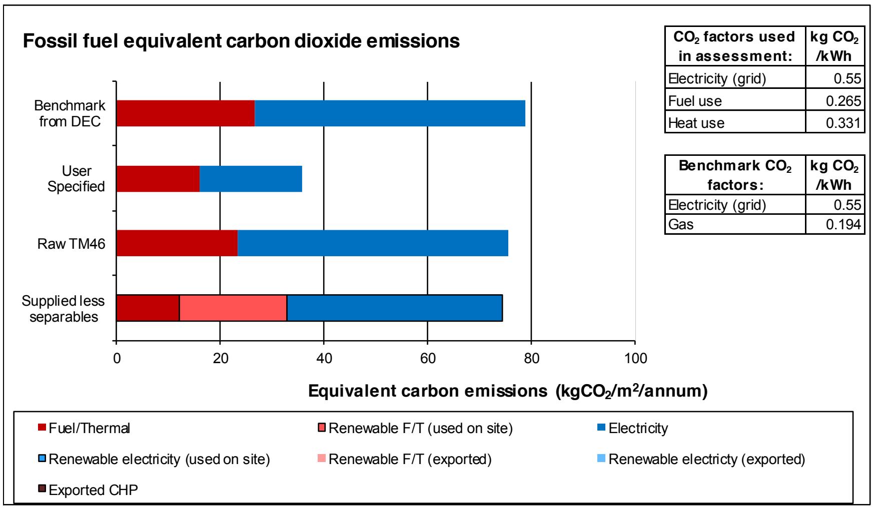


Fig 7.44 Fossil fuel equivalent carbon dioxide emissions.

Detailed Assessment of Energy Use

Fuel/Thermal Breakdown

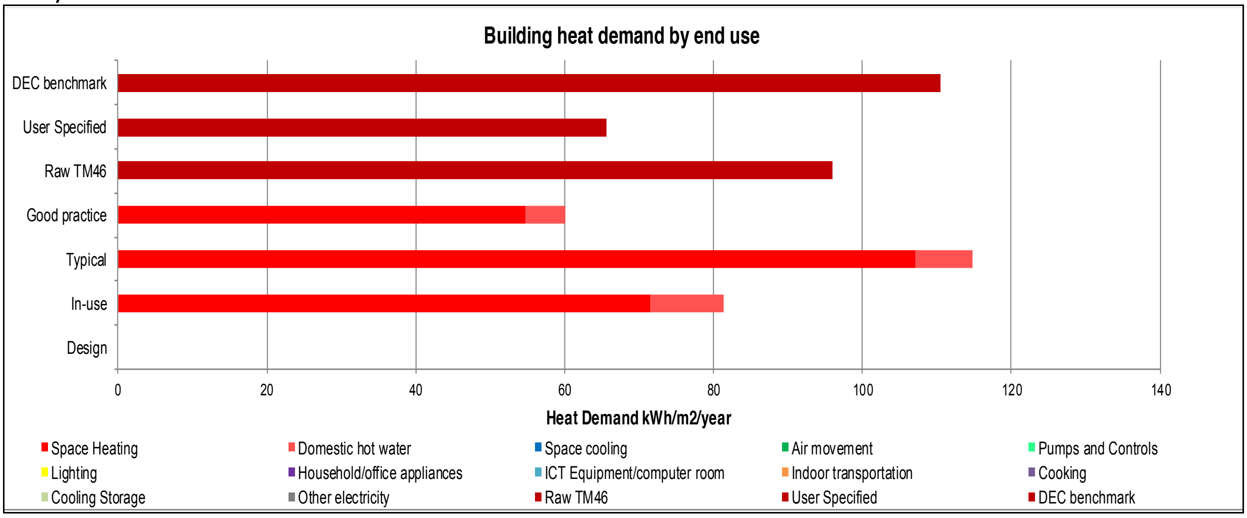


Fig 7.45 Building heat demand by end use

Fig 7.45 shows the heating and hot water usage for the building in use. The performance of the building falls between typical and good practice benchmarks.

Electricity Breakdown

This example shows the Building's Performance next to ECON 19 benchmarks for a Type 3 Office Building (Air Conditioned Standard).

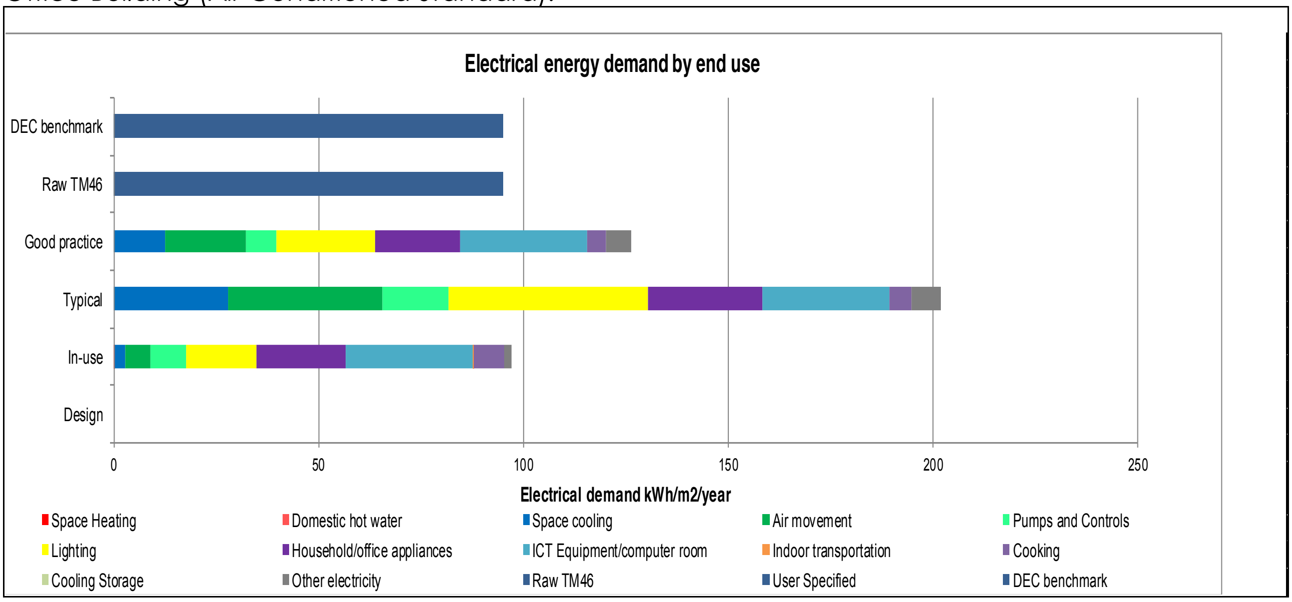


Fig 7.46 Electrical energy demand by end use

System	Design (kWh/m²/year)	In-Use (kWh/m²/year)	Typical benchmark (kWh/m2/year)	Good practice benchmark (kWh/m2/year)	Design electricity (kWh/m2/year)	In-use electricity (kWh/m²/year)	Typical benchmark (kWh/m2/year)	Good practice benchmark (kWh/m2/year)
Space Heating	0.0	71.5	121.0	64.8	0.0	0.0		
Domestic hot water	0.0	9.9	7.2	5.0	0.0	0.3		
Space cooling	0.0	0.0			0.0	2.5	27.9	12.6
Air movement	0.0	0.0			0.0	6.3	37.8	19.8
Pumps and Controls	0.0	0.0			0.0	8.7	16.2	7.2
Lighting	0.0	0.0			0.0	17.1	48.6	24.3
Household/office appliances	0.0	0.0			0.0	21.8	27.9	20.7
ICT Equipment/computer room	0.0	0.0			0.0	31.0	31.0	31.0
Indoor transportation	0.0	0.0			0.0	0.2		
Cooking	0.0	0.0	0.0	0.0	0.0	7.6	5.4	4.5
Cooling Storage	0.0	0.0			0.0	0.0		
Other electricity	0.0	0.0			0.0	1.7	7.2	6.3
Total	**0.0**	**81.4**	**128.2**	**69.8**	**0.0**	**97.2**	**202.0**	**126.4**
Metered building energy use	0.0	91.6			102.1	102.1		
Variance TM22 versus metered total	0.0	-10.2			-102.1	-5.0		
Variance TM22 versus metered total	#DIV/0!	-11%			-100%	-5%		

Fig 7.47 Electrical energy demand by end use with ECON 19 Benchmarks

This example shows the Building's Performance when compared to ECON 19 benchmarks for a Type 2 Office (Naturally Ventilated Open Plan).

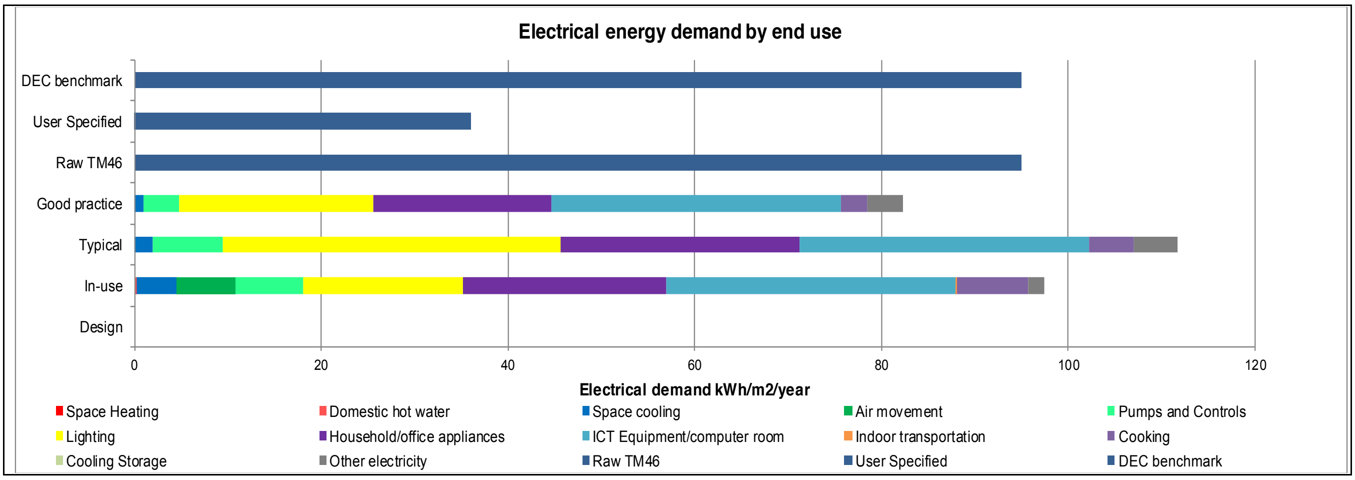


Fig 7.48 Electrical energy demand by end use against benchmarks

System	Heat demand (kWh/m2/year)				Electricity demand (kWh/m2/year)			
	Design (kWh/m²/year)	**In-Use (kWh/m²/year)**	**Typical benchmark (kWh/m2/year)**	**Good practice benchmark (kWh/m2/year)**	**Design electricity (kWh/m2/year)**	**In-use electricity (kWh/m²/year)**	**Typical benchmark (kWh/m2/year)**	**Good practice benchmark (kWh/m2/year)**
Space Heating	0.0	71.5	107.2	54.7	0.0	0.0		
Domestic hot water	0.0	9.9	7.6	5.3	0.0	0.3		
Space cooling	0.0	0.0			0.0	2.5	1.9	1.0
Air movement	0.0	0.0			0.0	6.3	0.0	0.0
Pumps and Controls	0.0	0.0			0.0	8.7	7.6	3.8
Lighting	0.0	0.0			0.0	17.1	36.1	20.9
Household/office appliances	0.0	0.0			0.0	21.8	25.7	19.0
ICT Equipment/computer room	0.0	0.0			0.0	31.0	31.0	31.0
Indoor transportation	0.0	0.0			0.0	0.2		
Cooking	0.0	0.0	0.0	0.0	0.0	7.6	4.8	2.9
Cooling Storage	0.0	0.0			0.0	0.0		
Other electricity	0.0	0.0			0.0	1.7	4.8	3.8
Total	**0.0**	**81.4**	**114.8**	**60.0**	**0.0**	**97.2**	**111.8**	**82.3**
Metered building energy use	0.0	91.6			102.1	102.1		
Variance TM22 versus metered total	0.0	-10.2			-102.1	-5.0		
Variance TM22 versus metered total	#DIV/0!	-11%			-100%	-5%		

Fig 7.49 Electrical energy demand by end use against benchmarks

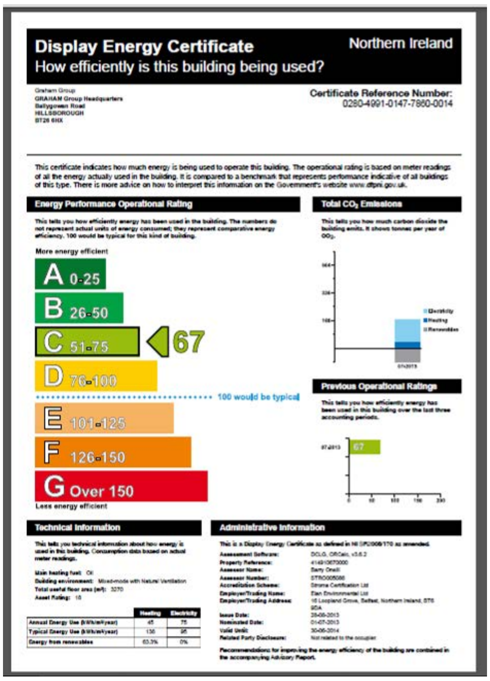
When compared to Econ 19 benchmarks the building performs better than air conditioned offices (Type 3) good practice benchmarks but when compared to naturally ventilated open plan (Type 2) it falls between typical and good practice benchmarks. The office is predominately an open plan naturally ventilated space therefore Type 2 benchmarks are probably more suitable. However the building does have some air conditioned spaces and as such appears to be performing better than benchmarks for this office type.

