National Composites Centre

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InnovateUK Evaluator	Unknown (Contact www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Industrial	Bristol	Design and build	2011
Floor area (GIA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
8413 m^2	2	B (39) / N/A	Excellent

Purpose of evaluation

The study objectives included documenting the design intent and reviewing the building services specification, reviewing the delivery, handover and commissioning procedures, quantifying energy by end use, evaluating the as-built performance of the PV array compared to the as-designed performance, comparing the overall energy use with existing benchmarks for similar buildings, providing energy performance data on industry process loads such as autoclaves, evaluating the indoor environment during occupation, and identifying opportunities for reducing energy use. The building was tenanted.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
Yes	Yes (2013)	Partial

Estimated electricity use: 298 kWh/m² per annum (including 7.96 kWh/m² per annum photovoltaic contribution); thermal (gas): 185.2 kWh/m² per annum. Note the report does not explicitly state figures for power and thermal consumption. A significant source of wasted heat was identified. The research uncovered significant problems with commissioning of energy submeters which impeded efforts to monitor energy use. Around 10% of annual electricity consumption was not connected to the BMS. Analysis of energy generation data revealed that the performance of the 138 kWp photovoltaic array exceeded expectations. Overall the electricity demand at the NCC was significantly higher than benchmarks relevant to the building type.

Occupant survey (2012)	**Survey sample**	**Response rate**
BUS, paper-based	121 of 156	76%

Two BUS surveys were performed. A second survey was conducted only a year after the first survey (note: this is not recommended practice due to methodological issues and biases). Occupant satisfaction was generally high in comparison to the BUS methodology non-domestic benchmark set. The occupants particularly liked the design of the building and the collaborative atmosphere it generated. Thematic analysis was performed by the BPE team who chose common themes from the BUS data and ranked them.

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About this document:

This report, together with any associated files and appendices, has been submitted by the lead organisation named on the cover page under contract from the Technology Strategy Board as part of the Building Performance Evaluation (BPE) competition. Any views or opinions expressed by the organisation or any individual within this report are the views and opinions of that organisation or individual and do not necessarily reflect the views or opinions of the Technology Strategy Board.

This report template has been used by BPE teams to draw together the findings of the entire BPE process and to record findings and conclusions, as specified in the Building Performance Evaluation - Guidance for Project Execution (for domestic buildings) and the Building Performance Evaluation - Technical Guidance (for non-domestic buildings). It was designed to assist in prompting the project team to cover certain minimum specific aspects of the reporting process. Where further details were recorded in other reports it was expected these would be referred to in this document and included as appendices.

The reader should note that to in order to avoid issues relating to privacy and commercial sensitivity, some appendix documents are excluded from this public report.

Contents

1 Introduction and overview

1.1 Introduction

This report explains the findings of the Building Performance Evaluation (BPE) of the National Composites Centre (NCC), a new two-storey, state-of-the-art industrial research centre. The NCC provides facilities to develop new technologies for the design and manufacture of high-quality composite products used in various applications such as aerospace engineering. The BPE was led by AECOM, with support on the Building Use Studies (BUS) Methodology from the University of Reading, and has been funded by the Technology Strategy Board (TSB) under their BPE programme. The two year study began in May 2012 and was completed in April 2014.

The BPE has found that overall the NCC is successful in delivering its primary function of providing facilities to bring together both the design and manufacturing processes for industrial composite materials. Occupant satisfaction is generally high in comparison to the Building Use Studies (BUS) Methodology non-domestic benchmark set and the occupants particularly like the design of the new building and the collaborative atmosphere in generates.

The BPE did, however, discover that the internal conditions for the three designated clean rooms were not being maintained over weekends, resulting in possible consequences for the processes conducted within them. Additionally, it uncovered significant problems with commissioning of energy submeters (with some recording incorrect timestamps and some simply not connected to the building management system, BMS), which impedes efforts to monitor energy use. Although it was not specified to do this, long term energy monitoring is hindered with a hardware limitation affecting the BMS' ability to store large amounts of data. Furthermore, when any of the installed energy submeters records a cumulative total over 1,000,000 units, the least significant digit is 'lost' in the BMS record, leading to an erroneously recorded value a factor of 10 lower. This may be the case in other buildings with identical submeters and BMS installed.

Analysis of energy generation data has shown that while the performance of 138 kWp photovoltaic (PV) array is exceeding design expectations, overall the electricity demand at the NCC is significantly higher than published industry benchmarks in part due to high electrical industrial process loads, but also due to high energy consumption for certain end uses within the scope of Building Regulations. (However, the suitability of those benchmarks for comparison with the NCC building is uncertain.) A significant source of wasted heat was identified in that heating is supplied to main workshop (during the heating season of October to April inclusive) outside operational hours from Monday to Friday (i.e. overnight) and during holiday periods, such as Christmas. Without the BPE, it is highly unlikely that many of these issues would have been identified and acted upon.

Specifically, the study objectives were to:

- document the design intent and review the building services specification for the NCC,
- review the delivery and handover procedure, including the commissioning stage, as well as the fit-out of the major equipment in the workshop,
- quantify energy by end use over an extended period of time,
- produce a 'CIBSE TM-22 model' of energy consumption,
- evaluate the as-built performance of the PV array and compare this to the as-designed performance,
- compare the overall energy use with existing benchmarks for similar buildings,
- survey the NCC staff about their overall satisfaction with the new building,
- provide energy performance data on industry process loads, such as autoclaves,
- identify opportunities for how energy use could be reduced,
- evaluate the indoor environment during occupation, and
- regularly feedback performance data to the building occupants and the facilities management (FM) team.

The later Sections describe the processes and analysis undertaken to successfully complete the above objectives.

1.2 Project Background

The NCC is situated at the Bristol and Bath Science Park (referred to as SPark) and has a total gross building area of approximately 8,500 m^2. Development of the building was led by the University of Bristol (UoB), who are the owner, in partnership with industry and public-sector investment. A rapid build programme of 10 months led to the building being handed over in June 2011 and occupied in November 2011. The building comprises of a large double-height workshop space with several specialised laboratory spaces adjacent to it. There are three separate open plan offices on the 1st floor, with individual kitchens and associated meeting rooms and circulation areas. A number of commercial sector clients are now tenants in the building.

Figure 1.1. National Composites Centre - general site plan (left) and external view (right).

1.3 Key findings

The BPE team considers the following to be the overall key findings for the project:

- A low carbon strategy for the building (but excluding industrial process loads) with good levels of insulation, mixed mode ventilation, limited mechanical cooling, good daylight provision, low energy electric lighting, with appropriate automated building services controls and a 138 kWp PV array forms the basis of the design as built.
- In practice, the large industrial process loads result in substantial electrical and additional gas consumption. Moreover, in part due to these loads, the NCC currently uses about 4.5 times more energy than the Energy Performance Certificate (EPC) indicates. An EPC is not required to take into account such process loads.
- The use of NCC is dynamic, and there have been several alterations to the arrangement of space and services since completion (particularly within the Main Workshop space) to accommodate different functions. These will have an associated impact on building operation and energy consumption, but there is no management system in place to ensure that energy end uses are separately submetered for new or adjusted functions.
- Benchmarking of NCC shows that while its energy consumption for fossil fuel is comparable to other (possibly) relevant benchmark datasets, electricity consumption is much greater. This is indicative of the high electricity consumption for industrial processes. It was not possible to separately consider the industrial process loads as the majority (although submetered) are not connected to the BMS.
- Specific technical concerns encountered during the BPE project included:

  - An issue was discovered with BMS generated energy reports, which erroneously omit a digit when submeters reach 1,000,000 units, hindering long term energy management in this and possibly other buildings.

- A large proportion of the electrical submeters were commissioned without time stamps being correctly set, causing significant difficulties for monitoring and targeting energy reductions from their associated systems.

- Around 10% of annual electricity consumption is not connected to the BMS including the office areas and, importantly, most of the industrial process loads.

- Analysis of energy use has revealed possible wasted electricity with the external lighting being left on for longer periods than necessary and small power appliances in the office areas being left on out of hours.

- The PV array is generating approximately 133,000 kWh_e per year, 3% more electricity than the design estimates.

- Space heating and domestic hot water (DHW) is being supplied on certain occasions when the building is unoccupied.

- The large Main Workshop area is being maintained at a relatively high temperature set point causing excessive energy use.

- Internal conditions to clean rooms are not being maintained over weekends, as the AHUs to these areas are automatically turning off. This presents contamination, temperature and humidity related risks for any processes being carried out in these areas.

- Recommended areas to be targeted to reduce energy use have been identified, along with estimates made of approximate payback periods. Most of the payback periods are estimated to be less than one year (see Section 8).
- Two separate occupant satisfaction surveys following the BUS Methodology were carried out roughly one year apart. In comparison to the BUS Methodology benchmark dataset, NCC performs reasonably, scoring around average against the dataset for the majority of assessed criteria. In terms of thermal comfort the occupants seem to be largely satisfied with how the building and its services are operating. However, there are indications from the second survey of the air being perceived by occupants to be too hot in the summer. (The AHUs for the office spaces provide heating in winter, but do not supply active cooling in summer: Although the design allows the use of thermal mass and natural night ventilation for passive cooling in summer, this was disabled after the first survey due to squirrels entering the building through the automatic windows.) Interestingly, for an open plan office environment, the NCC performs particularly well with respect to noise. The occupants also like the collaborative environment and that desk based research can take place close to the workshop areas.
- The NCC has proved to be a commercial success and therefore the University of Bristol (UoB) decided to procure additional land at the SPark for a second NCC building (NCC2). The intention is for the new building to be directly adjacent to the original NCC and similar in size and use. NCC2 is scheduled for completion in April 2014 and will have an access corridor into the NCC. NCC2 is being designed by an almost identical team as NCC, providing a rare opportunity to directly feedback information from the BPE study into the design of a building with the same use and end client. Therefore, the BPE study team have attended NCC2 design stage meetings and provided briefing notes on findings from the occupant satisfaction surveys, as well as on the metering and commissioning review for NCC.

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

2.1 Design intent

From the outset, the NCC project had a low carbon design intent for the building excluding the industrial process loads. This was mainly driven by the standard client requirement that any new building must obtain BREEAM Excellent accreditation, which it achieved post completion when assessed under the BREEAM: Bespoke scheme. Under the BREEAM accreditation scheme, reduction of energy-related CO_2 emissions forms a significant aspect of the overall rating achieved, although there are a number of other unrelated aspects that also need to be addressed. Relating specifically to energy use and related CO_2 emissions, the NCC was constructed in accordance with the Building Regulations Approved Document L2A 2006 (ODPM, 2005). Note that neither BREEAM nor the Building Regulations assess the industrial processes taking place within the building.

In terms of the indoor environment, the design team referred to CIBSE Guidance documents. Client clarification about the requirements for the indoor environment was sought for any areas with specialist uses that were not covered by CIBSE guidance.

The orientation of the building minimises solar heat gains in the office spaces, which are situated on the north and east sides of the building, and the large south-facing roof optimises the generation of the solar PV panels, which are mounted on north-lights that provide good levels of daylight directly into the double height workshop space.

The building construction is a solid web steel portal frame structure, clad with an encapsulated, insulated panel system. The roof for the office spaces has a composite metal deck system and cast concrete, introducing thermal mass as part of the summer night-time ventilation cooling strategy. Table 2.1 summarises the design U-values for the various opaque construction elements. Table 2.2 summarises the design U-values for the glazing.

The building was designed to have reasonable airtightness with air permeability as defined under Part L of the Building Regulations required to be 6 $m^3/(h.m^2)$ @ 50 Pa. An airtightness test was carried out by the contractor on 14th May 2011 and the building achieved a result of 4 $m^3/(h.m^2)$ @ 50 Pa (ATTMA, 2011), signifying a reasonably good level obtained in practice.

Table 2.1: Summary of design thermal properties for opaque construction elements.

Construction Element	Summary of Construction Element	Area Weighted Average Thermal Transmittance (U-Value), W/m2K
External Wall	*Ext – Eurobond Panel Extra* Steel, Rockspan Extra Insulation, Steel	0.27
Internal Wall	Int – Plasterboard Stud Partition Plasterboard, Cavity, Insulation, Cavity, Plasterboard	-
Internal Floor / Ceiling	*Ceiling – Corus Comflor 80* Metal Deck, Cast Concrete *Ceiling – Corus Comflor 80 with Metal Panel Ceiling* Steel Panel, Cavity, Metal Deck, Cast Concrete *Ceiling – Corus Comflor 80 with Plasterboard Ceiling* Steel Panel, Cavity, Metal Deck, Cast Concrete	- - -
Roof	*Roof – Kingspan Thermataper & Corus Comflor 80* Metal Deck, Cast Concrete, Kingspan Thermataper Insulation, Waterproofing Layer *Roof – Kingspan Thermataper with Metal Panel Ceiling* Steel Panel, Cavity, Metal Deck, Cast Concrete, Kingspan Thermataper Insulation, Waterproofing Layer *Roof – Kingspan Thermataper with Plasterboard Ceiling* Plasterboard, Cavity, Metal Deck, Cast Concrete, Kingspan Thermataper Insulation, Waterproofing Layer *Roof – Kingspan Thermataper & Steel Frame* Metal Deck, Kingspan Thermataper Insulation, Waterproofing Layer *Roof – Kalzip Standing Seam Roof* *Aluminium, Rockwall Insulation, Steel*	0.16 0.16 0.15 0.16 0.20
Ground Floor	*Floor – Concrete Slab with Edge Insulation* Cast Concrete, Vertical Edge Insulation *Exp Floor – Corus Comflor 80 with External Insulation* Steel, Rockspan Extra Insulation, Metal Deck, Cast Concrete	0.19 0.27
Door	*Door – Large Metal Door* *Door – Pedestrian Metal Door*	1.5 2.2

Table 2.2: Summary of assumed thermal and other properties for glazing.

Glazing Reference	Thermal Transmittance (U-Value), W/m2K	Solar Transmittance (G-Value) [BS EN 410]	Light Transmittance
Planitherm Total 6/16/6	1.7	0.61	0.77
Planibel Energy NT 72/44	1.7	0.44	0.73

2.2 Design process

The NCC building is the first of its kind, and brings together diverse industrial processes under one roof for the first time. During the design process, this meant that there was little previous experience or case studies to which the team could refer. Although the driver to obtain BREEAM Excellent emphasised sustainability, the main influencing factor on the NCC's design was the space requirements for the various industrial processes expected to be carried out at the site. As the intention for the NCC was to rent out facilities to different industry tenants, the client was unsure of the full range of processes that would need to be accommodated and their associated spatial requirements. This led to a relatively broad brief from the client and required the design team to ensure a degree of flexibility in the design. The design team often worked on the assumption that the largest component that would be created at the NCC would be a blade for a wind turbine and based many spatial requirements for the main workshop area on a standard blade's dimensions.

The delivery period from conception to handover for the NCC was only 18 months due to funding restrictions. This very short process meant that there was little time to evaluate alternative design ideas against the brief. Discussions with members of the building services design team indicated that this pressure may have actually been beneficial, as it led to an engaged client and design team and generated focused decision making to respond to the brief.

2.3 Building overview

As a state of the art research facility, the NCC provides a mixture of workshop, laboratory, and open plan office spaces, as well as conference and meeting room facilities. Table 2.3 shows the different areas of the building and their uses. There are no central catering facilities; instead each open plan office has a small kitchen attached to it.

In total, there are around 200 employees working at the building, the majority of whom (approximately 160) are based in the three open plan office areas. There are around 20 workshop technicians who work in the main workshop area and specialised laboratory spaces. The NCC is open from around 07:00 to 19:00 Monday to Friday with only occasional weekend operation. The building is designed for a total occupancy of 606 based on core operation hours of 37.5 hours per week.

The office areas have mixed mode ventilation with heating provided using air handling units (AHUs), but without mechanical cooling. Outside of the heating season, temperature and indoor air quality control are achieved through automated windows operated by a building management system (BMS) based on information from air temperature and carbon dioxide (CO_2) sensors respectively. The automated windows are integral to the night time cooling strategy employed during warmer months for temperature control.

Table 2.3: NCC area breakdown.

Ground Floor	Gross Internal Area (m^2)
General Workshop area	3382
Cellular Workshop area	842
Plant areas	324
Office meeting rooms	302
Amenity, WCs etc	120
Clean Room areas	869
Circulation areas	320
First Floor	
Workshop Storage Area	202
Circulation Area	258
Plant Areas	401
Office Areas	1393
Total area (m^2)	**8413**

The main double height workshop area has nine specialised laboratories leading directly from it, including three which are designed as Class 8 Clean Rooms (EN ISO 14644) (ATL/AFP Rapid Deposition [1], Clean Room, and Ply Cutter). This classification means that these spaces need to be carefully controlled for pressure, temperature and humidity. This is to prevent any contaminants entering the areas and to provide stable, known environmental conditions. As Class 8 spaces, the rooms are designed to achieve a particle count of 832,000 @ 1 micron per m^3 and 29,300 @ 5 micron per m^3 (EN ISO 14644).

To maintain the requisite internal conditions, the Class 8 clean rooms have separate AHUs that are required to run 24 hours per day (including over the weekend) providing pressure, temperature and humidity control. These specialised laboratories have no external windows, but do have internal windows facing onto the main workshop area to allow natural light. The main double height workshop space itself uses displacement ventilation with air being supplied at a low level and extracted at high level. The AHU to the main workshop is used for heating, but supplies no active cooling. It also has a large shutter door for deliveries with no air lock or interlock feature to prevent the ventilation running when open. The remaining specialised laboratory spaces use independent variable refrigerant volume (VRV) air conditioning systems, each with separate external air cooled condensing units.

[1] ATL refers to *Automated Tape Laying*. AFP refers to *Automated Fibre Replacement*. Both are processes used in the creation of composite materials.

A key feature of the low carbon design is a large south facing 138 kWp PV array mounted on the roof north lights. The NCC also features a 38,000 litre rain water harvesting system to supply water for flushing toilets.

2.4 Transport links

The NCC is situated in the Bristol & Bath Science Park (SPark) near Emersons Green, off junction 19 of the M4. The SPark opened in Summer 2011 and consequently public transport links are not yet well developed. There are only infrequent buses to and from Bristol and Bath. The nearest train station is Bristol Parkway, which is 6 miles away by road.

There is a large parking area to the rear of the building for 155 cars, with eight accessible parking bays and eight visitor parking spaces at the front of the building. There are facilities for cyclists with sheltered storage and showers.

2.5 Construction process

Development of the building was led by the UoB, who are the owner, in partnership with industry and public-sector investment comprised of large grants from the Department of Business, Innovation and Skills managed by the Technology Strategy Board, the European Regional Development Fund (ERDF), and from the South West Regional Development Agency (SWRDA). The NCC was procured through a design and build contract with the client's original design team novated to the Main Contractor. Construction of the NCC began in early autumn 2010 and a rapid build programme led to practical completion in June 2011.

Although the commissioning and handover process contained some aspects that are fundamental to BSRIA's Soft Landings framework, the NCC did not formally follow the Soft Landings process and was not required to do so. The UoB appointed their own independent commissioning contractor who in general they engage to oversee commissioning on any new university building. The UoB typically continue the commissioning contractor's appointment into the first year of operation to ensure that the building is seasonally commissioned and the building services are operating as specified. In the first year of occupation the commissioning engineer was on site for 2 to 3 days per week, which was successful in identifying issues with the building's performance, resolving some metering issues on the BMS and ensuring that ad hoc training was provided for the Facilities Manager (FM).

Although general commissioning management was carried out by the independent commissioning contractor, the practical water and ventilation commissioning, as well as the validation of the Clean Rooms, was completed by a commissioning specialist. The PV array and BMS were also installed and commissioned by separate specialist contractors. All commissioning was carried out in accordance with the CIBSE Codes shown in Table 2.4.

Table 2.4: CIBSE codes used for commissioning.

CIBSE Commissioning Code
Code M: Commissioning management
Code A: Air distribution systems
Code B: Boilers
Code C: Automatic controls
Code L: Lighting
Code R: Refrigerating systems
Code W: Water distribution systems

2.6 Discussion and key findings

The design of the building appears to be generally sound and most of the key principles relevant to a low carbon building were incorporated. These principles include a very well insulated and airtight building fabric, energy efficient building services with appropriate controls, the application of passive design to reduce the use of or to eliminate the need for energy using systems (such as good daylight design reducing the use of electric lighting), and the integration of a large PV array for electrical generation.

Although integral aspects of BSRIA's Soft Landings Framework were included in the project (particularly during the handover and aftercare period), it was not a formal requirement during the process and no specific performance targets were set.

The relatively fast delivery time of only 18 months led to a fully engaged client and design team. However, it has meant that some design and construction decisions were made in a shorter time period than normal.

3 Review of building services and energy systems.

3.1 M&E Specification

A particular element of this BPE study has been to review the Mechanical and Electrical (M&E) Specification (AECOM, 2010) and to suggest, if necessary, changes that could be made to such specifications to improve the performance of similar buildings. In fact, the importance of this element increased during the BPE study as the client procured the NCC2 building. This allowed potential improvements to be identified and fed back directly to the NCC2 Building Services Design team.

The following sections of the NCC M&E Specification have been reviewed:

- Lighting systems
- HVAC systems
- Renewable systems
- Automatic windows
- BMS and controls
- Metering and monitoring

3.1.1 Lighting systems

3.1.1.1 Main workshop

The design of the double height workshop allows daylight through 11 rows of north lights in the roof. This would reduce the need to use electric lighting (through daylight dimming) provided by 105 high level suspended 'T5' fluorescent fittings (320 W per fitting) and 16 low level (80 W per fitting), giving an installed load of around 35 kW. The workshop space was designed to achieve a 2% average daylight factor to minimise lamp burnout and reduce maintenance costs. The lights can be controlled automatically through the central lighting control system and there is a single manual override light switch located at the entrance to the workshop from the main reception area (Figure 3.1).

Figure 3.1: Manual lighting control for the workshop area.

3.1.1.2 Specialised laboratory spaces

For the various specialised laboratory spaces off the main workshop area, the initial design lighting strategy was to have electric lighting controlled by PIR sensors. The intention was to have lights automatically turn off if no occupancy was detected for 20 minutes. However, later in the design process this was changed to a manually operated system as it was realised that these areas would only be lightly occupied (one or two technicians) with tasks regularly involving hazardous materials and equipment. There was a clear risk that the Passive Infra-Red (PIR) sensor would not detect the occupants if they remained relatively still while working and incorrectly turn the lights off.

3.1.1.3 Lighting master controller

The M&E Specification indicates that *'…a central control computer, screen and software located in the ground floor data room to allow the client to control as minimum via windows based screen presentations layouts of all the light fittings with floor plans in the background.'* This should allow changes to:

- Date / time settings
- Illuminance (Lux) levels
- Daylight settings
- Rate of dimming (where dimming control gear installed)
- Run on time settings for occupancy sensors
- Photocell sensitivity and run on time
- Override internal on an area by area basis
- Override external on an area by area basis (allow at least 5 areas)

The BPE team confirmed that a software package, Delmatic lighting management (Figure 3.2), was installed on the FM's dedicated PC, which allows the FM to adjust the above criteria.

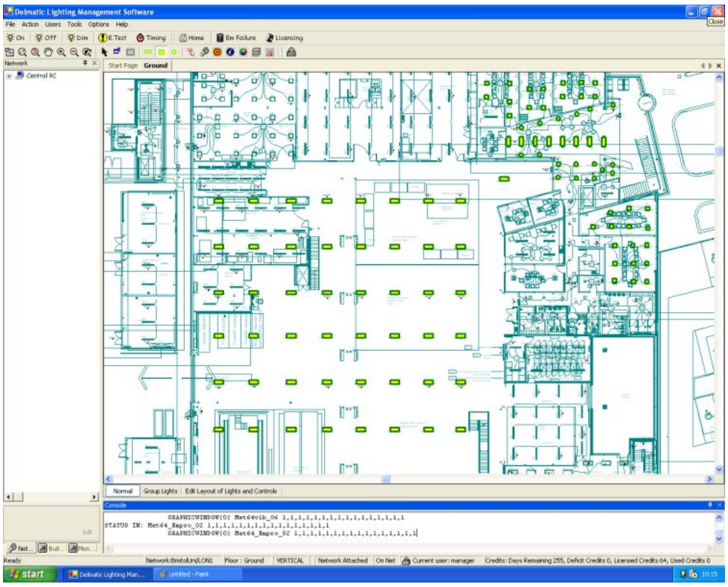


Figure 3.2: Screen shot of lighting master controller software package.

3.1.1.4 Offices and circulation spaces

In all other spaces (offices, meeting rooms, circulation spaces, and toilets), PIR sensors were specified to automatically turn lights on and then off after an unoccupied period of 20 minutes. There is also daylight dimming installed. There are large external windows in all office spaces, as well as internal windows viewing into the workshop area which allow for high levels of natural light. The three 1st floor office spaces were located to allow ingress of natural of light while minimising solar gain and glare: Tenant and North offices are situated on the north side of the building, while the East office has windows on the east facade.

3.1.2 HVAC systems

The NCC utilises a range of HVAC strategies for different parts of the building to suit the functions of specific spaces. Figure 3.3 shows the ground floor and first floor layouts of the NCC, while Table 3.1 shows the general ventilation strategies for the different areas.

The double height Main Workshop uses displacement ventilation with air supplied at a low level and extract at high. The Ply Cutter, Clean Room, and ATL/AFP Rapid deposition laboratories all have their own separate AHUs for ventilation. Environmental control is provided by room mounted sensors for humidity and temperature and a return air sensor for CO_2. The North and Tenant offices are both served by one AHU (which is located on the roof of the Plant room along with the split units for the various laboratory spaces). The East office has its own separate AHU which is located on the main workshop roof. Additional independent VRV air conditioning systems each with separate external air cooled condensing units have been provided for the following areas:

- East Meeting rooms
- North meeting rooms
- Uninterruptible Power Supply (UPS) room
- Comms Room
- Various laboratory spaces

Originally there were 6 separate AHUs at the NCC. When a new Clean Room was created at the south east corner of the Main Workshop, another AHU was added. Table 3.2 lists the AHUs, their electrical ratings, and which areas they serve.

Table 3.1: Breakdown of areas and ventilation strategies.

Area type	Untreated (%)	Naturally ventilated (%)	Mechanically ventilated (%)	Mixed mode (%)	Full air conditioning with humidity control (%)	Gross internal area (m^2)
Ground Floor						
Main Workshop	0	0	100	0	0	3382
Specialised laboratories	0	0	60	0	40	842
Plant rooms	100	0	0	0	0	324
Meeting rooms	0	0	100	0	0	302
Amenity, WCs, etc	0	0	100	0	0	120
Clean rooms	0	0	100	0	0	869
Circulation	0	50	50	0	0	320
First Floor						
Workshop Storage	0	0	100	0	0	202
Circulation	10	0	90	0	0	258
Plant rooms	100	0	0	0	0	401
Offices	0	0	0	100	0	1393
Total area (m^2)						**8413**

3.1.2.1 Heating

There are five 110kW Potterton Sirius WH100 Boilers gas boilers located in the Boiler room that supply LTHW heating for the entire building. The boilers were sized to meet a theoretical peak heat load (i.e. on a Monday morning, -4°C external temperature, with no occupancy) of around 440kW. The boilers are 4 duty and 1 standby with the lead boiler cycled by the BMS depending on hours run. There is provision for an additional boiler should it be required in future to meet additional load from additional air handling plant or process equipment.

Figure 3.3: Annotated ground floor (left) and first floor (right) layouts of NCC with main workshop and other laboratory spaces and open plan offices highlighted.

Table 3.2: List of AHUs at the NCC.

AHU	Supply fan rating (kW)	Extract fan rating (kW)	Area served	Heating & Cooling?
North office	7.5	5.5	North and Tenant offices	Heating
East office	7.5	5.5	East office	Heating
Main workshop	45	30	Main workshop	Heating
Ply Cutter	2.2	4	Ply Cutter	Heating & cooling
Clean Room	15	18.5	Clean Room	Heating & cooling
Rapid Depo	11	18.5	ATL/AFP Rapid Deposition	Heating & cooling
New Clean Room	Unknown	Unknown	New Clean Room	Heating & cooling

Heating setpoint temperatures for all spaces are controlled through the BMS. There are no local heating controls.

3.1.2.2 Domestic Hot Water (DHW)

Domestic hot water (DHW) is provided to the building via two 650 litre Lochinvar SHW60 natural gas-fired condensing direct domestic hot water heaters located in the Water Tank Room. DHW is used for showers and washroom taps, but not for any industrial processes.

3.1.3 Renewable generation systems

There is a 138 kWp PV roof mounted array at the NCC (Figure 3.4). Details of the PV performance can be found in Section 6.4.6.

Figure 3.4: Photovoltaic array mounted on the roof of the NCC.

3.1.4 BMS and controls

The NCC has a Trend BMS. There is a dedicated PC for the BMS located in the Facilities Management office. The FM has the ability to remotely access the BMS from offsite.

The M&E Specification refers to the BMS as a Building Energy Management System (BEMS). To obtain the BREEAM credit Ene 3 the M&E Specification states that: *'The BEMS shall be set to provide trend logs of all temperatures measured over 14 day cycles.'* and *'The BEMS shall monitor energy/water sub meters for the following systems as a minimum:*

- *Heat from boilers*
- *Incoming gas supply*
- *Gas supply to the heating boilers*
- *Gas supply to the hot water heaters*
- *Incoming waters supply at site boundary*
- *Incoming water supply (in building)*
- *Water supply to building*
- *Cooling Plant*
- *Fans (major only)*
- *Lighting*
- *Small power*

- *Incoming electrical supply*
- *PV electrical supply'*

Investigation by the BPE team revealed that the installed BMS does store data logs, but for only 10 days before they are overwritten. Also, it monitors the submeters for the above systems, apart from the PV electrical supply. Instead the PV generation is separately monitored by the specialist installers through their own data loggers. While this arrangement may satisfy the Building Regulations requirement to separately submeter all renewable technologies, it impedes successful implementation of the overall metering strategy, as certain other meters at the NCC can register negative readings as a result.

3.1.5 Metering and monitoring

The NCC is equipped with extensive submetering, with 74 electrical, 3 gas, 7 water meters. Full metering hierarchies can be found in Appendix 10.2. The majority of end uses are separately submetered, satisfying the M&E Specification, which states that building systems should be provided with energy meters to ensure at least 90% of the estimated energy consumption of each fuel can be assigned to the various end uses in the building.

The electrical meters are manufactured by Schneider and are connected to the Trend BMS through ModBus. The Trend BMS is intended to act as the energy monitoring system at the NCC and its installation is used to satisfy BREEAM credit Ene 3. However, there are issues with the length of time energy reports are stored by the BMS as well as the potential of data loss (see Section 7.2).

3.2 Process loads

As an industrial research facility, a large proportion of the NCC's energy consumption is related to industrial process loads. Although many of these are submetered, there are many instances where these submeters have not been properly connected to the BMS, so there were no 30-minute data available for them during the course of the BPE study. This is a general building performance monitoring issue and a missed opportunity for the BPE study, as one of the project objectives was specifically to provide feedback on energy performance data about industrial process loads.

In terms of energy consumption, the most significant process loads at the NCC are likely to be the autoclaves. Autoclaves are pieces of industrial equipment that are used in the manufacture of high performance composite materials. Autoclaves apply heat and pressure to materials to reduce resin voids leading to lightweight and strong composite materials. This process is often referred to as 'curing' the material and can take many hours (typically between 10 and 12) to achieve.

Figure 3.5: The large autoclave (Autoclave 1).

There are two autoclaves at the NCC; one large (224 kW) and one small (16 kW). Somewhat confusingly, these are labelled ‘Autoclave1’ (Figure 3.5) and ‘Autoclave’ respectively on the BMS and other systems at the NCC. The same convention has been adopted here. Both use a combination of natural gas and electricity to achieve the required thermal and pressure conditions. Autoclave1 also uses an inert nitrogen atmosphere that reduces the risk of fire occurring when superheating composites under high pressure.

Initially, the BPE team identified the autoclaves and their associated appliances as areas of potential energy savings, because they represent major energy loads at the NCC. In fact, combined they represent around 34% of the NCC’s annual electricity and 6% of its annual gas consumption. However, after investigation it became clear that the operational processes of both autoclaves are largely computer controlled and there is no potential for energy to be wasted through inappropriate operation by the building occupants. The NCC also has a plan in place to improve the efficiency of the gas burners for Autoclave1.

3.3 Rain water harvesting

The building employs rain water harvesting for the flushing of toilets. Water is collected from the roof where it is directed via pipes directly through the Tenant office to a 38,000 litre tank situated in the basement. Installation of the tank required digging out bedrock with significant cost implications for the project. Although the NCC was awarded BREEAM credits for the inclusion of this technology, there were no targets set for amount of water that rain water harvesting should save.

3.4 Discussion and key findings

This section has briefly reviewed the building services and other energy systems at NCC, which are comprised of:

- Electric lighting - For the main workshop and office areas, the design follows good practice with efficient lamps and a control strategy that responds to available daylight and actual occupancy. The main workshop has a high installed load with manual control; although this is straightforward to operate, there would be an increased possibility of unnecessary use with a high energy penalty.

- Heating - Heat is generated by five gas-fired condensing boilers. Heating periods and temperature are operated by the BMS. It is therefore important that the FM operates the system proactively to make sure that heating is not supplied at inappropriate times, i.e. when the building will be unoccupied, or left at inappropriate temperature setpoints.

- Cooling - This is only provided to meeting rooms and the specialised laboratory spaces where the conditions need to be carefully controlled.

- Ventilation - The natural ventilation approach used for office spaces is generally suitable for its intended purpose. However, the lack of feedback to occupants about the indoor air quality control may lead to them not understanding why the windows are operating.

- Process loads - Many of these are connected to submeters, but these have not been properly connected to the BMS, hindering detailed energy monitoring. The two autoclaves account for around 34% of the annual electricity consumption.

Key findings of this review of the building services and other energy systems are that:

- In general, there are properly considered features of the building and services design (excluding the industrial processes) that support the low energy and carbon intent with good levels of insulation, mixed mode ventilation, little installed active cooling, good daylight provision and low energy electric lighting, with appropriate automated building services controls and a large capacity PV array.

- The large industrial process loads on site would be expected to result in significant energy use. At the design stage, the characteristics of the process loads were not well defined and their energy consumption was not a key driver. Moreover, these loads would not be expected to closely follow occupancy patterns, as many processes may need to operate intermittently or over extended periods of time.

- The use of the NCC building is highly dynamic, including the industrial processes taking place, so changes to the spaces for different functions will have an associated impact on performance and energy consumption.

An analysis is presented in Section 6 to indicate whether the building services are actually operating as intended.

4 Occupant survey, interviews and other feedback

4.1 Introduction

An important aspect of the BPE study is to capture the experiences and opinions of the building occupants. Information of this nature provides context to the analysis of the building services and is essential in determining whether the building's performance is meeting the needs of the occupants. To achieve this, occupant satisfaction surveys following the Building Use Studies (BUS) Methodology, as described in TSB guidance notes (TSB, 2011), were conducted and informal interviews were carried out with key stakeholders.

Over the course of the BPE study, two building occupant surveys were carried out. The first of these followed the complete BUS Methodology. The purpose of the BUS Methodology is to collect and analyse the experiences of the occupants (with particular emphasis on thermal comfort) which can highlight potential problems with the building's performance. Although it was a project requirement to complete only one BUS Methodology survey, the BPE team carried out a second roughly a year after the first to determine whether occupant satisfaction had changed over this period.

The BPE team made regular visits to the NCC at approximately quarterly intervals for the full project duration. While the main purpose was to download data for temporary electricity monitors, informal feedback received from occupants on these visits has been recorded throughout the project. Noteworthy comments received in this way have been included within Section 4.5.

4.2 Building Use Studies

The two BUS Methodology surveys followed the same general procedure. Emails were sent to all NCC employees a week before, and a day before each survey was to be carried out, explaining the purpose of the survey and instructions for its completion. The standard BUS Methodology questionnaire was used with an additional question to allow the BPE team to pinpoint in which part of the building the respondent typically worked. As a result respondents were split into the following groups:

- East Office
- North Office
- Tenant Office
- Workshop / Lab
- Other

On the day of each survey, the BPE team arrived at the NCC at 07:30 and distributed paper based surveys to employees as they entered the building at the two main entrances:

- Main visitor and staff entrance and reception area (East)
- Staff entrance close to car park and cycle storage (West)

When handed the survey, participants were reminded it would take about 10 minutes to fill out and that, once completed, they should be placed in drop boxes situated at the two entrances or they would be collected from their desk at 15:30.

At around 10:00 the surveyors carried out a walk around of the office and workshop areas to distribute questionnaires to any employees who had been missed and to carry out a rough employee head count. Walk arounds were carried out in the afternoon to encourage participation and collect any completed surveys. A final collection was conducted at around 15:30.

4.2.1 Interpreting results

As part of the TSB funded BPE, results from the first BUS Methodology survey were analysed to produce to two separate reports: 'Data Tables' (see Appendix 10.1.1, which includes the quantitative analysis) and 'Comments' (see Appendix 10.1.2, which lists all the written comments from the survey in alphabetical order). The analysis displays the qualitative results graphically in two different forms: a slider bar and a chart. The interpretation of each of these are illustrated in Figures 4.1 and 4.2.

