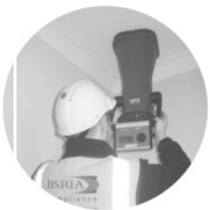
Building Performance Results

Foots Cray Depot

By Roderic Bunn

23 July 2015



Carried out for:	Jablite Limited Infinity House, Anderson Way Belvedere, Kent, DA17 6BG
Contract:	
Issued by:	BSRIA Limited Old Bracknell Lane West, Bracknell Berkshire RG12 7AH UK
Telephone:	+44 (0) 1344 465600
Fax:	+44 (0) 1344 465626

Email: roderic.bunn@bsria.co.uk
Website: www.bsria.co.uk

QUALITY ASSURANCE

Issue	Date	Prepared by:	Checked by:
Final	*23/07/2015*	*Roderic Bunn* *Building Performance Analyst*	*Colin Pearson* *Head of Building Performance*

DISCLAIMER

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1 INTRODUCTION

This report contains the results and analysis of the energy consumption, internal environmental conditions, and occupant satisfaction of the Foots Cray Depot following the application of Jablite Dynamic Insulation.

The report focusses on the monitoring carried out by Roderic Bunn of BSRIA from March 2014 when the Jablite system and background ventilation were installed.

Energy analysis was carried out using data from fiscal meters installed in the building and monitored by the London Borough of Bexley.

Physical condition measurements, including *in situ* monitoring of ventilation temperature and relative humidity, were carried out by BSRIA and completed in April 2015.

BSRIA conducted two Building Use Studies occupant surveys in the building, a pre-refurbishment survey on 20 March 2013, and a follow-up post-refurbishment survey on 19 May 2015.

This report should be read in conjunction with the previous reports issued by BSRIA and summarised in the Jablite Interim Report.

1.1 ENERGY ANALYSIS

The analysis of energy use in the Foots Cray Depot relies on the automatic metering records maintained by Kent County Council's LASER Energy Buying Group (www.systems-link.com). Data for the Depot's monthly gas and electricity consumption was entered into the CIBSE TM22 energy analysis tool, and compared against relevant benchmarks.

Two TM22 models have been created: a pre-refurbishment (in-use) model based on 12 months energy consumption to August 2012, and a post-refurbishment (improved) model using 12 months energy consumption to April 2015. The in-use profile can be viewed in Appendix A: TM22 Tool v2.16 Foots Cray depot 2012-13 V3.0, and the improved model in Appendix B: TM22 Tool v2 17 Foots Cray 19052015.

1.2 ENVIRONMENTAL ANALYSIS

The performance of the building's environmental systems were monitored by BSRIA using Testo 175 dataloggers installed within the fan boxes of the Jablite dynamic mechanical ventilation system. The dataloggers were installed on the inlet and outlet spigots of four systems on the ground and first floors.

Data was gathered on a 15 minute cycle, enabling comparison with data gathered by dataloggers installed by Cambridge Architectural Research (CAR) within the Jablite insulation system and from room condition sensors located in occupied spaces on each floor. External conditions were obtained from an external weather station.

CAR's monitoring devices recorded air quality and the temperature in the cavity of the insulation at lower and upper levels in each cavity for each elevation.

Winter, mid-season, and summer fortnight periods have been selected for detailed analysis. The original graphs and data is available in Appendix C: Foots Cray Depot_ventilation system datalog readings_2014-2015 V1.0.

1.3 OCCUPANT SATISFACTION SURVEYS

An occupant survey of the permanent occupiers in the Foots Cray Depot was carried out prior to the Jablite installation on Wednesday 20 March 2013. A post-refurbishment survey was performed on Tuesday 19 May 2015. Best practice in surveying occupants is to allow at least two years between surveys.

The survey used the Building Use Studies Methodology (otherwise known as the BUS Methodology, or BUS for short). The method has been in use since 1985, originated by Building Use Studies. Arup acquired the intellectual property in 2008.

The BUS survey is based on an adaptable, generic, manually-applied questionnaire created for any non-domestic building type with permanent occupants. It collects feedback from building users about how well buildings work.

Results of the 2013 and 2015 surveys are supplied as data appendices:

- Appendix D1 2013 and D2 2015: Results for benchmarked and descriptive variables (PDF)
- Appendix E1 2013 and E2 2015: Comments of occupants (PDF)

2 ENERGY ANALYSIS

2.1 PRE-RETROFIT ENERGY ANALYSIS

A pre-refurbishment energy survey of the Foots Cray Depot was carried out as part of the initial assessment of the building and its suitability for retrofitting with the Jablite external dynamic insulation. The building is a rectilinear, brick-built, flat-roofed, local government office of 1179.8 m^2 of treated floor area over two storeys.