Out of Hours Base Load

From information on the TEM the out of hours base load is approximately 11.6 W/m2. About a quarter of this is coming from the server room. According to TM22 typical office base loads are in the 10-15 W/m2 range. The building does not seem to have an excessive base load however out of hours usage for lighting and small power is high.

Display Energy Certificate (DEC)

Elan Environmental produced a Display Energy Certificate for the GRAHAM Headquarters Building in August 2013. The consumption was from August 2012 – July 2013. A copy of the certificate has been included below. The rating is a C rating of 67 which Elan Environmental have said is a reasonably good rating for an office building of this size.


Display Energy Certificate Northern Ireland
How efficiently is this building being used?

Graham Group
GRAHAM Group Headquarters
Ballygowan Road
HILLSBOROUGH
BT26 6HX

Certificate Reference Number:
0280-4991-0147-7860-0014

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

Energy Performance Operational Rating

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

More energy efficient
A 0-25
B 26-50
C 51-75 — 67
D 76-100
100 would be typical
E 101-125
F 126-150
G Over 150
Less energy efficient

Total CO_2 Emissions

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

Electricity
Heating
Renewables

Previous Operational Ratings

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

07-2013 67

Technical Information

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

Main heating fuel: Oil
Building environment: Mixed-mode with Natural Ventilation
Total useful floor area (m²): 3270
Asset Rating: 18

	Heating	Electricity
Annual Energy Use (kWh/m²/year)	45	75
Typical Energy Use (kWh/m²/year)	138	95
Energy from renewables	63.3%	0%

Administrative Information

This is a Display Energy Certificate as defined in NI SR2008/170 as amended.

Assessment Software: DCLG, ORCalc, v3.6.2
Property Reference:
Assessor Name:
Assessor Number:
Accreditation Scheme: Stroma Certification Ltd
Employer/Trading Name: Elan Environmental Ltd
Employer/Trading Address:
Issue Date: 28-08-2013
Nominated Date: 01-07-2013
Valid Until: 30-06-2014
Related Party Disclosure: Not related to the occupier

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

Although the DEC certificate is for the entire building the electricity consumption for the Server Room and the Future Workshop were not included in the final DEC rating. Server rooms are removed from office buildings in the DEC methodology. The future workshop was not included as GRAHAM were able to prove that this meter was measuring electricity usage outside of the building and not connected with the building services or any other functions of the main building. This means that just over 1/3 of the electricity consumption measured was removed from the DEC calculation. If sub-meters had not been in place for measuring the Server Room or Future Workshop this electricity consumption would have been added to the overall consumption for the building and the DEC rating would have been a D or an E.
The use of the Biomass boiler has also significantly improved the DEC rating. If the biomass boiler had not been used and the heat demand was met solely by the oil boiler, the DEC rating could have fallen to a D or an E rating.

Data Collection and Metering Issues

The data reported here is the most accurate data that could be gathered for the building from September 2012 to August 2014. There were a number of challenges associated with collecting the data for GRAHAM HQ. They can be summarised as follows: -

- The TREND BMS System was originally only storing 11 days' worth of data from the sub meter before overwriting it with new data. GRAHAM was under the impression that historical energy data was being recorded and stored when in fact it wasn't. This means when the project started there was no historical data to reference.
- The TSB BPE project was used to purchase the Trend Energy Manager (TEM) front end and storage for carrying out Automatic Monitoring and Targeting for the building
- A number of issues arose around the sub metering when the TEM system was installed. The physical sub meters were not labelled and did not always match the meters on the BMS or TEM system. Physical meter readings were taken on a weekly basis of all the sub-meters to check the consumption being recorded and that the meters were set up appropriately on the system. The sub meters for the heating circuits are labelled as ground floor, 1st floor and 2nd floor when they are configured as north, south and core on the BMS. Caldwell consulting the original engineer on the project has confirmed that the configuration is north, south and core; therefore the labelling appears to be incorrect.
- The main electrical meter had never been connected to the BMS. The system was recording the sum total of all the sub meters as the total electricity consumption. This was inaccurate as it did not account for non-sub metered energy usage. This has been repaired and is now connected to the TEM system. This only came on line in January 2013 therefore overall electrical usage data was taken from the electricity bills for September – January.
- The DHW hot water meter was faulty and had to be replaced. This was fixed as of February 2013. Therefore there is no data on hot water consumption until this date.
- The site mains water meter is not recording accurate readings and still requires to be replaced. It has not been possible to gain access to the meter as it is located underneath the main staff car park.
- Sub meters CP5 and CP6 for fans, pumps and controls have not been activated and are powered down on site. The metering contractor claims the issue is the fault of the building owners and need to be connected by the GRAHAM before they can be added to the TEM system
- A virtual meter was created for the Biomass and Oil Boiler on the TEM system in order to view the data in kWh

- A number of powercuts and faults with the metering system have resulted in numerous weeks of data being lost. This has happened on six separate occasions. Each time there was no alarm to indicate the system had stopped working. Only when the TEM system was accessed was it apparent that the system had stopped recording.

- The readings from the meters have caused issues in that a high number of them record very low and very high readings as if self-calibrating. Some of these readings make it impossible to use historical graphs and data from the TEM. This has been reported to the metering controls contractor however they have been unable to resolve the issue.

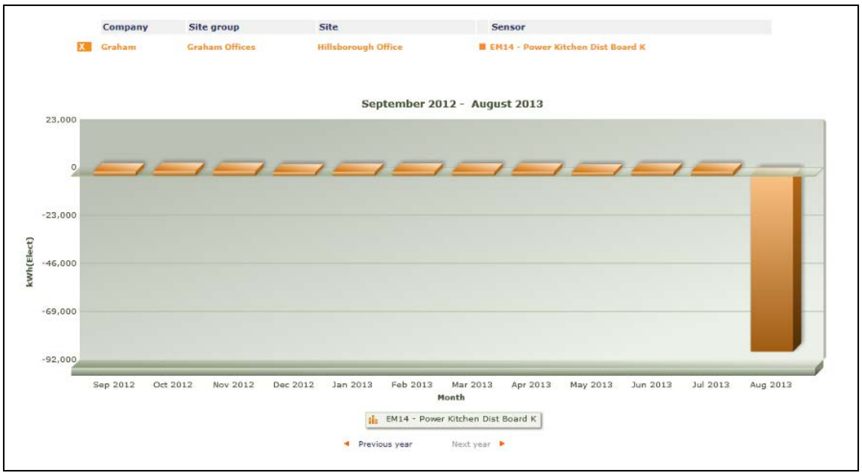


Fig 7.38 Kitchen Monthly Consumption – August figures high negative value

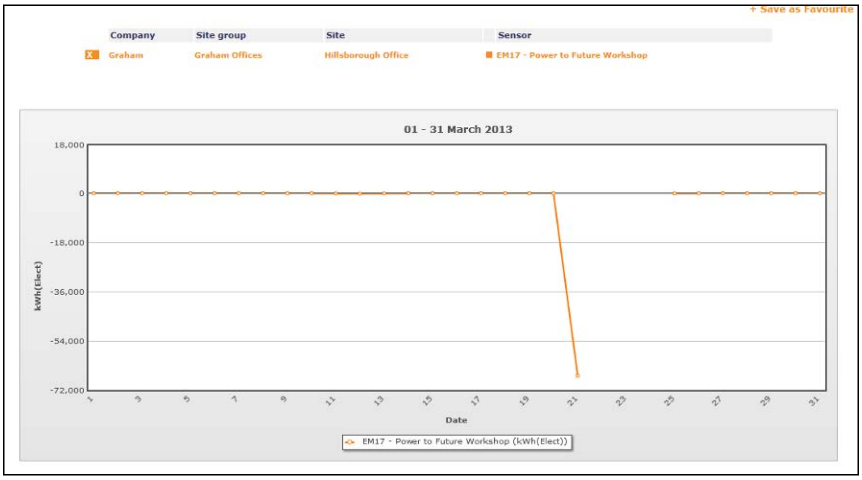


Fig 7.39 Future Workshop Consumption – High negative value

GRAHAM have decided to appoint a new contractor for the maintenance of the BMS and metering systems at the headquarters office. It is hoped that the new contractor can assist in resolving some of the data collection issues. In addition there are issues with BMS sensors and controls which also require attention.

Overall the service provided by the BMS maintenance company was poor and they were reluctant to investigate or fix any issues arising with the monitoring software and/or meters. This may be due to unreliable hardware and systems. However there is a lack of knowledge with regards to how much maintenance these systems require, particularly if detailed reliable information is required.

8 Environmental Data

Internal Environment

As a part of the Building Performance Evaluation of GRAHAM HQ, an analysis was undertaken of the environmental data from the BMS. The data collected from the BMS includes temperature and CO_2.

Temperature

Typical thermal comfort levels, in terms of temperature, vary dependent upon the building users clothing type and activity. For an office environment, it is assumed that the majority of activities involve sitting and wearing normal to heavy clothing. Therefore, typical comfort levels should range from between 18 to 21°C for most spaces, as can be seen in Table 8.1.