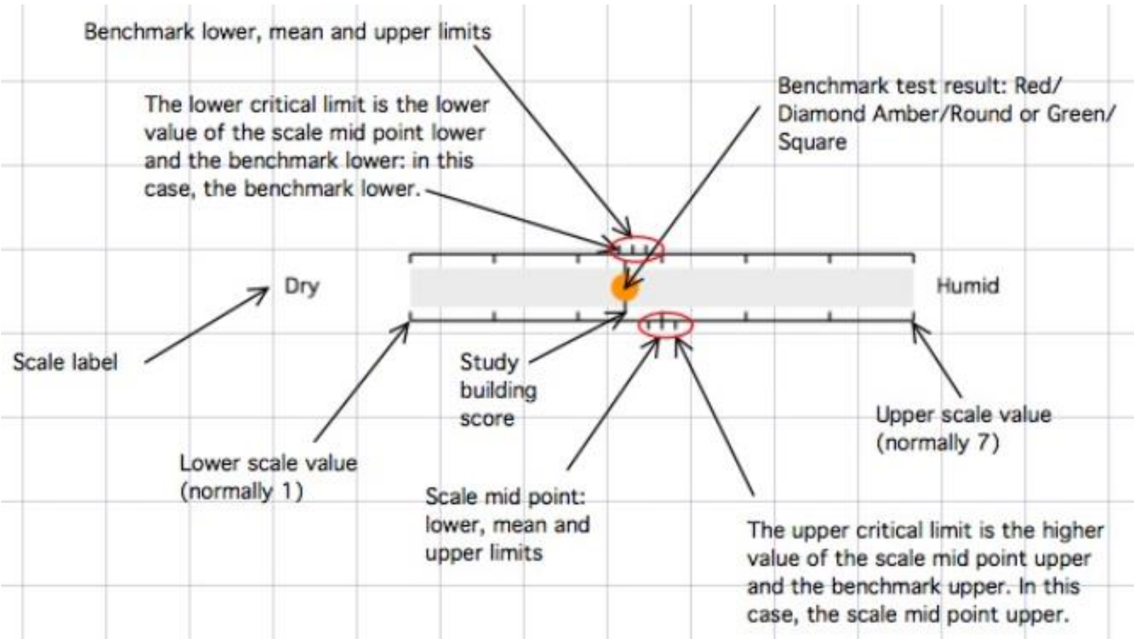


Figure 4.1: Diagram indicating how BUS Methodology slider bar should be interpreted.

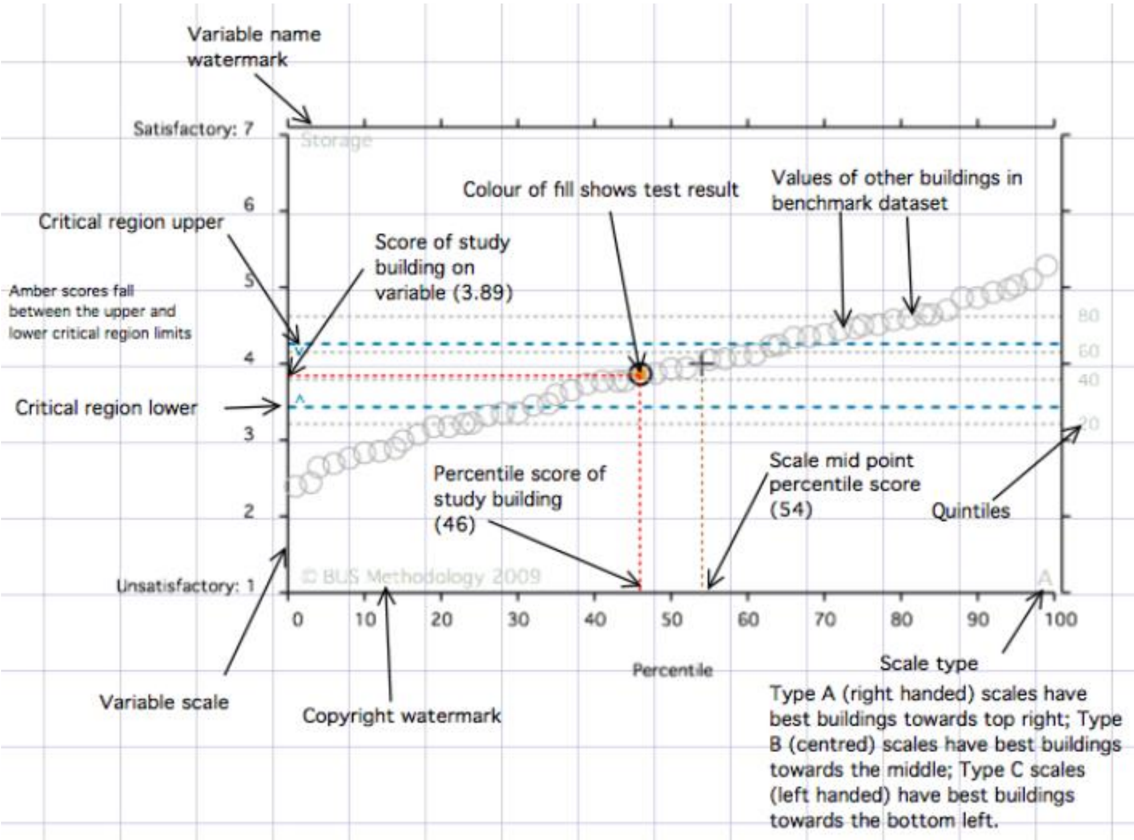


Figure 4.2: Diagram indicating how BUS Methodology chart should be interpreted.

4.3 BUS Methodology Survey 1

The first BUS Methodology survey (BUS 1) was carried out on Tuesday 20th November 2012 by the BPE team. The weather on the day was wet and rainy with full clouds. The temperature was approximately 11°C, with low outdoor light levels due to dense cloud. The surveyors observed that due to the heavy rain, there was considerable noise from the rainwater collection pipes which run through the Tenant office. At the end of the day, 156 surveys had been handed out with 121 surveys returned, giving a response rate of 76%.

Observation in the main reception entrance (East):

- Automatic double doors (airlock) were overridden by reception staff to keep them fully open immediately upon their arrival. When asked why they did this, they responded that 'it gets too hot in the reception area if they are not kept open'.

4.3.1 Feedback on day: BUS 1

Some feedback was provided to surveyors verbally on the day of the survey. Although, there may be some duplication with the BUS survey form responses, this is also noted separately here:

- **Canteen facilities**. Lack of canteen facilities means that people have to bring their own food in, have shorter breaks and are less sociable. With planning for the new NCC2 building underway, there may be a business case for larger canteen facilities.
- **WC facilities**. There are 150 staff members on the first floor [offices] with only 4 WCs. This is insufficient and should be looked at for the next building.
- **Automatic window opening**. The window openings in the reception area are erratic and were taking place overnight. There have been issues with squirrels getting into the building overnight and eating the staff's food. The automatic night time cooling by window opening has now been disabled.

4.3.2 Quantitative results analysis: BUS 1

Figure 4.3 shows the BUS 1 simplified feedback chart showing the quantitative performance of the NCC over key assessed categories. The NCC performs in line with the average for the majority of assessed criteria, but above average for Comfort: overall, Image to visitors, and Noise: overall.

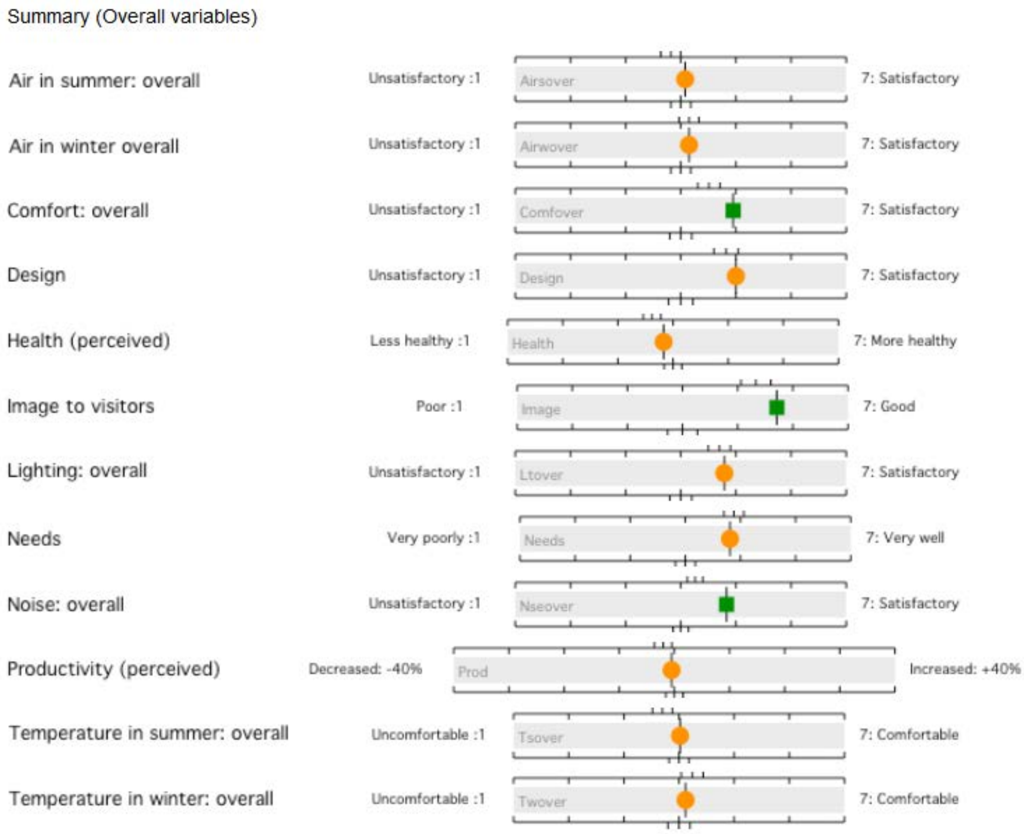


Figure 4.3: Simplified feedback chart to show the BUS Methodology results for key categories at the NCC.

4.3.2.1 Highlights from analysis

The full analysis is included in Appendix 10.1, but several of the more interesting results are highlighted here. In terms of the key questions regarding Summer Temperature Overall, Winter Temperature Overall, and Lighting Overall, the NCC performs averagely well compared to the benchmark data set.

Question: Temperature for summer and winter - stable / varies

The perceived internal temperature during the summer varies more than the majority of buildings from the benchmark data set. Interestingly, in winter the temperature is perceived to be more stable. Therefore, it is likely that the automatic windows in offices used for natural ventilation are causing high levels of temperature variation and resulting in occupant dissatisfaction.

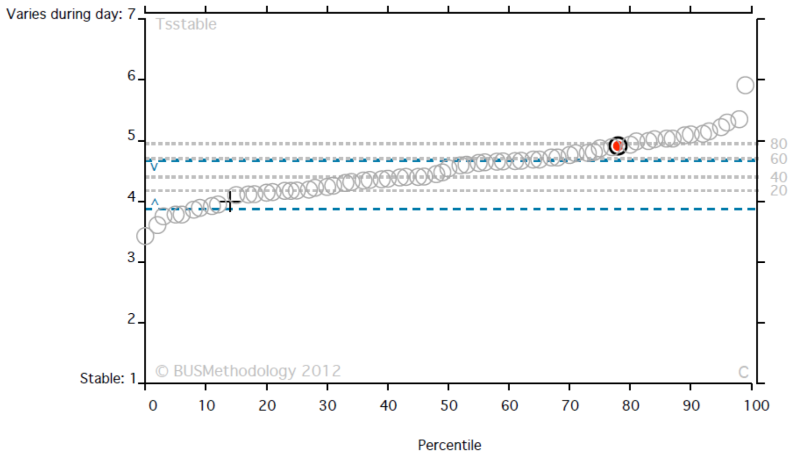


Figure 4.4: Temperature stability in Summer.

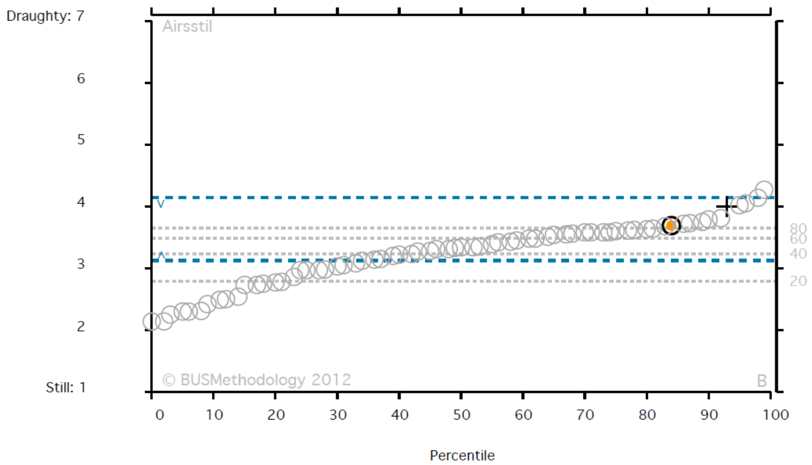


Figure 4.5: Temperature stability in Winter.

Question: Temperature for summer – too hot / too cold

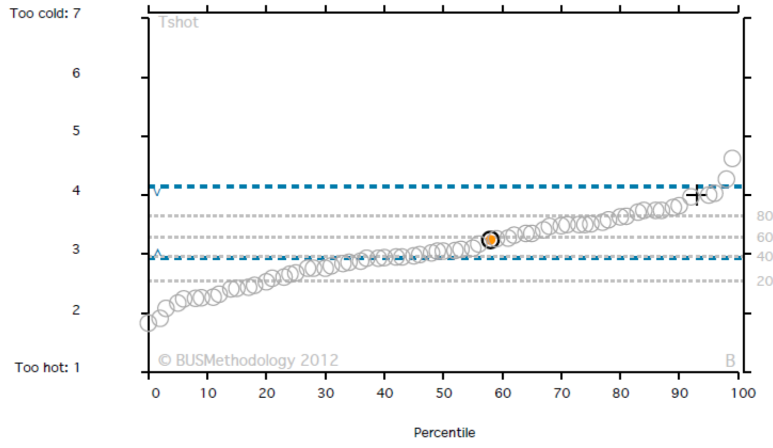


Figure 4.6: Temperature in Summer.

Question: Storage space

Compared to the other buildings from the benchmark data set, storage space throughout NCC is rated as unsatisfactory. As previously mentioned the comments have identified this to be a result of poor desk and workshop storage, as well as storage in the shower rooms.

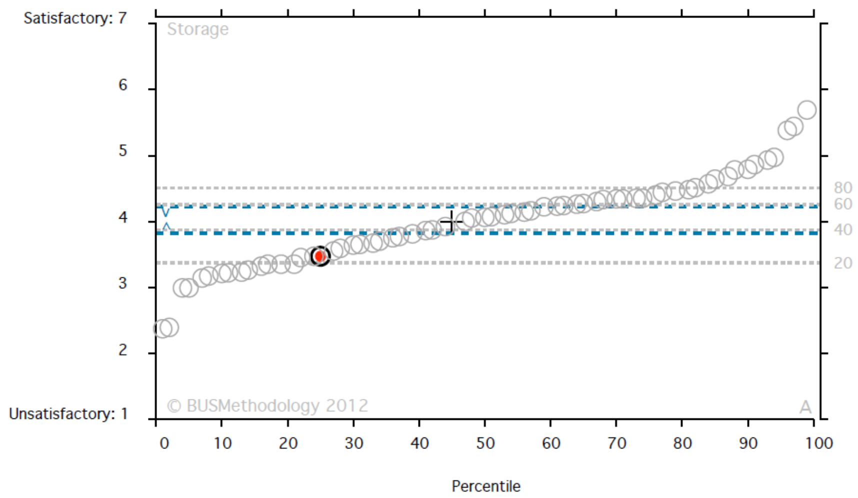


Figure 4.7: Storage space

Question: Noise – Overall

The NCC performs well in terms of overall noise compared to the other buildings from the benchmark set.

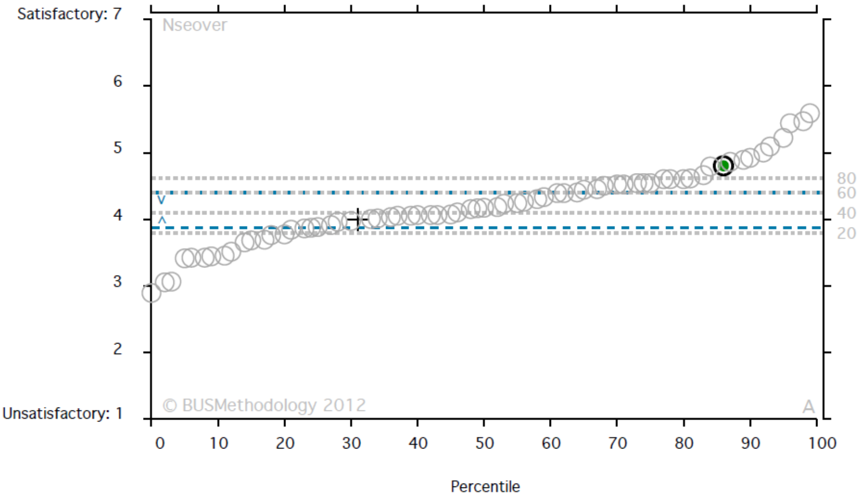


Figure 4.8: Noise overall

Other aspects

- Occupants rate the furniture as good.
- There is limited control over building services, which is in line with the design.
- Image to visitors is rated as good compared to other benchmark buildings.
- Occupants in general report that there is a low level of glare from lights.
- Meeting room availability is towards satisfactory compared to other buildings from the benchmark set.

4.3.2.2 Analysis by office

To further the analysis, the questionnaire differentiated between staff working in the three different offices at the NCC; Tenant, East, and North. A comparison was made between the 3 offices to see if there were any obvious differences in the performance regarding overall noise, overall lighting, and overall temperature in summer and winter. Figure 4.9 shows a spider diagram for the relevant questions. Although there is not much variation regarding these factors between the offices there is perhaps a more comfortable temperature in East office during the summer than Tenant and North office and a more comfortable temperature in the North office during the winter than Tenant and East office. The Tenant office is perceived as being nosier compared to the other two which may be a result of the Tenant office operating at a higher occupant capacity than the East or North offices.

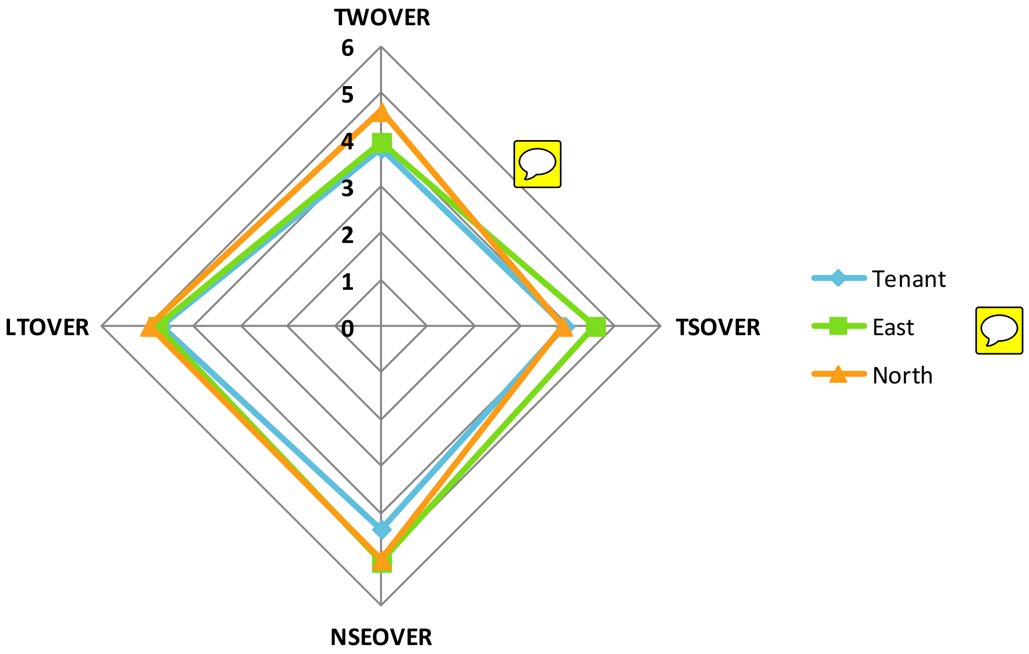


Figure 4.9: Spider plot of temperature summer overall (TSOVER), temperature winter overall (TWOVER), noise overall (NSEOVER), and lighting overall (LTOVER): mean BUS Methodology scores for the 3 offices.

4.3.3 Qualitative results analysis: BUS1

The analysis of the qualitative data supplied to the BPE team involved simply listing them in alphabetical order. To gain a more in-depth understanding of the occupant satisfaction issues at the NCC, the BPE team therefore carried out a thematic analysis of this data. The thematic analysis involved systematically drawing out the common themes from the data and ranking them in order of appearance.

The survey also yielded some positive qualitative responses regarding particular building features:

- Collaborative environment
- Lots of natural light
- Breakout areas
- Wifi
- Being close to manufacturing facility can be very motivational

Note that Percentages refer to the percentage of total completed surveys that mentioned this particular issue.

A number of other issues became evident from the qualitative findings of BUS 1. These are presented below.

- **Lack of men's WCs.**
  In response to the 'Needs' question 16 out of 46 (13%) comments were related to the lack sufficient toilet facilities.

- **Distracting noise from rainwater down pipe in office areas.**
  In response to the 'Noise' question 13 out of 39 (11%) comments were related to the unwanted noise coming from rainwater reclamation pipes that run through the North office.

- **Varying temperatures throughout the day from automatic windows opening and closing**.
  There were 48 'Request for changes' comments; 14 of these (12%) were related to the automatic windows causing uncomfortable and variable internal temperatures. There is also an associated problem with 6 (5%) out of 39 'Noise' comments indicating that the noise from the window actuators was distracting.

- **Frustration with automatic lights going on/off while people are still in the office or meeting room.**
  Of the 40 comments regarding Lighting; 30 (25%) complained about the automatic lighting switching off inappropriately, particularly in meeting rooms.

- **Workshop layout not suitable.**
  For the 'Your work requirements: hinder' question, 6 out of 26 comments (5%) related to the perceived poor design and layout of the workshop space. It should be noted that there were only 12 workshop staff surveyed so this response represents a significant percentage of people working in this area.

- **Lack of storage space for desk areas, lockers for cyclists, and workshop materials and tools**.
  The 'Storage' question led to 48 response; 10 of these (8%) claimed that there was insufficient cycle and locker storage, 11 (9%) said that there was insufficient storage for tools or large components in the workshop, and 12 (10%) pointed to the lack of storage in the offices, especially local storage at desks.

- **Lack of canteen and vending machines.**
  The 'Needs' question also prompted 11 out of 46 respondents (9%) to mention the lack of canteen facilities or vending machines.

4.3.3.1 New issues

The following are new issues that had not previously been picked up by the BPE study or design teams.

- Chemical smells from Liquid Resin Cell and RTM lab to North office
- Changing room smells vent to East office.
- IT video link to Tenant office.
- Stairs in reception area can be unsafe as people trip.
- Automatic night time cooling by window opening has been disabled due to squirrels being able to enter the building and scavenge for food.
- Daylight and view out hindered in East office due to metal grilles covering window.
- No cold water in toilets

- Need for a desk lamp to reduce eye strain from tube lighting.
- Change window override button from a timer (1 hour) to a simple open / closed as more often than not only required for 10-12 minutes.

4.3.3.2 Workshop specific issues

These are issues relating to the design of the workshop (in contrast to organisational issues such as how to book equipment). From the survey responses it should be noted that a high percentage of workshop staff highlighted these issues.

- Lack of extract specific workshop areas
- Workshop layout is “wrong”.
- No windows in Materials Lab.
- Crane in wrong place.
- Lack of defined space to put tools, parts and equipment.
- Humidity control in clean rooms is too erratic
- Glare from side windows dangerous for fork lift drivers.
- Temperature and humidity should be clearly visible in all clean rooms.
- Incomplete software in autoclave and DDF

4.4 BUS Methodology Survey 2

The second BUS Methodology survey (BUS 2) was conducted on Tuesday 15th October, 2013 by the BPE team. At the end of the day (15:00), 153 survey forms had been handed out, with 112 surveys returned giving a response rate of 73%, which is slightly down on the 76% response rate achieved during BUS 1.

4.4.1 Comparison with BUS 1

As there was no available funding for BUS 2 to be analysed in the same way as BUS 1, a separate analysis was carried out by the BPE team. Rather than replicating the previous analysis, the BPE team determined whether there had been any discernible change in occupant satisfaction over the period between the two surveys. Specifically, a T-Test statistical analysis was used to see if there were any significant differences in the quantitative answers between the two BUS Methodology surveys carried out roughly one year apart. The mean and standard deviation for each quantitative question was calculated for both surveys. Table 4.1 shows the results of the T-Test on the mean for each quantitative question for both BUS 1 and BUS 2. Green background in the table indicates a statistically significant result for $p < 0.05$. If significant, the difference is unlikely to be as a result of chance. Note that this T-Test does not simply look at the difference between the means, it also considers the standard deviation. This is why the result can still be significant even if the means look similar.

Table 4.1: Results of T-Test on means of BUS 1 and BUS 2.

	BUS 1 Mean	BUS 2 Mean	T-Test (Signif.)
DESIGN	5.00	4.98	0.89
NEEDS	4.77	4.50	0.21
SPACEBUILD	4.83	4.83	0.62
IMAGE	5.71	5.76	0.51
SAFETY	5.69	6.02	0.01
CLEANING	5.68	4.96	0.00
MEETING	4.95	4.21	0.00
STORAGE	3.26	3.84	0.02
WORKREQ	5.03	5.04	0.95
FURNITURE	5.17	5.39	0.21
SPACEDESK	3.74	4.10	0.03
TWOVER	3.58	3.45	0.80
TWHOT	3.66	3.78	0.01
TWSTABLE	4.09	3.87	0.44
AIRWSTIL	2.31	2.87	0.00
AIRWDRY	3.08	2.86	0.97
AIRWFRESH	3.75	3.14	0.01
AIRWODOURL	2.59	2.68	0.06
AIRWOVER	3.70	3.49	0.54
TSOVER	3.36	3.29	0.14
TSHOT	2.64	2.53	0.02
TSSTABLE	4.04	4.38	0.93
AIRSSTIL	3.04	2.98	0.12
AIRSDRY	3.31	3.56	0.82
AIRSFRESH	3.32	3.89	0.23
AIRSODOURL	2.77	3.20	0.17
AIRSOVER	3.47	3.42	0.25
NSEOVER	4.71	4.51	0.45
NSECOLL	4.32	4.32	0.92
NSEPEOPLE	4.16	4.19	0.78
NSEINSIDE	4.07	4.06	0.75
NSEOUTSIDE	3.69	3.85	0.17
NSEINTERRUPTION	3.83	3.93	0.53
LTOVER	4.64	5.00	0.14
LTNAT	3.59	3.82	0.19
LTNATNGL	2.99	3.06	0.54
LTART	3.93	3.88	0.46
LTARTNGL	3.08	2.85	0.18
COMFOVER	4.74	4.61	0.31
PROD	4.79	4.46	0.12
HEALTH	3.79	3.63	0.99
CNTHT	1.50	1.50	0.92
CNTCO	2.01	1.87	0.54
CNTVT	2.32	2.20	0.74
CNTLT	1.43	1.58	0.33
CNTNSE	1.57	1.57	0.92
IMPCNTHT	0.24	0.30	0.32
IMPCNTCO	0.28	0.29	0.33

	BUS 1 Mean	BUS 2 Mean	T-Test (Signif.)
IMPCNTVT	0.30	0.21	0.33
IMPCNTLT	0.21	0.17	0.38
IMPCNTNSE	0.15	0.17	0.67
RESYN	1.54	1.46	0.50
SPEED	1.61	1.71	0.86
EFFECT	1.60	1.67	0.92
BEHAVIOUR	1.55	1.38	0.13

The completed analysis shows that there is a significant *improvement* in perceptions of:

- Storage
- Safety
- Space at desk

And significant *reductions* in perceptions of:

- Cleaning
- Availability of meeting rooms

There were also significant differences in thermal comfort. These are answered using a 7pt likert scale, so 4 is a neutral response.

Winter

- Too hot/too cold – towards neutral from too hot
- Still/draughty – towards neutral from still
- Fresh/stuffy – towards fresh from neutral

Summer

- Too hot/too cold – towards too hot from neutral

The results of the T-Test indicate that the perceptions of thermal comfort during winter have improved over the course of the year with employees considering the air to be less hot, less still, and fresher. However, perceptions of temperatures during the summer have worsened over the same period. It is understood that the time of year the survey is administered can have an effect on responses. BUS 2 was administered in October after a hot summer during which the temperature in the naturally ventilated offices (without mechanical cooling or natural night ventilation) was approaching and even exceeding 30°C on occasions. It is therefore possible (as well as useful feedback to design teams) that the occupants were less satisfied with the temperature than they had been during the previous summer. However, this may have altered their perception of temperatures in winter, possibly causing them to report an improvement in satisfaction.

It is also unclear why there have been reductions in the perception of cleaning. There were no reports of fewer cleaning staff at the NCC over this period.

There was a gradual increase of staff numbers which may have caused pressure on the meeting room availability. There does not, however, seem to be a straightforward explanation for the increase in perceptions of storage, space at desk, and safety.

It is felt by the BPE team that this type of comparative analysis could be a useful tool in future BPE studies if carried out systematically over a longer period with perhaps two surveys per year. This may be possible if a simplified online BUS Methodology is used, but is impractical in the BUS Methodology's current form. It would also be perhaps more insightful if the changing satisfaction of specific (anonymised) individuals is assessed rather than the average of all occupants.

Analysis was also carried out on the mode of transport employees use to commute to the NCC and how this has changed over the course of a year (Tables 4.2 and 4.3 and Figures 4.10 and 4.11). This showed an apparent decrease in the amount of employees driving to work over the year which seems to have been as a result of an increasing number of employees cycling or taking the bus.

Table 4.2: BUS 1 results of transport question

	Count	Percentage
Car (solo)	95	79%
Bicycle	11	9%
Walk	4	3%
Bus	3	3%
Car (share)	3	3%
Taxi	2	2%
Train	1	1%
Motor Cycle	1	1%
Total	120	

Table 4.3: BUS 2 results of transport question

	Count	Percentage
Car (solo)	70	67%
Bicycle	16	15%
Bus	7	7%
Walk	4	4%
Train	2	2%
Car (share)	2	2%
Motor Cycle	2	2%
Taxi	2	2%
Total	105	

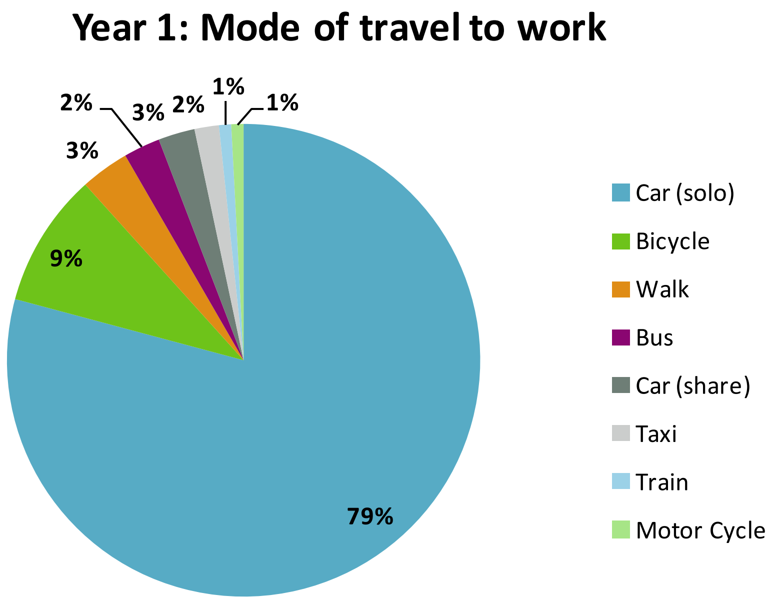


Figure 4.10: Proportions of the different modes of travel employees used to get to the NCC in Year 1

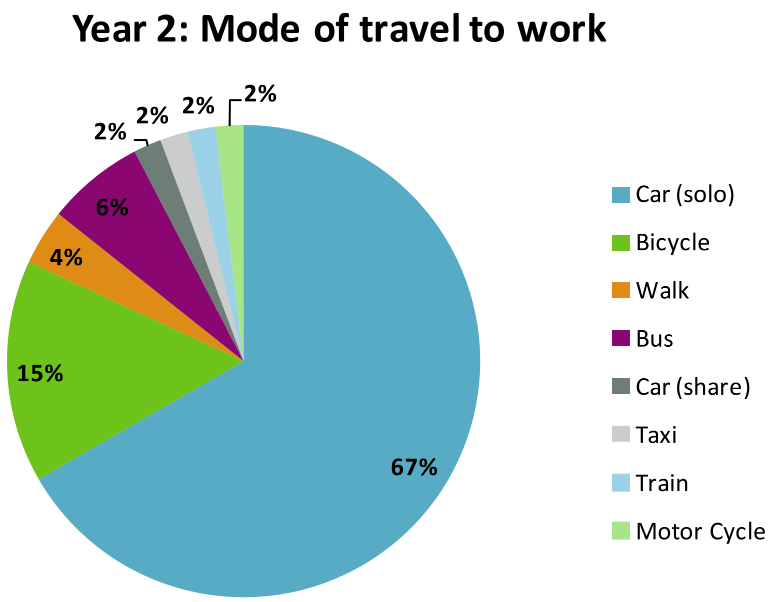


Figure 4.11: Proportions of the different modes of travel employees used to get to the NCC in Year 2

4.5 Informal staff interviews

During the quarterly visits to the NCC, the BPE team took the opportunity to discuss the performance of the building with various staff members, but primarily the FM. Information obtained in this manner has mainly been included in the relevant sections elsewhere in this report. Other observations included:

- The workshop staff reported that they only use the light switch for the main workshop as an on / off switch and do not use the other levels; it was unclear to the workshop staff from the labelling what the other levels actually did (see Figure 3.1).
- The metering and monitoring by the BMS is not used by the FM team as it is not useful to them. There are no alerts set up and therefore it currently provides meaningless data to them.

4.6 Design recommendations for NCC2

As mentioned previously, the new NCC2 building was being designed during the BPE study. This building will be located next to NCC and will be very similar in size and design. This situation presented a rare opportunity to feedback successful and less successful aspects of NCC's performance to the NCC2 design team. Results from BUS 1 highlighted several key areas concerning occupants that have been fed back to the design team for consideration for NCC2. These included recommendations to:

- Provide dimmable lighting as well as automatic on / off to have a gradual fade rather than sudden switching.
- Provide mesh on night time cooling windows to prevent squirrels getting into the building and allow night time cooling to be used in practice.
- Provide acoustic insulation on the rainwater down pipe in office areas.
- Consult with workshop staff and technicians to design a more appropriate workshop layout.
- Ensure there are no side windows in the workshop area, or provide blinds to prevent glare.
- Provide more Male WCs.
- Create a social hub within the building available to all.

4.7 Performance feedback to NCC stakeholders

Over the course of the BPE study, performance feedback sessions have been undertaken with key client stakeholders. During these meetings the BPE team explained the findings to date about the operation of the building and the client provided contextual details. These occurred on 12th July 2012, 1st May 2013, and 27th February 2014.

4.8 Discussion and key findings

The response rate for the two BUS Methodology surveys was 76% and 73% respectively. These are acceptable response rates and shows that the occupants were engaged with the BPE study.

In comparison to the BUS Methodology benchmark building data set, NCC performs reasonably. It scores around average against the benchmark set for the majority of assessed criteria.

In terms of thermal comfort the occupants seem to be largely satisfied with how the building and how its services are operating. However, there are possible indications of the air being perceived to be too hot in the summer. The AHUs for the office spaces provide heating, but no cooling, so this is an area of potential concern. A comparison between the two BUS Methodology surveys indicates that the perceived temperature in summer has increased. It should be noted that the second survey was conducted in October 2013 and the previous summer had been particularly hot.

Interestingly, within the open plan office environment, the NCC performs particularly well with respect to noise. This is possibly because the occupants are already prepared for a certain level of noise as the NCC is primarily an industrial research centre. The occupants also like the collaborative environment and that desk based research is close to the workshop areas.

Although working well for the office spaces (as they are densely occupied), the PIR sensors for the lighting in meeting rooms have been a particular problem with regard to occupant satisfaction. The PIR sensors regularly fail to detect occupants sitting still during meetings and frequently turn the lights off inappropriately.

Findings from the first BUS Methodology survey were fed back directly to the design team for NCC2 who were able to modify aspects of their design, such as providing acoustic insulation on the rainwater harvesting pipes and increasing the number of male WCs.

5 Details of aftercare, operation, maintenance & management

5.1 Introduction

This section sets out the operation of the NCC building from the first year of occupation. Specifically, it reviews the ongoing maintenance and management.

5.2 Aftercare

In the first year of occupation, from October to 2011 to October 2012, the commissioning contractors had an engineer present on site for 2 to 3 days per week. This was successful in identifying issues with the building, resolving metering issues on the BMS and helping to provide training for the new Facilities Manager (FM). However, observations from site visits indicated that the FM seemed to be generally reliant on the commissioning engineer to operate the BMS.

Additionally, the commencement of the NCC2 project has meant that there has been increased interest from the original design team and client, on the performance of the original NCC. The BPE study team recommended that both the commissioning engineer and the FM should be invited to the design team meetings, but it is understood that this did not take place.

5.3 Maintenance and management

From October 2012 the NCC operated with only one FM. If the FM is absent through illness or annual leave, there is no one in place to deal with any arising facilities issues. The general maintenance strategy at the NCC appears to be reactive in nature. For instance, when the BPE team was inspecting the rain water harvesting system submeter, the FM noticed that one of the UV lamps was not working and replaced it. The FM is also rarely notified in advance when a new piece of process equipment is going to be brought to site and installed.

From the point of occupation there was a 2 year maintenance contract in place with the controls specialists who installed and commissioned the BMS. However, this lapsed in September 2013 and there was no alternative maintenance contract in place. According to the FM, UoB procurement requested at least three quotes to be obtained for the provision of maintenance for the NCC before they would authorise a new contract. A new maintenance contract was eventually agreed from February 2014 with the original control specialists, but this resulted in a period of 4 months in which no maintenance support was available

5.3.1 HVAC System Management

5.3.1.1 Office areas

The FM conveyed to the BPE team that he often receives occupant complaints surrounding thermal comfort in the three first floor office spaces. This is a particular issue during the summer months when temperatures in the office areas can, on occasion, exceed 30°C. The FM believes that there is no provision to change the thermal comfort in the offices due to the mixed mode ventilation strategy. There is a BMS override switch to allow windows to be opened or closed (see Section 7.5 for details).