Annual energy consumption and carbon dioxide emissions estimated from energy supply company readings and AMR data from Kent County Council's LASER billing system. The metered data was compared against a breakdown of energy consumption by end use based on observation and assessment of power loads. Occupied hours were determined from entry card records. The building's electrical systems are not sub-metered. The meter room contains meters for the building, the external lighting and the refuse compactors for the adjacent waste recycling facility.

Based on 12 months readings to 2012, the building consumed 67,972 kWh per annum of gas for space heating, equating to 57.6 kWh/m^2 per annum (Note: the rolling average for the previous four years was higher at 84,875 kWh.) The annual data to August 2012 was about 20 kWh/m^2 per annum better than the best practice figure quoted *Energy Consumption Guide 19* (*ECON 19*). However this doesn't include hot water for washing and catering. Some staff at the Depot are also known to use electric convector heaters.

Electric point of use hot water heating was estimated to consume around 15 kWh/m^2 per annum compared with the *ECON 19* "Typical" value for hand washing and catering of 7 kWh/m^2 per annum, although this figure is very sensitive to changes in run-time assumptions. All the units in kitchens and toilets are switched on permanently.

Total electricity consumption was estimated at 146,714 kWh per annum, equating to 124.4 kWh/m^2 per annum. This was higher than the median *CIBSE TM46* benchmark of 95 kWh/m^2 per annum. The modelled end use breakdown estimates for the year to August 2013 (shown below) were estimated to be within two per cent of the fiscal meters. This was considered an acceptable tolerance based on the information available.

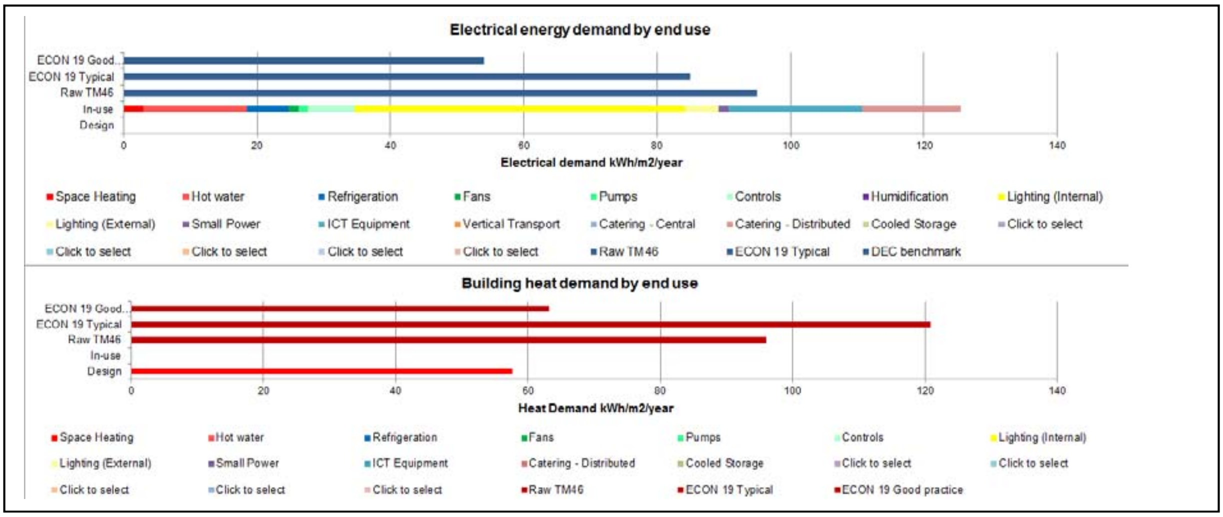


Figure 1: Annual energy consumption at Foots Cray Depot to August 2012 against benchmarks (Note: space heating appears in the TM22's "Design" category.