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

Table 8.1 - Comparative Temperature Levels ANSI/ASHRAE 55-2004

Temperature Results for GRAHAM HQ

There are approx. 60 temperature and CO_2 sensors at GRAHAM HQ which are used to control the heating and ventilation system to achieve optimum comfort levels. As part of the BPE study 6 of these sensors (2 on each floor) have been linked to the TEM energy management system. Data from these sensors has been collected and stored on the TEM at 15 minute intervals. A summary of the data for temperature over two years is as follows: -

Year 1

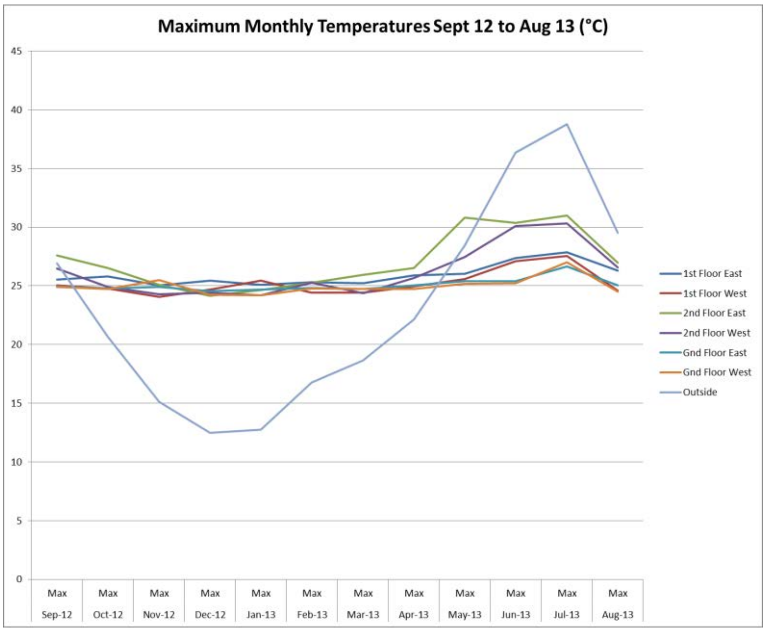


Fig 8.1 Maximum Monthly Temperatures Year 1 Sept 12 to Aug 13

From the graph above it is encouraging to see a certain amount of uniformity in the building. Maximum temperatures for most of the year are recorded between 25 and 27 degrees Celsius with a few notable exceptions. The 2nd floor East and West sensors recorded maximum temperatures between 27 and 31 °C in the months of May, June and July. On further investigation this was mainly happening for a few hours on isolated days in mid-afternoon/early evening. The table below shows the maximum monthly temperatures for Year 2. Again the 2nd Floor sensors are recording the highest temperatures but these are isolated incidents and could be caused by the large amount of glazing on the atrium and angles of the sun in relation to the sensors. Some of the higher temperatures were recorded on a Sunday when the building would be closed and the vents remain closed, allowing heat to build up. Overheating does not appear to be a significant problem in the building and it was not reported as an issue in the BUS survey.

The warmest external temperature in Year 1 was recorded as 38.76 °C on the 9th July 2013. The highest internal temperature recorded on the same day inside the building was 28 °C. This shows to some extent that the building is effective in keeping a reasonable temperature in peak summer.

Year 2

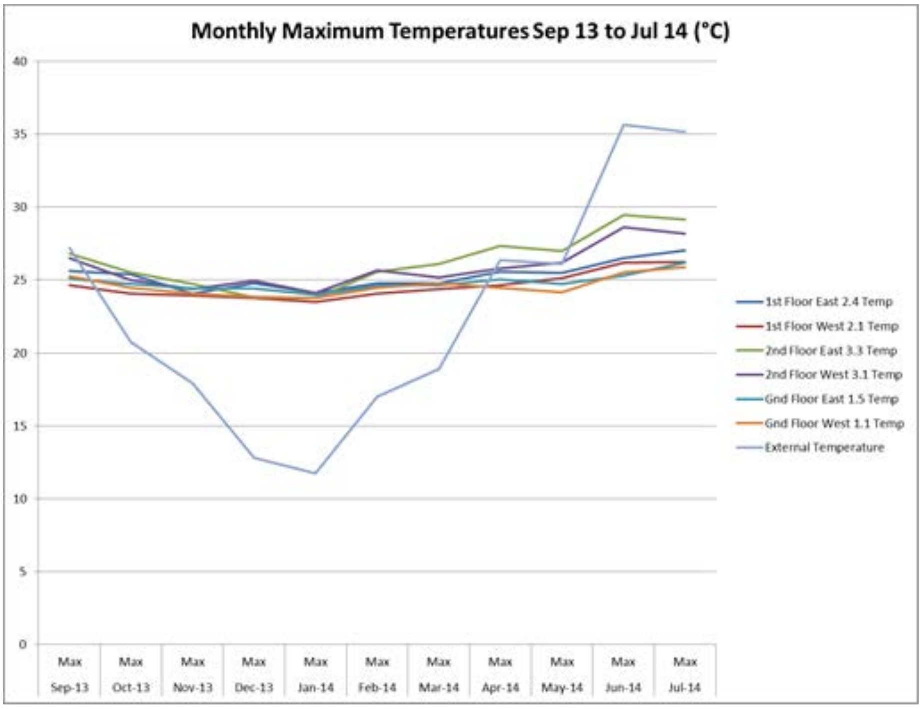


Fig8.2 Maximum Monthly Temperatures Year 2

Average monthly temperatures

Mean monthly temperatures have also been recorded. The mean monthly temperatures are between 20 and 25 °C. This includes overnight temperatures. The building does not significantly alter in temperature over 24 hour periods in winter and summer. See graphs below from TEM. This could be due to the exposed concrete pillars and ceilings providing thermal mass and having a stabilising effect on internal temperatures.

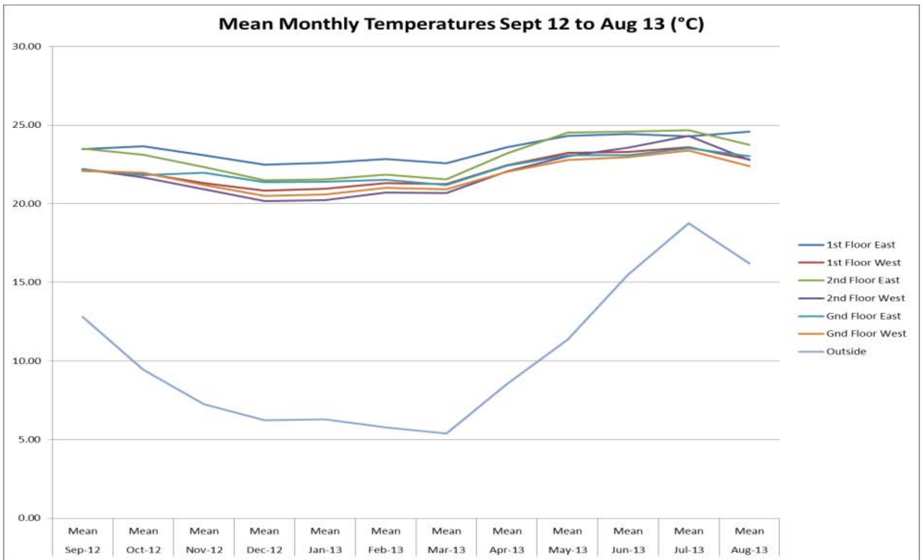


Fig 8.3 Mean Monthly Temperatures Year 1

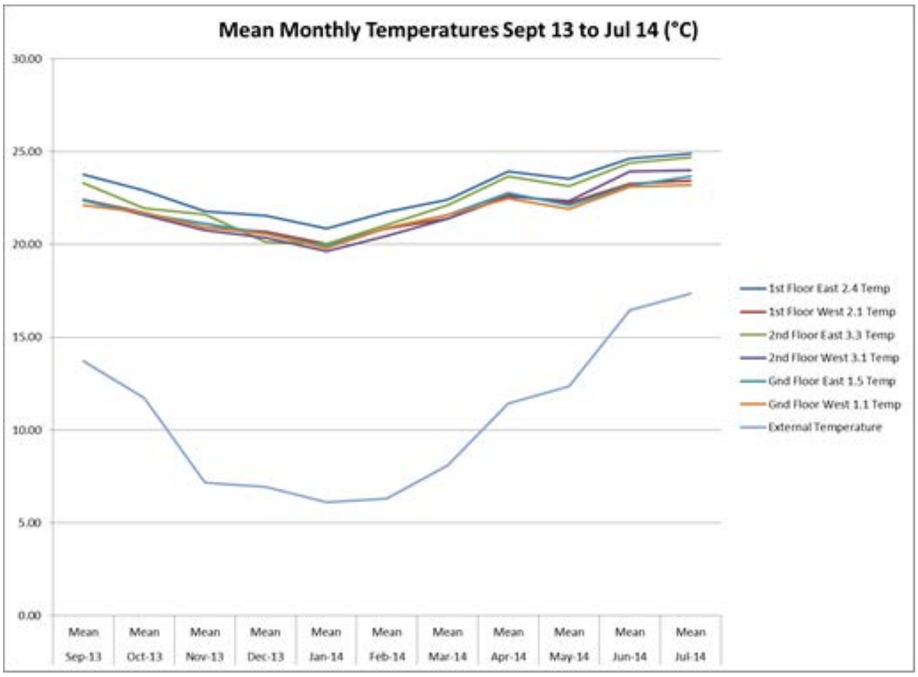


Fig 8.4 Mean Monthly Temperatures Year 2

24 hour temperatures Winter 2013

Winter temperatures are normally between 20 and 25 °C in winter months as shown below. Weekends can be lower as the building cools down slightly when not in use and the heating is turned off. See below for preceding Sunday and Monday profiles in Winter 2013. Monday mornings are slightly cooler and may require extra pre-heat from boilers to get the spaces up to temperatures. However the temperatures do not fall far below 17 degrees even overnight.