5.3.1.2 Main Workshop

The temperature setpoint and the operating hours for the AHUs for the Main Workshop can be controlled through the BMS, but there are no local controls. The FM received complaints that the temperature in this space was too low over the winter of 2013. At some point (although the BPE team cannot pinpoint exactly when) the supply temperature for the Main Workshop AHUs was increased from 21°C to 30°C (see Section 6.5.2 for details).

The Main Workshop also has a roller shutter section door on the west facade. This is used for deliveries. Anecdotally, it was communicated to the BPE team that the shutter door was often left open during the day, particularly in summer for cooling, but also at points during winter. However, the BPE team were unable to accurately assess the frequency of this door being left open, or its impact on energy consumption.

5.3.1.3 Clean rooms

The three specialised laboratory spaces of ATL/AFP Rapid Deposition, Clean Room, and Ply Cutter are designated as Clean Rooms and as such require careful management of their internal environmental conditions. It is important that the environmental conditions and an indication that the AHUs are operating correctly in these areas are reported by the BMS. Ideally, the FM would also be able to maintain required pressure differences and modify heating, cooling and humidity setpoints in these areas via the BMS, depending on the process operating requirements during a particular period.

Energy analysis revealed that conditions in these rooms were not being maintained over weekends (see Section 7.4). Inspection of the BMS revealed that the user could not modify the run hours for the AHUs in these areas and (although the user can see the internal conditions) they cannot modify internal setpoints.

5.4 Metering strategy

As well as fiscal meters for electricity, gas, and water, the NCC is extensively metered with 74 electrical, 3 gas and 7 water meters. Full metering hierarchies can be found in the Appendix 10.2. The large number of submeters generally satisfies the Building Regulations Part L requirement that at least 90% of the estimated energy consumption of each fuel can be assigned to the various end uses in the building. These submeters are linked back to the Trend BMS, where kWh for electricity and m^3 for gas and water are displayed cumulatively on the BMS Front end (Figure 5.1). Data are also stored in 15 minute format energy reports as plain text files in a folder on the BMS' dedicated PC. These energy reports are overwritten every 10 days.

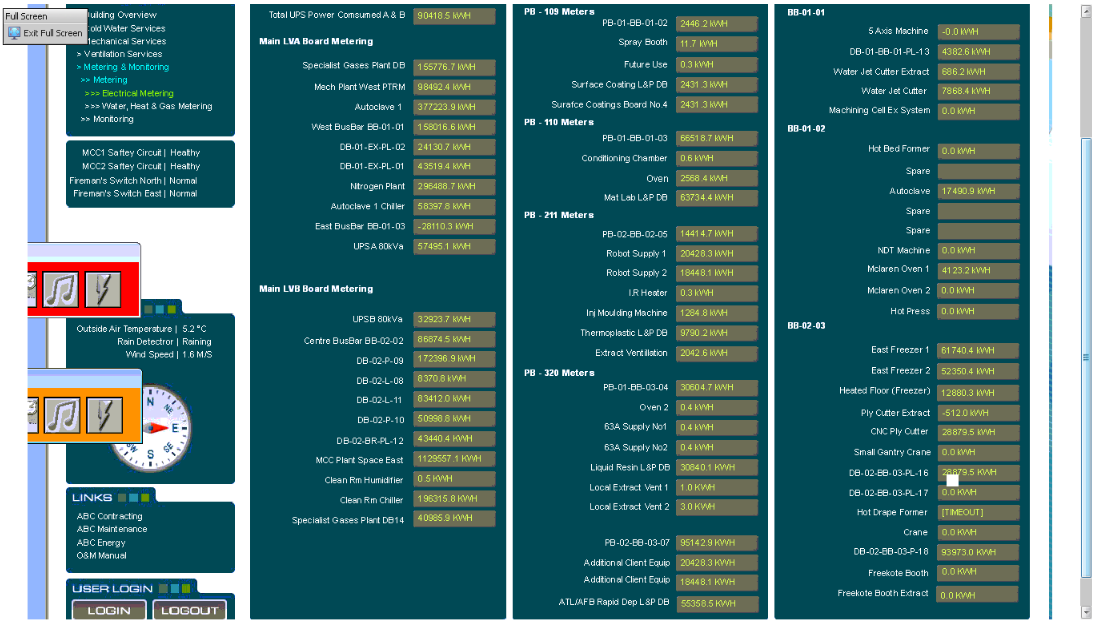


Figure 5.1: Screen shot of the BMS electrical metering front end. Note submeter consumption is displayed cumulatively since meter commissioning.

The BPE team found a number of cases where although submeters had been installed, they had not been successfully connected to the Trend BMS. This seems to be a particular issue with regards to the industrial process equipment such as the 5 axis machine, NDT machine, Hot Drape former, and Hot press, which were submetered, but not connected properly to the BMS. Although this issue was highlighted by the BPE team to the FM and controls specialists, they have not as yet been rectified. Taking into account the small power and lighting consumption for the office spaces (which was never intended to be connected to the BMS) over a quarter (27%) of annual electricity consumption at the NCC is not connected to the BMS (see Section 6.4).

5.4.1 Time stamp error

When initially analysing the electricity submeter consumption and comparing this to the fiscal incoming data a large discrepancy was noticed, in particular that a typical 'Sunday' low-profile on the incomer, was happening on a different day from the typical 'Sunday' low-profile on the submeters. As a result, the BPE team investigated the time stamps on the submeters. First of all, the raw data were checked to ensure that there was no issue with transferring data from the BMS to the AECOM Smart database (see Section 6.3). Spot checking of dates was used and confirmed that date / time stamps were identical. Next, the controls specialists were contacted to see whether there was a way to manually check submeter timestamps. An engineer remotely checked and on 13th February 2013 and confirmed the following:

'I have investigated the controllers at NCC and found that 1 of the controller time modules was out by 5 days and 3 hours. I have corrected this and checked the other controllers and all appear OK. This may have been caused by loss of power. Hopefully this will sort out the time difference on the data you collect from site. The controller time module effected [sic] is: LAN 21 – IQ Controller 11-32'

This implied that all of these meters had been affected in the same way (e.g. 5 days and 3 hours out). The controls specialists were then able to adjust all of the affected submeters, but data prior to this and held in the AECOM Smart database had to be altered manually. Table 10.1 in Appendix 10.3 lists all affected submeters. Without the BPE study, it is highly unlikely that this error would have been detected.

5.4.2 Incorrect installation

During the energy audit carried out to inform the creation of the CIBSE TM-22 model (see Section 6.4.1), it was discovered that some pieces of equipment were not installed onto their designated submeter; instead they were wired directly into the room's distribution board. There seems to have been a lack of communication between the design team and installers to ensure that the metering strategy was correctly implemented.

5.5 Flexible dynamic space

Since completion of the NCC the client has developed a better appreciation of how the building is used by the tenants. Consequently, there have been alterations to the designed spaces. Figure 5.2 shows the ground floor layout with the locations of new rooms and pieces of equipment that have been added over the course of the BPE study.

A new Clean Room, complete with airlock, has been created in the south east corner of the main workshop space. This was commissioned early on during the operation of the NCC when the client realised that the tenants required more space for specific tasks. This Clean Room has its own independent AHU (Figure 5.3) which has been installed within the main workshop. This will contribute to heat gains in the space.

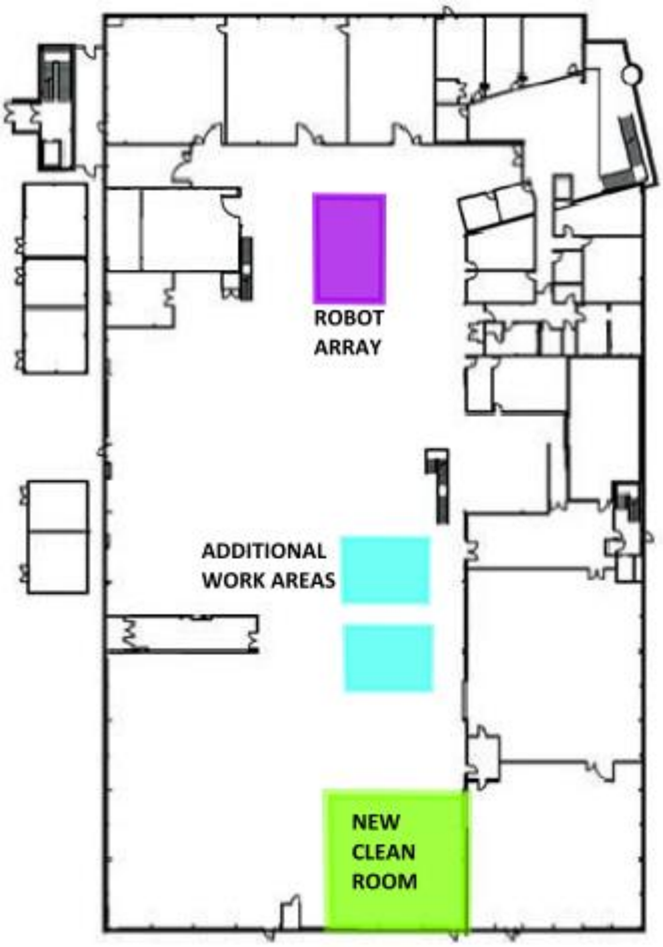


Figure 5.2: Annotated ground floor layout showing the locations of the new Clean Room, additional work areas, and the Robot array.

Figure 5.3: New clean room AHU unit inside the Main Workshop.

Additionally two small rooms were created in the Main Workshop space. These both have small VRV units to provide comfort cooling and do not have air locks. A large robot array was installed in the north east corner of the Main Workshop near the main entrance. This did not require its own room, but the area has been partitioned off for health and safety reasons.

All of these additional rooms and pieces of equipment have been installed since the opening of the NCC. They are not independently submetered and are wired directly into the nearest busbar, usually the East busbar (where the PV array is directly wired into) leading to further complications with analysing the metered data. The client has no plan in place to separately submeter new rooms or pieces of equipment or to connect them to the BMS.

5.6 Discussion and key findings

There have been some issues with the installation and commissioning of some of the submeters at the NCC. A time stamp error occurred to a significant proportion of the submeters. This problem should have been recognised if any reconciliation had previously taken place.

Certain items of equipment were not installed onto their designated submeters and were instead wired directly into a local distribution board. This is indicative of a lack of clear communication of the metering design intent.

Having a commissioning engineer onsite for the first year of operation was especially effective at responding to any arising issues with operational performance and seasonal commissioning. It also allowed for the FM to receive ad hoc training on the building systems.

The dynamic use of the NCC building has meant there have been alterations to the space as the client has developed a better understanding of the operational requirements of the tenants and building users. There is at present no system in place to ensure that these new areas are separately submetered. Instead these are simply directly wired into the nearest busbar. This could confuse the metering strategy in place at the moment and would have ramifications for future monitoring and targeting to reduce energy consumption.

Presently, the maintenance strategy being carried out by the FM team is rather reactive in nature. This is emphasised by the maintenance contract with the controls specialists lapsing for a period of several months during the BPE study. This meant that the efforts of the BPE team to ensure that the electrical submeters for some of the process loads were communicating properly with the BMS could not be completed as no maintenance engineer would visit the site.

6 Energy use by source

6.1 Introduction

Table 6.1 provides an overview of how energy is consumed annually at NCC. The BPE team were unable to obtain any energy bills to get exact cost information but were provided approximate values from the client.

Table 6.1: NCC Fiscal Supplies - November 2012 to October 2013

Utility	Consumption (kWh p.a.)	Typical cost (£ p.a.)	GHG emissions (tCO_2e p.a.)	Emissions factors ($kgCO_2e/kWh$)
Grid electricity	2,236,900	£213,600	1,010	0.4528
Solar PV electricity	133,000	£0	0	0.0000
Gas	1,558,600	£46,800	290	0.1846
	TOTALS -->	**£260,400**	**1,300**	

For the BPE study, energy data were obtained from four separate sources:

- **Fiscal electricity and gas data**
  Supplied in 30 minute intervals by the energy provider: kWh for electricity and m^3 for natural gas. This was supplied to the BPE team by the client's Energy Manager.

- **Direct submetered data**
  The BMS generates reports for each connected submeter. This data shows the cumulative reading at 15 minute intervals since commissioning. This data is only stored for the previous 10 days by the BMS before being overwritten, so the BPE team implemented an automatic system to remotely interrogate the BMS and collect this data every week. This system is referred to throughout this report as the 'AECOM Smart system'.

- **PV generation**
  The 138 kWp PV array is not separately submetered at the building. The specialist installers collect the PV generation data using data loggers that transmit hourly generation data, which is then available for download by the client over the Internet.

- **Office spaces**
  The submeters for the small power and lighting for the three first floor open plan office spaces and the ground floor meeting rooms and circulation areas were not connected to the BMS. To obtain daily profiles for these, clip on wireless electricity monitors were used. Data from these are generated in kWh per hour for an assumed voltage of 240V.

6.2 The relationship between an Energy Performance Certificate and actual consumption

Energy Performance Certificates (EPCs) only consider a building's 'regulated' energy consumption which is the consumption for the fixed building services such as heating, ventilation, cooling, and internal lighting for assumed occupancy schedules. EPCs do not consider 'unregulated' consumption such as small power loads and external lighting.

The EPC results show that the NCC achieved an asset rating of '39' within band 'B' (Figure 6.1).

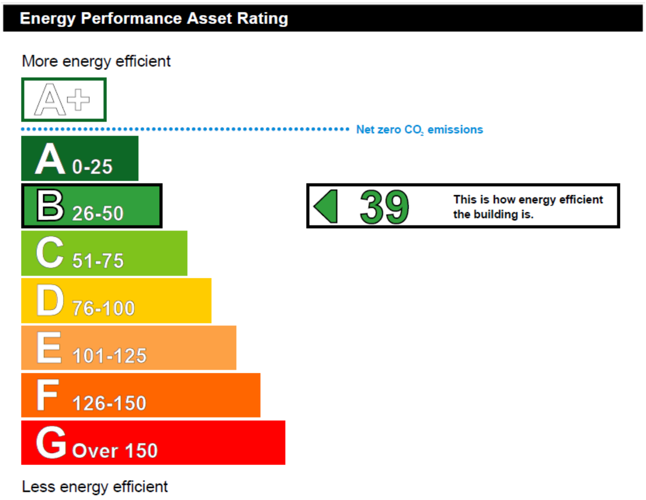


Figure 6.1: National Composites Centre Energy Performance Asset Rating

By accessing the original Part L compliance model, the anticipated consumption for the fixed building services for heat and electricity was determined. This was then compared to metered electricity consumption and heat consumption (calculated through an estimated boiler efficiency of 90%) for the NCC. The results are displayed in Figure 6.2 and show that the EPC anticipated consumption is around 4.5 times less than actual metered consumption. This Figure also shows the actual regulated consumption split into heat and electricity. This is further subdivided into its components. For heat, this is space heating and domestic hot water. For electricity this is the consumption for power and lighting, cooling, and fans, pumps and controls. These values have been derived from BMS readings between November 2012 and October 2013. The heat consumption for actual regulated and actual is very similar, as the only industrial process that uses natural gas (which is the only source of heating at the NCC) is the Autoclave. However, the actual electricity use is much greater than both the EPC and the actual regulated. This is largely due to the significant amount of energy used for industrial processes at the NCC.

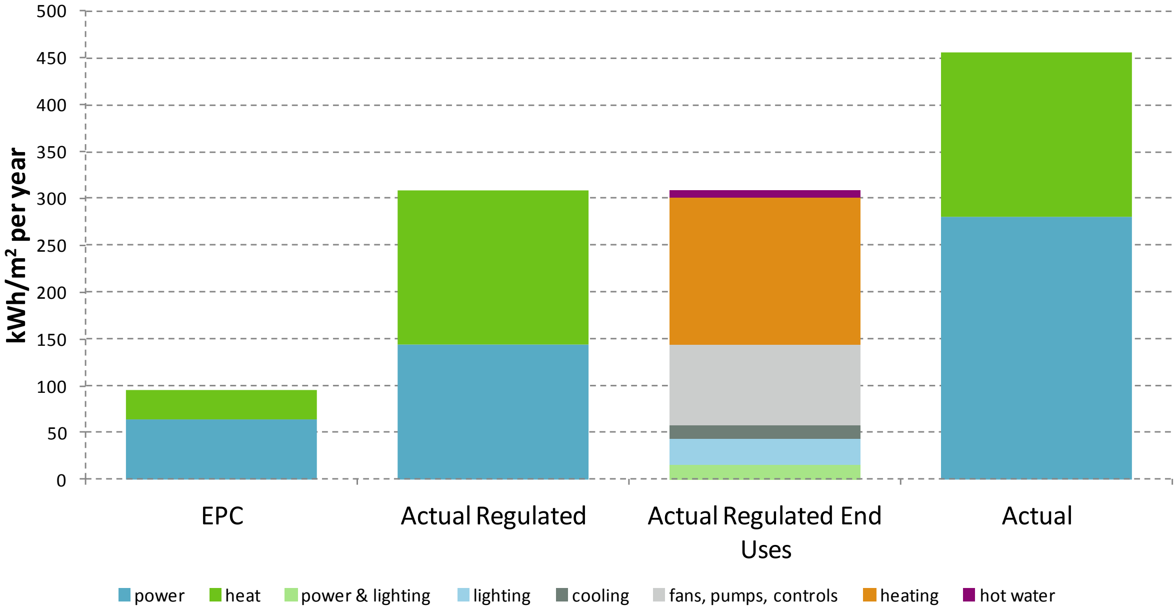


Figure 6.2: EPC calculated heat and electricity consumption against actual consumption for the NCC.

6.3 AECOM Smart System

The initial approach to monitoring the electricity consumption at the site was to establish the meter hierarchy. The NCC has 74 electrical submeters. These submeters are manufactured by Schneider and are linked to the Trend BMS through ModBus. Every week, the BMS produces meter reports in the form of plain text files. Data are produced for all connected submeters in 15 minute intervals, allowing high resolution analysis. However, the BMS only stores the previous 10 days of files before over writing them. As such, it is not suitable for long term energy management. This is not a fault with the BMS system, as it was not specified to store long term energy data. Instead, they are intended to control the building services in response to environmental conditions.

The BPE team asked the controls specialists (the BMS installers and maintenance contractor) to adjust the BMS computer settings to automatically save the BMS reports to a separate location on the computer's hard drive to prevent the files from being overwritten. (The FM team were also asked to manually save these files once every week as a backup in case the automatic data collection system failed. However, although this process was followed while the commissioning engineer was still on site, it was not continued later on.)

To allow the BPE team to be able to utilise the 15 minute data produced for all submeters connected to the BMS, a bespoke software programme was designed and implemented. This system automatically and remotely accessed the BMS PC and uploaded all energy data reports to a Microsoft Sharepoint site. This Sharepoint site adjusted the data into 30 minute periods for ease of comparison with fiscal billing data and allowed the BPE team to access and download data for each connected submeter. This became a very useful and powerful tool as part of the BPE study for analysis of the large amount of submetered data.

6.4 Electricity consumption

Analysis of electricity consumption shows that the NCC uses around 2.4 GWh annually. Figure 6.3 shows how the electricity consumption is split across the high level submeters based on consumption between November 2012 and October 2013 inclusive. As can be seen, the largest proportion (21%) is for the MCCP Plant Space East submeter. This submeter monitors consumption of the supply and extract fans for the AHUs for the main workshop, specialised laboratory spaces, and East office. Other areas of large consumption are the Nitrogen Plant (11%) which is associated with the operation of the Autoclave1 (6%), manufacturing lighting (6%) which is the lighting to the main workshop area, and lighting and power to the 3 office spaces and the ground floor meeting areas (9% combined). There is a large proportion (10%) which is referred to as 'not connected to the BMS'. This proportion includes the Comms room (representing around a 40kW constant load for servers) that is not submetered. It also includes some process equipment such as the Hot Press and Hot Drape Former, which are submetered, but the connection to the BMS was not working correctly. It should be noted that the submeters for Office Power and Office Lighting were also not connected to the BMS, but the annual figures have been estimated using temporary electricity monitors (see 6.4.7)

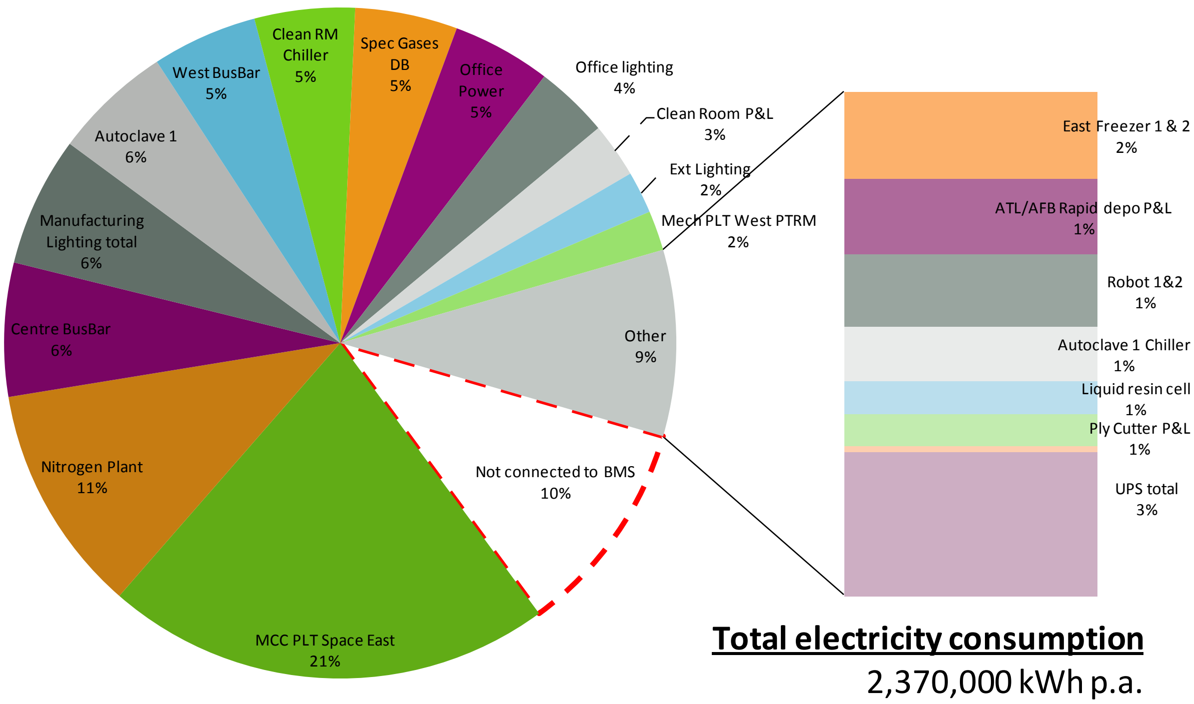


Figure 6.3: Proportions of electricity consumption from each high level submeter.

The AECOM Smart system allowed the submetered electricity consumption data to be compared to the fiscal electricity data. Data for PV generation and the office power and lighting submeters had to be converted from an hourly format to 30min data before comparison. Charts created using Microsoft Excel allowed the BPE team to look at the profiles for specific days or weeks allowing for in-depth analysis of how and where electricity was being used at the NCC (see Figures 6.4 and 6.5).

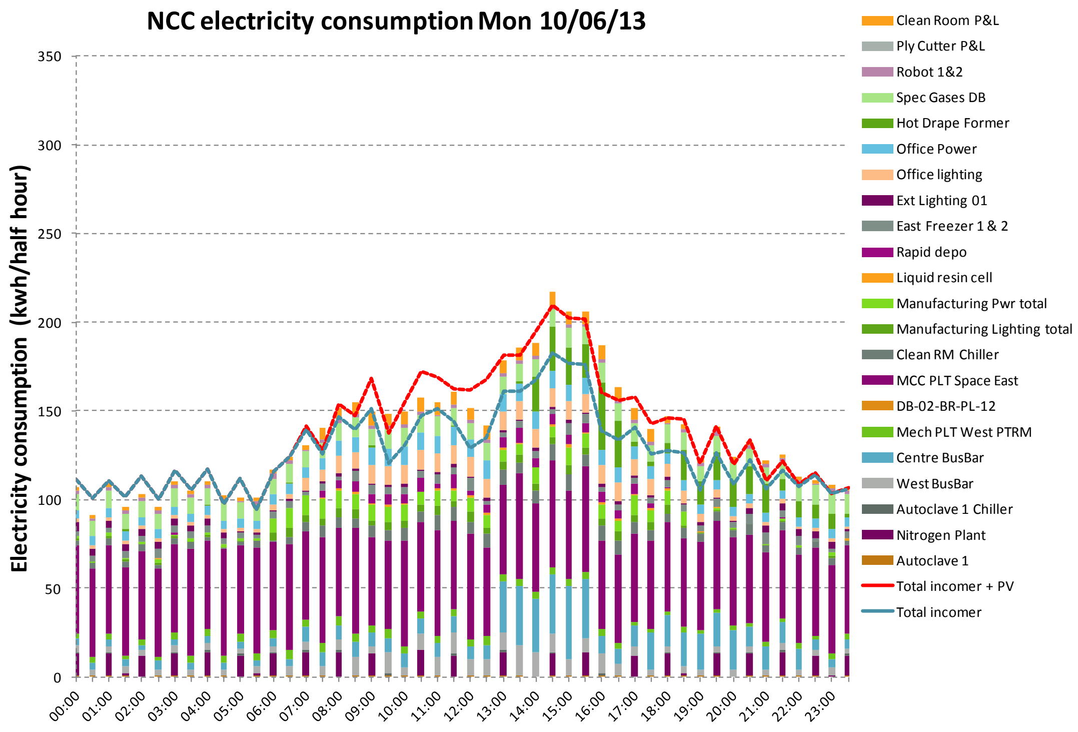


Figure 6.4: Example of a daily electricity profile for the NCC.

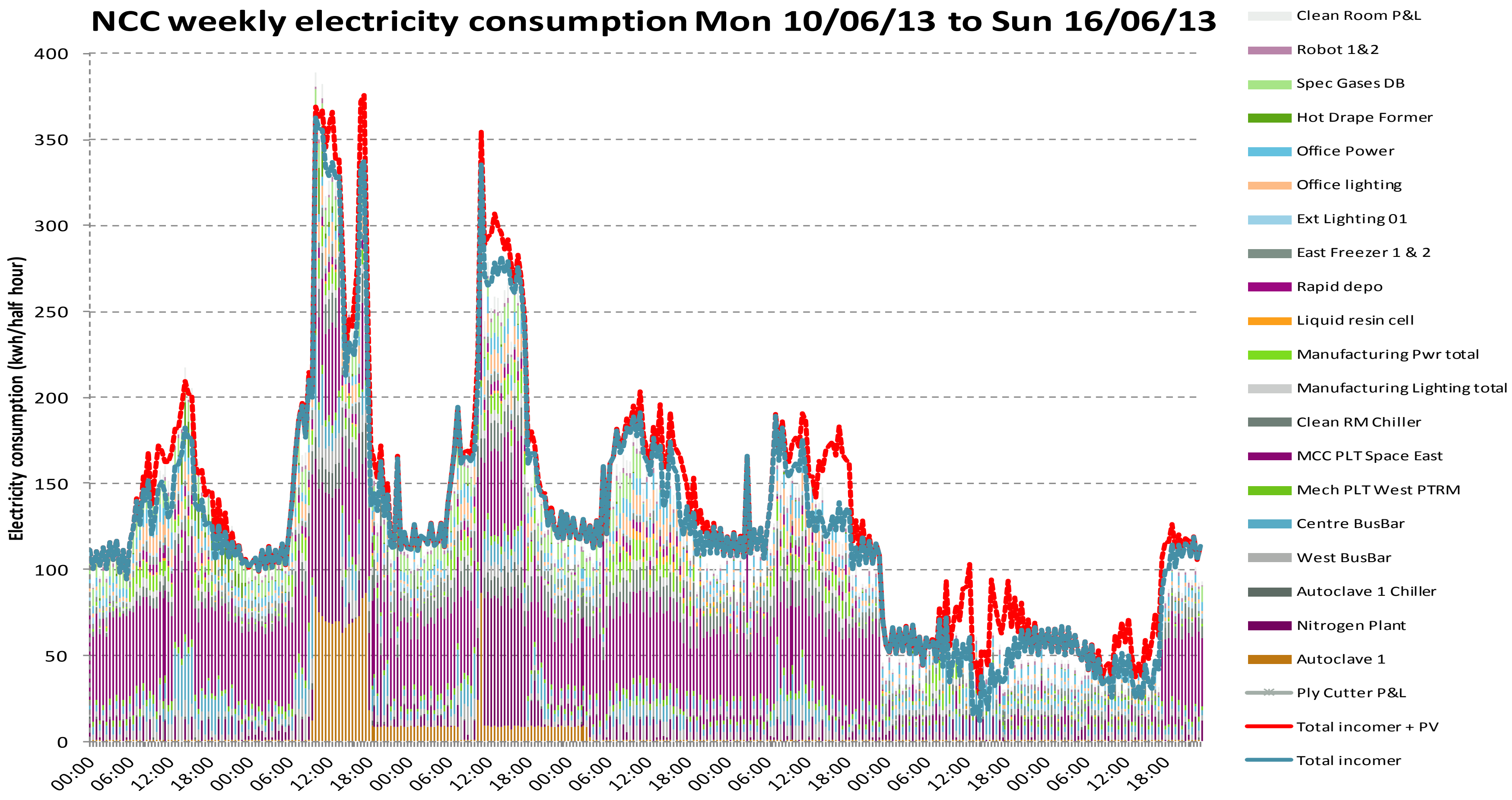


Figure 6.5: Example of a weekly electricity profile for the NCC.
Notes: (a) Autoclave1 was used on the Tuesday and Wednesday, significantly increasing overall electricity consumption, and (b) the increase at 18:00 on the Sunday.

Analyses of this kind identified several technical issues:

- Several of the submeters had incorrect time stamps, see Section 5.4.1 for details.
- Some items of equipment had not been installed on their designated submeter. Instead the equipment had been wired directly into the room's distribution board.
- When a submeter reaches a cumulative total of 1,000,000 units it does not reset to 0, instead it loses a digit (resulting in a reading of 100,000) as the BMS cannot store anymore data, see Section 7.2 for details.
- The naming of submeters on the schematics and the corresponding labelling for the BMS frontend were unhelpful.

The analyses also highlighted several operational issues:

- The submeter MCC Plant Space East, which monitors consumption for the AHU to the main workshop, East office, and specialised laboratory spaces, indicates the AHU is operating for 24 hours per day Monday to Friday and off on weekends until 18:00 on a Sunday, see Section 7.3 for details. (In this case, the AHU not operating at weekends may reduce energy use, but at the expense of meeting the required indoor environmental conditions.)
- Lighting for the main workshop is occasionally being left on overnight, see Section 6.4.3 for details.
- Despite there being very limited weekend occupancy, there is a relatively high weekend baseload demand of around 100 kW. This mainly comprises of the unmetered Comms room (40 kW), office small power (10 kW), freezers (10-15 kW), Nitrogen plant (12 kW), laboratory spaces small power and lighting (10 kW), equipment attached to busbars (6 kW), and office lighting (2 kW - 4 kW).
- The weekday night-time baseload demand is around 200 kW. This baseload is comprised of similar loads in the weekend baseload above, but with the addition of consumption for the AHUs monitored by the MCC Plant Space East submeter (100 kW). There is also a slightly greater number of office and laboratory small power appliances being left on than over weekends.

6.4.1 CIBSE TM-22 analysis

A key part of the BPE study involved using the CIBSE TM-22 Energy Assessment methodology. This methodology provides a framework for estimating the expected energy consumption of individual end uses through a bottom-up approach based on considering how the building is intended to be used and managed including operating hours and management characteristics. TM-22 uses locked Microsoft Excel pro forma spreadsheets for data entry. A limitation of this approach is that it only allows for 50 submeters to be entered, while at the NCC there are 74 electrical submeters. Consequently only 'high level' submeters were entered (Figure 6.6). Furthermore, the TM-22 workbook does not allow for detailed analysis of gas submeter consumption in contrast to the treatment of electricity consumption. For this reason only electricity consumption outputs are discussed in detail here.

Sub-meter	Full meter reference (used in tool)	Reference	Description	Location	Meter type	Normal electricity or defined separable?
No sub-meter	No sub-meter					Electricity
E01	E01 - Mech PL Power Supply West Plant		Mech PL Power Supply West Plant		Half hourly	Electricity
E02	E02 - Autoclave 1		Autoclave 1		Half hourly	Electricity
E03	E03 - 5 Axis Machine		5 Axis Machine		Half hourly	Electricity
E04	E04 - Machine Shop P&L		Machine Shop P&L		Half hourly	Electricity
E05	E05 - Water Jet Cutter P&L		Water Jet Cutter P&L		Half hourly	Electricity
E06	E06 - Water Jet Cutter		Water Jet Cutter		Half hourly	Electricity
E07	E07 - Oven 32A		Oven 32A		Half hourly	Electricity
E08	E08 - Mat Lab P&L		Mat Lab P&L		Half hourly	Electricity
E09	E09 - Surface Coating Combined L&P		Surface Coating Combined L&P		Half hourly	Electricity
E10	E10 - External P&L VM1		External P&L VM1	Sums 2 ext ltg mtrs	Half hourly	Electricity
E11	E11 - Nitrogen Plant		Nitrogen Plant		Half hourly	Electricity
E12	E12 - Autoclave 1 Chiller		Autoclave 1 Chiller		Half hourly	Electricity
E13	E13 - UPSA 80KVa		UPSA 80KVa		Half hourly	Electricity
E14	E14 - East Freezer 1 & 2 VM2		East Freezer 1 & 2 VM2	Sums 2 Freezers	Half hourly	Electricity
E15	E15 - Ply Cutter Extract		Ply Cutter Extract		Half hourly	Electricity
E16	E16 - Ply Cutter P&L		Ply Cutter P&L		Half hourly	Electricity
E17	E17 - Hot Drape Former		Hot Drape Former		Half hourly	Electricity
E18	E18 - Cleanroom P&L		Cleanroom P&L		Half hourly	Electricity
E19	E19 - Freekote Booth		Freekote Booth		Half hourly	Electricity
E20	E20 - Freekote Booth Extract		Freekote Booth Extract		Half hourly	Electricity
E21	E21 - Liquid Resin Cell P&L		Liquid Resin Cell P&L		Half hourly	Electricity
E22	E22 - Robot 1 + 2 VM3		Robot 1 + 2 VM3	Sums 2 robots	Half hourly	Electricity
E23	E23 - Rapid Depo L&P-DB		Rapid Depo L&P-DB		Half hourly	Electricity
E24	E24 - Manufacturing Lighting VM5		Manufacturing Lighting VM5	Sums 2 ltg DBs	Half hourly	Electricity
E25	E25 - Manufacturing Power VM6		Manufacturing Power VM6	Sums 2 pwr DBs	Half hourly	Electricity
E26	E26 - Boiler Room P&L		Boiler Room P&L		Half hourly	Electricity
E27	E27 - MCC PLT Space East		MCC PLT Space East		Half hourly	Electricity
E28	E28 - Clean Room Chiller		Clean Room Chiller		Half hourly	Electricity
E29	E29 - UPSB 80KVa		UPSB 80KVa		Half hourly	Electricity
E30	E30 - Unmetered Office Power VM7		Unmetered Office Power VM7	n of 3 Efergy Meters	Half hourly	Electricity
E31	E31 - Unmetered Office Lighting VM8		Unmetered Office Lighting VM8	n of 3 Efergy Meters	Half hourly	Electricity
E32	E32 - Autoclave		Autoclave		Half hourly	Electricity
E33	E33 - Hot Press		Hot Press		Half hourly	Electricity
E34	E34 - Various Workshop Equipment VM4		Various Workshop Equipment VM4	Sum of 7 DBs	Half hourly	Electricity
E35	E35 - Robot (Airbus)		Robot (Airbus)		Half hourly	Electricity
E36	E36 - Thermoplastic L&P-DB		Thermoplastic L&P-DB		Half hourly	Electricity
E37	E37 - Unsubmetered spares VM13		Unsubmetered spares VM13	on these and read 0	Half hourly	Electricity
E38	E38 -				Half hourly	Electricity
E39	E39 -				Half hourly	Electricity

Figure 6.6: CIBSE TM-22 model showing the 37 submeters and virtual meters that were entered.

To inform the TM-22 model, a comprehensive walk around energy audit was undertaken on 18th June 2012 following TSB's Walkthrough template. All areas of the building were visited and particular attention was paid to the electrical equipment and lighting fittings monitored by each individual submeter. This energy audit allowed the creation of 'Design' and 'In Use' estimations for the NCC within the TM-22 model (Figure 6.7). The 'In Use' tab has been modified to include the additional small power equipment that was not anticipated during the building design process as well as the new areas and equipment (see Section 5.5), which have been added since the building was completed.

The TM-22 model allowed the BPE team to compare the actual metered consumption for each submeter to the predicted consumption considering the kW rating of the equipment on the submeter and its anticipated run hours. This can be particularly useful in revealing if certain pieces of equipment on particular submeters are running for inappropriate lengths of time.

TM-22 provides useful data on consumption for various end-uses. These data are displayed in Figure 6.8, showing the typical calculated annual proportions for electricity consumption at the NCC. This Figure shows that a significant amount of electricity is calculated to be used for industrial process loads and the operation of air handling plant.