SIMPLE ASSESSMENT					
Absolute values	Energy supplied (kWh)		Carbon dioxide emissions (kg CO_2)		
Type	Fuel/thermal	Electricity	Fuel/thermal2	Electricity3	TOTAL
Supplied	67,972	146,714	13,187	80,693	93,879
Exported CHP	0		0		
Unit values	Energy supplied (kWh/m² GIA)		Carbon dioxide emissions (kg CO_2/m² GIA)		
Type	Fuel/thermal	Electricity	Fuel/thermal2	Electricity3	TOTAL
Supplied	57.6	124.4	11.2	68.4	79.6
Exported CHP	0.0		0.0		
Raw TM46	120.0	95.0	23.3	52.3	75.5
ECON 19 Typical	151.0	85.0	29.3	46.8	76.0
ECON 19 good practice	79.0	54.0	15.3	29.7	45.0

Figure 2: The energy consumption and carbon dioxide emissions for the year to August 2012 calculated in CIBSE TM22 (V2.16).

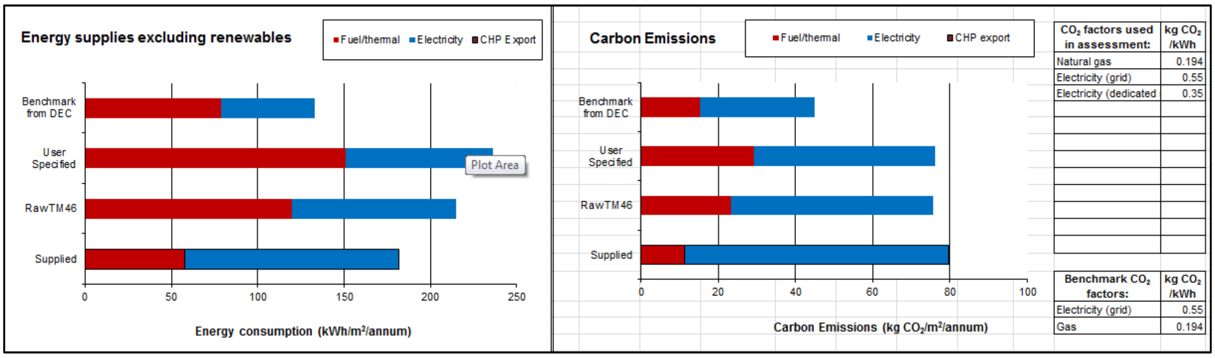


Figure 3: The energy consumption and carbon dioxide emissions graphed for the year to August 2012. Note the carbon dioxide factors used in the assessment. For consistency these factors were also used for the 2015 comparison below.

2.2 POST-RETROFIT ENERGY ANALYSIS

A second energy analysis was conducted for the first 12 months operational period of the Jablite external dynamic insulation from March 2014 to April 2015.

Note that the data and analysis that follows is for the initial period of operation of the Jablite insulation and background ventilation system. Best practice in Building Performance Evaluation (BPE) is to use the initial 12 month period of operation to monitor and gather data in order to identify areas of improvement and adjustment. The initial 12 months of operation should therefore not be a judgement of a building's long-term performance (or, in this case, the product innovation). The data and its analysis should therefore be considered with this proviso.

Metered gas and electricity data for the 12 months to April 2015 was gathered from the LASER website serving the Foots Cray Depot (www.systems-link.com). The website enables the user to perform a range of analyses. In addition, data analysis carried out by the Directorate of Customer and Corporate Services at the London Borough of Bexley has been included in this report.

2.3 GAS CONSUMPTION

Based on 12 months readings to April 2015 (including the 7-month 2014-15 heating season from October 2014 for which gas consumption was recorded), the building consumed 80,164 kWh per annum of gas for space heating, equating to 68.2 kWh/m^2 per annum. This is an 18 per cent increase for the 2014-15 heating season with the Jablite external insulation compared with 2013-14 season without the Jablite insulation.