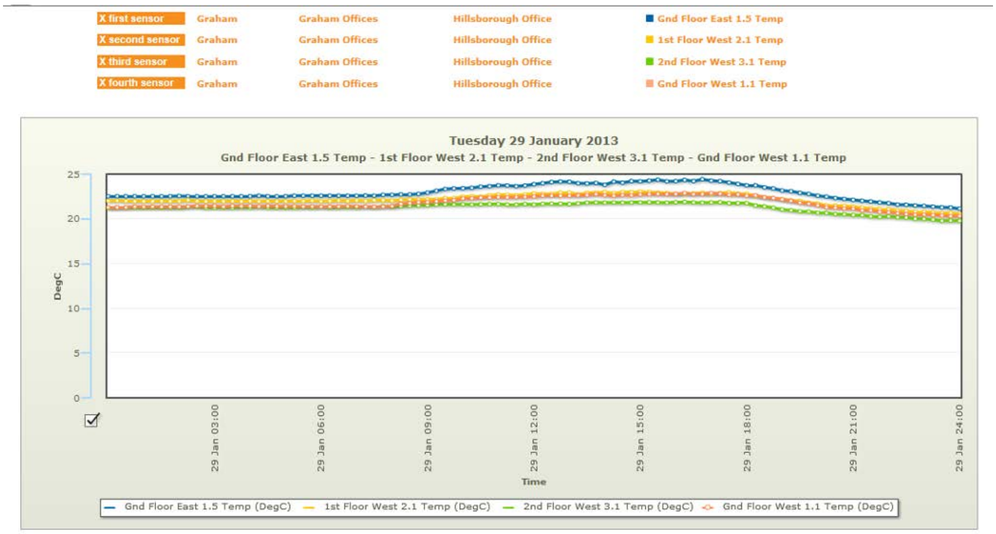


Fig 8.5 24 hour temperatures Winter 2013 Weekday

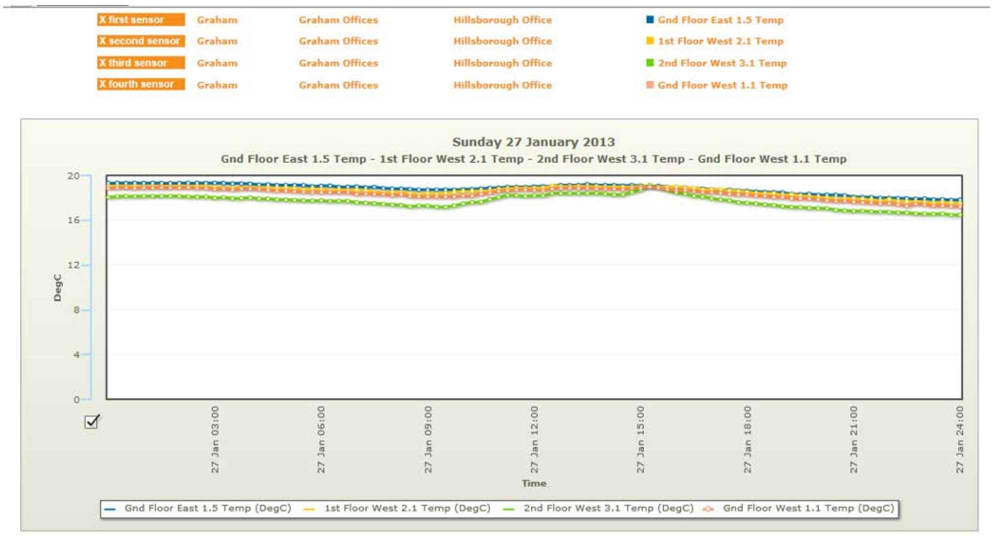


Fig 8.6 24 hour temperatures Winter 2013 Weekend

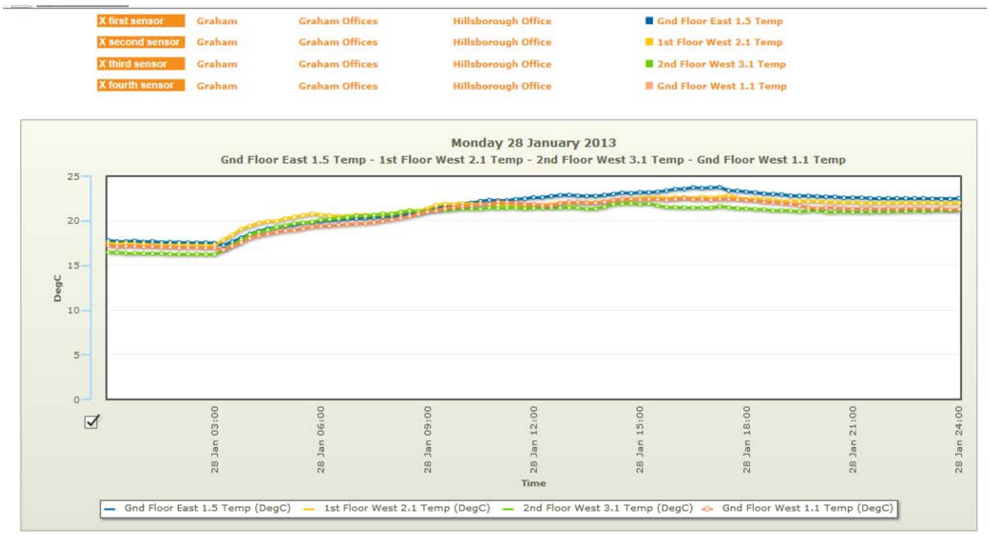


Fig 8.7 24 hour temperatures Winter 2013 Monday

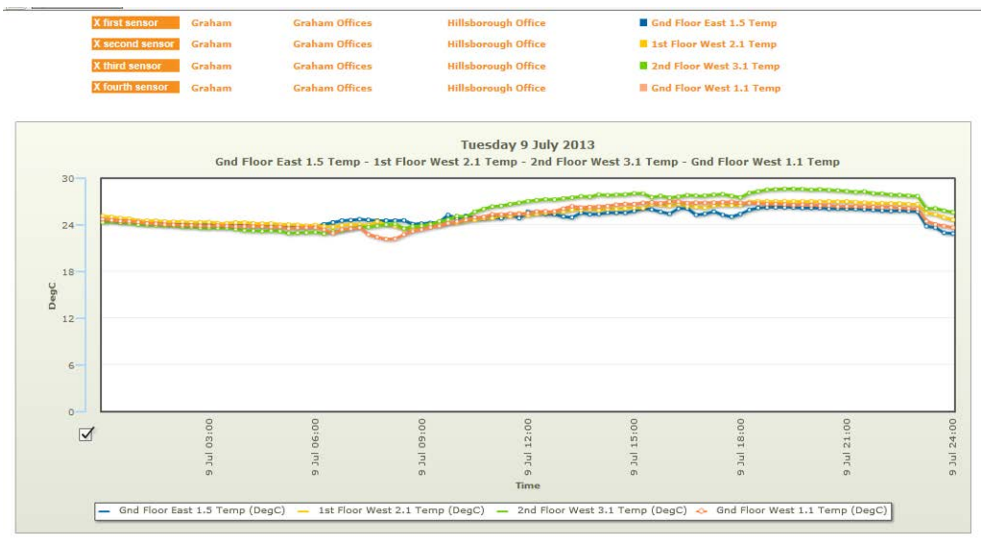


Fig 8.8 24 hour temperatures Summer 2013

One of the warmest days recorded in July 2013 was the 9th July. The above graph shows the temperatures inside the building over the 24 hour period. Again the 2nd floor seems to be the most susceptible to overheating. However the highest temperatures were recorded after 6pm when the working day was over. Overheating is not prolonged, however this could cause discomfort to occupants located underneath the atrium or in direct sunlight. No substantial complaints have been made about overheating on the 2nd floor.

Minimum monthly temperatures

Minimum monthly temperatures are more erratic. However Year 1 results show that temperatures within GRAHAM HQ never fall below 15°C even when external temperatures are as low as -1 °C. This could be the building's ability to store heat as thermal mass or it could be that the building is being heated for longer periods than it needs to be. Year 2 minimum temperatures were around 14 °C in January 2014. This occurred just after the Christmas/New Year holidays on a Sunday when the building had been closed for two weeks. This perhaps shows more efficient usage of the heating system which was switched off during the Christmas period of Year 2 but not in Year 1. The building was heated up to temperature by lunchtime on Monday 6th January however it took longer than a normal Monday morning.

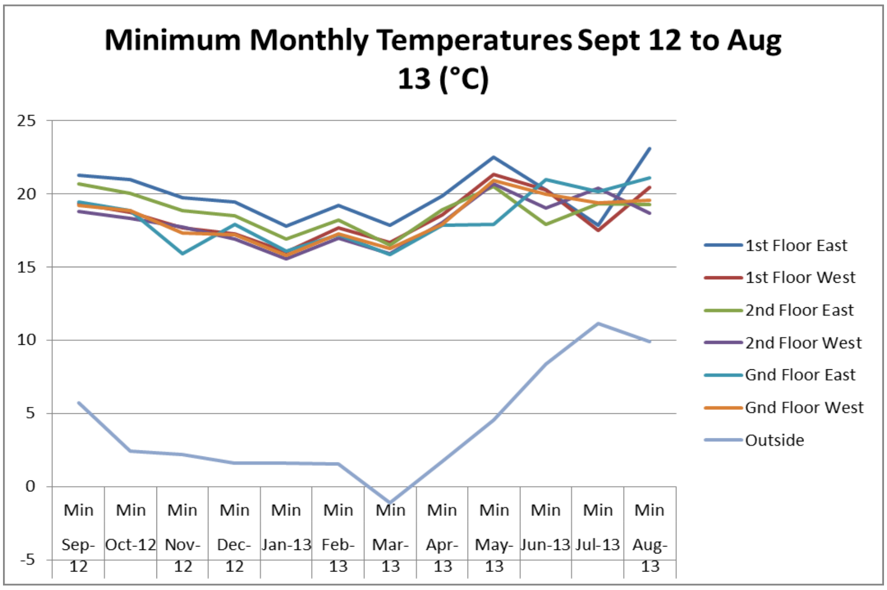


Fig 8.9 Minimum Monthly Temperatures Year 1

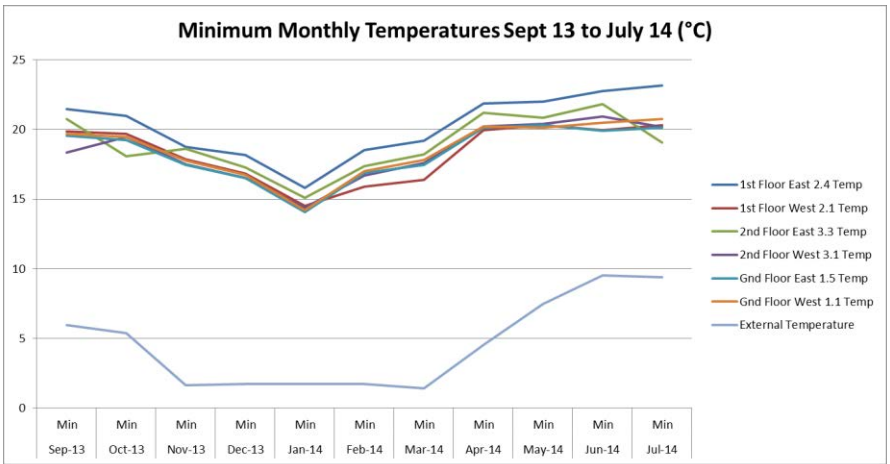


Fig 8.10 Minimum monthly temperatures Year 2

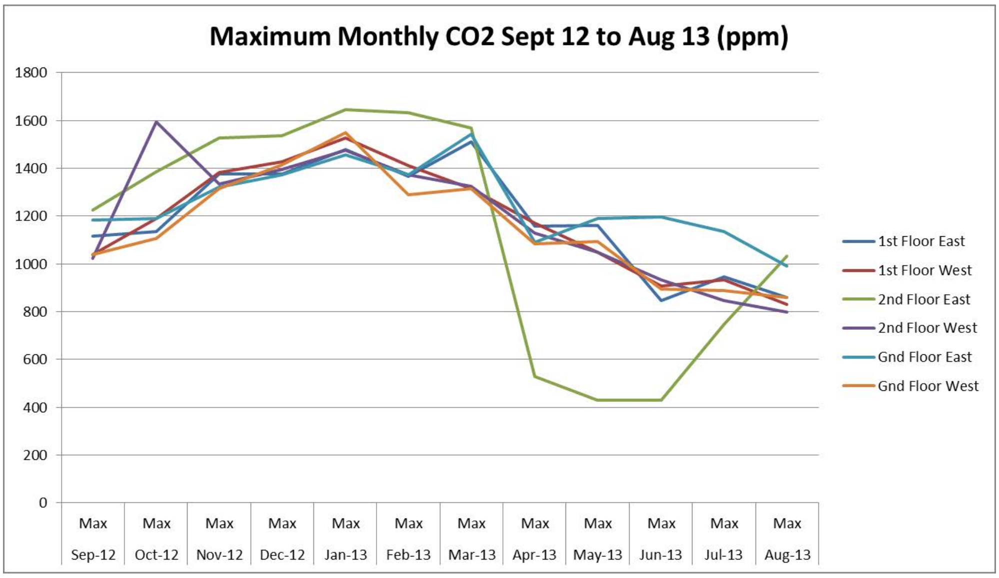
Accuracy of data

The data in this section of the report comes from the permanent temperature and CO_2 sensors which are located on the walls around GRAHAM HQ. It has been known for staff and visitors to on occasion manipulate the sensors (by breathing on them to increase CO_2 or to hold something cold or hot against the sensor) in order to open a vent or increase/decrease the heating temperature. Although this is discouraged it means that not all of the sensor readings are accurate although the data has been 'cleaned' as much as possible (i.e. if there is one reading which is much higher or lower than subsequent surrounding readings taken over a 5 min period then these readings have been removed. This didn't happen very often but could alter the max/min and average readings so removal was thought to be best option available).

Air quality

Air quality is a measurement of the level of CO_2[1] within the internal environment, and is measured in parts per million (ppm). Typically, 'Good' practice levels should be below 1000 ppm and ideally less than 600 ppm as when CO_2 levels are in excess of 1000 ppm, drowsiness and lethargy can be common side effects and could contribute towards a noticeable drop in productivity and concentration. Levels of between 1,000 and 2,700 ppm have been shown to have an adverse effect on building occupants wellbeing and up to a 14% reduction in cognitive function.

Year 1 Air Quality Results



From the above results it can be deduced that there is a fault with the sensor on the 2nd Floor East. This was recognised by FM and the sensor has since been replaced. Apart from this sensor other readings indicate that the maximum CO_2 ppm detected in the building is somewhere around 1500 – 1600 ppm. To ascertain if this is a once constant occurrence or a one off daily profiles need to be investigated. See below for TEM graphs showing air quality results.

[1] CO_2 – Carbon dioxide

Year 2 maximums show that the 2nd floor east and ground floor east require further investigation. The ground floor east was found to be faulty in July 2014 and requires to be replaced. The winter months have higher maximums on average than the summer months. This would make sense as most occupants prefer the vents closed in winter to keep warm. The mechanical ventilation takes over in winter from the automatic vents.