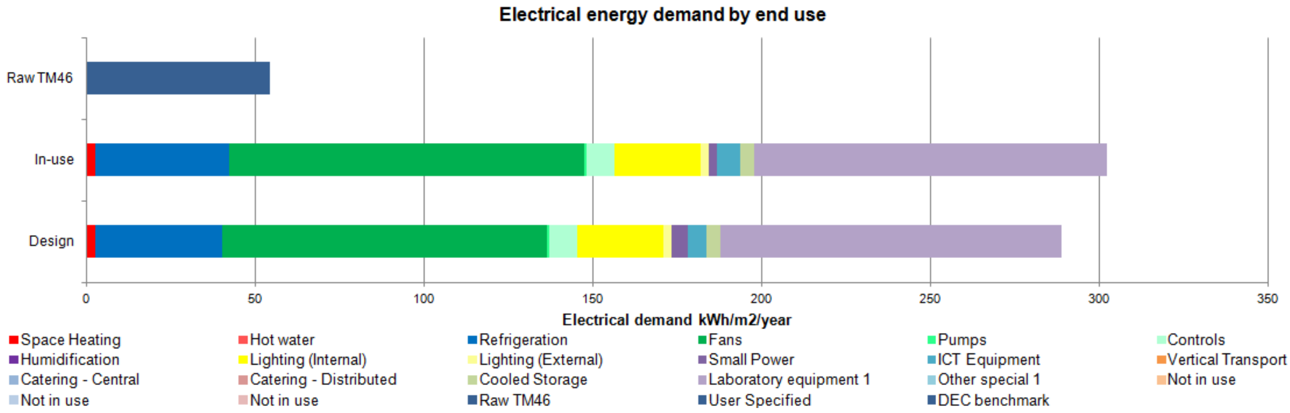


Figure 6.7: TM-22 output which shows the end use electrical demand for both design and in use. Note the increased Fans

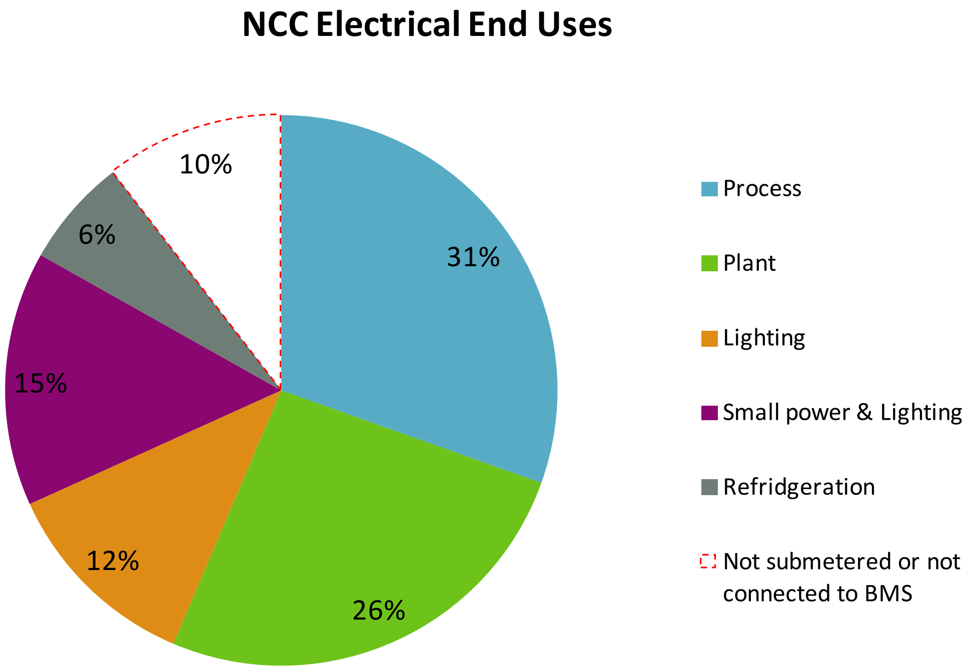


Figure 6.8: TM-22 Electricity end use breakdown for NCC between dates November 2012 and October 2013.

6.4.2 Manufacturing lighting

At the end of the working day during a normal week (19:00), the last person to leave the workshop is tasked with locking up and conducting a check of the workshop area to make sure that no one else is still present. They will then turn lights off using the manual switch (Figure 2.1), and leave through the main doors. As can be seen from the weekly electricity profile shown in Figure 6.9, this process is regularly carried out. However, Figure 6.10 shows the weekly electricity profile for the following week, which indicates that occasionally this process is not followed and that lights are left on overnight. Analysis of the energy data over the course of the BPE study has revealed that there is a 10% chance that these lights will not be switched off at the end of the day and will remain on overnight

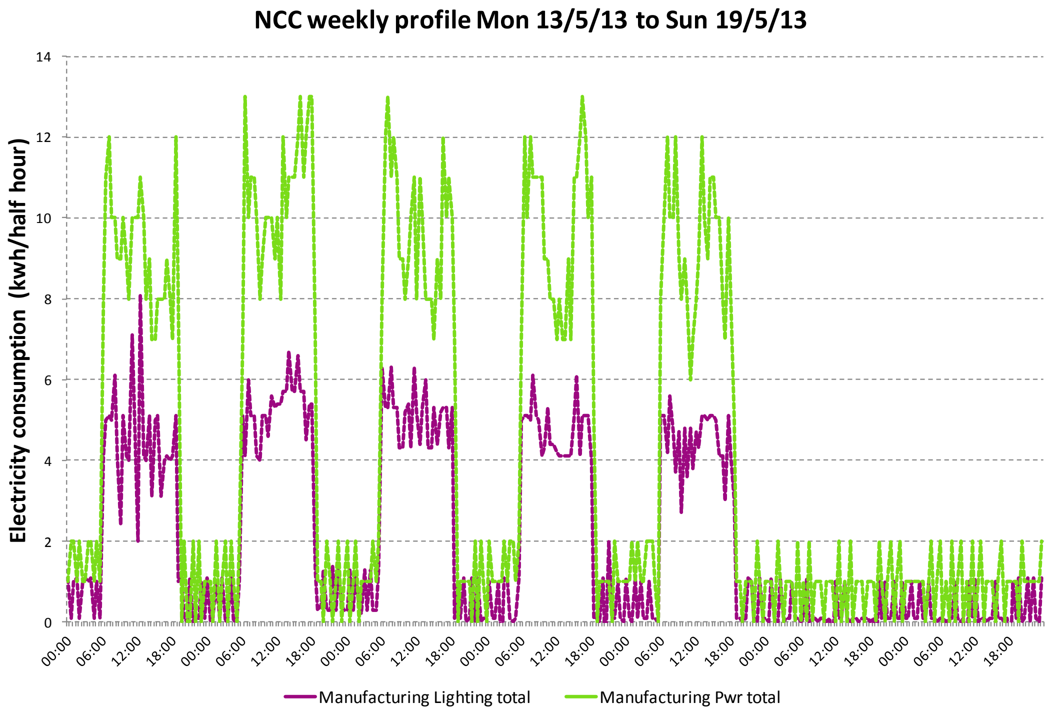


Figure 6.9: NCC - Weekly electricity profile for 13th May 2013 to 19th May 2013 showing manufacturing lighting and manufacturing power submeters consumption.

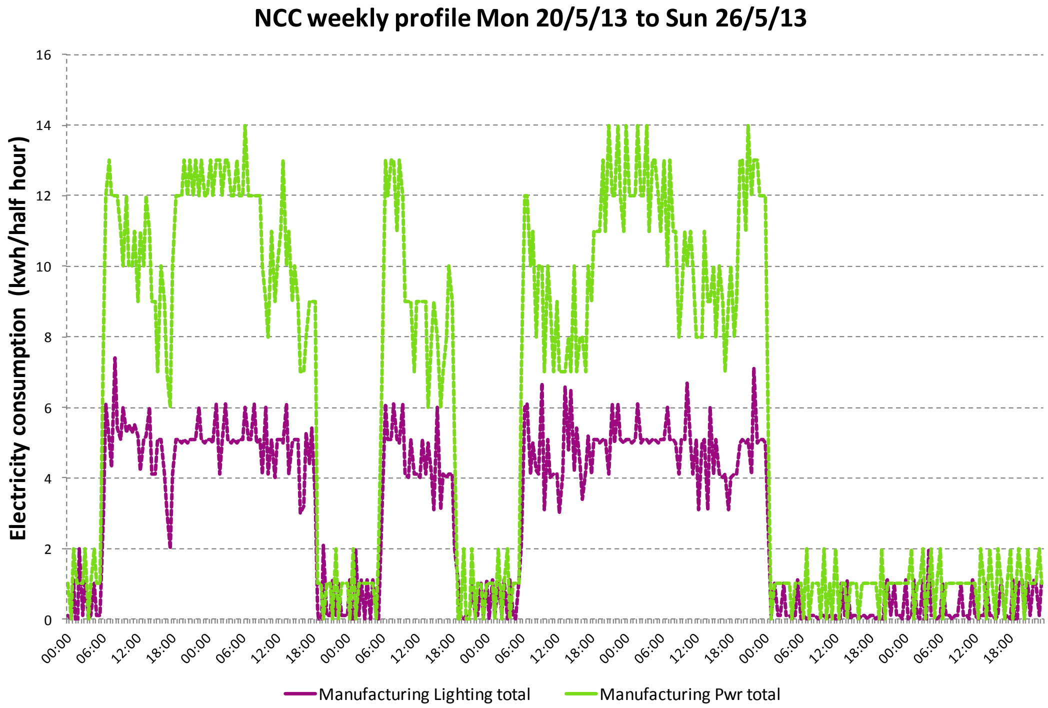


Figure 6.10: NCC - Weekly electricity profile for 20th May 2013 to 26th May 2013 showing manufacturing lighting and manufacturing power submeters consumption.

Examining the electricity consumption weekly profiles for the virtual submeters 'manufacturing lighting' and 'manufacturing power' (shown in Figures 6.9 and 6.10), it can be seen that they follow each other very closely. In fact, it is likely that the manufacturing lighting and manufacturing power virtual meters both actually represent lighting circuits. There seems to have been some confusion in the labelling of these submeters during commissioning. Discussions with the FM during a site visit (15th October 2013) confirmed that the light switch is the only control that is regularly used at 19:00 and that there is no common 'kill' switch for workshop appliances. This can be confirmed by looking at Figure 6.11, which indicates that the combined load of the virtual meters would be around 36 kW. This matches the total installed load for the workshop lighting. Consequently, it is concluded that 'manufacturing power' should be re-labelled as 'manufacturing lighting 2'.

Figure 6.9 shows the weekly profile for only the manufacturing lighting submeter for the period Monday 13th May 2013 to Sunday 19th May 2013. This shows that the daylight dimming is having an effect with the peak load reducing during the day in the region of around 60%.

The issues with part of the submetering for the main workshop lighting being incorrectly labelled as 'Manufacturing Power' and presented as such in the BMS front end has been described above. Analysis of the TM-22 model clearly shows this discrepancy (Figure 6.11), where the in-use consumption (predicted by TM-22) for the submeter Manufacturing Lighting is greater than its actual metered consumption by a factor of around 2. Conversely the submeter Manufacturing Power shows a large actual metered consumption but no prediction from TM-22. Here it should be noted that the metered consumption for both submeters combined is greater than the in-use consumption (predicted by TM-22) for the submeter Manufacturing Lighting. As the rating of the installed lamps on this circuit was verified during a site visit, this indicates that the lighting is operational for longer than the TM-22 model suggests, which should be Monday to Friday 07:00 until 19:00.

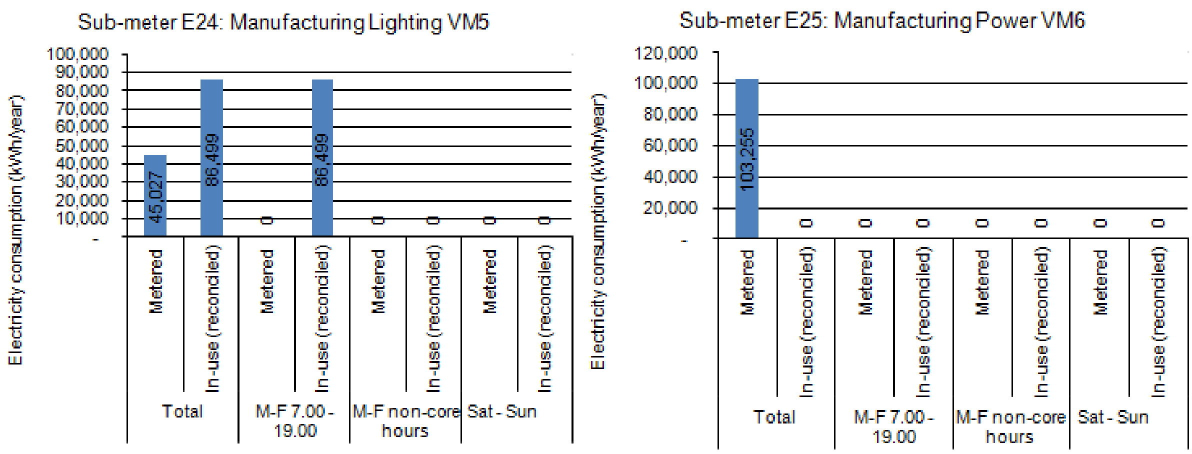


Figure 6.11: Submeter reconciliation with TM-22 outputs for Manufacturing Lighting and Manufacturing Power.

6.4.3 External lighting

Analysis of the submeter reconciliation for External Power & Lighting indicates that the external lights at the NCC may be being left on for longer periods than the TM-22 model suggests, which should be no more than 12 hours per day (Figure 6.12).

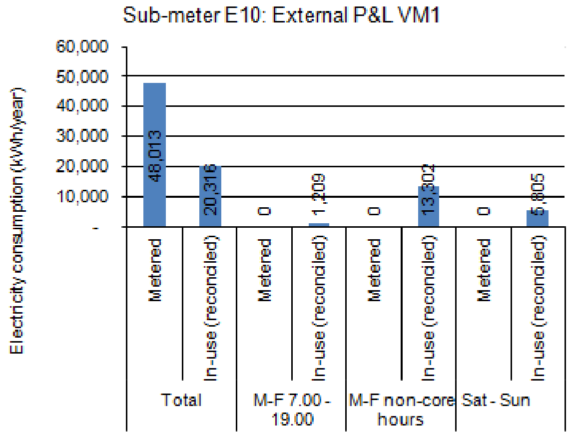


Figure 6.12: Submeter reconciliation TM-22 outputs for External Power and Lighting.

6.4.4 Process loads

Although many of the process loads at the NCC are separately submetered, a large proportion are not adequately connected to the BMS. Figure 6.13 shows an example, in which the Hot Press, according to the TM-22 model based on its load and expected run hours, is likely to be consuming a significant amount of electricity, However, the BPE team was unable to compare this to any metered consumption as the submeter is not communicating correctly with the BMS.

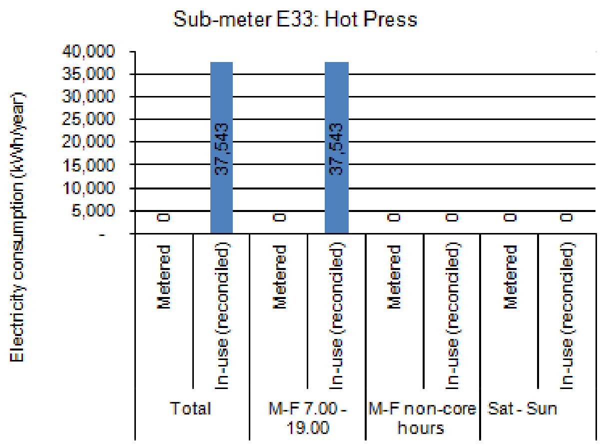
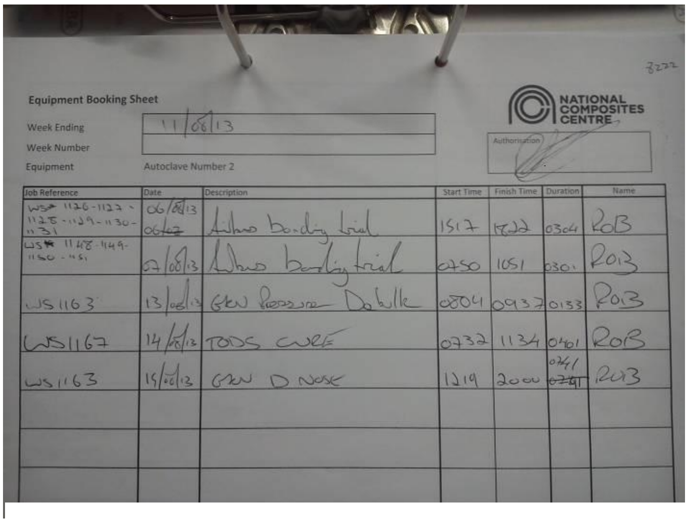


Figure 6.13: Submeter reconciliation TM-22 outputs for the Hot Press

6.4.4.1 Small autoclave booking

The small autoclave ('Autoclave') does not have as sophisticated a computer operating system as the large autoclave and time spent using it is recorded through manual booking sheets (Figure 6.14). Although data were patchy, the BPE team compared some of the recorded times against submetered electricity consumption and this showed that they matched up closely (Figure 6.15).



Equipment Booking Sheet

Week Ending: 11/08/13

Week Number:

Equipment: Autoclave Number 2

NATIONAL COMPOSITES CENTRE

Authorisation

Job Reference	Date	Description	Start Time	Finish Time	Duration	Name
WS 1126-1127-1128-1129-1130-1131	06/08/13	Airbus bonding trial	1517	1822	0304	ROB
WS 1148-1149-1150-1151	07/08/13	Airbus bonding trial	0750	1051	0301	ROB
WS 1163	13/08/13	GKN Pressure Doublle	0804	0937	0133	ROB
WS 1167	14/08/13	TODS CURE	0732	1134	0401	ROB
WS 1163	15/08/13	GKN D NOSE	1219	2000	0741	ROB

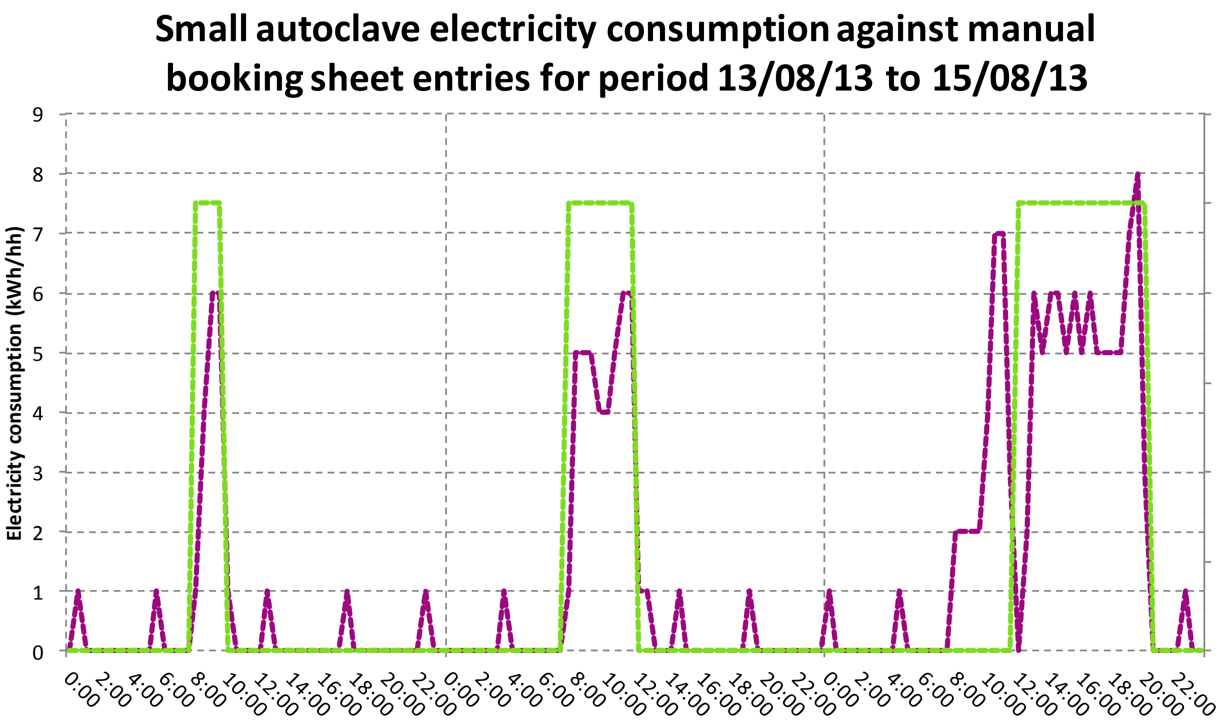


Figure 6.15: Autoclave (small) electricity consumption against booking times manually recorded over a 3 day period. The green line indicated the period this was booked; the purple line indicates the electricity consumption.

6.4.4.2 Nitrogen plant & Autoclave chiller

The NCC contains plant which is capable of extracting nitrogen from the atmosphere and storing it on site. The process of capturing nitrogen from the atmosphere is highly energy intensive. Use of the Nitrogen plant is associated with use of Autoclave1. Autoclave1 needs to be cooled after use and energy consumed for this is associated with the Autoclave Chiller. Figure 6.16 shows the electricity consumption for Autoclave1, Nitrogen Plant, and the Autoclave Chiller. Note the spiking of Autoclave1 and Nitrogen plant and the constant base load of the Nitrogen plant. Investigation revealed the latter to be associated with trace heating in pipes and pumps.

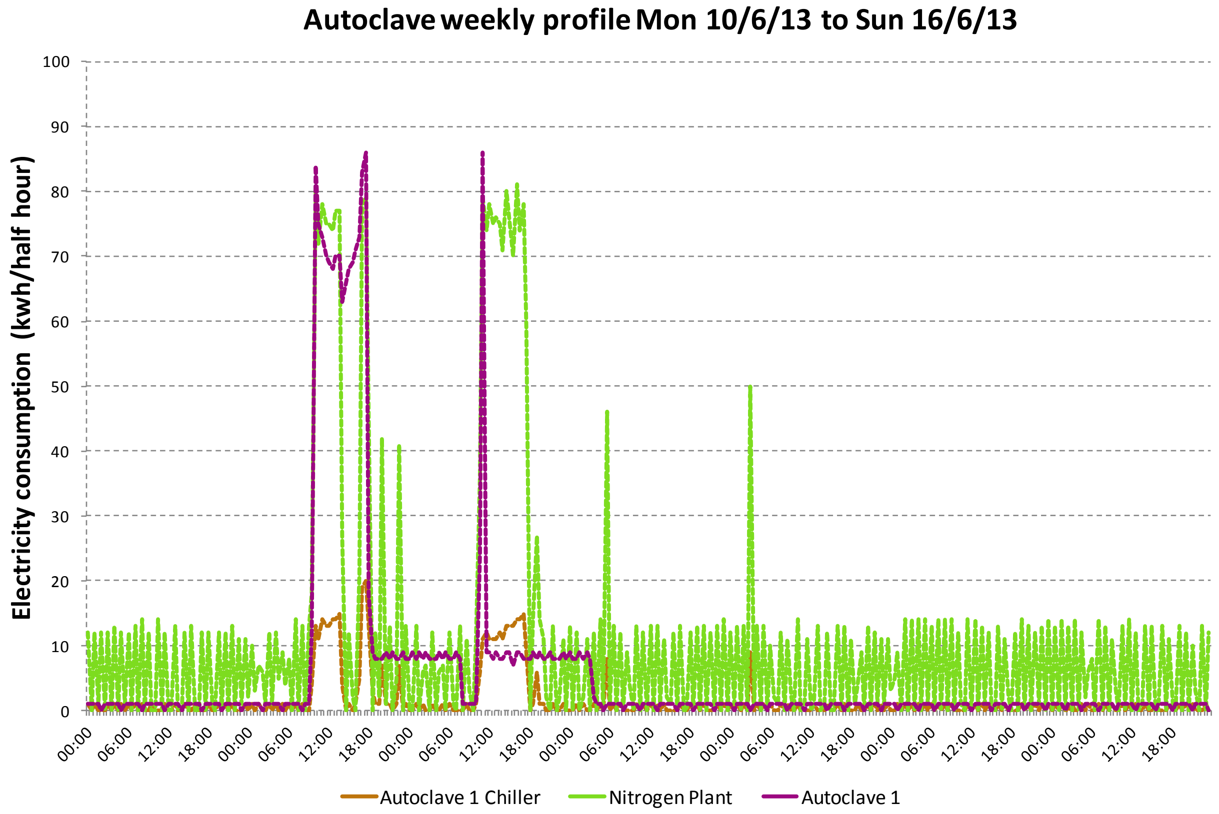


Figure 6.16: Autoclave1 related submeter electricity consumption over a week long period.

6.4.4.1 Large Autoclave

The financial cost of running Autoclave1 during the curing process is difficult to calculate due to its inherent variability. Autoclave1, Nitrogen Plant, and Autoclave Chiller together represent 18% of annual electricity demand. Therefore, the annual cost for electricity of operating the large autoclave is somewhere in the region of £47,000. The gas submetering indicates that the two autoclaves use 6% of the annual gas demand, but does not allow separation between them. Due to their relative sizes, a conservative estimate would be that 4% of annual gas is attributable to the larger, Autoclave1. This means that the annual cost for gas for Autoclave1 is somewhere around £2000.

The 30 minute electricity consumption data indicate that the large autoclave demands an average of around 160 kW when in operation. The Nitrogen plant operates after the curing process to replenish the consumed nitrogen and its load varies between 20 kW to 160 kW. As such, it is impossible to attribute a particular level of electricity consumption to the time taken for Autoclave1's operation. However, as the Nitrogen Plant consumes more electricity annually compared to Autoclave1 (11% to 6% respectively), a conservative estimate would be that it would demands an average of around 160 kW in operation. Autoclave Chiller is used to cool the internal temperature of the Autoclave1. Again, due to the disparity in its operating time in comparison with Autoclave1, it is difficult to associate exact consumption figures with it. However, the 30 minute data indicate that it demands an average of around 30 kW when in operation. Approximate electricity consumption costs for Autoclave1 per hour are given in Table 6.2.

Table 6.2: Approximate electricity consumption costs for Autoclave1 per hour.

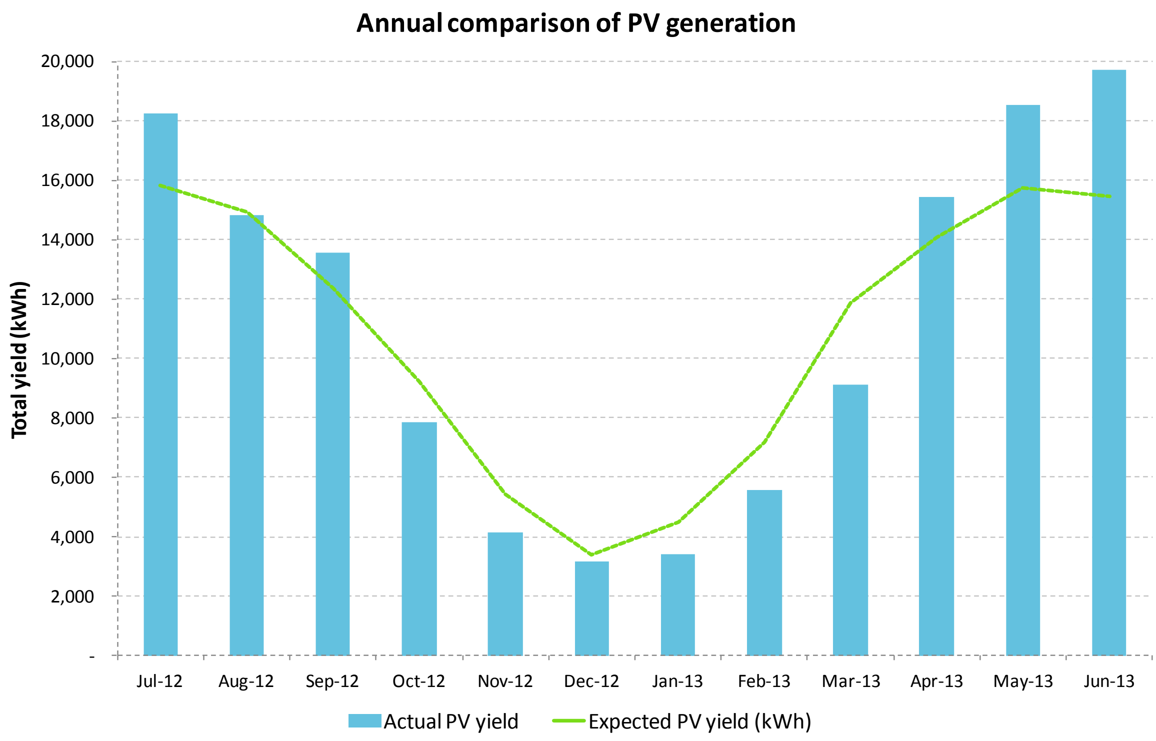
Autoclave component	Electricity average demand (kW)	Cost if used between 17:00-19:00 (£)	Cost if used at other times (£)
Autoclave1	160	£36	£15
Nitrogen plant	160	£36	£15
Autoclave chiller	30	£7	£3
Total	**350**	**£79**	**£33**

Based on these approximate calculations (and factoring in the variable pricing for electricity between 17:00 and 19:00 at the NCC) a typical 12 hour curing process would cost about £490 excluding gas consumption.

6.4.5 PV generation

The NCC has a 138 kWp south facing PV array installed on the workshop roof. The system was installed by a specialist sub-contractor. The original design performance target was an annual output of 130,000 kWh with approximately 67,000 kWh of that to be used on-site. This target was based on the installer's calculations, which were carried out using software package PV*SOL Expert 4.0. There was no Feed in Tariff (FiT) available as the NCC was built with partial European Union public funding and consequently was ineligible.

After Year 1, an analysis was carried out for the PV array. Results showed it produced 133,000 kWh between July 2012 and June 2013 inclusive and is therefore performing around 3% better than predicted (Figure 6.17). However, the PV generation during this period represented only 5.4% of total electricity consumption at NCC. Consequently, very little electricity is actually being exported to the Grid although original design estimates anticipated that 47% would be. Manual reading of the site electricity meters (14th August 2012) indicated that 6% had been exported since the installation of the PV array (18th April 2011). It seems that much of this export occurred when the PV array had been initially installed and the NCC was not yet fully operational (October 2011). Examination of the fiscal electricity data for the NCC suggests that the building only rarely exports now it is operating near to full capacity. However, avoiding the use of grid electricity by onsite generation generally creates a greater cost saving per unit (by avoiding purchasing electricity) than the financial gain would be from exporting the on site generated electricity (i.e. selling to the grid)



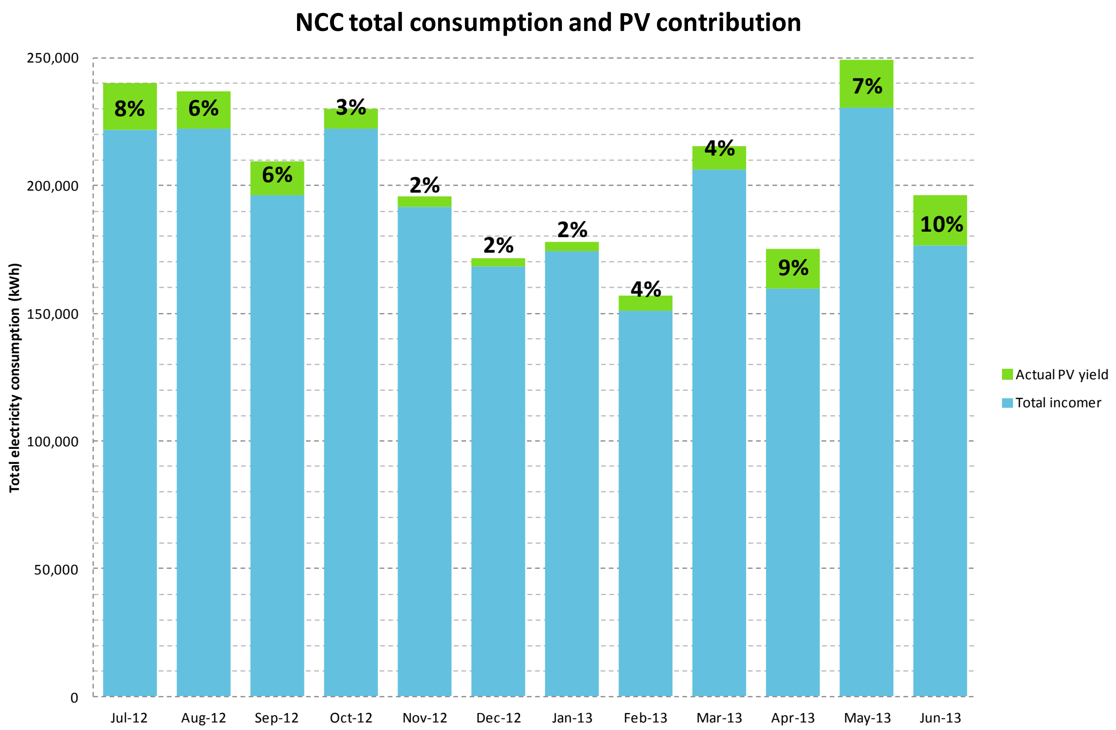


Figure 6.18: Contribution to monthly electricity consumption of PV generation.

The PV array is not separately submetered, although this was required by the M&E Specification. Instead data loggers owned by the PV commissioning specialist collect the hourly electricity generation. The client can then access this data by visiting the installer's secure website. The BPE team regularly downloaded the generation data and manually adjusted it into 30 minute format to allow comparison with the fiscal electricity data and the BMS submeter reports. Typically with PV installations, the PV array is wired into the main incomer with a separate export meter. However, 'string invertors' have been used in the NCC installation, so that the PV is wired directly into the East Busbar. This presents a problem in that it is difficult to reconcile the PV generation with the total loads on the East Busbar.

An inspection by the BPE team of the PV array during a site visit on 3rd December 2013 revealed that the PV panels were fairly dirty (Figure 6.19). This is probably partially due to the construction of the NCC2 immediately adjacent to it. The FM was informed, who said that the panels would be cleaned when construction work for NCC2 has finished and its PV array installed.

Figure 6.19: PV array on roof of NCC. Note the dirt covering the panels which will reduce the performance.

6.4.6 Office small power and lighting analysis

As it was not a requirement of the M&E specification, office power and lighting submeters were not connected to the BMS. It should be noted that in general the submeters for key plant and equipment have been successfully connected to the BMS.

The office areas are split into the following sub areas:

- North Office
- Tenant Office
- East Office
- Ground floor offices (including meeting rooms)

To monitor small power and lighting consumption of these four office areas, temporary 3-phase wireless data monitors were installed. Eight Efergy E1 monitors were installed on the small power and lighting distribution boards for the four areas. Efergy monitors have clip on 'CT sensors' that transmit wirelessly over a relatively short range (around 50 metres) to a monitor (Figure 6.20). Both the monitor and transmitter are powered by standard batteries. Efergy monitors assume a voltage of 240V and calculate the kWh/h consumption based on the recorded current. Data were downloaded from the monitors during regular site visits every few months.

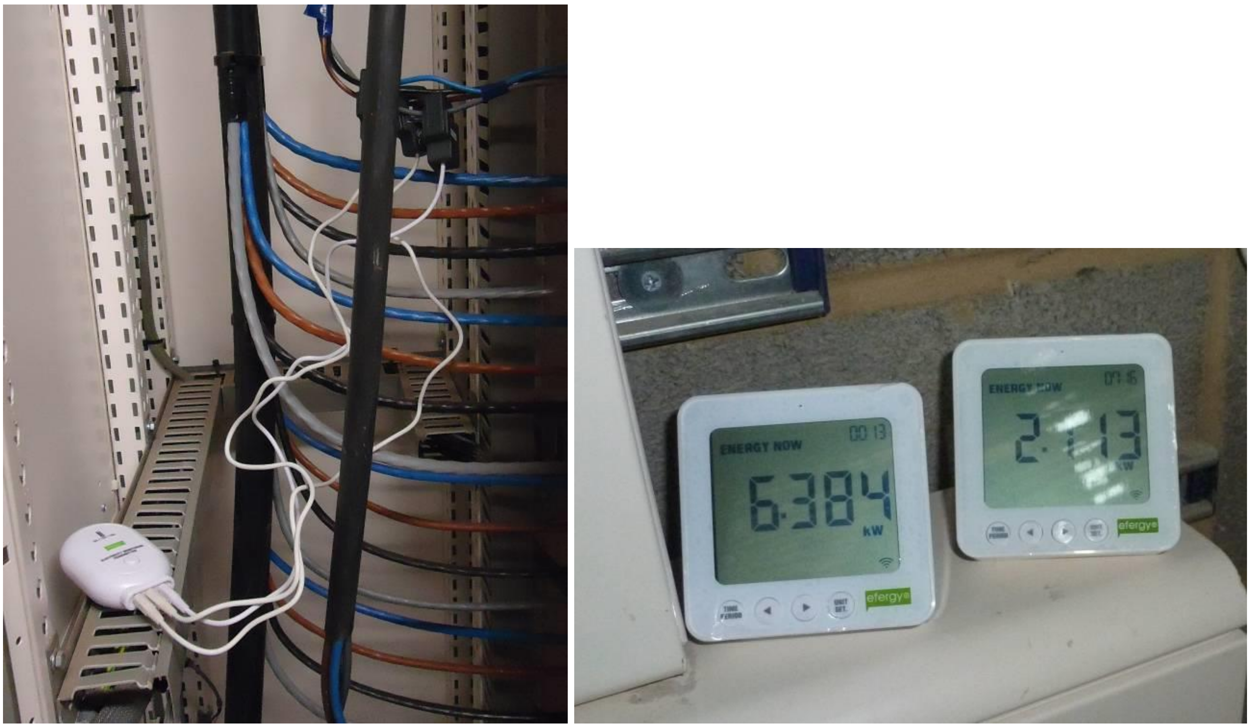


Figure 6.20: Installation of Efergy transmitter (left), note CTs attached to the different supply phases and Efergy monitors (right).

These distribution boards were monitored for a six month period. However, the end result was only four months reliable data due to some problems, highlighting the limitations of this approach. The loggers are essentially designed as single domestic units (although additional CT sensors can enable them to monitor 3-phase circuits). If multiple units are used within one building, they can interfere with one another. A function of the device allows modification of the transmission rate between three separate settings, which can reduce the chance of interference, but when large numbers of units are being constantly used in a small space and are being re-linked this was a likely situation. In this instance, two months of data were lost as a result.