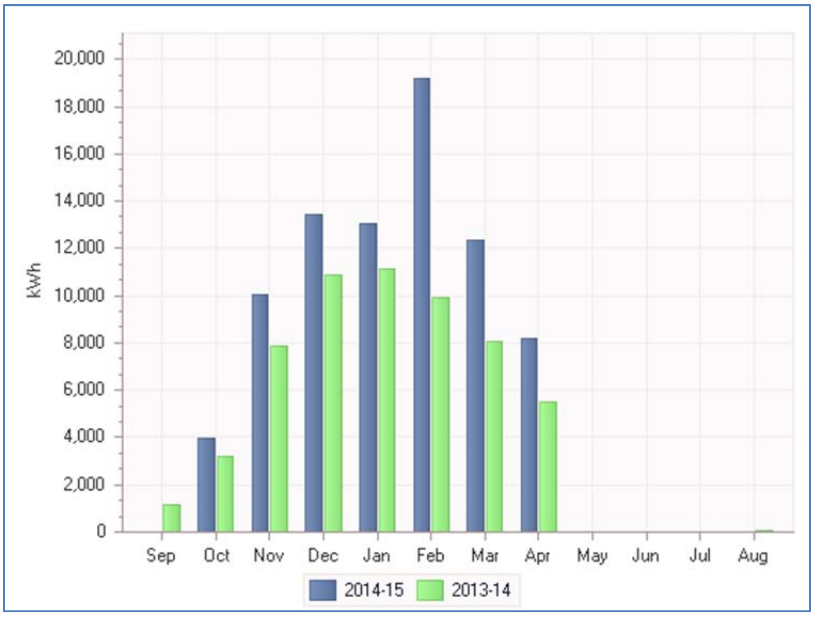


Figure 4: Gas consumption recorded by the LASER automatic metering system for 2013-24 compared with 2014-15.

Month	2014-15	2013-14	Variation	
	kWh	kWh	kWh	%
Sep	0	1,122	-1,122	-100
Oct	3,970	3,221	749	23.26
Nov	10,013	7,897	2,116	26.8
Dec	13,455	10,848	2,607	24.03
Jan	13,060	11,125	1,935	17.4
Feb	19,183	9,912	9,272	93.54
Mar	12,327	8,041	4,286	53.3
Apr	8,156	5,470	2,686	49.1
May	0	0	0	0
Jun	0	0	0	0
Jul	0	0	0	0
Aug	0	55	-55	-100
Total	80,164	57,690	22,474	38.96

Figure 5: Actual data for Figure 4.

The rolling average for gas consumption over the four years to 2011 was higher at 84,875 kWh per annum. However, while heating energy consumption for 2014-15 is lower by 5.5 per cent compared to the rolling average, this also needs to be considered in relationship to the fluctuations in heating degree-days for the four years to 2015.

Heating degree-days (the number of days that external temperature has fallen below 15.5C, therefore necessitating space heating, based on data from a relevant weather station).

The year to June 2013 was a relatively cold year for the location, with 25% more heating degree days compared with 2012. The year to June 2014 reversed that trend, being 29% warmer than 2013. For the most recent year to May 2015 (the period the building had external insulation), the degree day data used for the South London area was 2% warmer than 2014.

Figure 6 shows degree-day analysis provided by the Directorate of Customer and Corporate Services at London Borough of Bexley for the period January 2012 to December 2014. This shows that the heating energy consumption at the Depot tracks below the degree day data, indicating that the heating system is controlled well against monthly external ambient. This reinforces the TM22 analysis of 2012 which indicated that gas consumption was better than *ECON19* benchmarks.

However, Figure 6 combines data from before and after the installation of the dynamic insulation and MVHR system, so arguably one regression line should not be used for data sets that should be graphed separately. On that basis it has limited value. Note that the data for winter of 2014/15 only extends to December 2014 and not to April 2015 as in the consumption data in Figures 4 and 5.

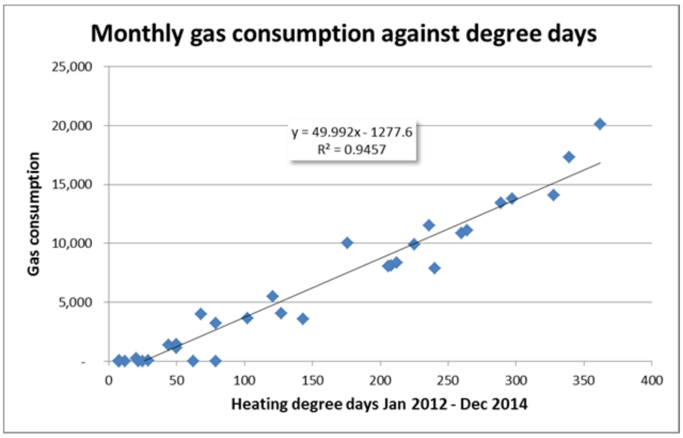


Figure 6: Monthly gas consumption compared to heating degree days. An R^2 (Pearsons correlation) value of 94.5% indicates an accurate relationship between actual gas consumption on site and the theoretical amount of gas required over the same period. (Source: Enda Mitchell, London Borough of Bexley.)

The heat recovery system was installed in February 2014, and the system commissioned in March 2014. As the winter of 2014/15 represents the only heating period that can be used to assess performance, and that the year to May 2015 was 2% warmer than the previous year, it should be expected that heating energy consumption should be proportionately lower, and lower still due to the presence of external insulation which should have improved the building's wall U-values.