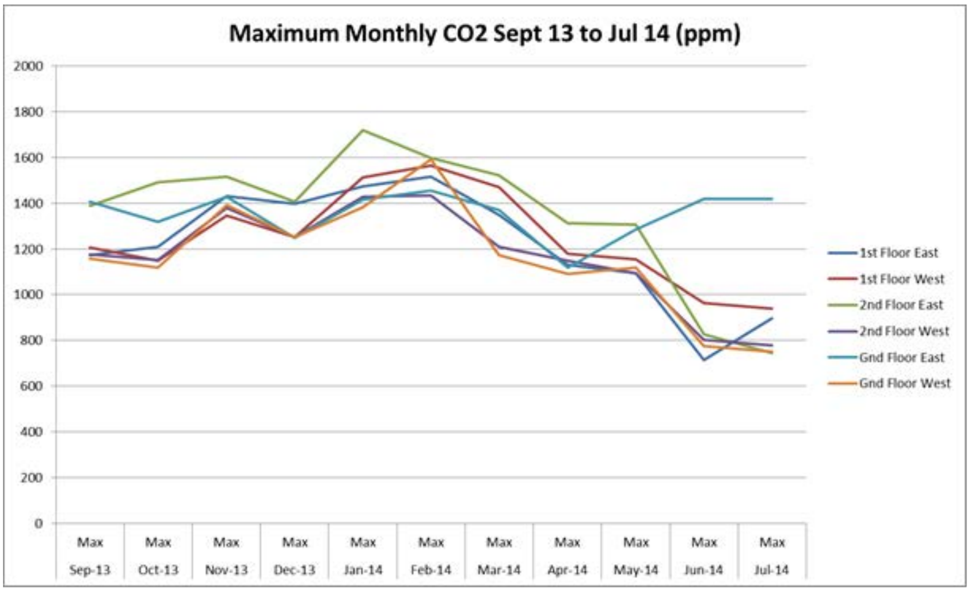


Fig 8.12 Maximum monthly CO_2 Year 2

Daily Profiles CO_2

Winter

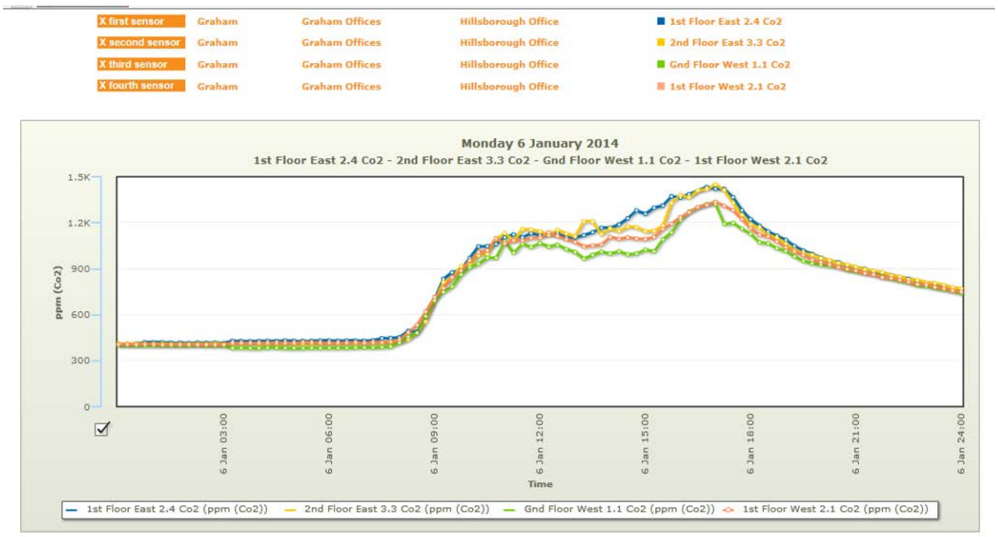


Fig 8.13 Winter Profile CO_2 24 Hour Weekday Year 2

The graph above is indicative of most winter days and some autumn/spring days. It shows levels of CO_2 building throughout the day and then peaking at the end of the day. Levels always return back to normal overnight. The summertime profiles have much lower CO_2 levels probably because windows and vents are open due to higher temperatures. This means air quality (in CO_2 terms) is typically better in the summer than in the winter. There are also some differences between the different floor although they all follow roughly the same patterns. The 2nd and 1st floor east locations are slightly worse in winter than the ground floor however in the summertime the 2nd floor east is marginally better ventilated than some of the other floors. Reasons for this could include lower levels of occupancy on the 2nd floor and proximity to vents in the atrium which would be open in the summertime but closed in the winter.

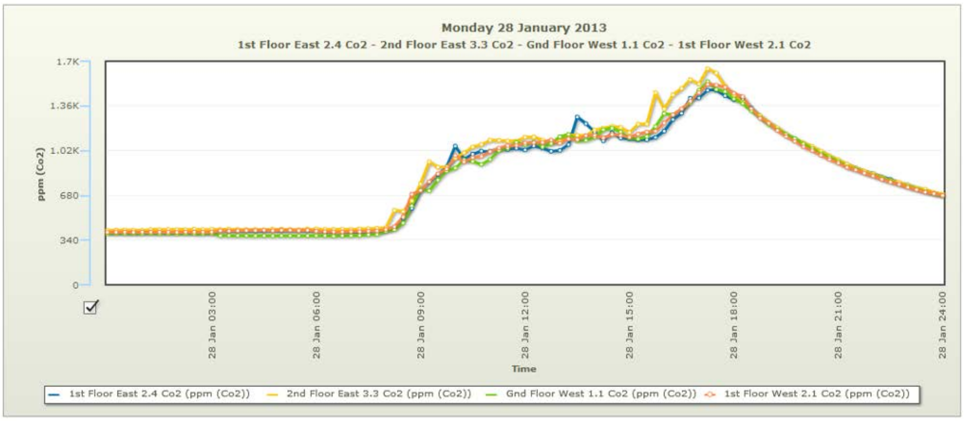


Fig 8.14 Winter Profile CO_2 24 Hour Weekday Year 1

Summer

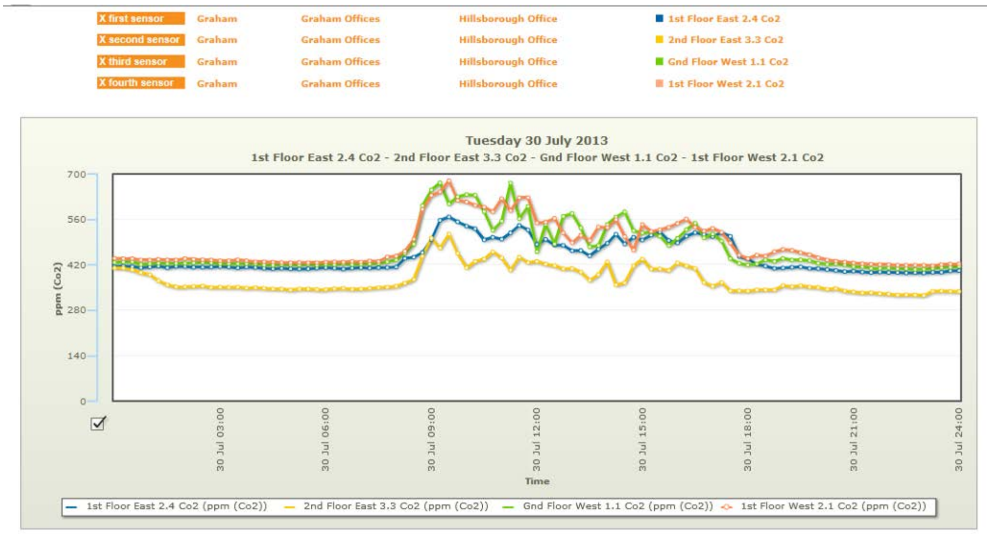


Fig 8.15 Summer Profile CO_2 24 Hour Weekday Year 1

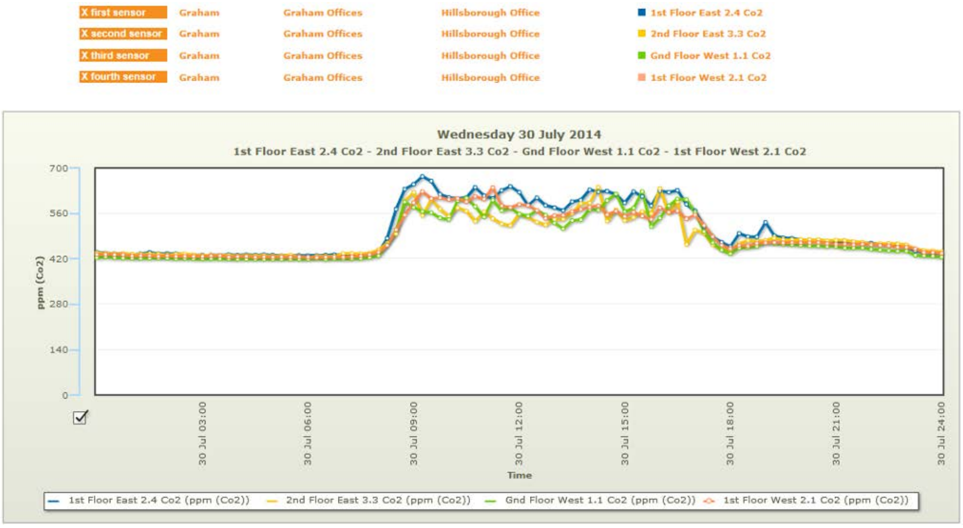


Fig 8.16 Summer Profile CO_2 24 Hour Weekday Year 2

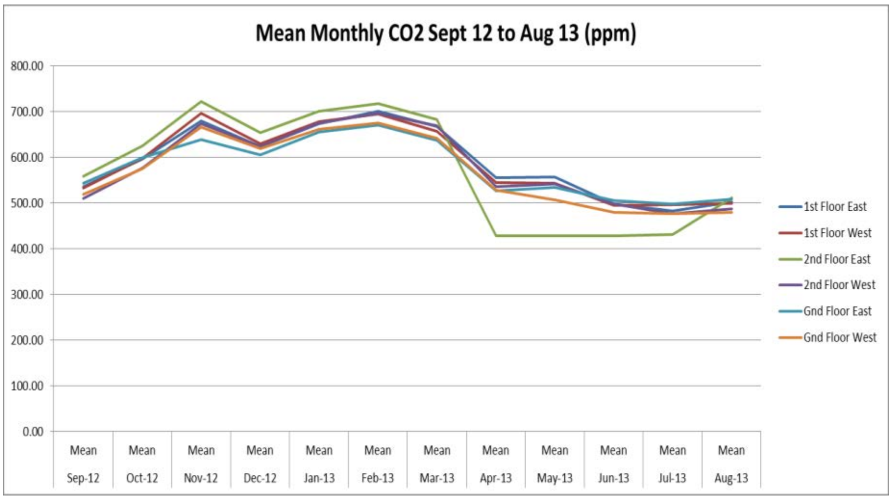


Fig 8.17 Mean monthly CO_2 Year 1

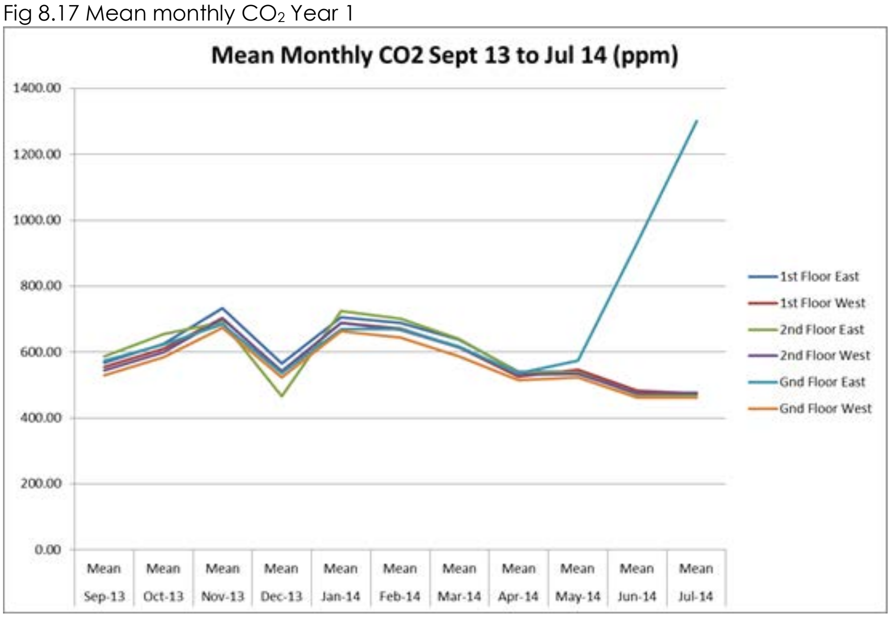


Fig 8.18 Mean monthly CO_2 Year 2

The graph above shows clearly a fault with the Gnd Floor East sensor which is due for replacement.