Data gathered using the Efergy monitors were used to establish the typical weekly profiles for the different offices spaces (Figure 6.21). The more intensive electricity consumption that can be seen in the Tenant office is due to the presence of a secure server which is directly connected to the power distribution board.

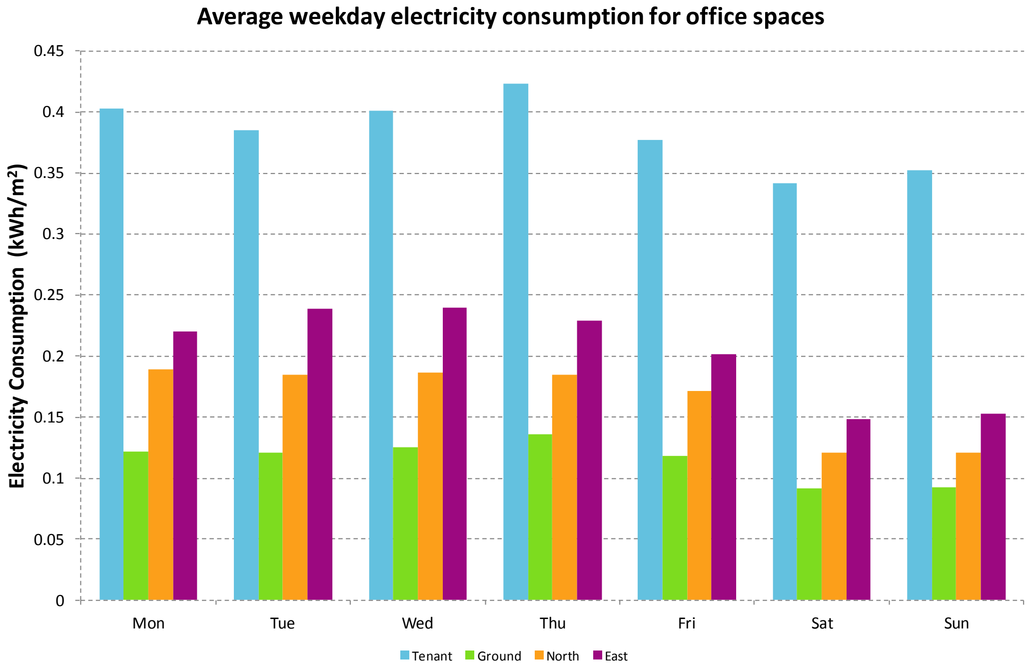


Figure 6.21: Average weekday electricity consumption by area for the 4 office spaces.

Average daily profiles were created for each of the four office spaces (North, East, Tenant, and Ground). Figures 6.22 and 6.23 show the average daily lighting profiles for the East office and the Tenant office respectively. In general, these show that the lights are being well controlled by the PIR sensors for occupancy. However, base loads are present in all profiles indicating that some lighting is left on continuously. Note also the lights turn off earlier on a Friday compared to other working days in the Tenant office. This reflects the tenant company's policy of only working half days on a Friday.

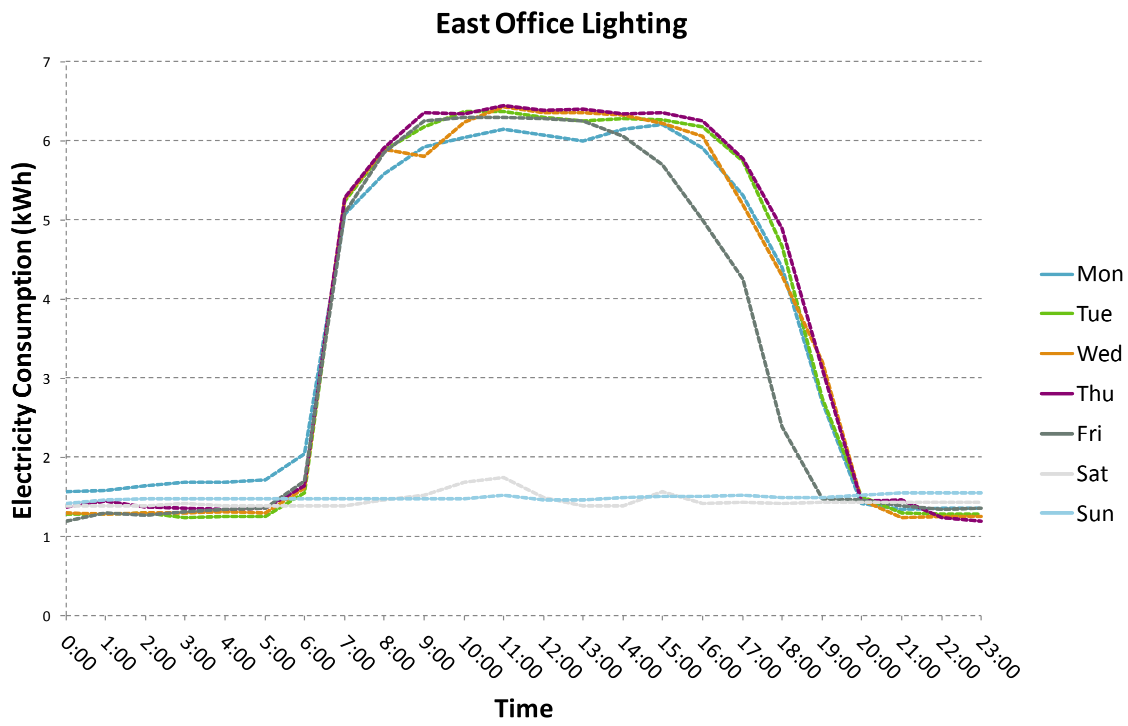


Figure 6.22: Average daily lighting profiles for the East office over a week period.

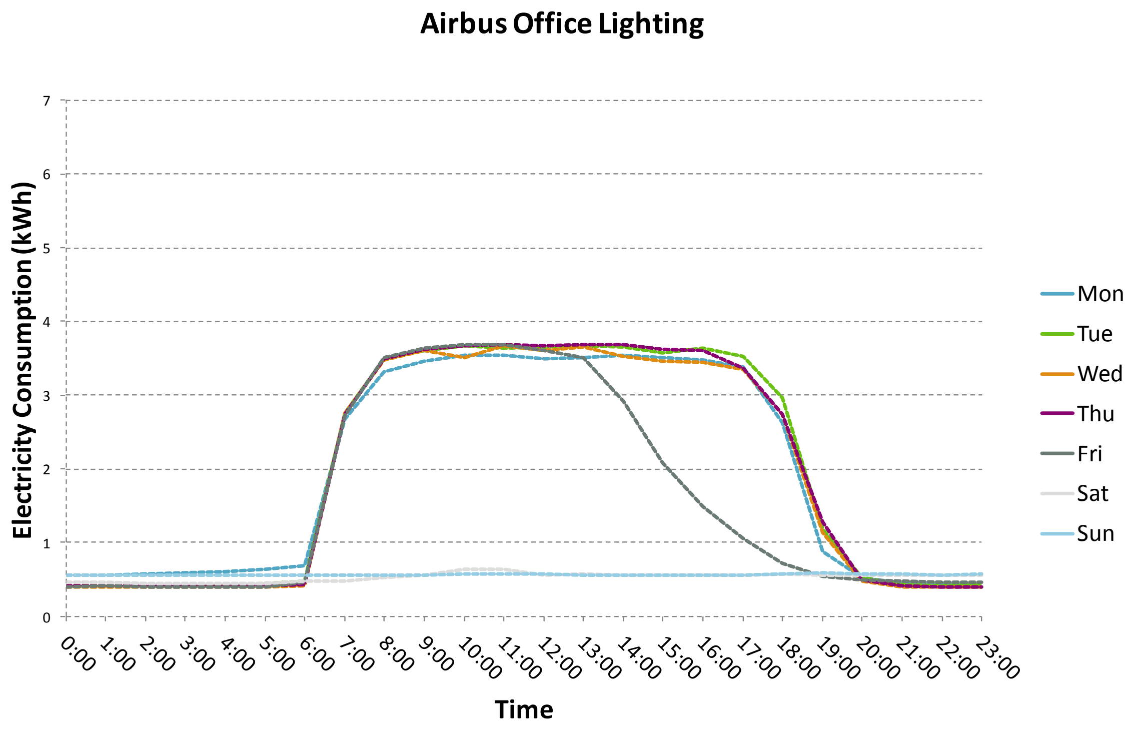


Figure 6.23: Average daily lighting profiles for the Tenant office over a week period.

Figure 6.24 shows the TM-22 submeter reconciliation output for small power electricity consumption and the lighting electricity consumption for the three open plan offices (North, East, and Tenant), as well as the ground floor meeting room and conference areas. Here the TM-22 outputs show that both are over twice as high as the TM-22 model suggests they should be. This indicates that small power equipment and lighting is operational for longer periods than is indicated in the TM-22 model and is an area of potential energy savings.

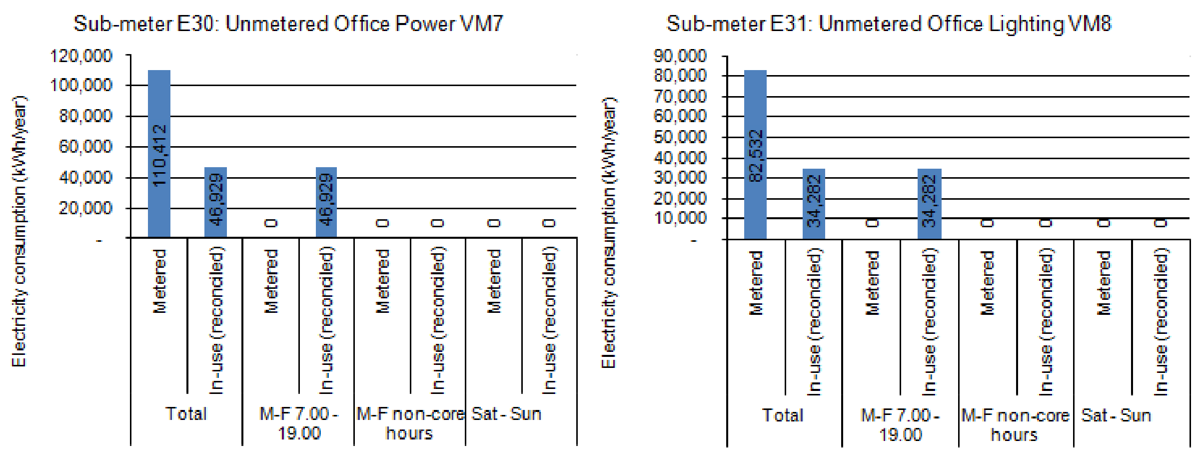


Figure 6.24: Submeter reconciliation TM-22 outputs for Office Power and Office Lighting.

6.5 Gas consumption

One of the limitations with the CIBSE TM-22 methodology is that it does not allow in-depth analysis of submetered gas data in the same way as it does for electricity. Instead, it only provides a simple overview of gas consumption in the building. Therefore, the BPE team used their own analysis software to determine where and when gas was being consumed at the NCC.

Natural gas is used for three purposes at the NCC: space heating, domestic hot water, and industrial processes (i.e. the autoclaves). These three end uses are all separately submetered and connected to the BMS. Figure 6.25 shows the gas meter hierarchy.

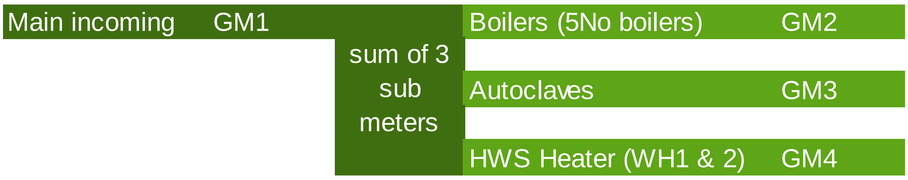


Figure 6.25: Gas meter hierarchy for the NCC.

6.5.1 Gas consumption analysis

The gas submeters GM2, GM3, and GM4 were all analysed as part of the AECOM Smart system. A comparison of the submetered BMS energy reports with the fiscal gas data was carried out. This allowed the BPE team to examine in detail daily and weekly gas consumption profiles for the NCC.

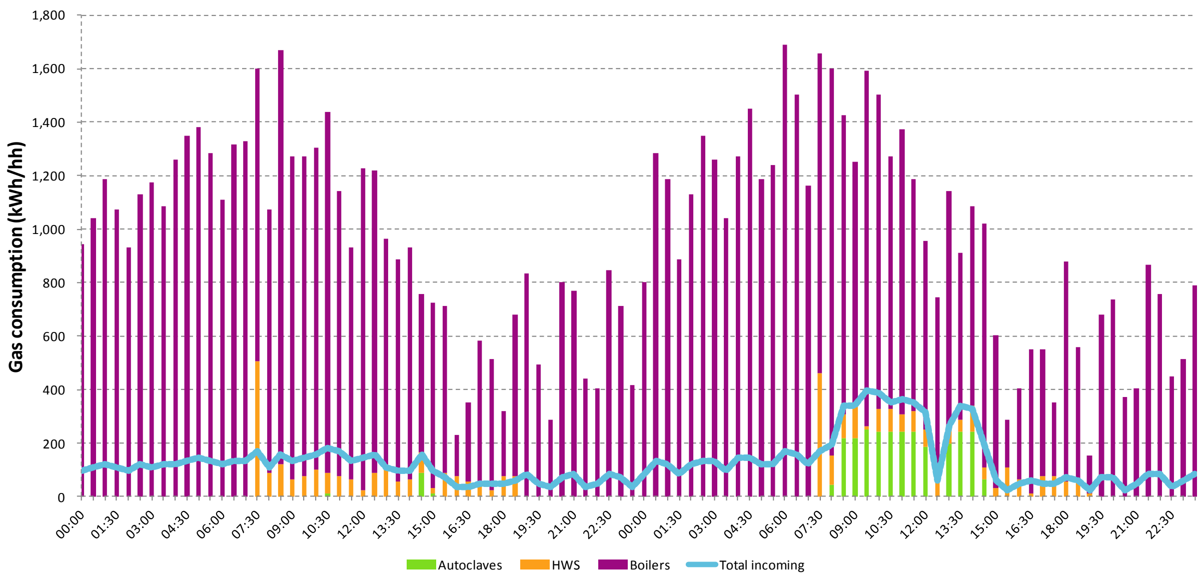


Figure 6.26: Uncorrected gas consumption profile for NCC for Monday 17th June 2013 and Tuesday 18th June 2013, illustrating the metering discrepancy for the HWS and the Boilers.

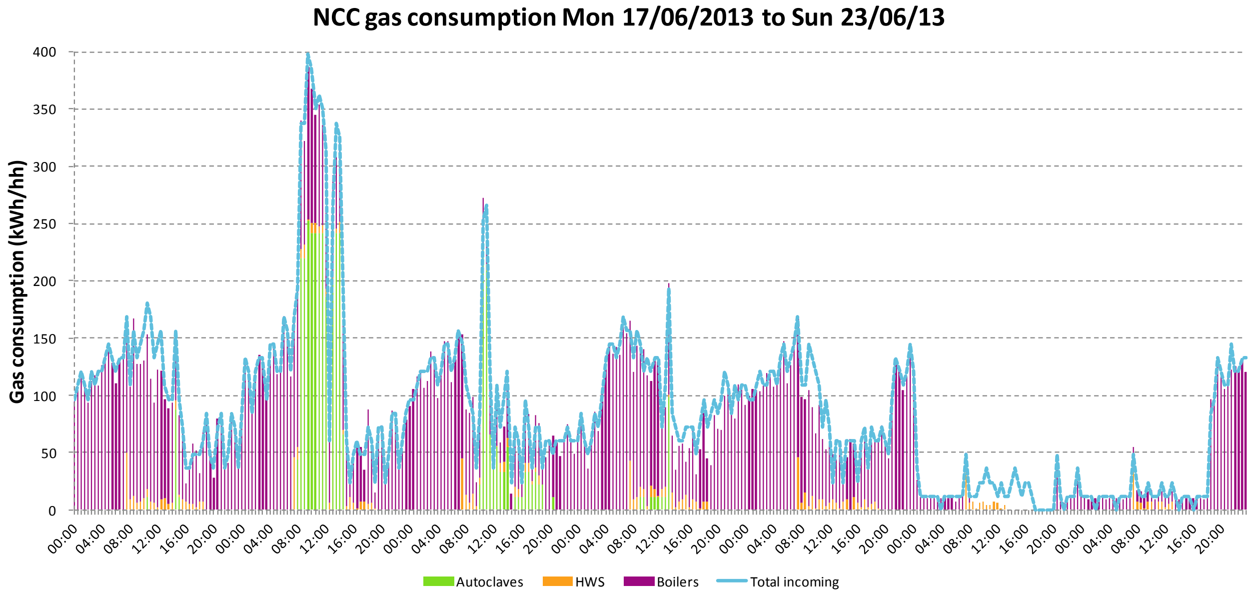


Figure 6.27: Corrected weekly gas consumption profile for NCC between Monday 17th June 2013 and Sunday 23rd June 2013. Note the gas consumption spike when an autoclave was used on the Tuesday.

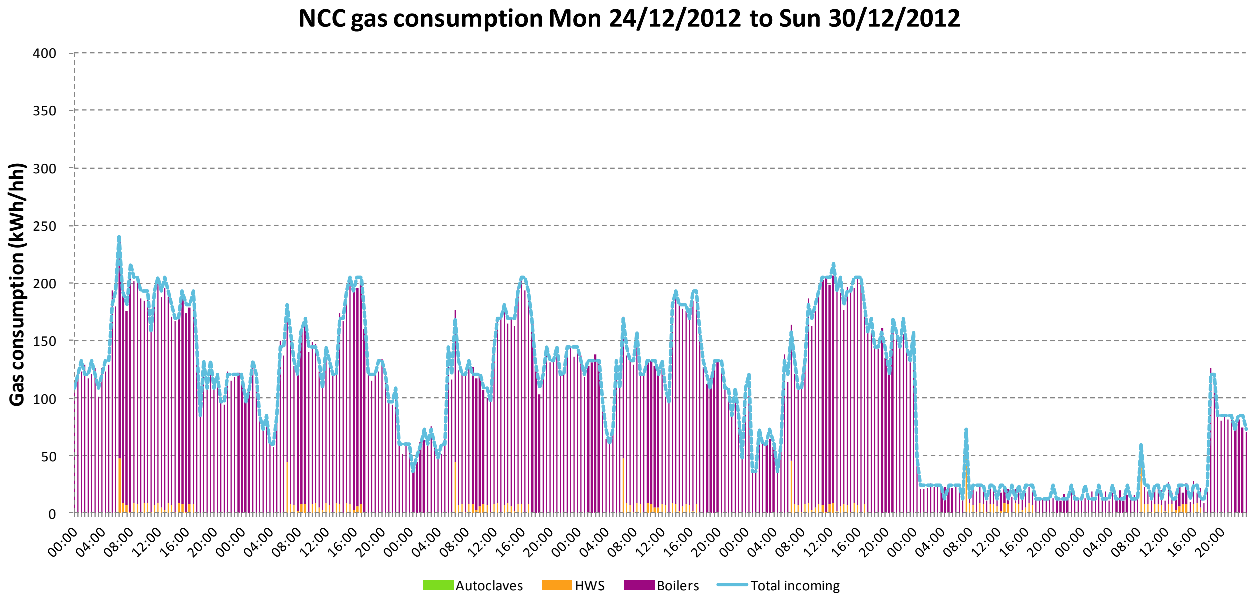


Figure 6.28: Corrected weekly gas consumption profile for NCC between Monday 24th December 2012 and Sunday 30th December 2012. Note the boilers and HWS are operational even though this is a period of zero occupancy.

This analysis revealed that the combined total of the gas submeters GM2, GM3, and GM4 was much greater than the total of the fiscal incomer. Examples of these readings are shown in Figure 6.26. By taking both physical submeter readings and screen shots simultaneously of the BMS, the BPE team were able to show that gas submeters GM2 Boilers and GM4 HWS were both reading a factor of 10 too high on the BMS. GM3 Autoclaves was reading correctly.

It also revealed several operational issues:

- The HWS is heating water on weekends and when the building is not occupied e.g. over the Christmas holiday period.
- Similarly, heating is still being supplied to the NCC when the building is not going to be occupied e.g. over the Christmas holiday period.

Figure 6.29 shows how gas use is split amongst the three end uses during Year 1. Gas used by the boilers accounts for by far the largest consumption.

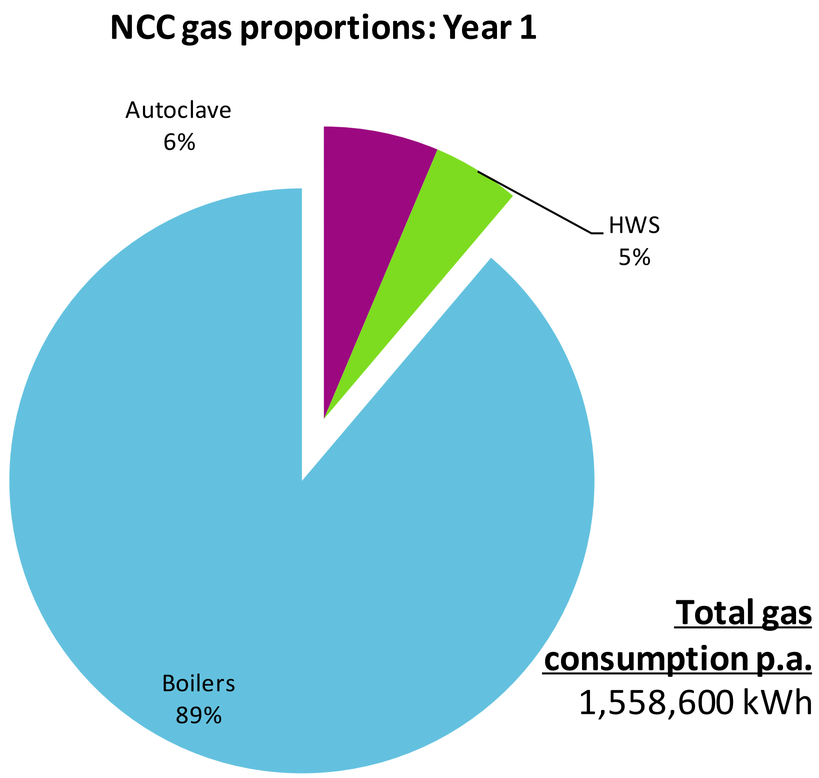


Figure 6.29: Annual proportions of gas consumption at the NCC for each submeter.

A degree day analysis of the gas consumption was carried out for gas consumption at the NCC (Figure 6.30). As can be seen, there is around 75,000 kWh per month of weather independent gas consumption. This is likely to be associated with the DHW for showers and taps. Interestingly, the gas consumption does not seem to strongly correlate with the monthly degree days. Instead it reduces in 'steps', for example November, December and January have similar gas consumption, this then reduces for February and March and reduces further for April, May and June. This suggests that the space heating may be being adjusted on a seasonal timer rather than responding directly to the external temperature.

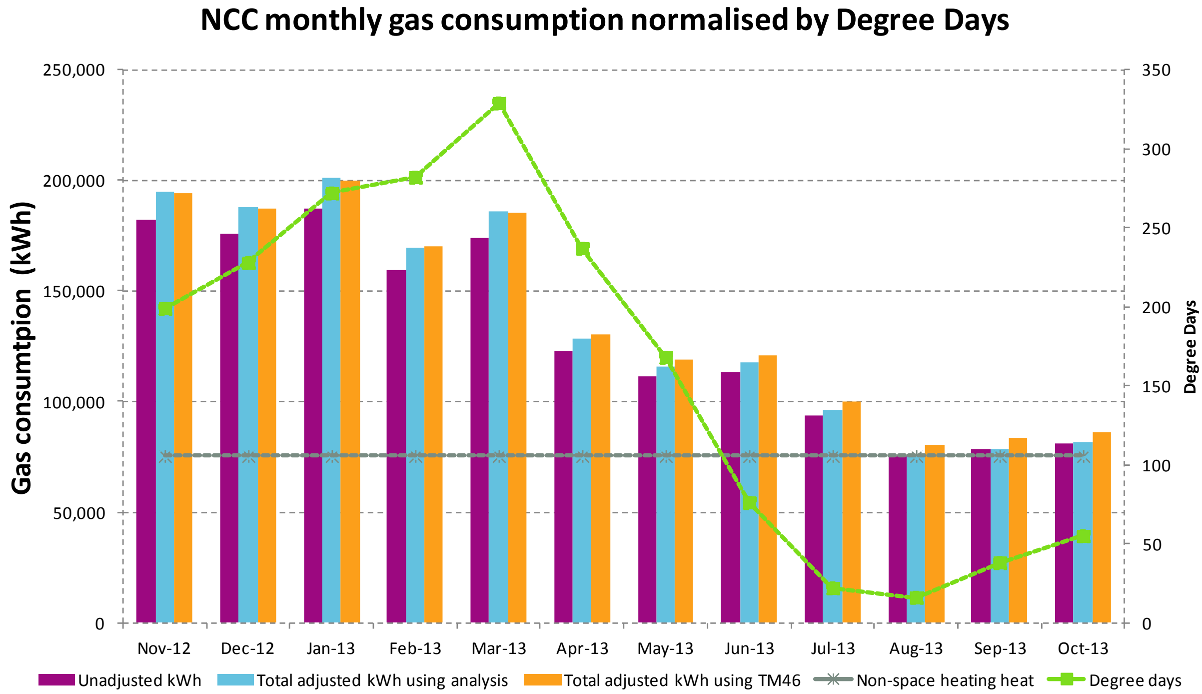


Figure 6.30: Monthly gas consumption at the NCC adjusted for heating degree days.

6.5.2 Supply and extract temperatures for main workshop AHU

Figure 6.31 shows a BMS interface screen shot of the AHU for the main workshop. Analysis was carried out on the supply and extract temperature for the Main Workshop's AHU when it was noted during a site visit that the workshop felt very warm. It was also realised that the temperature setpoint for the supply air has been retrospectively set to 30°C. This was not the case at the start of the BPE study, so there seems to have been a change made at some point during the study. Discussions with the FM did not reveal why this set point had been increased.

To further examine the 30°C setpoint for the Main Workshop, the supply and return temperatures for the AHU were examined. Although the BMS was not configured to save data logs of the supply and extract temperatures, the BPE team were able to manually download 15 minute data for the previous 24 hours by remotely interrogating the BMS. This was systematically carried out for slightly over a week from the 12th December 2013 to the 21st December 2013. However, due to the non-standard nature of this procedure some data were lost through software error.

Figure 6.32 shows the supply and extract temperatures for the Main Workshop AHU. It shows that the space temperature in the Main Workshop is being tightly controlled around 21°C. When the extract temperature reaches this point the supply temperature drops off sharply. When the space temperature in the main workshop cools to around 20°C the supply temperature rapidly increases to 30°C in an attempt to bring the space up to temperature as quickly as possible. It should be noted that this is occurring all through the night, even though the building is unoccupied between 19:00 and 07:00.

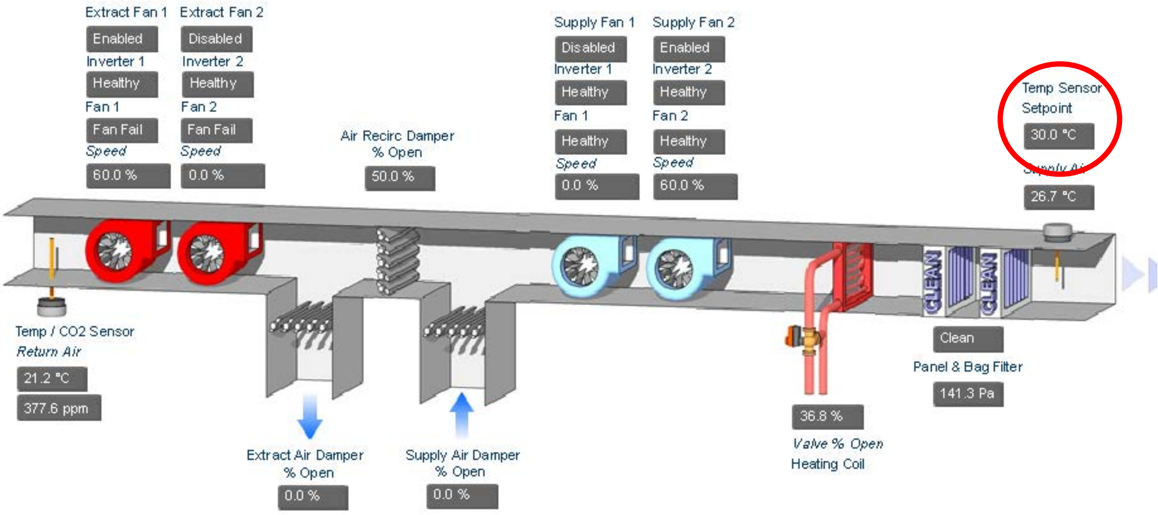


Figure 6.31: Screen shot of main workshop AHU as it appears on the BMS. Note the 30°C temperature set point for the supply air and that the supply air is at 26.7°C.

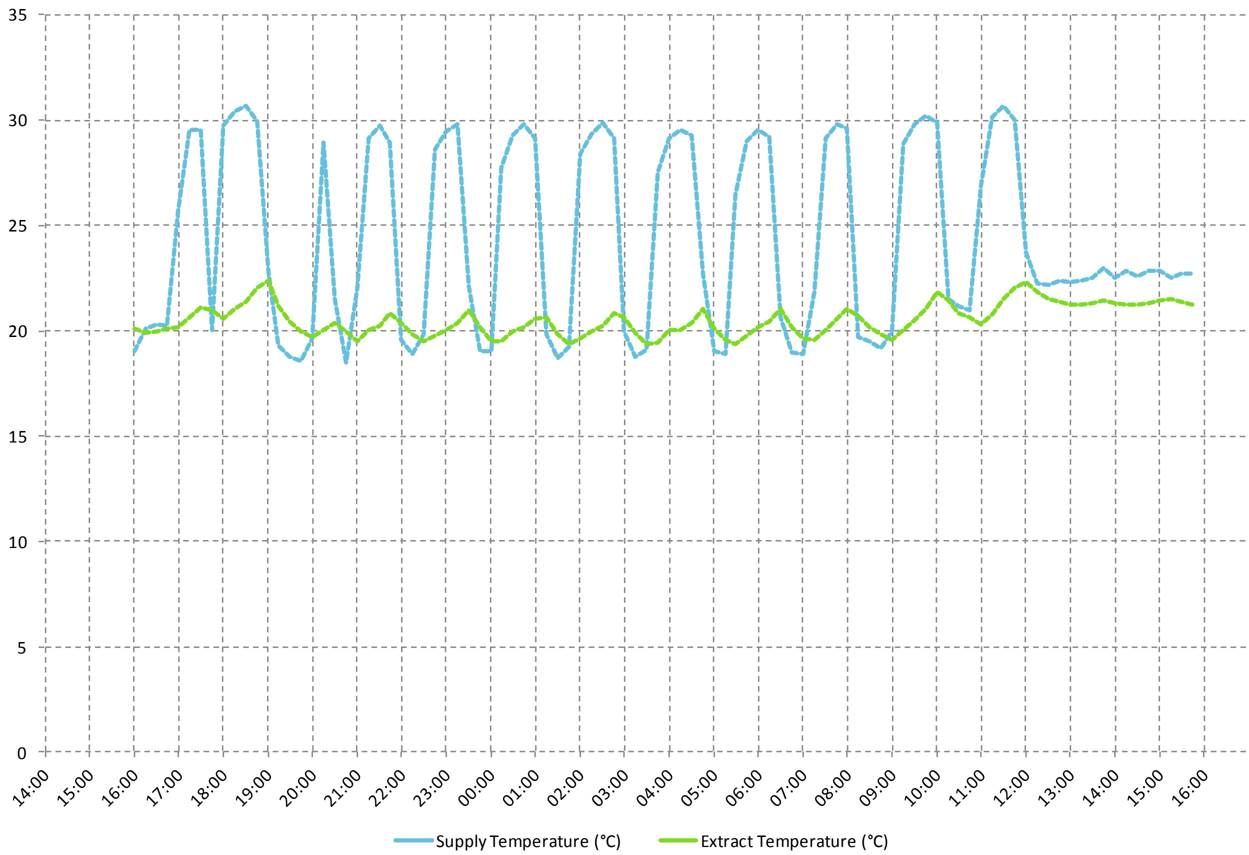


Figure 6.32: Supply and extract temperatures for Main Workshop AHU from Thursday 19th December 2013 to Friday 20th December 2013.

Figure 6.33 shows the supply and extract temperatures for the Main Workshop AHU over a weekend. It can be observed that the close control around 21°C does not occur over a weekend. However, on a Sunday at 18:00, the supply temperature increases to 30°C and the main workshop temperature is brought up to 21°C. This is also seen in analysis of the energy data. In this situation the rapid cooling and subsequent heating that occurs during a typical weekday is not seen. This could be a result of the shutter door to the main workshop which is used for deliveries. During weekdays, the shutter door is regularly left open for long periods leading to heat loss, but is closed over the weekend.

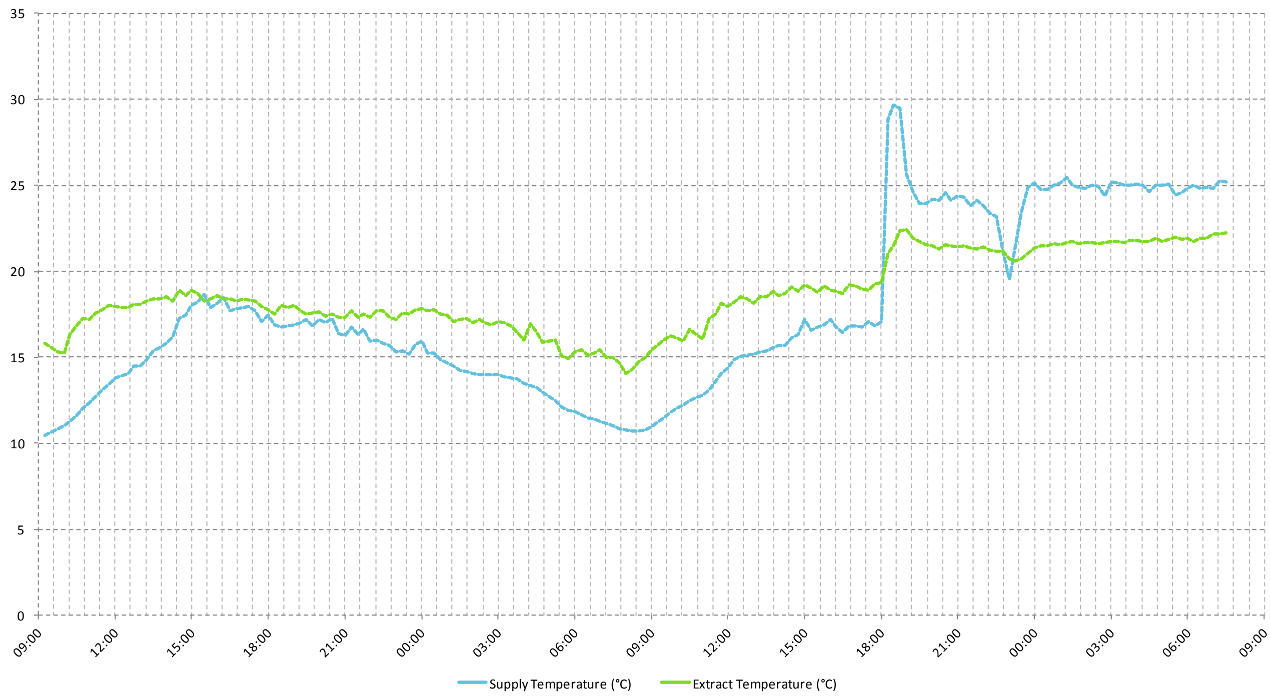


Figure 6.33: Supply and extract temperatures for Main Workshop AHU from Saturday 14th December 2013 to Monday 16th December 2013.

There are clearly potential energy savings in the operation of the main workshop AHU as follows:

- The temperature set point could be reduced so that temperature in the Main Workshop is not being maintained around 21°C.
- The 'deadband' for space temperature could be widened so that the space is allowed to cool below 20°C before heating resumes.
- Although heating is not carried out over the majority of the weekend, it does begin at 18:00 every Sunday. This could be adjusted to the early hours of Monday morning without any significant impact on thermal comfort.
- Operation of the main workshop shutter door could be examined more closely to see if there is potential to encourage the users to keep the door shut more regularly during spring, autumn and winter.

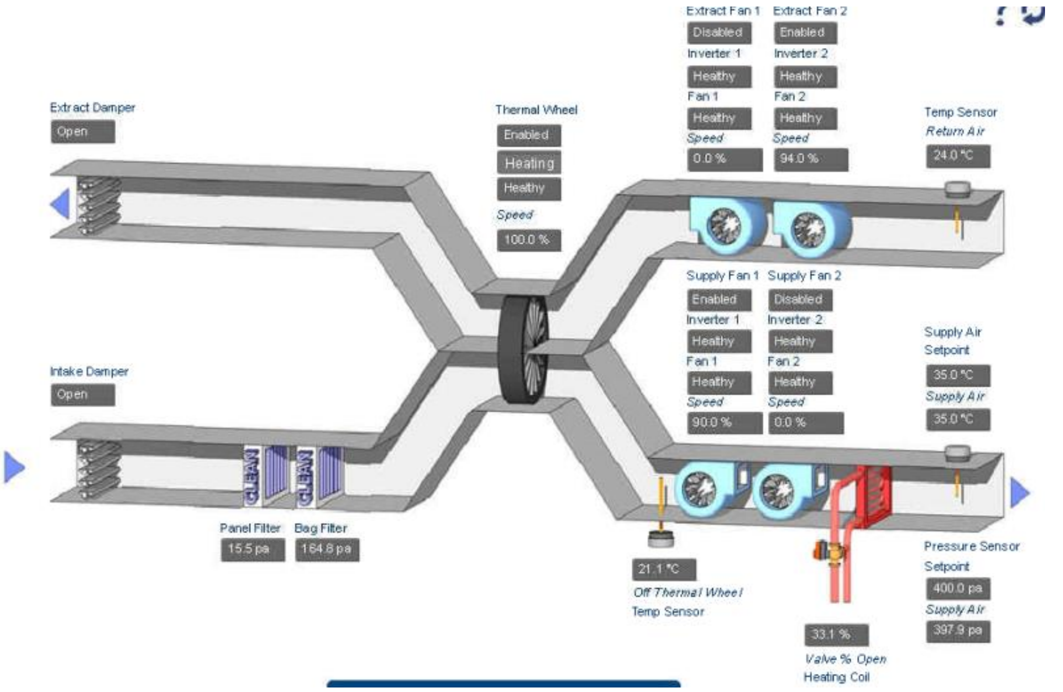


Figure 6.34: Screen shot of East Office AHU as it appears on the BMS. Note the thermal wheel.