Thermal Mannequin Study

As part of a Technology Strategy Board investigation of the building performance of GRAHAM headquarters building in Hillsborough, University of Ulster's Centre for Sustainable Technologies were commissioned to undertake a thermal comfort study using a thermal mannequin to gather temperature and comfort data for a number of locations around the building.

The architectural design of this building is predominately a natural ventilation strategy. The open plan design suits this, with a central atrium to draw warm stale air up through the centre of the building, with cool fresh air being drawn in from outside. However naturally ventilated or 'free running' buildings can be difficult to predict / manage. Some complaints, primarily of draughts have been made and this study sought to identify whether there is an issue.

The testing was undertaken over a four week period in November and December 2013. During this time the ambient conditions varied, but in general the external envelope of the building was subject to cold temperatures. A full copy of University of Ulster's Thermal Mannequin Report can be found in Appendix G.

Thermal Mannequin Study of GRAHAM's building.

This study sought to quantify whether there are thermal environment anomalies in the Hillsborough HQ of GRAHAMs. The thermal comfort mannequin, see figure 8.1, was used to assess the environmental conditions. The mannequin was placed at various desk locations on the three floors of the building so that the thermal conditions may be assessed and compared.

Figure 8.19: Thermal comfort mannequin

ISO 7730 defines thermal comfort as 'that condition of mind which expresses satisfaction with the thermal environment". The human body is susceptible to changes in the thermal environment as a result of heat loss from the body. The inner core temperature of the body is maintained at 37°C with a skin temperature of around 34°C. The body maintains this inner core temperature through the consumption of food (energy), and then heat loss from the skin and exhaled air (sensible heat loss) and evaporation from the skin and water vapour in breath (latent heat loss). This heat loss maintains the body in equilibrium. Human sensation of temperature depends upon the rate of heat loss. We will feel hot if we cannot loose heat from the body, and cold is felt if we are losing too much heat. The transfer of heat from the body takes place by:

- convection to the air,
- radiation to the surrounding surfaces,
- conduction via direct contact with the skin
- evaporation from the mouth and skin.

Conduction from the body is limited as only a small proportion of the body is usually exposed to touch contact with surfaces. A final method of heat transfer is perspiration. This takes place when excess heat in the body needs to be removed quickly and the usual methods listed above are working at their maximum rates. The thermal conditions that affect these four methods of heat transfer are:

- air temperature – this controls the rate of convective heat loss from the skin

- air velocity – this also controls the rate of convection heat loss from the skin and it also affects evaporation
- surrounding surface temperature – this controls the radiation heat exchange of the body with the surroundings and is also affected by the emissivity of the surfaces and skin (the ability of a surface to radiate energy as compared to a perfect emitter).
- Humidity of the air – this affects the ability of a body to loose heat via evaporation, the higher the relative humidity, more difficult it is for a body of air to absorb water vapour.

There are two other conditions affecting thermal comfort, clothing – its coverage and insulation effect, and activity. Activity is measured by the metabolic rate; as the building concerned is an office, normal activity is sedentary and has a met level of 1.2 which equates to around 70 Wm-2 per person, or for the average person, around 100 Watts.

Mannequin

The mannequin is a life-size 'doll' with a system of nickel wires inlaid just below the surface of the skin. The body is split into a number of elements so that variations in thermal comfort across the body can be identified, for example foot, heat, back, hand, forearm etc. There are a number of scenarios that can be chosen:

1. Skin maintained at 34°C and the power consumption measured,
2. Thermal comfort where the mannequin seeks to control skin temperature against a set power input,
3. Temperature measurement – the body elements record the temperature of the immediate surrounding air.

Scenarios 1 and 3 were used in various locations. The first gives an indication as to whether there are variations in comfort across the body, which will lead to discomfort. A body is more likely to feel discomfort if part of it is exposed to a different sensation to another, for example stepping out of a shower onto cold tiles, a cold draught under a door. The third scenario allows the user to investigate whether there are temperature differentials in the local area affecting the result. Problems that may be spotted will include:

- Temperatures too high or too cold for comfort,
- Asymmetric radiation leading to discomfort
- Draughts will show up as localised cooling resulting in higher power consumption by the body element.

Test Sites
A number of locations in the GRAHAM Headquarters Building in Hillsborough were assessed:
- Ground floor
  - far right of entrance (salaries and wages)
  - near lift shaft and immediately to the right of entrance (accounts)
  - far left of entrance immediately below atrium (IT)
- 1st floor
  - far left of building (QS)
  - far right of the building (Civils QS)
- 2nd floor
  - near Jackie Gibson's desk at curtain walling.

A further site was identified, amongst the Civils team on the 2nd floor, on the far right and back of the building where the open office extends to the rear wall. However the schedule did not allow for that space to test within the time-frame available.

Results

Ground Floor
The position of the mannequin in Salaries and Wages was with her back to a window that looked out on to the A1 junction. This window had a very cold frame; however the rear of the mannequin is not affected by this cold radiation source. In Accounts there was a similar trend with little asynchronous temperature differences across the body to suggest the mannequin was subject to localised cooling or draughts.

The mannequin was dressed with trousers, a blouse and cardigan, giving it a clo value of 0.8, but even with this it was registering a low PMV (predicted mean vote). A PMV of 0.5 to -0.5 would be seen as an acceptable condition, but this was never achieved in Salaries and Wages, even though the temperature in that location was around 23°C, which would be seen as an adequate temperature for sedentary office work. The body parts have higher energy consumption in Salaries and Wages and Accounts, when compared to IT. This may demonstrate that in IT there is a more uniform temperature and the PMV calculation during office hours falls within the acceptable 0.5 to -0.5 band. The IT location was in the centre of the building below a large LCD monitor.

First Floor
The results for the 1st floor show a uniform result demonstrating temperatures over the body are within 1.5°C which is a very good result. Vertical temperature differences of below 2°C gives a 95% predicted satisfied (PPD), which is as good as can be achieved. Again the data shows how close the temperatures are over the course of a number of days. The only concern at these locations is the cooling of the foot, but a reason for this could not be determined on site.

Second Floor
When the work was planned it was envisaged that a location next to civil engineering on the 2nd floor would be investigated, but time did not allow this to be fitted in. The location on the second floor was next to a wall dividing the work space from the tea and coffee area. It was next to the curtain walling and above a floor vent that is sealed. The temperatures shown are lower than the other areas however none of the body segments had a temperature that was significantly at variance with the other segments. There are noticeable spikes in the data in the morning of the 15 December and just after lunch at the 18 Dec, this may have occurred as a result of a short period of solar gain, but this cannot be verified.

Conclusions
The results of the testing at GRAHAMs demonstrate that a naturally ventilated office can operate with an acceptable temperature profile. There are issues with regard to temperature variations in some of the spaces demonstrated by the acceptable PMV result in IT compared to that in Salaries and Wages which is considered cold and below the acceptable threshold. The 1st floor locations demonstrated uniform and acceptable results while the upper floor was cooler but again temperature differentials were very low and therefore acceptable.

University of Ulster did note on visits to the building that there are issues pertaining to thermal comfort which were not identified by the mannequin. The curtain walling installed has a cold frame, while the glass is comfortable to touch. This suggests that there is thermal bridging in the frame and hence this is a source of heat loss and localised cooling near the building perimeter.

The choice of sliding doors into the building is a pleasant architectural feature but at times architectural features are counter-productive when seeking to conserve energy or provide a thermally comfortable environment. There are subtle air flows in the building, such as around the base of the lift shaft from the rear door towards the Accounts department. The reason for this is difficult to comprehend. A barrier between the reception area and the Accounts department may solve this but this would take away from the desk layout, which is uniform throughout the building. With hindsight it may have been better to have placed a meeting room immediately to the right of the front entrance which would have moved the open plan office environment away from the direct path of air leakage through the rear doors.

Another noticeable feature when studying the thermal comfort of the building is the cold columns. Exposed concrete helps increase the thermal mass of a building, dampening temperature fluctuations. An investigation of the performance of the building thermal mass may be of interest.

University of Ulster did note some differences among men and woman and the level of clothing worn by each on the 2nd floor. The area to the rear of the building was occupied predominantly by female staff while to the front by male staff. The female staff were wearing company fleeces while the men were in shirt-sleeves. This difference in apparel may be down to the activity being undertaken, the men using the desks for 'hot desking', having been on site or regularly leaving their desk to discuss work with colleagues elsewhere in the building. Both activities may then lead to the men feeling warmer. Those visiting the office would be conditioned to being on site and hence in a colder environment, and may find the office warm as a result. Those moving about the office are generating internal heat through metabolic activity.

There is a perceptible air movement on the 2nd floor between the atrium area and the open office area that stretches to the back wall. This may be due to ventilation air movement taking place to the façade. University of Ulster are not aware of the air movement strategy developed by the architect and building services engineer during the building design stage, but often such open areas are required to allow air to pass to and from the building façade. The open plan design with an open atrium may contribute to some of the discomfort reported by the staff, but to take away these architectural features would weaken the beauty of the building, put barriers to the movement of air, requiring the introduction of mechanical ventilation and roll back the architectural statement of equality that an open plan office projects.

The building demonstrates that it is possible to design, construct and operate a naturally ventilated office to a high standard. The subtle and perceptible air flows and 'cold spots' demonstrate that further research is required to investigate air flow in buildings, especially naturally ventilated buildings with an open plan design. The owners and operators should note that 95% satisfaction amongst building users is the best that can be achieved.
For many years thermal comfort promoted a small region on a psychometric chart where comfort could be achieved. The work of Nicol, Humphries and Roaf (2012) now promotes a different approach, that of adaptive thermal comfort. This allows for a variation in temperature based upon ambient conditions. It also seeks to persuade people to accept variations in comfort. It may take a generation for society to once again become used to naturally ventilated offices after a life time in mechanically ventilated spaces.

9 Technical Issues

The key technical issues associated with the GRAHAM HQ building are listed below under technology types: -

Design

- The natural ventilation strategy is mostly working well and has resulted in a minimum use of air conditioning and mechanical ventilation. Natural ventilation has not worked so well in cellular offices and some of the meeting rooms. Additional mechanical ventilation has been retrofitted to Meeting Room 4 on the ground floor.
- The inclusion of exposed thermal mass seems to be working as designed as the temperatures within the building are relatively steady.
- Occupation of the building is at maximum levels now and some areas of the building are showing strain. The number of gent's toilets in the building is an issue for staff and in hindsight more gents toilets could have been installed at design stage.
- Increase in staff numbers have meant that portacabins have been added to the rear of the building to accommodate more staff that have joined GRAHAM since the building was completed. These portacabins are not as efficient as the main building and have an effect on energy consumption as shown on the 'Future Workshop' sub-meter.
- Storage space is an issue for the building and for facilities management staff. There is no dedicated storage area (apart from filing cabinets) for documents in the building. This has resulted in outside portacabins being used for storage of documents which has impacted greatly on energy consumption due to electric heaters installed to keep portacabins warm (see future workshops consumption). In addition lack of storage resulted in the biomass boiler not being used for part of winter 2013/2014.
- The BMS system was designed to afford the user a high level of control with features including boiler optimisation, night time cooling, energy and water management. Feedback from the original M&E engineer is that a lot of the functionality of the BMS system is not being used and that the system is over-specified for the facilities management team in charge of the building and their remit within the building. Night time cooling mode has never been used and the sub-meter data was not being collected or analysed prior to the BPE study.
- Although the BMS is over specified in some areas, items such as winter and summer modes have not been included and would have been useful.
- Some areas where cost savings have been made at design stage include: the decision to have an electronic sliding door at reception instead of a revolving door. This has had some repercussions, particularly areas on the ground floor where draughts are an issue.
- U-values in the building fabric could have been to a higher standard but costs at design stage made this prohibitive.
- Daylight sensors for the lighting were discussed at design stage but were omitted due to cost implications.

Handover and Commissioning

- Handover and commissioning of GRAHAM HQ was not overly fraught with issues. This is mainly because the client was the main contractor and most of the original design team are still frequent visitors to site. Caldwell Consulting has been particularly helpful in explaining the BMS and building systems/controls.

- GRAHAM FM is the management company in charge of the building. This is a unique relationship and one that mostly works well. The building was handed over to occupants but the current FM manager was not involved in the handover (as is often the case) and as such did not benefit from training etc. provided by sub-contractors.
- The meters on the BMS system do not seem to have been commissioned properly at building handover and as no one is responsible for collecting data from the meters, this was not discovered until the BPE project commenced. Meters monitoring the Air Handling Units and Kitchen Extract were never connected and wiring was inadequately sized for their operation (CP5 and CP6).

Building Fabric

- The U value of the walls and curtain walling in the building performed close to the as designed value. The roof construction did not perform as well but the results were inconclusive.
- Air tightness values were very similar to as built values and were still under 5 m3/hr/m2. However gaps in the front doors at reception and in particular the sliding doors were causing air movement (as witnessed during the smoke test) to the right hand side of the reception area were complaints of cold draughts have been made by building occupants.
- The majority of the building presented no serious issues as a result of the thermal imaging survey. Some areas for concern were cold spots around the frames of the curtain walling, possible thermal bridging on the two gable walls at the floor/wall junctions and an area at the curtain walling/masonry wall junction on the top floor at the rear of the building.

Heating

- Heating setpoints have been adjusted in areas such as the Ground Floor West where draughts have been reported (probably as a result of the sliding doors). This has caused increased energy consumption. Extra heating was also retrofitted here.
- Internal temperatures in the building are usually between 20-25 °C. This is higher than the 18-21°C which is commonly cited as comfortable for office workers. This could be causing increased energy consumption.
- In addition the temperature in the building rarely falls below 20°C during the week and rarely below 16°C over the weekend. This could be a sign of thermal mass performing well and maintaining stable internal temperatures or it could be a sign that the building is being heated out of hours when heating is not required.
- The boiler optimisation programme seems to bring the boilers on at the same time every day in the winter regardless of the starting temperature. The boilers are typically coming on at 3am when most occupants do not arrive for work until 8am. This should be investigated to see if adjustments can be made to improve the efficiency of the optimisation programme.

Ventilation

- FM has had complaints about the automatic vents in the office areas. Occupants would probably prefer manual individual control to adjust them to their ideal. However as each vent can be controlled individually via the BMS the FM manager can adjust these to suit occupants. This is time consuming for the FM manager but at least the system can be overridden. However overriding the ventilation control can sometimes result in high levels of CO_2 building up in a particular area causing poor air quality.

- Natural ventilation and air quality appears to perform best in the summer months when temperatures outside are high. In the winter with the vents closed the CO_2 levels increase to high levels which could affect employee performance and also puts additional strain on the mechanical ventilation system.
- Some internal office areas (Meeting Rooms 3&4) have resulted in complaints about poor ventilation and overheating. These rooms are internal and have only one ventilation supply and one extract. If complaints persist in this area FM may have to consider installing air conditioning.

Cooling

- Air conditioning has been minimised throughout the building and is present only in the server room and meeting/conference rooms. One of the main issues with the air conditioning in the meeting/conference rooms is the control strategy. Users can manually switch on the air conditioning however as use of these rooms is intermittent, the air conditioning usually stays on long after it is required. In some cases it has been left on overnight. The air conditioning is not linked to the BMS and requires manual operation. It was thought that the air conditioning would switch itself off after a set time period of half an hour but the load profiles from TEM do not correlate with this.
- The new server room in the IT workshop now has two mobile air conditioning units. These are high energy users and alternatives are currently being looked at to replace them.
- Overall cooling consumption is relatively low in this building and is not frequently used.

Lighting

Internal

- Essential lighting in the central atrium are left on permanently to light the stairs. These lights can be manually switched on and off but only by the facilities manager with a key. They are almost always on but this is mostly due to a safety precaution. Levels of lighting are very good under the atrium so it probably isn't necessary to have these lights on during the day.
- The daylight study showed that lighting levels in the building are of a high standard. Daylight sensors in certain areas around the perimeter of the building could have resulted in increased energy savings.
- Most of the lighting in the office areas of the building are PIR presence controlled lights and there is no manual override. There have been issues in the past with over sensitive PIR sensors coming on at night activated by traffic and/or birds. This could be causing unnecessary energy usage out of hours and a master switch similar to that installed in the atrium would have been useful for FM to shut down the lighting overnight and at weekends.

External

- External lighting is on a timer and photocell control. Apart from a fault in the timer in Year 1 the external lighting is working well and consuming relatively small amounts of energy.

Small Power

- Small Power is one of the largest energy users in the building. Most of the small power loads can be attributed to office equipment. Large amounts of out of hours usage indicates that small power appliances are being left on during evenings and weekends. Some housekeeping measures are in place to switch off monitors at the end of the day, however more work is required in this area to identify savings.

- With the expansion of the business and addition of new staff the small power consumption will also increase unless more is done to minimise IT demand and keep out of hours usage to a minimum.

Server Room

- The server room load continues to grow with the expansion of the business. A new server room has now been added to the existing server room formerly known as the IT workshop. The server room has a 24 hour load and it is essential to the operation of the business. GRAHAM systems to advise on what more can be done here to save energy.

External Areas

- A lack of storage areas inside the building have resulted in portacabins located at the back of the building being used for document storage. The cabins are heated by electric heaters with no timer or temperature control. They are manually switched off in summer and on again in winter by FM. This has caused a large increase in the building's energy consumption.
- Portacabins for additional staff members were added in 2013/2014 but were heated by their own oil supply so did not impact on the building as significantly as they could have. Small power and lighting was supplied via the main electricity supply increasing electrical consumption.

Controls

- Staff have no manual control of the heating or electric lighting however the BUS survey results reflect high levels of occupant satisfaction. FM have a high degree of control over the heating system but they would prefer to have individual control over heaters rather than zones as individual occupants could be catered for more effectively.
- Overall the quick response of the FM manager to occupant requests for changing heating and vents seems to be working. This might not be such an effective arrangement if the FM manager was located on another site.
- There is some occupant control of ventilation if you are seated near a window. Also the vents can be overridden and controlled individually via the BMS. This does sometimes mean that you are at the mercy of whoever is sitting closest to the window or the vent in terms of control.
- The BMS can also control the mechanical ventilation in different zones but again occupants cannot control this.
- Air conditioning controls could be improved. They seem to be left running too long when the building is unoccupied.
- Manual control over PIR operated lighting could result in energy savings.

BMS

- Some of the functions within the BMS are not being used (night time cooling for example). Also the alarms in the BMS have either been overridden or weren't set up properly because they are not being used either. Re-commissioning of the system and further training for FM could help to improve this.
- The Building Management System included connection to a high number of sub-meters. However as a Building Energy Management System was not specified (due to cost savings), the data from the meters was only collected for 11 days before it was erased from the system. Spreadsheets from the system could be exported every 11 days however this relies on the data from the spreadsheets being interpreted for reporting. A BEMS front end enables easier monitoring and targeting of energy to take place. It can be an essential part of energy management but was not included in the building's original design.

- The main issues which were reported about the BMS were CO_2 sensors not reading accurately, inaccurate sub-meter readings and wind speed sensor not working. These issues have caused some operational issues within the building including vents opening when they shouldn't (because the BMS read CO_2 levels were high when they weren't). In addition the atrium windows are supposed to close when wind speeds are high. There was one instance during a storm when this became an issue. As the wind speed sensor was broken the windows did not close, this caused the motor to break, and causing rain to pour into the 2nd floor office space as the window remained permanently open. This has now been repaired. A manual override for the window vents could have prevented this.

Metering

- Setting up, checking and repairing the metering for the building was one of the biggest challenges of the project.
- The metering had not been commissioned properly and as GRAHAM do not have an energy manager no one had checked the sub-metering or readings for accuracy (apart from the M&E engineer who undertook monitoring during the 1st year of occupancy).
- Issue with setting up the meters included: -
    - No coherent labelling system on the sub-meters or BMS
    - Sub-meters set up incorrectly on the BMS (names didn't match physical meter numbers)
    - Meters stopped recording on BMS, TEM system would freeze and would lose data
    - Meters recording inaccurate readings
    - Poor information on what meters are actually measuring – resulting in difficulties completing TM22
    - Main meter for electricity not connected to the BMS
    - Hot water meter faulty and had to be fixed as part of the project
    - Site mains water meter not set up properly on BMS
    - Sub-metering for fans and pumps not powered up on site (CP5 & CP6)
    - Lack of physical readings to compare BMS readings with
    - Poor service from BMS provider (lack of interest and long response time to fix issues). BMS provider often used the excuse that fixing the system (that they installed) was not part of their maintenance contract even if the system had never been set up properly in the first place.

10 Responses to Main Study Questions

The following key study questions were included in the original TSB BPE application. These questions have been answered as much as possible throughout this report. For clarity the questions have been listed and a response prepared against each of them.

Main Study Questions

1. What is the overall energy consumption of the building and how does this compare to industry benchmarks and other office buildings in the UK and the BPE programme? How is the energy use broken down and how does this compare to known benchmarks?

This question is answered in more detail in Section 7. In summary the building is performing well however not all areas of energy use are in the good practice range for similar building types. IT server rooms and external areas are using almost half of the building's electricity consumption. The building is close to good practice benchmarks for lighting, and is around typical practice for small power, fans/pumps and controls. Fossil fuel usage is mid table between good practice and typical practice. There is room for improvement but performance of the building itself is ok.

2. What is the performance of the Biomass system?

Section 7 contains a summary of the Biomass data gathered so far. The Biomass system is well used in the building and makes a positive contribution in terms of reducing carbon dioxide emissions and keeping costs down. One of the limitations of the Biomass boiler is that it there has to be a manual switch over in Autumn from the oil boiler. The FM manager is keen to maximise the usage of the Biomass boiler but is not quite sure when the right time to switch over. They have been using a rule of thumb that when the heating system is required for more than 3 consecutive days it is time to switch on the Biomass boiler. Using the biomass boiler for a longer period would help to reduce carbon emissions even more. Therefore optimisation of the biomass would be a key area for further investigation.

3. How does the building fabric perform compared to design defaults?

Section 4 contains all of the results of the building fabric testing and section 9 contains a summary of these results. Overall the building performed well in terms of u-value measurements (exception of the roof) thermal imaging and daylighting

4. How does the air tightness performance vary from as built results?

Section 4 contains all of the results from the air tightness testing and Caldwell Consulting produced a video of the air tightness and smoke test. The building achieved a slightly better result than at building handover (4.63 m3.h-1.m-2 @ 50 Pa) although the smoke test revealed some draughts and air movement at the ground floor reception area.

5. How do building services perform compared to design defaults and industry benchmarks?

Section 7.0 contains all of the energy data gathered during the study period. These results have also been summarised in section 9.

6. What are the levels of building occupant satisfaction? How can occupant satisfaction be improved? How can building occupants influence further reductions in energy consumption?

Section 5 contains the results from the BUS survey and semi structured interviews, carried out throughout the 2 year monitoring period. The building scored very well in the BUS survey scoring in the top 5th percentile of the fixed 50 buildings used for benchmarking the BPE programme. Further energy reductions could be made by engaging users more with regards to the low carbon aspirations of the building. The Building User Guide should contain more information on saving energy and an awareness campaign could be run in conjunction with an overall energy management strategy for the building.

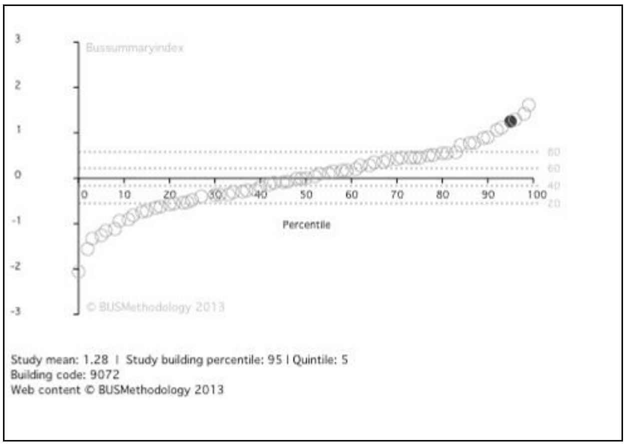


Fig 10.1 Summary Index from GRAHAM HQ BUS Survey.