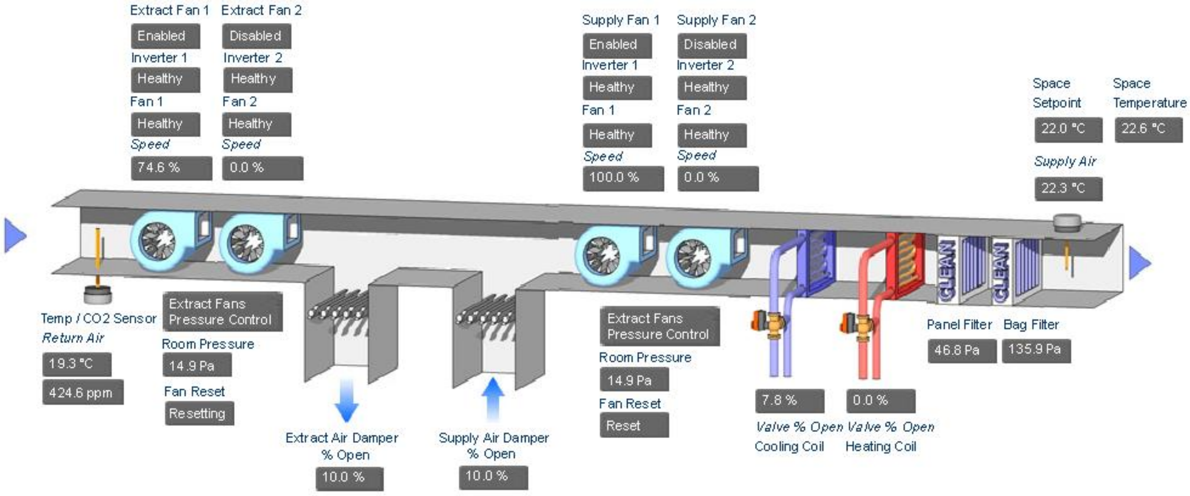


Figure 6.35: Screen shot of the Clean Rooms' AHU as it appears on the BMS. Note the heating and cooling coils.

AHUs for the three office spaces have thermal wheels and heating (but no cooling) coils (Figure 6.34). Cooling is achieved through automated windows which are controlled by the BMS and open when certain temperature and CO_2 conditions are met. (However, see Section 4.3.3.1.)

The AHUs for the Clean Room, ATL/AFP Rapid deposition, and the Ply Cutter laboratory all have heating and cooling coils (Figure 6.35). These three areas were designated as Class 8 clean rooms during the design process, so need to be carefully controlled for temperature and humidity and kept positively pressurised.

6.6 Benchmarking

The practice of comparing energy consumption of buildings against benchmarks is well established although there is awareness that some of the available benchmark data are either outdated or difficult to apply with ease, particularly when the building in question has very specialised uses. The NCC is an unusual and perhaps even unique building in terms of energy end uses. Naturally, it has many of the end uses of other buildings (such as lighting, heating and so on), but it also has a large number of specialist end uses (such as the industrial process loads) which make identifying a suitable benchmark difficult. Nonetheless, an analysis of the Year 1 energy data has been carried out and is presented below.

In an attempt to make the comparisons more meaningful, more than one benchmark has been used and a number of adjustments to both benchmarks and actual data have been made – these are clearly set out and a rationale for each adjustment given.

The benchmarks used for the comparison are from CIBSE Guide F and CIBSE TM46. The specific benchmarks are:

Source	Benchmark
Guide F	Office – Type 2 (Open plan, naturally ventilated), Table 20.9 General Manufacturing – Type 8, Table 20.18(b)
TM46	Category 1 - General Office Category 27 – Workshop

The NCC has an extensive area of office accommodation on the first floor which might be considered unusual in either a general manufacturing or workshop environment. To account for this, constructed benchmarks have also been used which apportion energy by combining Type 2 office and General manufacturing benchmarks in the case of Guide F and General Office and Workshop benchmarks in the case of TM46.

6.6.1 Adjustments to benchmarks

Comparing the NCC's energy performance to other buildings is problematic as there are few buildings similar in design and use to the NCC. To make the process as meaningful as possible, benchmarks from CIBSE Guide F (Offices) have been adjusted based on treated floor area rather than gross floor area. The adjustment factors given in Guide F have been used (Figure 6.36).

The analysis of the total building shows that although the fossil fuel use is comparable, the electricity consumption is significantly more than both the published and constructed CIBSE Guide F benchmarks. This may be expected due to the high industrial process loads present.

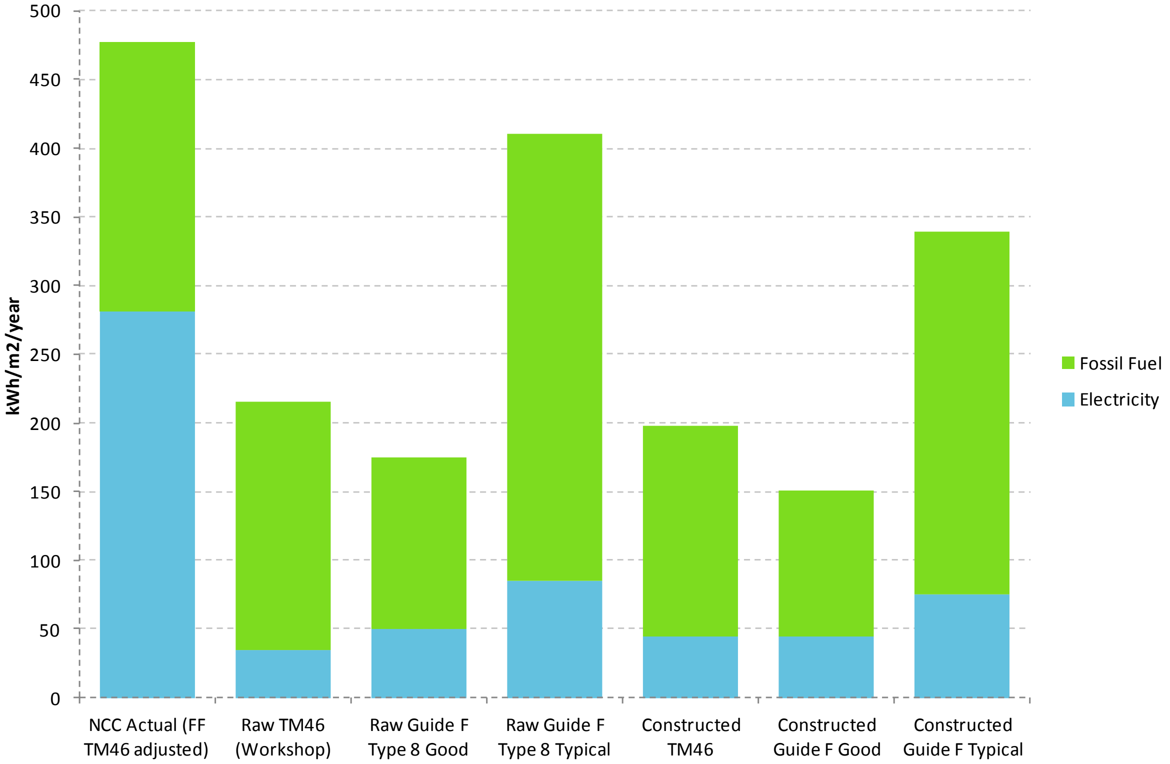


Figure 6.36. Total energy intensity for NCC against published and constructed benchmarks.

6.7 Discussion and key findings

The NCC is consuming about five times more energy than the Energy Performance Certificate (EPC) indicated. This is may be anticipated, as the NCC has very high industrial process loads that are not taken into account during the EPC calculations.

The PV array is generating about 3% more electricity than the initial design estimates. However, it has only exported around 5% of its generation, as opposed to the 47% that was initially estimated. Again, this is due to the high amount of 'unregulated' electricity being consumed on site. The PV array is also becoming dirty (especially with the adjacent construction of the NCC2), so its performance may drop.

In hindsight, the decision to not separately submeter the PV array and instead to rely on the data logger from the installer was disadvantageous, as this has led to negative readings on other submeters in the building. Renewable generation systems should always be separately submetered in the building.

Around 18% of the NCC's electricity consumption is not connected to the BMS. This is either because it was not seen as necessary during the design process, i.e. small power or lighting for the offices areas, or there are connection problems, i.e. the majority of the industrial process loads.

The CIBSE TM-22 analysis revealed possible wasted electricity with the external lighting being left on for longer periods than necessary and small power appliances in the office areas being left on out of hours.

The HWS is heating water on weekends and when the building is not occupied, e.g over the Christmas holiday period and space heating is being provided when the building is not going to be occupied, e.g. over the Christmas holiday period. Improved building management could easily rectify these issues. (However, professional advice would also need to be sought by the client concerning the implications for the control of Legionella.)

The Main Workshop is being maintained at a higher than necessary temperature set point of 21°C and has a narrow 'deadband' of 1°C. This is a very large heated volume to maintain at this temperature and this will have a significant cost in terms of energy use. There are also indications that the BMS optimiser is delivering heating to the Main Workshop earlier than needed on a Sunday, meaning that AHUs are running inappropriately. This is explored in more detail in the following Section.

Benchmarking of the NCC shows that although its energy consumption for fossil fuel is comparable to other (possibly) relevant benchmark sets, electricity consumption is much greater. This is indicative of the high electricity consumption by industrial process loads.

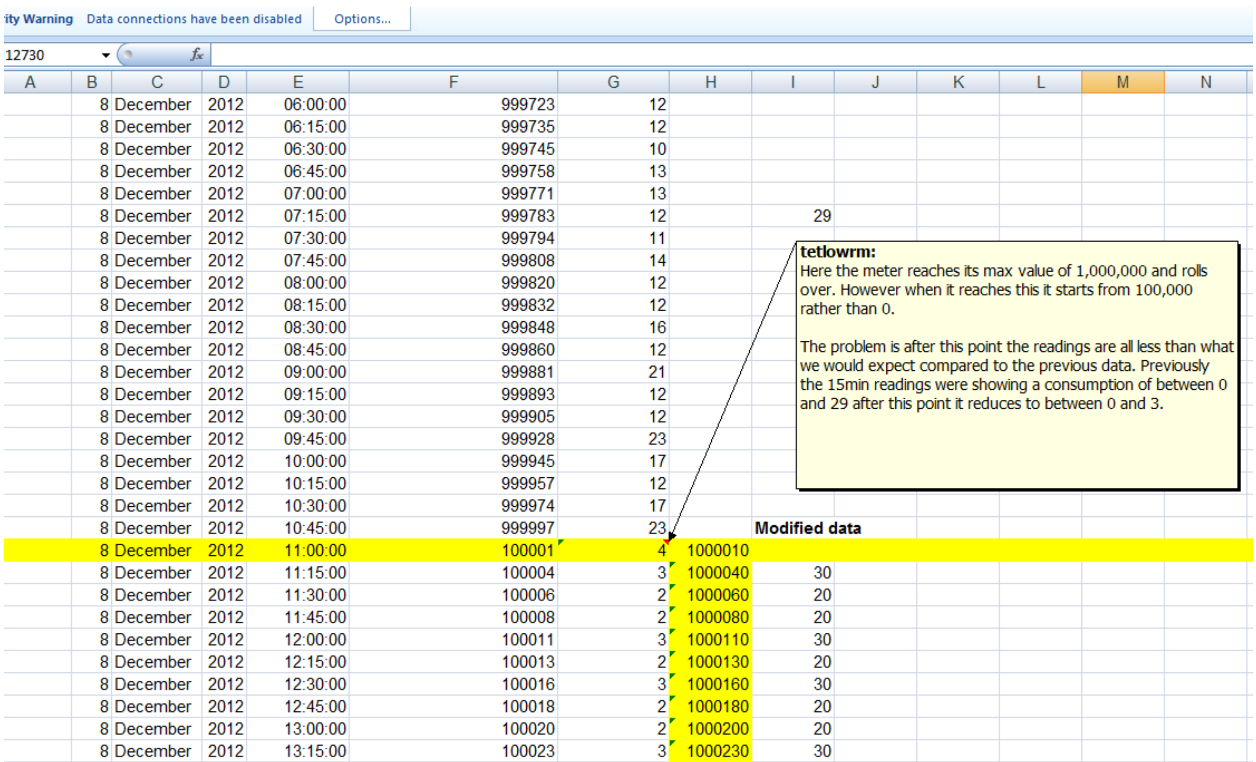
7 Technical Issues

7.1 Introduction

This Section explains the technical issues identified during the BPE study.

7.2 BMS energy reports

Energy analysis has indentified a problem with the daily energy reports that the BMS automatically generates. These energy reports are plain text files that contain the cumulative 15 minute data for the various submeters or sensors. The problem occurs when the cumulative reading reaches 1,000,000 (regardless of measurement units, but for electricity submeters this is in kWh). Figure 7.1 shows an energy report for the MCCP Plant Space East meter that has been imported into Excel. On 8th December 2012 at some point between 10:45 and 11:00 the cumulative reading reached 1,000,000. The reading at 11:15 however is 100,001 indicating that a digit has been omitted. This has a knock on effect of the calculated kWh used in that 15 minute period (column G) being a factor of 10 too low.



A	B	C	D	E	F	G	H	I
	8	December	2012	06:00:00	999723	12		
	8	December	2012	06:15:00	999735	12		
	8	December	2012	06:30:00	999745	10		
	8	December	2012	06:45:00	999758	13		
	8	December	2012	07:00:00	999771	13		
	8	December	2012	07:15:00	999783	12		29
	8	December	2012	07:30:00	999794	11		
	8	December	2012	07:45:00	999808	14		
	8	December	2012	08:00:00	999820	12		
	8	December	2012	08:15:00	999832	12		
	8	December	2012	08:30:00	999848	16		
	8	December	2012	08:45:00	999860	12		
	8	December	2012	09:00:00	999881	21		
	8	December	2012	09:15:00	999893	12		
	8	December	2012	09:30:00	999905	12		
	8	December	2012	09:45:00	999928	23		
	8	December	2012	10:00:00	999945	17		
	8	December	2012	10:15:00	999957	12		
	8	December	2012	10:30:00	999974	17		
	8	December	2012	10:45:00	999997	23		**Modified data**
	8	December	2012	11:00:00	100001	4	1000010	
	8	December	2012	11:15:00	100004	3	1000040	30
	8	December	2012	11:30:00	100006	2	1000060	20
	8	December	2012	11:45:00	100008	2	1000080	20
	8	December	2012	12:00:00	100011	3	1000110	30
	8	December	2012	12:15:00	100013	2	1000130	20
	8	December	2012	12:30:00	100016	3	1000160	30
	8	December	2012	12:45:00	100018	2	1000180	20
	8	December	2012	13:00:00	100020	2	1000200	20
	8	December	2012	13:15:00	100023	3	1000230	30

Figure 7.1: Energy report for MCCP Plant Space East submeter generated by the BMS

It is important to emphasise that this error was not observed on the physical meter (Figure 7.2), where the reading has gone over 1,000,000 kWh without resetting or indeed on the front end interface of the BMS. It only occurs in the BMS-generated energy reports and without the BPE team's investigation it is unlikely this issue would have been picked up. Although the readings for the MCCP Plant Space East submeter can be adjusted by multiplying by a factor of 10 to partially compensate for this error, the least significant digit is lost. It will also be a much greater problem with submeters for lower energy consuming equipment, as omitting the least significant digit in the BMS energy report values may result in an inferred zero value for energy use during a 15 minute period.

The BPE team raised this problem with the controls specialists (who holds the maintenance contract with the NCC). Site meetings with the control specialist's engineer for NCC confirmed that this error occurs and will happen to every electrical submeter on site whenever they reach 1,000,000 kWh. It is apparent that the specific problem is with the Trend BMS hardware, which is incapable of storing the extra digit (perhaps a similar problem to that of the well known 'Y2K' programming issue). To resolve this issue, the controls specialists have proposed a building energy management system (BEMS) upgrade to the BMS at a capital cost to the client in the region of £2k to £3k.

7.3 MCCP Plant Space East AHU

The MCCP Plant Space East submeter (Figure 7.2) monitors the electricity consumption for the AHUs (supply and extract fans) for:

- Main workshop
- East office
- Ply Cutter laboratory
- Clean Room
- ATP/AFL Rapid Deposition laboratory

When operational this load usually varies between 40 kW and 100 kW. It is the most significant submeter at the NCC (in terms of electricity consumption) and was the first to read over 1,000,000 kWh.

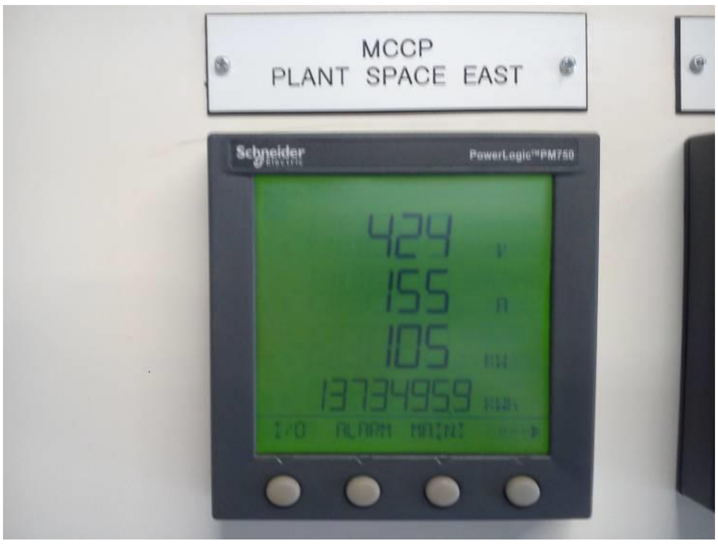


Figure 7.2: MCCP Plant Space East physical meter, located in main plant room.

Figure 7.3 shows a daily (Friday) electricity profile for the NCC. The stacked bar chart is comprised of various submeters, in which the blue line indicates the incomer (i.e. the fiscal meter) and the orange line shows the contribution of the PV generation added to the incomer. The MCCP Plant Space East submeter is shown as the red bar and indicates that the AHUs on the MCCP Plant Space East are continuously on during the working week, including out-of-hours.

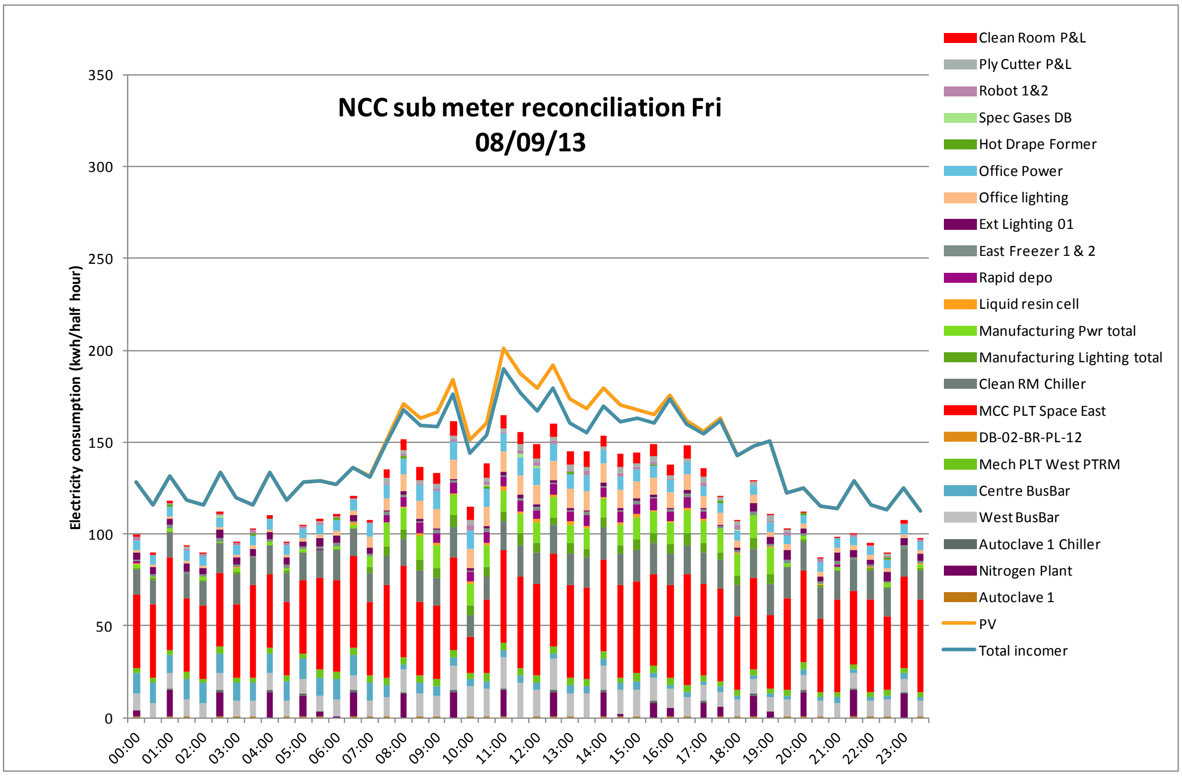


Figure 7.3: Daily electricity profile for NCC on Friday 8th September 2013.

Figure 7.4 shows the profile for the following day, a Saturday. As can be seen, the MCCP Plant Space East consumption is substantially lower (and only pulses on occasionally), indicating that all AHUs being metered have been switched off. Figure 7.5 shows the daily profile for the next day, a Sunday. This shows that the MCCP Plant Space East AHUs have come on at around 18:00 (quickly reaching typical weekday levels of energy use).

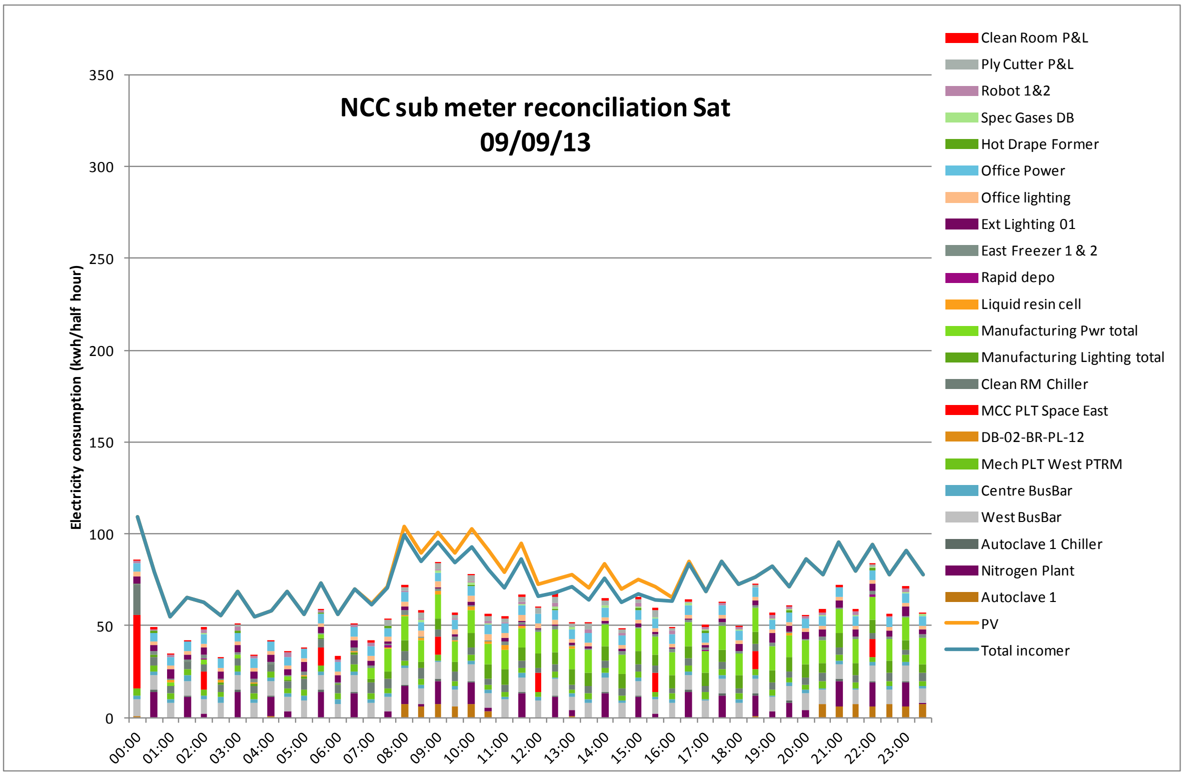


Figure 7.4: Daily electricity profile for Saturday 9th September 2013.

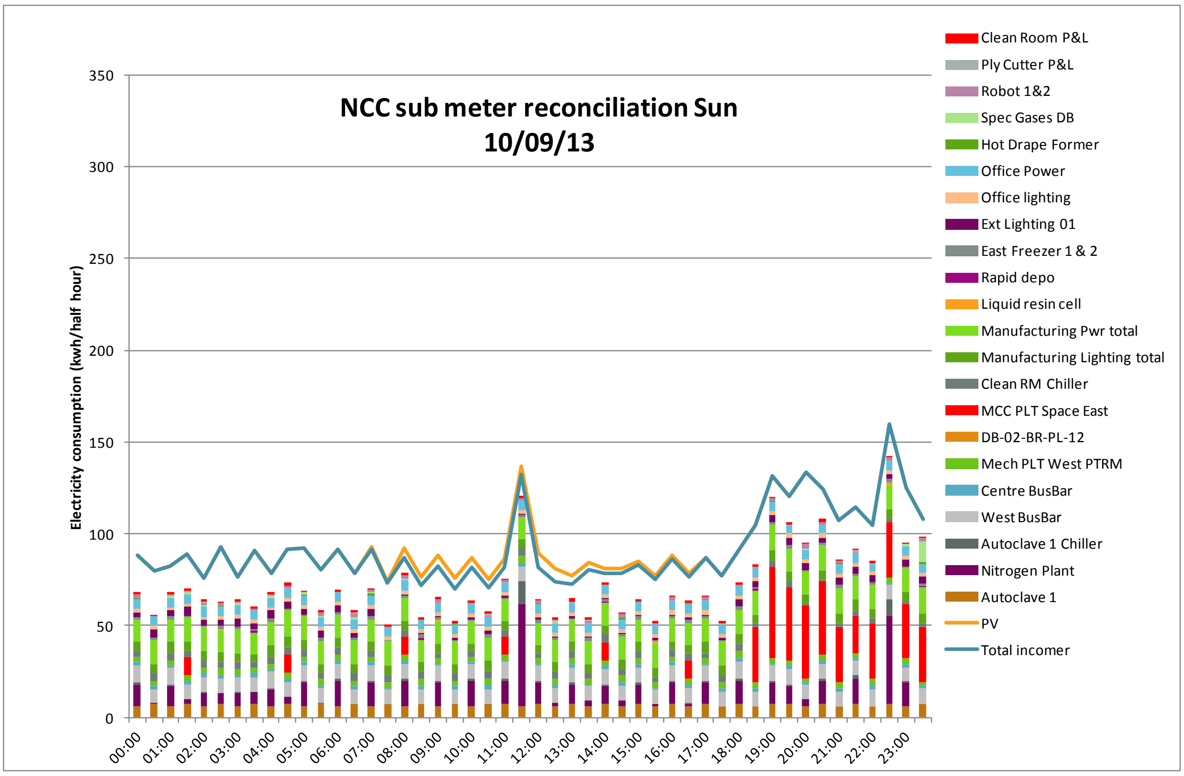


Figure 7.5: Daily electricity profile for Sunday 10th September 2013.

These observations led the BPE team to investigate whether the time clock settings for the AHUs could be individually changed, as different internal conditions are required in the laboratories (24 hour air conditioning) and the main workshop (only during working hours). If conditions can be separately controlled, then there is a large potential for energy saving, as although more energy would be needed to maintain the internal conditions of the laboratory spaces 24 hours per day, the more significant energy use by the main workshop fans could be reduced out of working hours and turned on later than 18:00 every Sunday. Investigation of the Main Workshop's AHU time schedule selected on the BMS showed that it was set to come on at midnight on the Sunday night rather than 18:00 on Sunday evening. This raises the possibility that the BMS optimiser is bringing the AHUs on earlier to achieve the required internal conditions by midnight on the Sunday night.

This led the BPE team to investigate the internal conditions for the various laboratory spaces served by the AHUs on the MCCP Plant Space East submeter (see Section 7.4). It is important to establish what conditions are actually required in the various laboratory spaces and whether the time clocks for the AHUs can be individually altered. Discussions with the controls specialists suggested they can be, however, there is a need to communicate with all key stakeholders at the NCC to determine which time settings can be adjusted.

7.4 Internal conditions for specialised laboratory spaces

The NCC has several laboratory spaces that tenants can use for different manufacturing processes. It is understood that three of these were specified during design as Class 8 clean rooms, which means that they need to maintain a constant positive pressure difference relative to adjacent spaces to prevent ingress of particles that may interfere with any manufacturing processes. They also need to be controlled for air temperature and air humidity.

In general, the NCC laboratory spaces are used for processes associated with the manufacture of high performance composite materials. These materials are highly humidity and temperature sensitive and exposure to increased levels of these can lead to defective materials. The specific processes that take place in these laboratory spaces vary, but in general terms they involve the gradual layering of composite fibres into a liquid resin. Once complete, this newly formed composite material will usually be placed in an autoclave, where they are subjected to high temperatures to 'cure' it. After this curing process, the composite material (then often referred to by workshop staff as a 'cure') will be returned to one of the laboratory spaces where it is left to settle. It is during this period that a cure can 'fail', meaning it cracks and becomes unusable. The rate of failure of 'cures' can be increased if the composite material has not been manufactured, or left to settle, in conditions that are closely controlled for temperature and humidity.

The NCC has three such Class 8 clean rooms (ATL/AFP Rapid Deposition, Clean Room, and Ply Cutter). The internal conditions for these spaces are controlled by separate AHUs linked to the BMS. The electricity consumption for the AHUs is metered via the MCCP Plant Space East meter, where it is amalgamated with the consumption for the AHUs for the East Office and Main Workshop. It is therefore not possible to determine electricity consumption for each individual laboratory space or indeed easily determine the different run hours for the associated AHUs. This makes it difficult to fully understand the energy used by different tenants when they use these areas and so for the client to accurately re-charge them for their energy use.

Pressure, humidity and temperature readings are logged every 15 minutes by the BMS for the three laboratory areas (ATL/AFP Rapid Deposition, Clean Room, and Ply Cutter). As by default the BMS would only store the previous 10 days of readings before overwriting earlier data, the BPE team arranged for an additional system to continually save data over the long term. This deficiency (which was not explained during the design process) meant that the NCC had to purchase stand alone battery powered humidity and temperature sensors and rely on these to supply readings for QA purposes.

Figures 7.6 and 7.7 show the relative pressure differences, temperatures and relative humidities for the ATL/AFP Rapid Deposition laboratory over 2 weeks in August 2013. As a clean room, this area should maintain positive pressure to prevent particulate ingress. As can been seen from these Figures, the pressure differences drop during weekends, indicating that the AHUs for this space are being turned off. The close control of temperature and relative humidity around the setpoint that can be seen during weekdays does not occur during weekends – again an indication that the AHUs are being switched off. These findings are reinforced by the electricity consumption submeter data, which also indicate that all AHUs are being turned off at weekends.

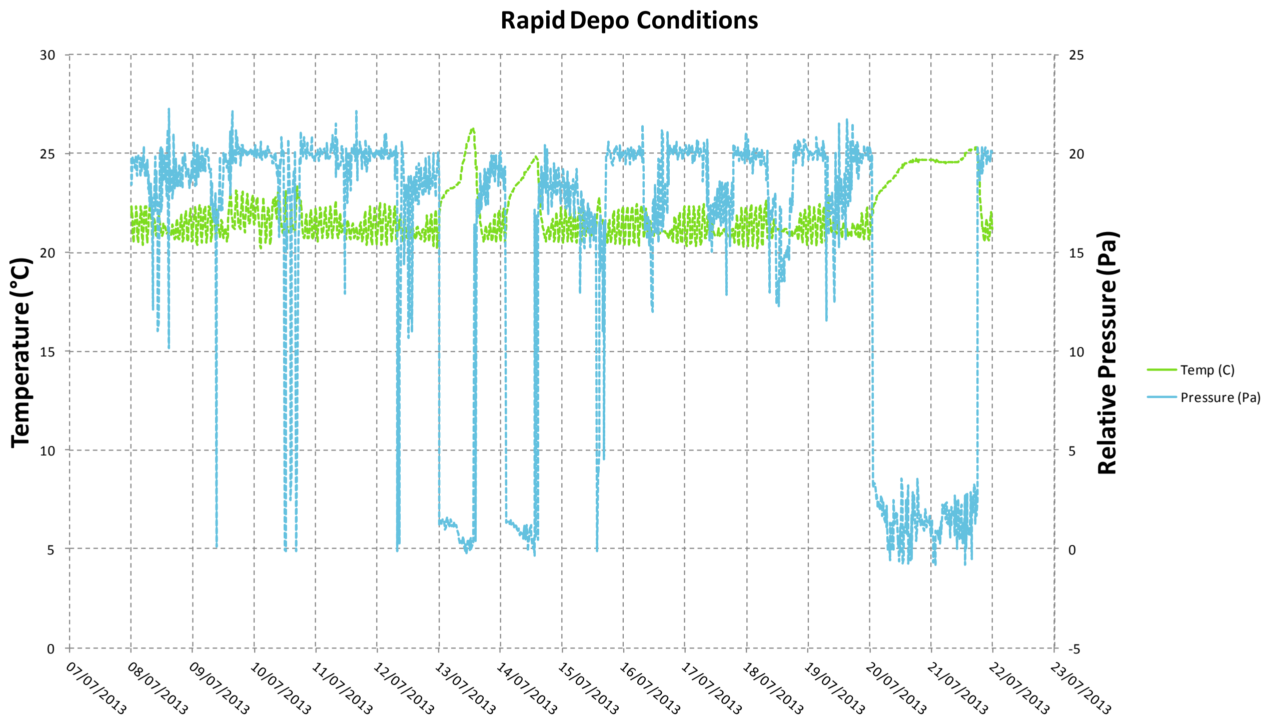


Figure 7.6: Air temperature and relative pressure for the Rapid Depo laboratory between 8th July 2013 and 22nd July 2013.

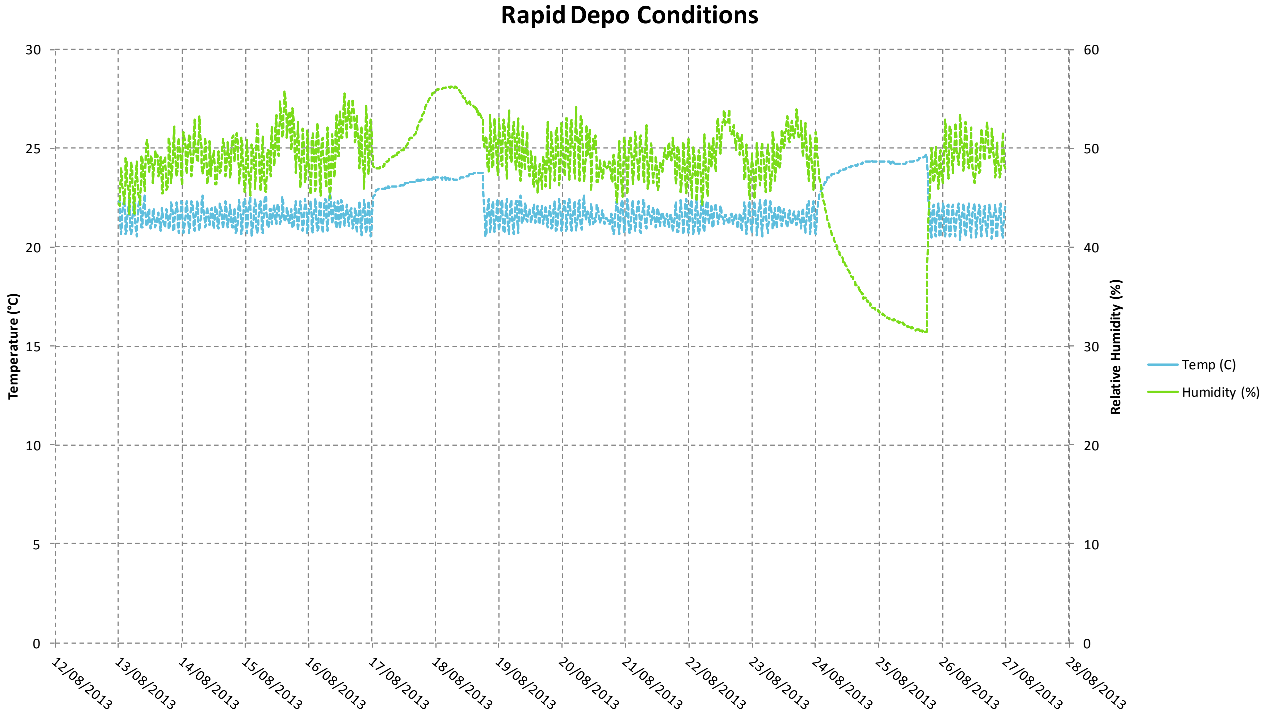


Figure 7.7: Air temperature and relative humidity for the ATL/AFP Rapid Deposition laboratory between 13th August 2013 and 27th August 2013.