7. What would be required to make this building a zero carbon building? How far away is the building from zero carbon status? What perceived impacts would this have on occupant satisfaction?

GRAHAM's Sustainability Manager has investigated the possibility of installing PV on the roof of the building or on an adjacent warehouse. A proposal was received for a 20kW PV installation with an estimated annual energy yield of 17,744kWh and a payback period of 5.9 years (taking into account grant support and ROCs available in Northern Ireland). This would supply approx. 4.5% of the building's current electricity demand.

The supplier goes on to say that a 50kW system is the preferred size of installation required on site as this would combine economy of scale and optimised revenue from the ROC incentive. A typical 50 KW could generate 40,000 kWhrs per year (10% of the building's current annual electricity usage). Typically, an installation of this scale would require an array of around 320 sq metres and the building roof area of the present building would not accommodate this. In addition, other aspects such as shading have to be taken into account and from the photograph below it can be seen that there is a shading effect which would dilute the investment value of siting additional panels on the right hand side of the roof. The warehouse adjacent to the main building may be able to accommodate this however structural studies would need to be carried out.

From the above proposal it is clear that there are options available for further improvements to the building's carbon emissions, and if energy efficiency was combined with a renewable technology or combination of renewable technologies then the building could improve performance. However the building would need in excess of approx. 3200m2 of PV panels to meet the current annual electricity demand.

Wind turbines could also be an option given the countryside location of the building. Financial incentives and grants are similar to those of PV. However a wind turbine is potentially more visually intrusive than PV and issues such as noise and wind speeds would need to be considered before a decision could be made on whether this technology was viable.

The biomass boiler contributes greatly to reducing carbon emissions at GRAHAM HQ saving 58.5 tonnes of CO_2 in Year 1 and 31 tonnes in Year 2. To make further savings and bring down the carbon emissions further, ways to use maximise use of the biomass boiler over the oil boiler should be further explored. Biomass CHP may also be an option for the building in the future however these systems commonly require 24 hour loads and this does not suit an office building as well as it would a hospital or care home for example.

Overall the building is still some way off achieving zero carbon status, however with improvements to energy efficiency and renewable technologies and with good energy strategies and management practices it is not completely impossible.

8. What results would a Post Construction Review BREEAM Assessment provide? Would the Design rating of 79% be retained or have items committed to during the design stage been lost during construction?

As part of the brief to achieve a sustainable building GRAHAM Construction set a target of a BREEAM Excellent Rating. The standard in use at the time was BREEAM Offices 2006. The project undertook a Design Stage BREEAM Assessment and achieved a score of 79.13%. A Post Construction BREEAM Assessment was not undertaken as it was not mandatory under BREEAM Offices 2006. The BREEAM Assessor (Caldwell Consulting) did gather evidence following the design stage BREEAM Assessment in case GRAHAMs wanted to pursue a PCR BREEAM Rating. As part of the TSB funded Building Performance Evaluation, GRAHAM have committed to revisiting the design stage BREEAM Assessment to ascertain if a similar BREEAM score would have been achieved for the building post construction.

Most of the credits achieved at design stage would still be achieved at PCR stage with a few exceptions. These are as follows: -

Man 4 Building User Guide – Although an induction booklet exists for the building this would not contain enough information for BREEAM recommendations. A more detailed Building User Guide would be of benefit to the building users and would help to ensure the design aspirations are captured and communicated to the building occupants.

Hea 6 Lighting zones – there is no occupant control of the lighting in the building.

Hea 09 Indoor Air Quality – the car park and exterior road is within 10m of openable windows – this credit would not be achievable at post construction stages.

Tra 02 Transport CO_2 – the calculator used for this credit was not available for checking however it was based on 122 car parking spaces being provided. A new car park has been opened up to the east of the building and therefore the score achieved here would probably reduce. There are 250 building occupants and approximately 84% of them travel to work by car. Therefore the indicative score has been reduced to 5 out of 10 as opposed to 7 out of 10.

Even with these amendments the indicative score post construction would still be a BREEAM Excellent rating of 73.64%. BREEAM was obviously a key driver for the building and the influence of the credit system is apparent in the building's design internally and externally.

9. What lessons can be learned from the design, procurement and construction of this building? How has this affected the energy performance and occupant satisfaction of the building?

Feedback on the design has been provided throughout the report and is summarised in Section 9.0. Overall the design has been a success although there have been some issues adjusting to new technologies. Overall more thought could have been given at design stage to who would manage the building's energy use and what type of BMS would best suit the building operators. The metering system has never been used by GRAHAM staff or GRAHAM FM for example. However this is more of an operational issue than a design issue.

10. What were the additional costs incurred in building a Low Carbon BREEAM Excellent Building?

Information on costs is not readily available. Items which probably incurred additional costs include: - biomass boiler and fuel hopper over a traditional oil boiler, automatic vents and controls associated with them, additional sub-metering, CO_2 and Temperature sensors, more advanced BMS, exposed concrete soffits and pillars, design of the atrium space over a traditional design, rain water harvesting system, PIR sensors on lighting. Although additional costs were probably incurred for some of the technologies listed above, savings would have been made by not installing air conditioning and comfort cooling throughout the building. In addition a number of the technologies which had an additional capital build cost will have resulted in energy and water savings especially the biomass boiler, lighting controls and rain water harvesting.

11 Key Messages for the Client

Overall the GRAHAM Headquarters building is performing well in a number of key areas however there is room for improvement particularly if GRAHAM have an aspiration to continue winning environmental awards and achieving the best practice performance achieved at design stage. A great deal of effort went into the design and construction of this building in order to achieve a low carbon, sustainable building. However this ambition and enthusiasm has to carry through to the operation of the building if design targets are to be realised. The following is a list of key recommendations for the client as a result of the BPE research: -

- **Consider implementing a company energy policy and strategy**. There are no formal arrangements for energy management at the GRAHAM HQ building and there is no energy policy. A commitment is required from senior management to devise and implement an energy strategy. A programme of monitoring and targeting could be implemented quite easily with the systems in place on site. Energy should be continuously monitored and improvements made wherever possible.
- **Allow time and resources for GRAHAM FM to play a more active role in energy management or appoint an independent energy manager.** Inefficient equipment and controls could be causing unnecessary energy usage. An energy manager will have the necessary skills and expertise required to ensure the design stage intention of a low carbon building becomes a reality. The building has a great deal of potential to be a best practice low carbon building however someone needs to take responsibility for this.
- **Repairs and improvements to the BMS and metering systems to ensure optimum control and monitoring of the building**. In particular issues with electric meters that are resulting in faulty readings requires attention. Also the site water meter requires to be repaired. Water consumption monitoring has not been able to take place as part of the BPE project as a result of this.
- **Investigate potential savings in ICT equipment.** Particularly the IT Server Room and Small Power equipment which make up over 50% of the building's electricity consumption and whose electricity demand is growing every month.
- **Using electric heaters in portacabins to heat records archive.** Consider replacing electric heaters in Portacabins with heaters that have timers and thermostats or arrange for another location for document storage.
- **Investigate out of hour's energy usage.** Lighting and Small Power meters indicate particular issues with regards to out of hours use. Investigate the possibility of having a central shut off switch to switch all lighting/small power equipment off at the end of the day or via an IT controlled shut off system.

- **Boiler optimisation programme.** Boilers are coming on at 3am every morning in the heating season. Further investigations should be carried out to ascertain if this is the optimum time considering occupants do not arrive on site until 8am. Consider reviewing the current arrangements for the boiler controls in the BMS system.

- **Small power is one of the biggest users of energy**. Recommend an energy campaign be carried out with staff to encourage switching off all unnecessary loads during and outwith office hours. Promote good housekeeping and energy efficiency incentives.

- **Investigate the possibility of introducing further energy efficiency measures and potentially renewable technology into the building**. Funding is available for energy efficiency measures and upgrades. Recommend that GRAHAM investigate funding channels to improve current efficiency as much as possible. Electricity consumption is particularly expensive and carbon intensive and renewable technologies such as PV or Wind Turbines could help to alleviate this.

Overall, the four main objectives established by GRAHAM at the beginning of their design brief for the building have been realised. A commitment to continue working towards these objectives should ensure the building builds on and improves current performance.

- *To provide a comfortable and inspiring work environment for staff.*
- *To make the building as sustainable as possible.*
- *To make it affordable.*
- *To be able to use it as a 'good practice' demonstration case study.*

Messages from the client

GRAHAM have provided the following feedback on the BPE process: -

'Undertaking the BPE study has allowed us to assess the quality of our workmanship of a building in operation, something very few contractors have the opportunity to become involved in.

We have gained an insight to soft landings and how design and in particular O&M manuals need to be translated and understood by end users and facilities managers. With funds available, we have been able to recalibrate and double check over 26 of our sub meters to allow maximum efficiency of appliances and systems, and thereby reducing energy costs and our carbon footprint. It has been a very positive experience working with designers, consultants and academia, some involved in the project and some new, to be proactive in spearheading improvements in low carbon building design, construction and end use.

We have been able to apply lessons learned to our existing clients and the PR benefits of undertaking a TSB study has no doubt impressed our existing and potential clients.

We feel we have accomplished a lot over the three years and that we have been able to make a contribution to low carbon buildings of the future. This is something we are proud to be engaged with and will encourage us to apply to similar collaborative networks for R&D projects in the construction sector.'

12 Wider Lessons

Some of the findings in this report may form useful learning for the construction and energy sectors. Wider lessons for the industry as a result of this study are as follows: -

- A building designed and constructed as a 'low carbon' or 'sustainable' building will not achieve these goals by itself. People are important and building users are key to achieving these goals. In particular how a building is managed and operated should be considered at design stages and their needs incorporated into the building wherever possible.
- Energy management is key to achieving a low carbon building. An organisation should have an energy strategy and clear goals for energy efficiency otherwise a building designed as best in class at design stages can produce mediocre results in operation.
- Design stage calculations for energy are not representative enough of buildings performance in use and do not account for factors such as out of hours usage and unregulated loads. The GRAHAM HQ building achieved an A rated EPC at design stages but only a C1 rating for their DEC. The project team were disappointed with this result even when it was explained that a C1 DEC was a relatively high rating. In part, this could be education of the industry as the two methodologies are completely different and therefore not comparable.
- There seems to be a technical expertise gap between the specifiers of BMS and controls systems and the building users who end up operating them. Design professionals need to be familiar with the end user and design systems which are easy to operate and understand.
- Reliability of sensors, metering and controls for monitoring equipment were an issue on this project and on other BPE projects. The service provided by the company who installed the BMS and metering equipment was poor and they were reluctant to come to site to fix problems (possibly because their maintenance contract did not cover the expense of such unreliable systems). This resulted in the maintenance contract being terminated and the client appointing another service provider.

Feedback for TSB on BPE Tools and Procedures

The project used TSB tools and templates to carry out the Building Performance Evaluation at GRAHAM HQ. Feedback specific to these tools and methods of BPE are as follows: -

- The BPE process produces interesting results but it is expensive and time consuming. If this is to be done regularly and on more buildings the process should be streamlined and easier for the construction industry/building user to implement

- The BUS survey was an effective way of providing a snapshot of user satisfaction and views with regards to the building. It was written for office users but may not be as effective for other types of building. This could be used again at a later date to measure changes to occupant satisfaction.

- TM22 was very time consuming to complete although some of the results provided worthwhile data which wouldn't otherwise have been picked up. The excel spreadsheet is unwieldy and has too many worksheets. Suggest if this is being developed as a software tool a more user friendly interface is designed. In addition TM22 would be easier to complete if the equipment audit was completed at design stage with the assistance of the M&E engineer. A good degree of accuracy in the equipment audit is almost impossible to achieve without the assistance of someone who knows the building intimately.