This may be of concern to the NCC if they are renting out these spaces to tenants on the basis that they are meeting certain defined environmental conditions. Discussions with one of the NCC Workshop Managers around this topic has led him to link the lack of continuously controlled conditions in these spaces during weekends with the high failure rate of ‘cures’. It is understood that failure of cures has cost implications for the NCC.

The Ply Cutter laboratory was designed as a clean room, but does not have an airlock (which both Rapid Depo and Clean Room do). The work currently being carried out in the Ply Cutter laboratory is not as temperature or humidity sensitive as the other laboratory spaces. This is shown in Figure 7.8, which shows that the internal conditions are kept at a lower positive pressure than the ATL/AFP Rapid Deposition laboratory. This is an interesting case of the space being used for processes other than that on which the design intent was based. From Figure 7.8, it can also be seen that the internal temperature for the Ply Cutter laboratory is not being closely controlled out of working hours i.e. 19:00 to 07:00 Monday to Friday (but it is being controlled for the ATL/AFP Rapid Deposition and Clean Room during this time). However, if the processes carried out in this laboratory space are not as temperature sensitive, it may be possible to widen the temperature setpoint deadband to prevent over cooling. This Figure is from August and the temperature is being kept constant at 21°C: energy savings may be achievable if it is only cooled to 23°C for instance.

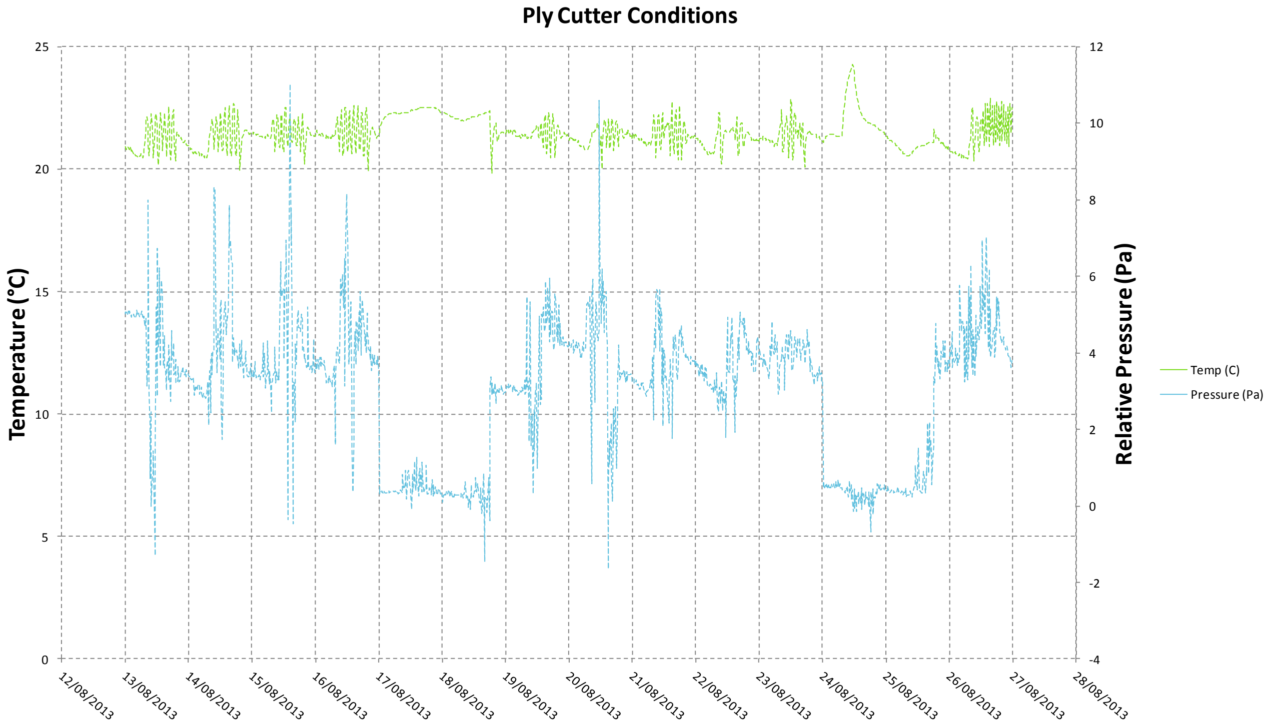


Figure 7.8: Air temperature and relative pressure for the Ply Cutter laboratory between 13th August 2013 and 27th August 2013.

If the internal conditions for the various laboratory spaces are acceptable, there is a possibility of saving energy by further reducing the operational times of the AHUs in the different areas and by adjusting temperature setpoints or increasing the temperature deadband. However, if current internal conditions are unacceptable, then the AHUs need to be on continuously during weekends and actual operational times need adjusting as a result. This problem has been brought to the attention of key stakeholders at the NCC. However, there is not currently a consensus about what conditions are required in these various spaces. Discussions are also taking place with the original Building Services Designers. The BPE team believe a workshop meeting is required to inform all parties about this issue and to agree what internal conditions are required. This may actually result in an increase in energy consumption if AHUs need to be operated for longer periods, but crucially for NCC and their clients, this could reduce the failure rate of composite materials manufactured at the facility.

7.5 Internal summer conditions for office spaces

In the three open plan first floor office spaces (East Office, North Office, and Tenant Office), the BMS was originally designed and installed to automatically open high level windows (Figure 7.9) during summer based on defined CO_2 and temperature criteria. There are also manually operated windows at low level. An override switch is present in each of the office areas to force the automated high level windows to stay open (Figure 7.10). Pressing the switch will automatically open the windows for one hour.

Night cooling during summer via the automated high level windows was also part of the design intent, but as explained in Section 4.3.3.1, this has been stopped during the BPE study period by the FM team. Also, during the daytime the automated windows sometimes cause occupant dissatisfaction, as they tend to operate on a narrow set point and can be perceived as noisy in operation. Furthermore, the override switches have been an issue, with rain occasionally coming in and the windows not automatically closing because the switch had been pressed.

Figure 7.9: (Left) Automated windows in a first floor office area and (right) East Office.

Figure 7.10: Manual override for automated windows.
Note the text discouraging occupants from using the control and the lack of explanatory labelling explaining.

To investigate the summer internal conditions of the three first floor office areas, Tinytag relative humidity and air temperature sensors were placed from the 7th August 2013 to the 1st October 2013. Figure 7.11 shows a floor plan of the first floor at NCC with the location of the Tinytag sensors marked in yellow. Corresponding measured external relative humidity and air temperature data for the start of this time period at a similar location to NCC were also sourced. (See also Appendix 10.4.)

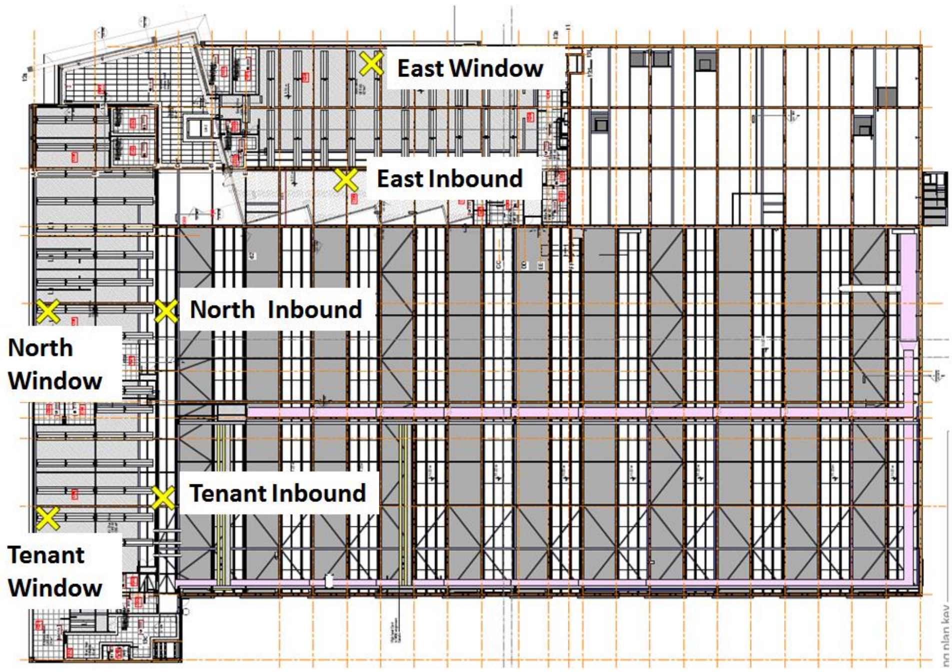


Figure 7.11 Locations of Tinytag sensors in first floor offices at NCC to measure indoor air temperatures and relative humidities.Yellow crosses indicate approximate placement of Tinytag sensors.

For each office area, Table 7.1 summarises the measured data in terms of minimum, mean and maximum values during occupied hours. The relative humidity levels and air temperatures are sometimes at the higher end of the acceptable range in terms of occupant comfort, which can occasionally be exceeded. For the East Window and East Inbound locations, a comparison of air temperatures is made in Figure 7.12. It is observed that the maximum air temperatures recorded at North Window and Tenant Window are reasonably high, although as can be seen in Figure 7.13, these peaks occur during a period of high external air temperature. The overnight closure of the automatic windows is also evident from the air temperature data, as the internal temperature does not decrease to approach the external temperature as would be expected if this were taking place. The results between the two BUS Methodology surveys also indicated a significant change in occupant perception from neutral to too hot (Section 4.4.1), confirming the detrimental impact of the lack of night cooling.

The humidity mixing ratio (HMR) of air is generally independent of temperature, except when evaporation or condensation processes occur. It is otherwise a function of ventilation / advection, local emissions from internal sources (e.g. people, domestic hot water, hydrocarbon combustion, industrial processes, etc), adsorption and desorption, with the latter two mechanisms involved in moisture buffering. For general office spaces, the main sources are likely to be the occupants and advection from the outdoor ventilation supply air. From the measured internal (and external) relative humidity and air temperature data, indoor and outdoor HMRs were inferred for occupied hours (assumed to be 07:00 to 19:00, Monday to Friday) from 7th August 2013 to 23rd August 2013.

Table 7.1 Summary of measured internal conditions in office spaces during occupied hours (07:00 to 19:00, Monday to Friday from 7th August 2013 to 2nd October 2013).

	North Window *Air temperature*	**North Window** *Relative humidity*	**North Inbound** *Air temperature*	**North Inbound** *Relative humidity*
Minimum	18.3°C	36.6%	19.0°C	33.2%
Mean	22.6°C	52.2%	23.3°C	52.1%
Maximum	29.1°C	66.9%	27.5°C	68.7%
	Tenant Window *Air temperature*	**Tenant Window** *Relative humidity*	**Tenant Inbound** *Air temperature*	**Tenant Inbound** *Relative humidity*
Minimum	17.4°C	33.4%	20.2°C	33.3%
Mean	23.3°C	50.6%	23.5°C	51.7%
Maximum	31.4°C	74.4%	28.0°C	69.5%
	East Window *Air temperature*	**East Window** *Relative humidity*	**East Inbound** *Air temperature*	**East Inbound** *Relative humidity*
Minimum	18.0°C	40.0%	19.4°C	34.4%
Mean	23.0°C	59.6%	23.1°C	53.0%
Maximum	26.5°C	77.9%	27.3°C	70.5%

The inferred internal and external HMRs are shown in Figure 7.14 for the East Window and East Inbound locations. The general trend is that the internal HMRs reasonably closely follow the external HMRs, implying that advection of outdoor moisture by ventilation is the dominant mechanism affecting the indoor HMRs. In fact, at all of the sensor locations, there is a strong linear relationship between the internal and outdoor humidity mixing ratios. These are presented in Figures 7.15 and 7.16 for East Window and East Inbound respectively. (Appendix 10.4 also includes the other sensor locations.) During the study period, the internal HMR was slightly less than the external HMR, except at the East Window location.

For this particular building, transported moisture originating from combustion or other industrial processes are also possibilities, but in general this does not seem to be the case from the measured data. It is noted that at the East Window location, the indoor HMR is consistently higher than the outdoor HMR, whereas the reverse is true for the other measurement locations. Assuming the East Window sensor is producing accurate readings, this could be accounted for by an indoor moisture source. Occupant reports of changing room odours in the East Office (see Section 4.3.3.1) suggest an internal natural ventilation air flow path may be present, which could also transport moisture generated by showering in the changing rooms into the East Office. Alternatively, the occupants may prefer to keep both manual and automatically East Office windows closed close to the measurement sensor, with a resultant low ventilation rate.

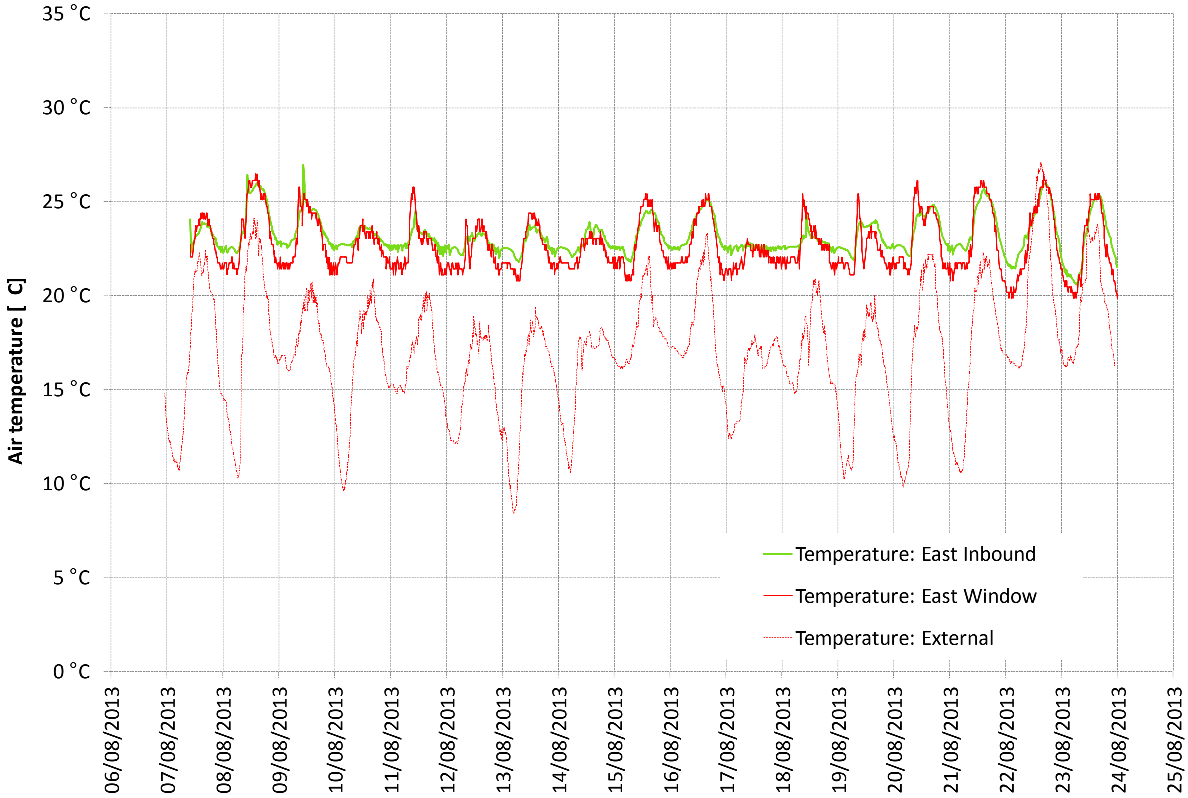


Figure 7.12: Measured indoor and outdoor air temperatures - 'East Window' and 'East Inbound' locations.

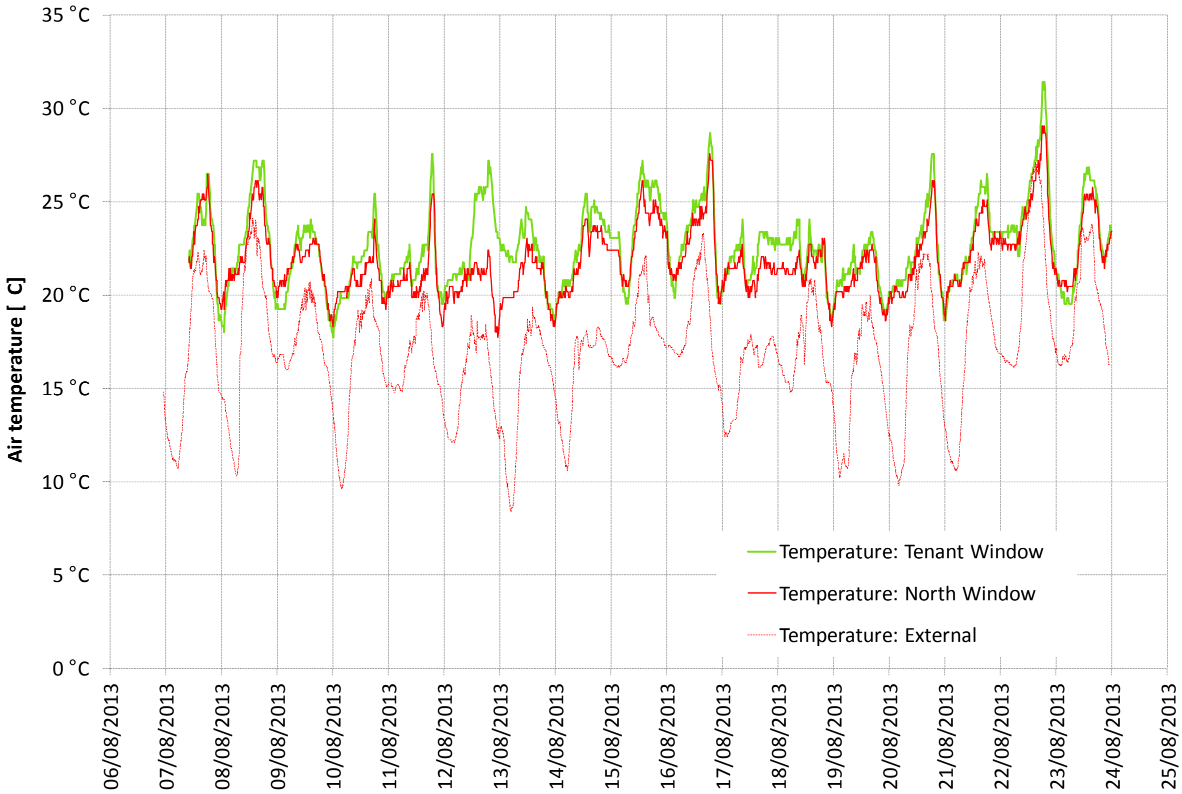


Figure 7.13: Measured indoor and outdoor air temperatures - 'North Window' and 'Tenant Window' locations.

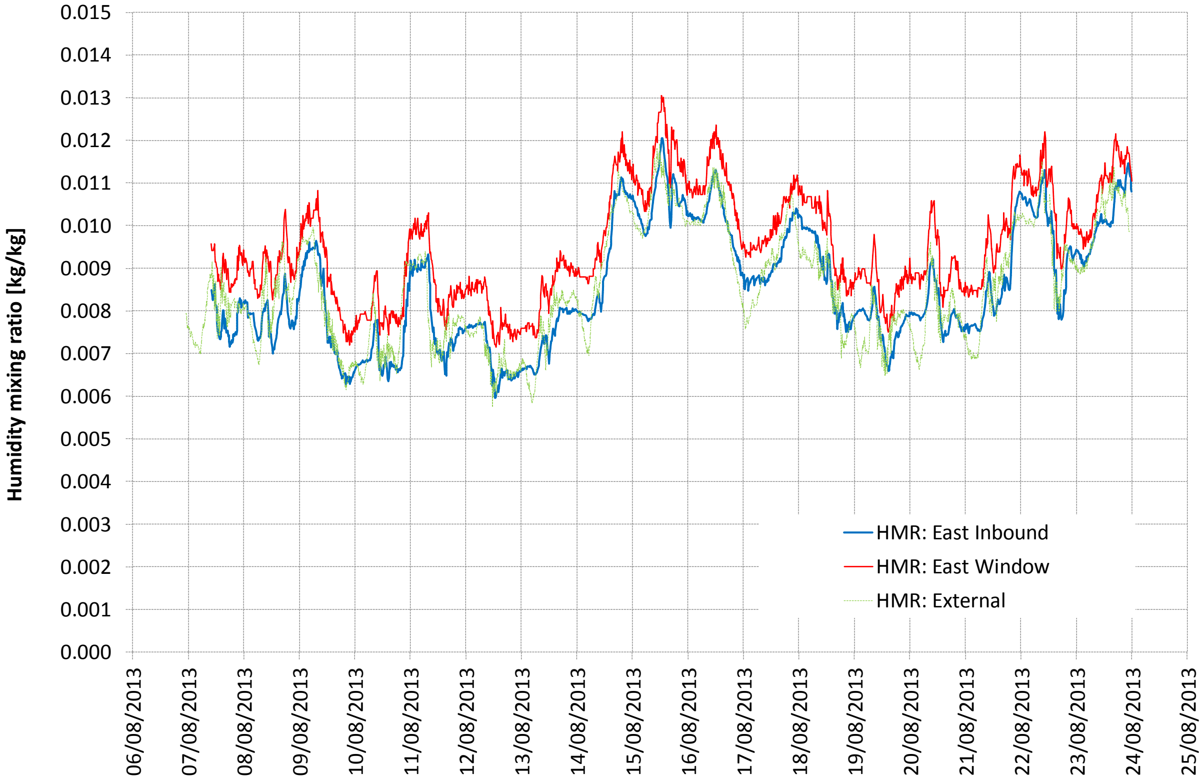


Figure 7.14: Inferred indoor and outdoor humidity mixing ratios - 'East Window' and 'East Inbound' locations.

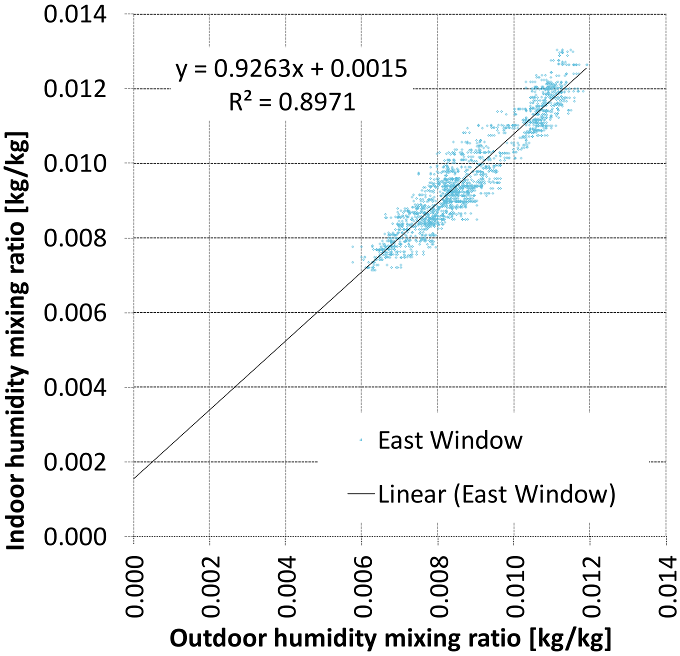


Figure 7.15: Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'East Window' location.

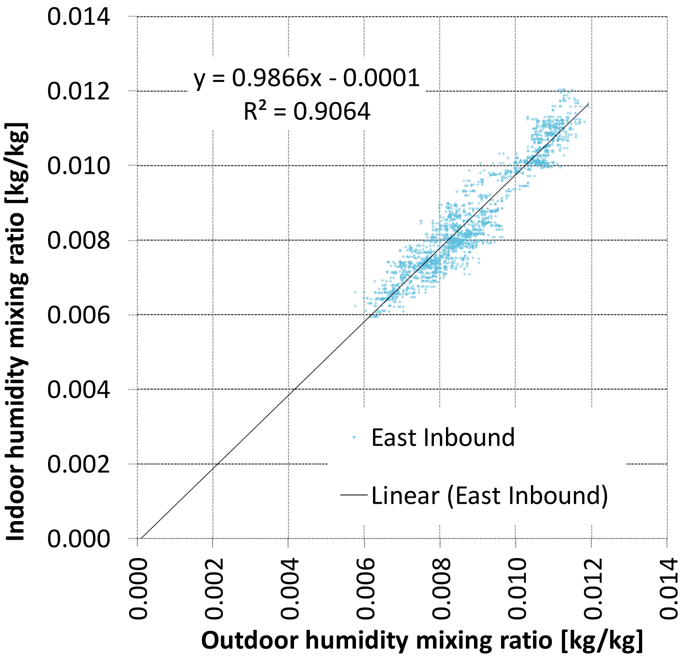


Figure 7.16: Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'East Inbound' location.

7.6 Out of hours gas consumption

Analysis of the gas consumption data has shown that heat is being used for space heating and DHW on days when the NCC is unoccupied. This particularly highlighted that this was occurring during periods (i.e. Christmas holidays) during which the NCC team would clearly know in advance that it would be unoccupied. With better building management and use of controls, the NCC team could significantly reduce the gas used to supply heat during these periods. Discussions with the BMS installers indicated that the BMS has the functionality to be pre-set with standard holiday periods. This seems to stem from insufficient training for the FM on the BMS, lack of management oversight to ensure that the building systems operates only when required, and a lack of communication between stakeholders – for example some areas of the building may need to operate over holiday periods to ensure that internal conditions are maintained e.g. Clean Rooms.

7.7 Discussion and key findings

The BMS log files can lose a digit when the submetered data reaches 1,000,000 units. This seems to be a hardware limitation with the BMS (similar to the well known 'Y2K' issue). It is likely that this is occurring at other buildings, but would only be seen by analysis of the BMS reports, as the physical meter and the BMS front end both did not manifest the error.

The AHUs monitored by the MCC Plant Space East submeter are all operating on the same time schedule, even though the spaces that they serve have different requirements. The BMS time scheduler for the specialised laboratory spaces cannot be modified directly by the FM on site and instead the controls specialists have to be contacted to do it.

The measured summer internal conditions of the first floor office spaces show that a practical solution needs to be found to allow summer night-time cooling using the high level automatic windows to resume. Fitting wire screen enclosures around might

8 Key messages for the client, owner and occupier

8.1 Introduction

The NCC is a generally a well-functioning building with an engaged client, design team, contractor and building management team. Nevertheless, certain technical and management issues have been identified during the BPE study.

The BPE team understands that there is no clear energy management function assigned within the client's Facilities Management team roles. For a building with high energy consumption such as NCC, this is a significant oversight. If an energy management function were to be created, most of the energy and other performance issues identified and summarised in this Section would become priority items for that function and could be quickly addressed at low capital cost with short estimated payback periods.

The study has managed to identify key areas where changes could be made to enhance the building performance, not only in terms of energy consumption, but also in improving the indoor environmental conditions necessary to perform its primary functions. It is likely that without the BPE study, these problems would only have come to light in the future much more slowly or possibly not at all. The resulting recommendations for energy saving measures are shown in Table 8.1.

Table 8.1: Overall list of recommendations for energy saving at NCC based on approximate costs.

Recommendation		Capital cost	Annual energy and CO_2 savings						Payback
			Electricity		Gas		Total Cost Saving	CO_2 Saving	
Project code	Detail	£	KWh	Cost	KWh	Cost	£	Tonnes	Years
1	Use variable speed drive for main workshop AHU	£2,800	235,900	£27,600	-	-	£27,600	107	0.1
2	Turn down main workshop AHU when building is unoccupied	£2,800	97,800	£11,400	201,900	£6,100	£17,500	82	0.2
3	Increase frequency of workshop lights being switched off	£800	9,700	£1,100	-	-	£1,100	4	0.7
4	Energy awareness campaign	£1,000	9,000	£1,100	-	-	£1,100	4	0.9
5	Turn off hot water system on weekends	£200	-	-	13,500	£400	£400	2	0.5
6	Reduce external lighting operating hours	£800	25,400	£3,000	-	-	£3,000	11	0.3
	TOTALS -->	**£8,400**	**377,800**	**£44,200**	**215,400**	**£6,500**	**£50,700**	**211**	**0.2**

8.2 Use variable speed drive for main workshop AHU

There are variable speed drives (VSD) installed on the supply and extract fans for the AHUs. VSDs allow the flow rate of the fan to be reduced to meet the needs of the space. The AHU for the main workshop has VSDs, but they are still running at full rate (50Hz). It is likely that these can be turned down slightly. Even a small reduction will save a significant amount of electricity consumption (Figure 8.1). Any adjustments to the VSD should be in incremental steps and the resulting internal conditions of the workshop tested to ensure that they still meet requirements. If the main workshop AHU was turned down by 20% to 40Hz for 24 hours per day then around £28,000 and 107 tonnes of CO_2 could be saved every year.

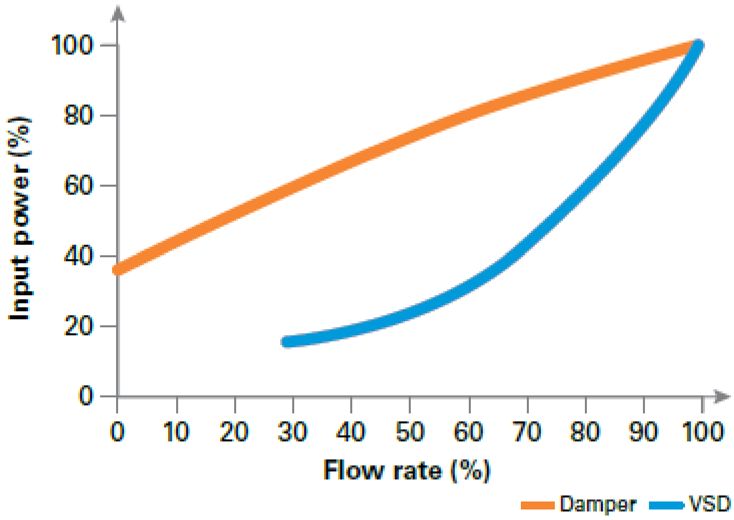


Figure 8.1: Chart showing how reducing the flow rate for an AHU through a VSD will reduce the required input power (Carbon Trust, 2011).

8.3 Turn down Main Workshop AHU when building is unoccupied

Energy analysis in Section 6.5.2 revealed that the Main Workshop AHU was operating and supplying heat for a 21°C internal setpoint. It was also operating at full capacity from 18:00 every Sunday. There is potential to reduce the supply and extract fans down to 30% flow rate (as a provisional level) when the building is unoccupied (e.g. from 19:00 to 7:00. During these unoccupied periods in the heating season (October to April) the temperature set point could be reduced to 12°C to prevent unnecessary heating. If these actions were carried out it could result in a saving of £17,500 in energy costs and 82 tonnes of CO_2 could be saved every year.

8.4 Increase frequency of workshop lights being switched off

The Main Workshop has a high installed lighting load of 35 kW. Although theoretically under the control of the lighting master controller, in practice the artificial lighting in this area is controlled through a manual light switch at the entrance, which is turned off by the last person to leave the workshop at around 19:00 on a typical working day. Although this action is often carried out, analysis of the energy data revealed that there is about a 10% chance that the lights will not be switched off. When this occurs they are left on all night, and if this occurs on Friday then they are left on for the whole weekend. It is recommended that prompts are used to remind the last person to leave to use the manual light switch. Prompts can be a low cost, but effective measure. In other research by the BPE team, it was found that simple prompts can increase the likelihood of people switching off lights with a manual light switch by over 30%. If this is implemented and the chance of failing to switch off the lights is reduced to an assumed 2%, then £1,100 and 4 tonnes of CO_2 could be saved every year.

8.5 Energy awareness campaign

An energy awareness campaign could be conducted. Research suggests that successful energy awareness campaigns can offer savings in the region of 5% to 20% for electricity consumption, through turning off lighting and small power appliances when not required. Energy analysis in Section 6.4.7 revealed that although lighting is controlled through PIRs, there are incidences of small power equipment being left on when not required. Successful energy awareness campaigns in practice are difficult to implement (especially in the initial stages) and require effort and persistence from the management team to realise the savings. To this end, a £1000 annual budget for materials for the campaign is assumed in the budget to assist with implementation. If successful in achieving an 8% saving for small power in the office areas then this would save £1,100 and 4 tonnes of CO_2 per year. In addition, such a campaign would help to reduce unnecessary heat loss if the external large roller shutter door to the Main Workshop area were to be kept closed when not required during the heating season.

8.6 Turn off hot water system on weekends

Analysis of the gas consumption for the hot water system shows that water is being heated over the weekend even though the building has a very low occupation. Turning off the hot water system over weekends would save £400 and 2 tonnes of CO_2 every year. (However, professional advice would also need to be sought by the client concerning the implications for the control of Legionella.)

8.7 Reduce external lighting operating hours

Analysis of the CIBSE TM-22 model has indicated that the external lighting at the NCC is operating 24 hours a day. While this remains to be confirmed, if this is found to be the case, then reducing the operating hours of the external lighting for just 12 hours over night every day would save £3,000 and 11 tonnes of CO_2 every year.

8.8 General points

8.8.1 Internal conditions for specialised laboratory areas

There is no consensus among the client's team as to what conditions in the specialised laboratory spaces and the Main Workshop should be. This is partly a result of change of use of the building since completion, but also due to a lack of clear communication between key stakeholders, the FM, and the controls specialists.

As the use of the NCC building is dynamic, it would make sense to take a dynamic and flexible approach to internal conditions of the specialised laboratory spaces. The scheduled work for a coming week in the relevant space could be assessed and the required internal conditions proactively set. This would include temperature deadbands – whether cooling is needed, and whether 24 hour conditioning is required.

8.8.2 Ownership of energy data

Over the course of the BPE study, the project team observed that there seemed to be only a low level of communication between NCC stakeholders over decisions involving the energy and environmental performance of the building. This conclusion was reached due to the Facilities Manager (FM) apparently not being informed of new pieces of equipment being installed or alterations to rooms / areas, which has implications for submetering, sensor locations, and the BMS.

New rooms / areas have been installed, apparently without considering the existing energy metering strategy. Moreover, most of these have been wired directly into the East Busbar, which is not ideal due to the PV electrical generation also being connected and obscuring the interpretation of the submetered data. The PV generation serves this busbar, but without separate submetering for the array (generation is monitored by data loggers owned by the specialist installer) the busbar can confusingly read negative electricity consumption. As a minimum, new rooms / areas should be installed with submetered tap-off units from the busbar. However, connection from these submeters to the BMS also needs consideration as that connection would need hardwiring. It should also be noted that the metering strategy was not communicated well during the original fit-out.

Another example of the lack of communication between the key stakeholders is the internal conditions of the laboratory spaces. The issue with the AHUs for these areas switching off on weekends was observed during the BPE study and communicated to various stakeholders at the NCC. While some realised the potential problems that this might be causing to the work carried out in these areas, there was no consensus from the NCC about how to tackle this problem.

8.8.3 Reinstate summer natural night ventilation to first floor office areas

It is recommended that external wire mesh screens should be provided on high level automated windows in the first floor office areas to prevent squirrels from entering the building. This would allow natural night ventilation to take place again to control summer daytime temperatures as per the design intent.

8.9 Feedback on the NCC2 design

In late 2012, the client confirmed that they wished to procure a second building adjacent to the NCC to provide further research and teaching facilities. The new building, to be called NCC2, was designed by the same team as the original NCC. An opportunity therefore presented itself for the BPE project team to provide valuable feedback to the NCC2 project. Part of this work included a review of the mechanical and electrical performance specifications, which was carried out prior to the completion of the detailed design. The findings were reviewed with the Building Services Designers and a technical note issued. This section summarises the findings of the review.

8.9.1 Metering

A potential problem raised is that the metering system is not listed as a separate system in the specification. Listing it as a system in its own right may ensure a greater focus on its delivery – an area which is a frequent source of poor performance in many projects.

From discussion with the designers, the intention for NCC2 is to have an integrated metering / BMS arrangement (i.e. delivered by a single contractor) to ensure that the systems are entirely compatible, but the lack of functionality in respect of metering observed in the NCC is also addressed. This is an improvement over NCC, but the intent could perhaps be more clearly expressed.

There is a section of the specification which deals with requirements prior to handover and it may be beneficial to ensure that contractor’s proposals include early verification of the metering installation as part of this work.

It was noted that the specification does not mention a gas submeter to the paint booth, but this is indicated on the gas distribution schematic.

8.9.2 Commissioning

The commissioning clauses do not specifically mention the planning of the commissioning process explicitly, but this is often an area which is compromised, particularly on projects with a very fast delivery programme such as the NCC2. The specification does mention BREEAM Issue MAN1 (credit requirements 18 – 21), which requires a specialist to be appointed at design stage and it would be useful to set this out explicitly rather than relying on the contractor's knowledge of BREEAM.

8.9.3 Insulation

Whilst insulation is very well specified generally, there may be the opportunity to provide insulating jackets for pump heads which are currently not listed.

8.9.4 Controls

Water boilers are specified in kitchen areas / tea points, but they do not have associated controls. It may be worth exploring the use of timers to ensure that heaters are off when the building is not occupied.

It is noted that the clauses specifying the VRV system state that it should be compatible for remote control from the BMS, but it does not specifically state that it will be connected – this issue would be worth clarifying when contractors' proposals are received.

The manual ‘extend’ buttons provided for AHU to give a 1 hour operation when areas are occupied outside normal hours should be clearly labelled and provide immediate feedback to users to indicate that something has happened when they are used. It seems the design of these systems in the NCC meet these criteria so the principle should also be adopted here ideally.

The control of ventilation systems such as Local Extract Ventilation, dust extract and so on are intended to be entirely manual. Whilst the use of automated control to these systems may not be appropriate, it would seem prudent to develop a clear strategy for ensuring that the systems are not left on when not required.

The control of the air curtains is likely to include a thermostat integral to the units themselves with manual on / off. It may be worth considering a method of ensuring they do not operate when not required – perhaps by incorporating a timed operation with each button push.

As is customary, many of the systems and equipment in the building will have a ‘hand’ or manual control function. It would be worth considering how it is made clear to FM staff that equipment is in ‘hand’ mode so that systems are not left in this condition for longer than necessary.

8.9.5 Heating

It may be worth considering the use of an arrangement which minimises heat losses through boilers which are not firing either through the use of automatic flue dampers and / or a shunt pump arrangement for each boiler. If shunt pumps were used, it would likely be possible to omit the primary circulation pumps from the design.

The pump set for the underfloor heating system is specified as being provided by the specialist contractor. Past experience suggests that, unless carefully managed, these interfaces can be points of failure so it is recommended that this and other similar occurrences are an area of focus.

8.9.6 Cooling

The refrigerant in the chilled water circuit may present an opportunity for heat recovery in the form of a de-superheater. Of course, a suitable use for the waste heat would need to be identified.

8.9.7 Ventilation

The principle of operation for the automatic windows and mechanical ventilation is that the automatic windows remain open when the mechanical ventilation comes on to maximise the opportunity for reducing internal temperature. Obviously, this is the established principle, but it could perhaps be more explicitly explained that the windows are to remain open.

It is noted that the clause describing when ventilation controlled by CO_2 sensors will come on that the text states that this will happen when CO_2 levels will go *below* acceptable levels, but it is assumed this should read when they go *above* acceptable levels.

Whilst different modes of operation are described for summer and winter, it does not seem to be entirely clear what defines when each applies. It seems that there is a clear understanding of this among the team, but this could perhaps be stated explicitly in the specification.

8.9.8 Other systems

A compressed air system is specified as part of the project – a system notorious for wasting energy. It may be worth considering the use of techniques to minimise energy wastage such as the operating environment of the compressor, the intake air temperature, heat recovery, etc, as part of the detailed design.

The detailed performance specification schedule provided for the PV installation could perhaps be made more robust by including a requirement for tenderers to indicate system output at given annual average irradiation (typically 1100 kWh/m^2) onto the PV panels, assuming they are at the optimum tilt of 36 degrees, and facing due south. They could also be asked to indicate output based on actual tilt and orientation if this differs thus allowing for ready comparison. It is also important to ensure that output is stated after taking into account inverter and cabling losses.

8.9.9 Influence of the BPE study on the NCC2 design

Elements of the NCC2 design have been influenced by the BPE study, and these are summarised below:

- PV array electrical design. In the NCC the PV array was directly wired into the East busbar causing negative readings on its meter. For NCC2, this was picked up through the BPE team's conversations with the design team, and the PV array feeds directly to the main switch panel.
- Rain water pipes through offices. Rain water collection pipes will not run straight through office spaces as they do for NCC. This was causing the occupants distraction on rainy days.

- Allocation of male/female toilets. NCC2 will have proportionally more male toilets than female toilets available for staff to better reflect their demographic.
- Screens are being provided on high level automated windows to prevent entry of squirrels.

8.10 Discussion and key findings

There are several key recommendations outlined above that if acted upon could save the client in the region of £50,000 and 211 tonnes of CO_2 per year. All of the identified recommendations should pay back within one year. The recommendations should be implemented in the above order as the savings calculations are based on cumulative reductions. Recommendation calculations are estimates only, so it would be important to monitor energy consumption before and after any changes to calculate the savings achieved in practice.

Other findings have indicated that an energy 'monitoring and targeting' strategy is not being followed by the FM team. It is important to have an individual designated as an Energy Manager who has ownership of energy data and acts upon it as necessary. Clearly, even for a building with extensive metering (as has been installed at NCC), savings will not be realised without such actions being implemented.

The internal conditions for the specialised laboratory spaces could be dynamically controlled and this could lead to significant savings, but the BPE team have not quantified these due to the complexity of the issue. The control systems and data exist to be able to control these conditions dynamically, but it would take a significant investment in terms of time for the NCC team to implement this.

9 Wider lessons

9.1 Introduction

This section contains a number of lessons that can be drawn from the BPE study for the NCC that have implications for the wider industry. These have not been ranked in any particular order.

9.2 High level meter reconciliation during aftercare following commissioning

The BPE study uncovered several problems with the commissioning of submeters. Some submeters were not supplying the correct data due to incorrect timestamp settings during commissioning. Other submeters were not connected to the BMS properly or at all. A high level submeter reconciliation should take place during the first month of operation. This should include an energy balance of submetered with fiscal meter data. This would highlight any potential problems with the submetering early on in the project when they can be more easily rectified (as the commissioning team will still be on site). This could also help to engage the FM with the energy data and would fit well as a standard part of BSRIA's Soft Landings Framework.

Lesson: Engage with industry (through, for instance, the Soft Landings User Group or CIBSE, etc) to ensure that a high level meter reconciliation during the first month of operation is defined as a specific activity.

9.3 Unsuitability of standard building management systems for long term energy monitoring

Standard building management systems (BMS) used primarily for the control of building services, as generally specified at present, are unsuitable for long term energy monitoring. In this case, the M&E Specification stated that all BMS data logs should be kept for 14 days, but this length of time is insufficient for either high level or in-depth long term energy analysis and is much too short to examine seasonal variations in the data. Dedicated building energy management systems (BEMS) should be specified and installed that can store data logs for indefinite periods to allow for long term understanding of how energy is being used seasonally and annually and how it changes over time. Data should be recorded at least at 30 minute interval resolution. Initial commissioning and aftercare for such systems should also include carrying out an energy balance of recorded submetered with fiscal data. Periodic cross checking is also needed between data indicated by meters, values displayed in BEMS interfaces and those stored in log files. BEMS should include integrated, understandable software to allow proper data analysis by the energy manager (see Section 9.4).

The industry also needs to be made aware of a problem with Trend BMS reports when submeter data exceed 1,000,000 kWh. In this instance, it is understood that this issue will happen to all the submeters on site whenever they reach 1,000,000 kWh and presumably is happening in other buildings that have a similar Trend BMS and submeter configuration. It is unclear whether this issue is confined to this specific BMS or whether it happens with other models.

Currently, installing submeters into buildings seems take place typically to satisfy to Building Regulations Part L compliance, rather than to provide improved functionality and energy management. So, Part L guidance and enforcement needs to be improved to reflect the above recommendations. If meters are installed they should be properly commissioned and connected to the BMS, as they are unlikely to be manually read in practice.

Lesson: At design stage, specify that building energy management systems should provide the functionality for long term storage and analysis of metered energy data to allow short term, seasonal and annual consumption to be properly understood.

9.4 Ownership of energy data throughout the building life cycle

For a building to be truly energy efficient the role of 'energy manager' is crucial. There needs to be someone who is actively monitoring energy data and making decisions based on it, as submetering will not lead to any savings without being used. The energy manager needs to have full ownership of the energy data, be able to review it in an accessible form and be able to draw conclusions from both short and long term data. The role of the energy manager can be fulfilled by the facilities manager (FM), but for that to be satisfactory they would need to be appropriately trained and the energy data presented to them in an accessible form. Currently, in this case, the BMS displays energy consumption for each submeter as a cumulative total from the point of commissioning, which is essentially unusable for energy management. There are now many different specialist energy management software packages commercially available that allow data collected through an automatic meter reading (AMR) system to be effectively displayed to the energy manager. The majority of these show 30 minute data as a minimum. If the data are not displayed in an accessible form, then the energy manager is highly unlikely to engage with them and will lack a useful tool for understanding how the building is performing.

Minimising energy consumption is not always the primary concern. Ensuring the building services are operating as intended is also important. At the NCC, the AHUs for the specialised laboratory spaces are turning off at weekends when (for correct operation) they should be on constantly. Energy data for the AHU consumption for the specialised laboratory spaces viewed in an accessible form (e.g, daily total consumption) would quickly inform the facilities / energy manager of such problems.

At NCC, the client rents out its facilities to tenants. At the moment, the energy metering in place does not allow them to accurately apportion energy consumption for different work areas (such as the Clean Rooms), as the AHUs are not separately submetered and many of the process loads' submeters are not properly connected to the BMS. A recommendation for this type of building is to ensure that large AHUs are individually submetered or at least according to the areas they serve, as well as ensuring that any installed submeters are connected to the BMS.

Lesson: As part of the facilities management team's responsibilities, ensure that an energy management function is assigned to an individual's role.

9.5 Communication of metering strategy between design team and installers

The BPE study showed that submetered pieces of equipment were not always installed on the submeters designated for their connection during fit-out. Instead, they were connected directly to the room's distribution board. This seems to stem from a lack of communication of the metering design to the installers. This could be improved by including permanent labelling on distribution boards advising what should and should not be connected and / or by improving the documentation / signage to make explicit what equipment should be connected to which submeter.

Lesson: During the design and construction of a new building, ensure that the building services designers, effectively communicate the metering strategy to the electrical contractor, controls and BMS contractor and that at all stages all drawings, specifications, reports and physical installations use identical labelling with a clearly explained hierarchy and purpose for each sub meter available.

9.6 PV design export assumptions should be made on regulated and unregulated energy consumption

Although initial design estimates indicated that the PV array would export around 44% of its generated electricity back to the Grid, in reality only less than 6% is exported. This large discrepancy can be attributed to the export assumptions being based only on regulated energy consumption. Due to the nature of activities carried out at the NCC, a large proportion of its energy consumption is associated with process loads which are not limited by Building Regulations. Although in this situation the export of electricity to the National Grid was of no concern (with no Feed-in-Tariff in place), for other buildings the business case may rely on this, so export calculations should be made on total estimated energy consumption, including all unregulated energy consumption.

Lesson: National Grid export estimates made during design of photovoltaic power installations should be made based on the total regulated (by Building Regulations) and unregulated energy demands of the building.

9.7 Fully consider rain noise during design

A BUS Methodology survey showed high levels of occupant dissatisfaction with the noise generated from the rain water down pipes on rainy days. Rain water down pipes should not be routed through occupied spaces. In this case, it is likely that this issue arose as the location of the underground storage tank dictated other aspects of the design.

Lesson: Rain water down pipes should not be routed through occupied spaces.

9.8 Summary

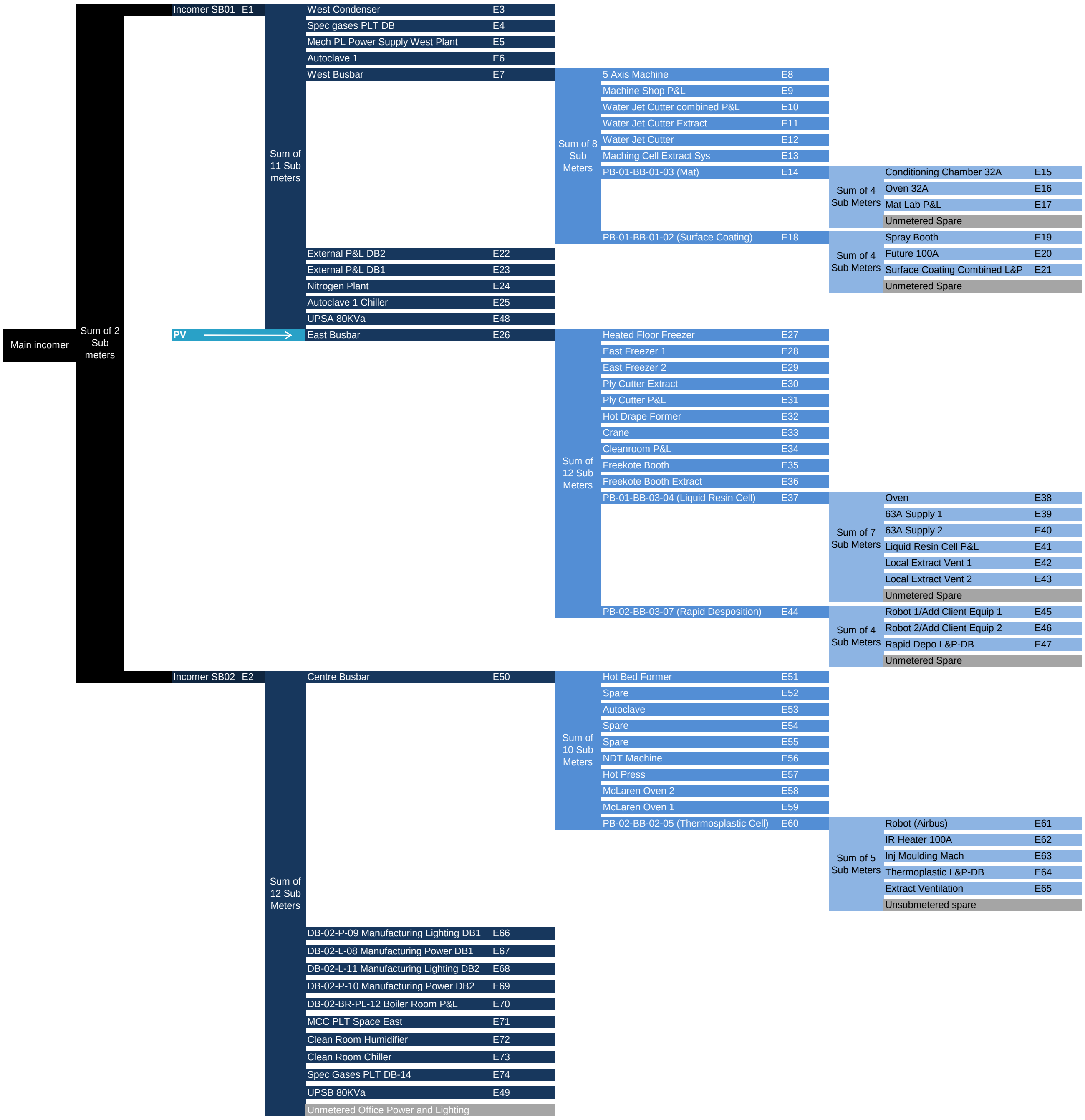
The NCC has been commercially successful. This has led to the procurement of another similar building: NCC2. As such the NCC should be considered to fulfil its primary purpose of providing facilities for the research and manufacture of high performance composite materials. All buildings suffer from some 'teething' issues, as each is essentially a prototype. In this case, the separate industrial processes and office spaces have not been brought together before in the same building. Additionally, the design team also had to provide flexibility in the design to provide facilities for tenants, but with the client themselves uncertain of the precise tenant requirements.

Many aspects of the operation and construction are very good especially considering the design and construction programme time constraints. The occupants also generally seem satisfied with the building performance. However, the BPE study was able to discover some commissioning and operational problems that may have gone unchecked and potentially similarly arisen in NCC2.The BPE study has also highlighted several problems which could be similarly occurring at other buildings. Where possible, solutions to these problems have been proposed. Other issues such as the loss of data on the BMS when a meter reaches 1,000,000 are likely to be happening in many buildings across the country jeopardising long term energy data monitoring.

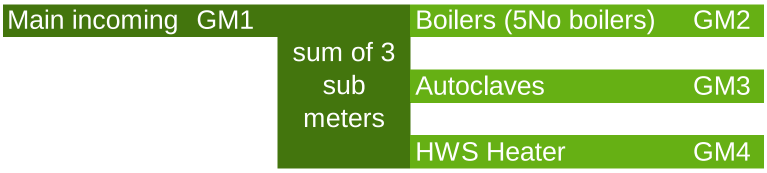
10 Appendices

10.2 Meter hierarchies

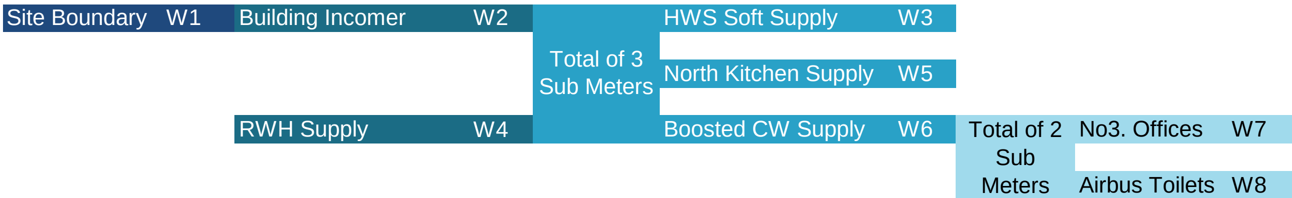
10.2.1 Electricity



10.2.2 Gas



10.2.3 Water



10.3 Submeters with timestamp issue

Table 10.3.1: List of submeters that were commissioned with the incorrect timestamp.

Meter Ref	TM-22 Meter Ref	Meter Name	Name on BMS	Meter on LAN21 and affected by date change
EM06	E02	Autoclave 1	Autoclave 1	Yes
EM25	E12	Autoclave 1 Chiller	Auto Clave 1 Chiller	Yes
EM50		Centre BusBar	Centre Busbar BB-02-02	Yes
EM73	E28	Clean RM Chiller	Clean Room Chiller	Yes
EM72		Clean RM Humidifier	Clean RM Humidifier	Yes
EM23		DB-01-Ex-Pl-01	DB-01-Ex-Pl-01	Yes
EM22		DB-01-Ex-Pl-02	DB-01-Ex-Pl-02	Yes
EM70	E26	DB-02-BR-PL-12	DB-02-BR-PL-12	Yes
EM67		DB-02-L-08	DB-02-L-08	Yes
EM68		DB-02-L-11	DB-02-P-11	Yes
EM66		DB-02-P-09	DB-02-P-09	Yes
EM26		East BusBar	East Busbar BB-01-03	Yes
EM69		Manufacturing Power DB-02-P-10	DB-02-P-10	Yes
EM71	E27	MCC PLT Space East	MCCP Plant Space East	Yes
EM05	E01	Mech PLT West PTRM	MECH Plant West Plant Room	Yes
EM24	E11	Nitrogen PLT	Nitrogen Plant	Yes
EM74		Spec Gases PLT DB-14	Spec Gases Plant DB14	Yes
EM48	E13	UPSA 80KVa	UPSA 80KVa	Yes
EM49	E29	UPSB 80KVa	UPSB 80KVa	Yes
EM07		West BusBar	West Busbar BB-01-01	Yes

10.4 Measured summer conditions in the office spaces

Relative humidity and air temperature data were measured at 15-minute intervals for 6 office locations at NCC from 7th August 2013 to 2nd October 2013. Tinytag sensors were placed in the three office spaces: 'North', 'Tenant', and 'East'. The locations are shown in Figure 10.4.1. There were 2 Tinytag sensors in each office space, one by the external windows and another by the inner windows. The Tinytag sensors were positioned at desk height as follows:

1. 'North Window' (by the external window)
2. 'North Inbound' (by the inner window)
3. 'Tenant Window' (by the external window)
4. 'Tenant Inbound' (by the inner window)
5. 'East Window' (by the external window)
6. 'East Inbound' (by the inner window)

In addition, for a location close to NCC, external relative humidity and air temperature data measured at 5-minute intervals were sourced as published by others on the Weather Underground website [2]. Figures 10.4.2, 10.4.3 and 10.4.4 present the measured air temperatures in 'North', 'Tenant', and 'East' respectively in comparison with the external air temperatures.

From the measured internal (and external) relative humidity and air temperature data, indoor and outdoor humidity mixing ratios (HMRs, the ratio of the mass of water vapour to the mass of dry air) were inferred for occupied hours (assumed to be 07:00 to 19:00, Monday to Friday) from 7th August 2013 to 23rd August 2013. These are presented in Figures 10.4.5 to 10.4.10. It can be seen that at all locations there is a strong linear relationship between the internal and outdoor humidity mixing ratios. During the study period, the general trend is that the internal HMR is less than the external HMR, except at the 'East Window' location. (However, the possibility of incorrect calibration of the East Window sensor exists.)

[2] www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=IBRISTOL21&month=8&day=8&year=2013

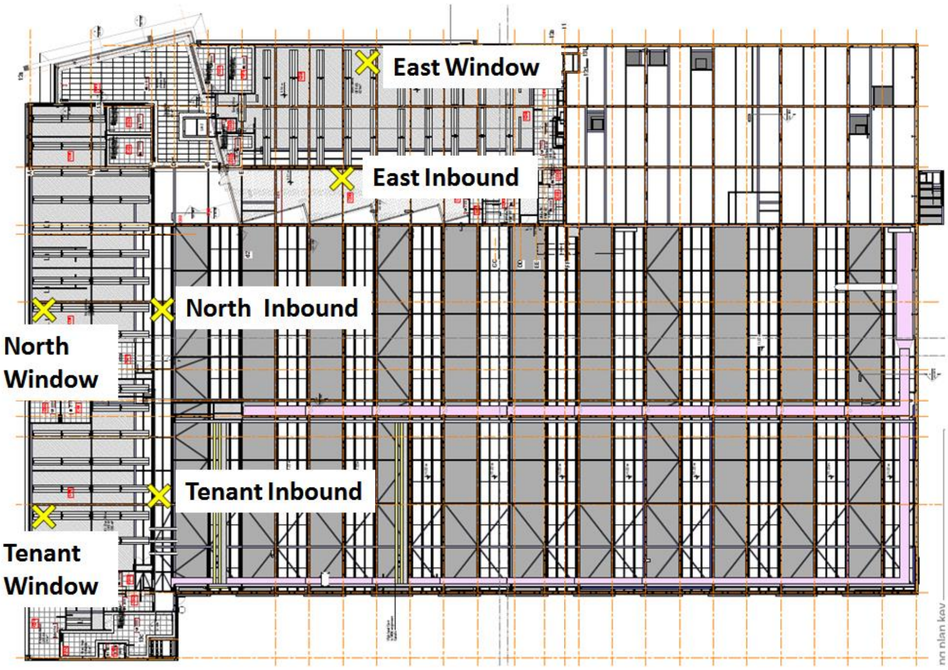


Figure 10.4.1. Locations of Tinytag sensors in first floor offices at NCC to measure indoor air temperatures and relative humidities.Yellow crosses indicate approximate placement of Tinytag sensors.

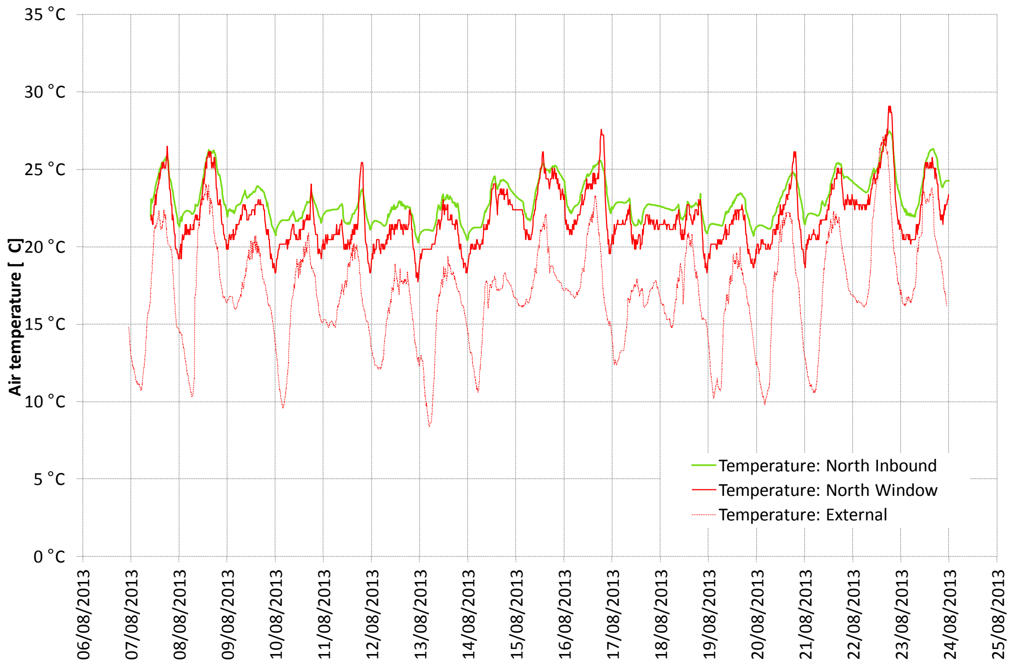


Figure 10.4.2. Air temperature from 7th August 2013 to 23rd August 2013 - 'North Window' and 'North Inbound' locations.

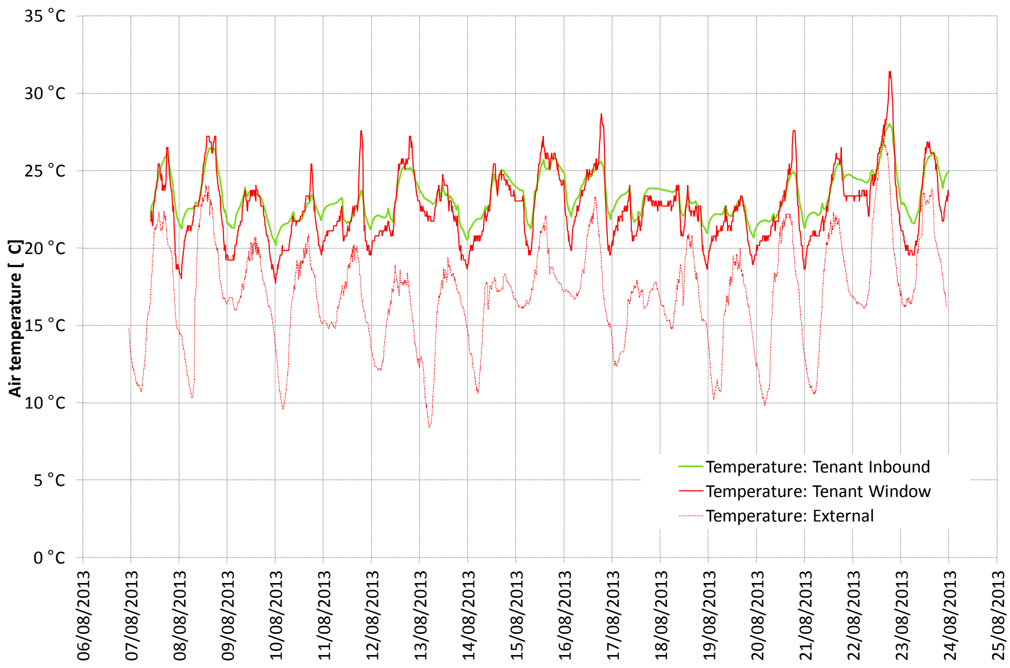


Figure 10.4.3. Air temperature from 7th August 2013 to 23rd August 2013 - 'Tenant Window' and 'Tenant Inbound' locations.

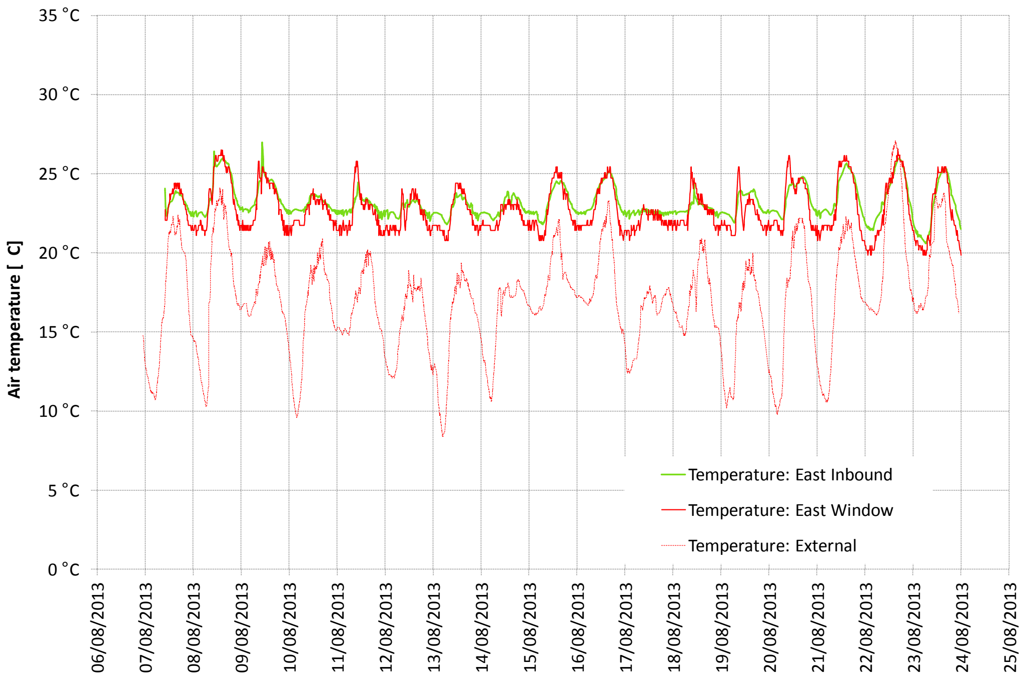


Figure 10.4.4. Air temperature from 7th August 2013 to 23rd August 2013 - 'East Window' and 'East Inbound' locations.

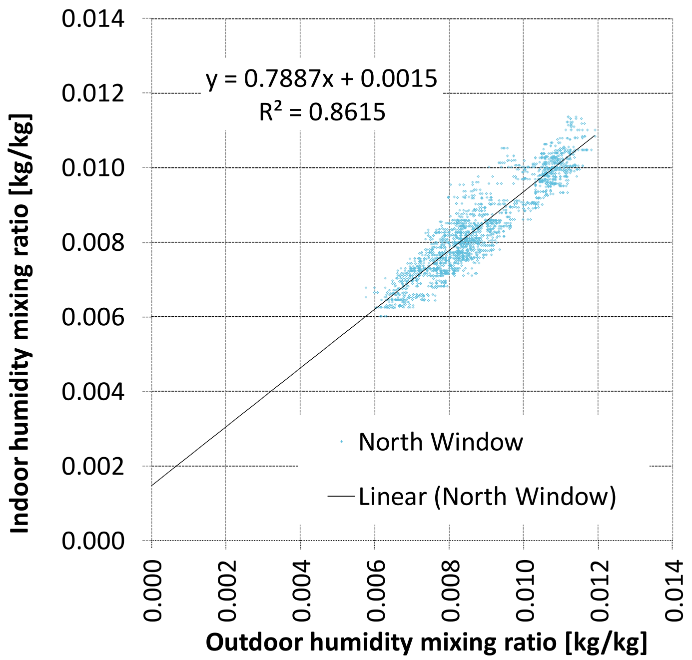


Figure 10.4.5. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'North Window' location.

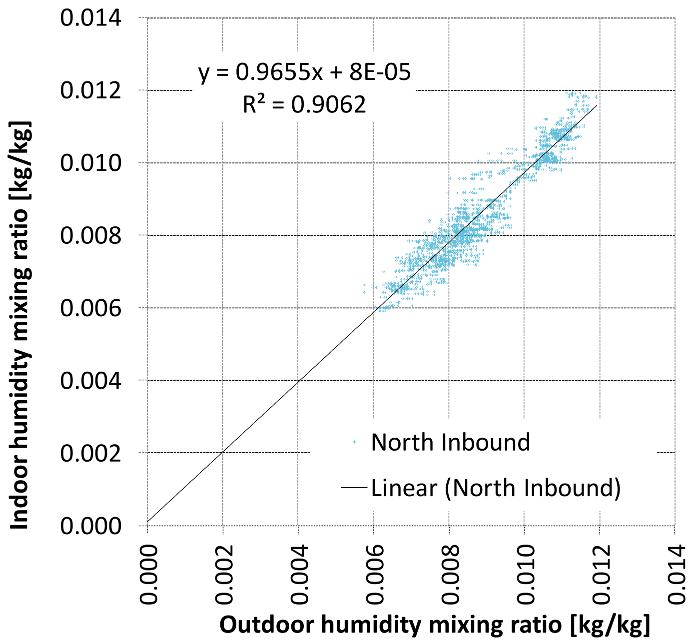


Figure 10.4.6. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'North Inbound' location.

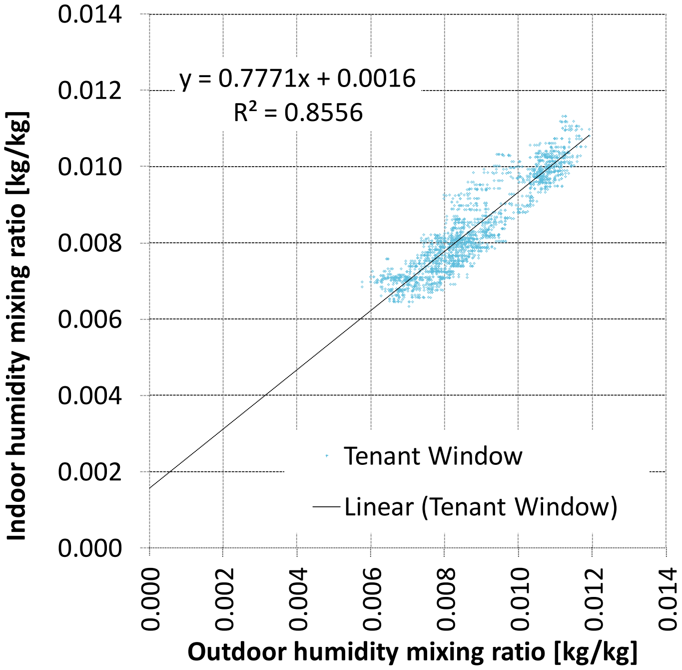


Figure 10.4.7. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'Tenant Window' location.

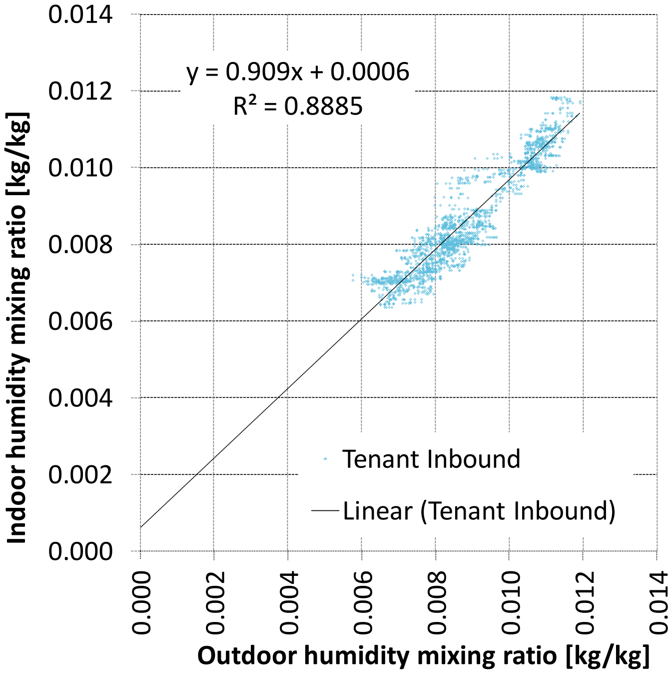


Figure 10.4.8. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'Tenant Inbound' location.

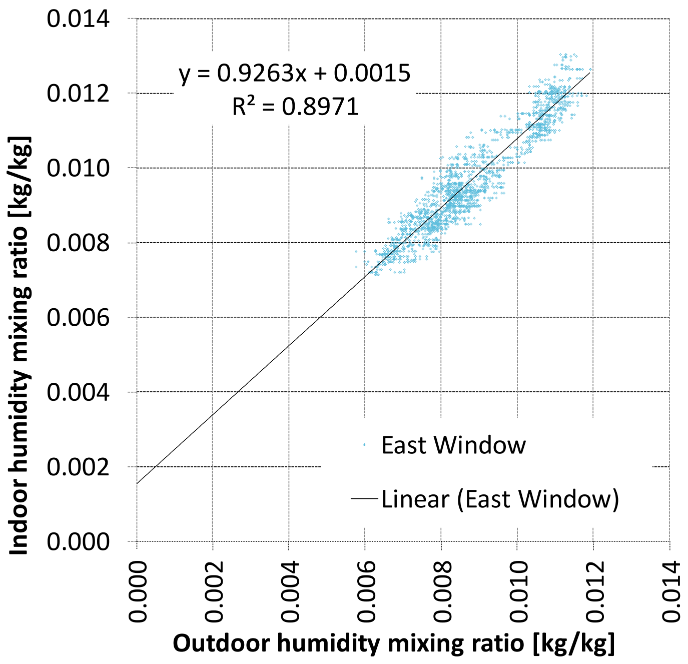


Figure 10.4.9. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'East Window' location.

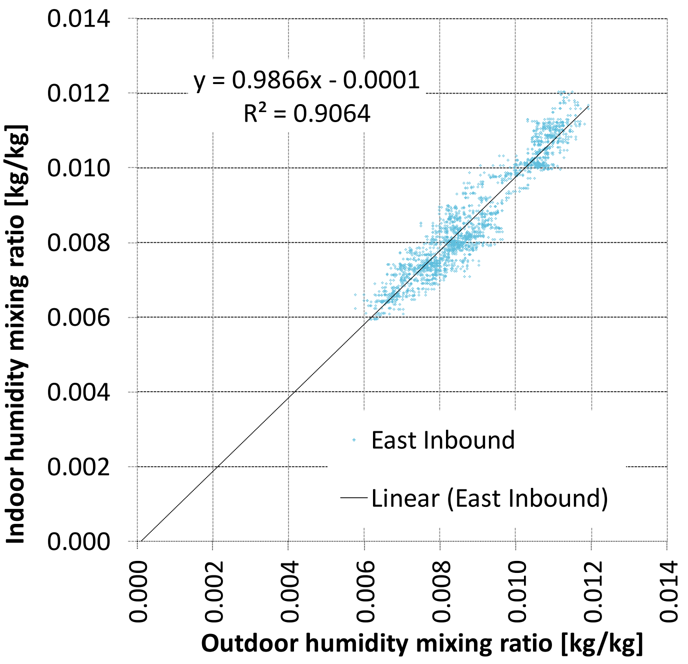


Figure 10.4.10. Relationship between inferred indoor and outdoor humidity mixing ratios during occupied hours from 7th August 2013 to 23rd August 2013 - 'East Inbound' location.