Note that the building was not subjected to a second airtightness test after the installation of the Jablite insulation. While the pre-retrofit test achieved an air permeability value of 8.91 $m^3.h^{-1}.m^{-2}$ at 50 Pa, the installation of the mechanical ventilation system involved penetrations through the fabric. The building's level of airtightness may conceivably be different.

Figure 7: Typical ductwork penetrations through the wall into the Jablite insulation. The airtightness of the installation was not checked. Note discontinuous insulation of the heating circuit.

Given that the gas consumption for the year to April 2015 was 18 percent higher than the previous 12 month period, and that the degree day data used for analysis shows that the climate was 2 per cent warmer than the previous year, it is therefore not possible to attribute any savings in gas energy consumption to the presence of the Jablite dynamic insulation.

It is therefore suggested that the building be monitored for a further 12 months to determine whether the entire system, including the background mechanical system, be tuned and modified in the light of the initial 12 months performance.

While it can be demonstrated that the building's heating system appears to be well controlled against degree day data, the surprisingly high gas consumption in 2014-15 warrants investigation of the set points used to determine heating system operation. In light of the findings in section X (environmental performance) and section Y (Occupant survey results), it may be that the Depot's heating system is operating unnecessarily, contributing to higher gas consumption and overheating.

2.4 ELECTRICITY CONSUMPTION

Based on 12 months readings to April 2015 the building consumed 162,391 kWh of electricity. equating to 137.6 kWh/m^2 (gross internal area) per annum. This includes six 80 W mechanical ventilation with heat recovery fans (mvhr) running constantly. All fans can be speed-controlled with an occupant-controlled manual boost setting (note that some fans are operating permanently at their maximum setting).

Electricity consumption increased in 2014/15 by 15,677 kWh per annum (10.7 per cent) compared to 2011/12, for which the mvhr is responsible for 3364 kWh per annum. Allocating the remainder involved revisiting the end-use electricity categories and revising run times and loads.

A CIBSE TM22 energy assessment was performed using 12 months data to April 2015 using the LASER automatic meter readings. The electricity end-use data from 2012 was imported into the TM22 'in-use' spreadsheet. An extract fan has been added for the ground floor kitchen, and adjustments have been made to account for changes in catering equipment and a new under-sink water heater. No changes were made to the use of desk fans or fan heaters, as no evidence was available.

The changes immediately accounted for the 10.7 per cent difference in consumption to the extent that the 2015 TM22 breakdown of end-use electricity consumption reconciles almost exactly with the fiscal electricity meter. This is regarded to be more of a fluke than justified accuracy. A tolerance of up to five per cent would be regarded as acceptable. The changes are highlighted in blue in the 'in use' tab of the TM22 model (Appendix B: TM22 Tool v2.17 Footscray 19052015).

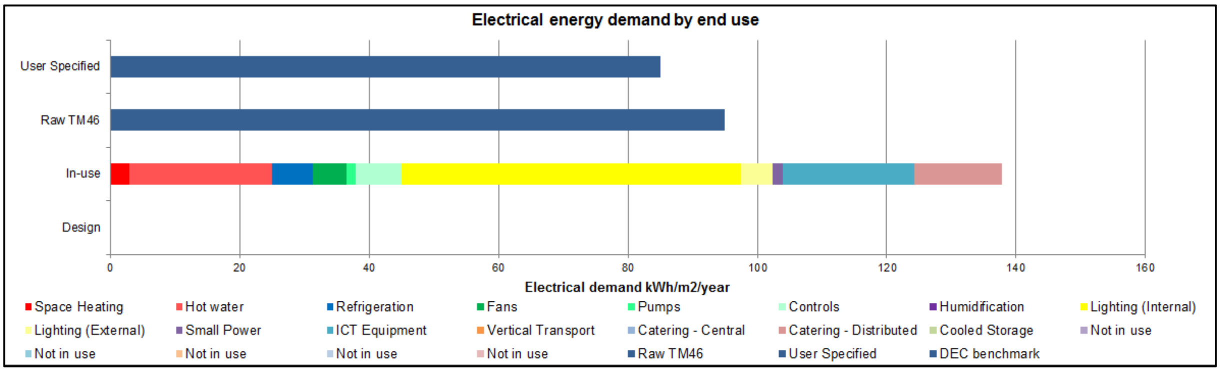


Figure 8: Electricity consumption by end use for the year to April 2015.

Absolute values	Energy supplied (kWh)		Carbon dioxide emissions (kg CO_2)		
	Fuel/thermal	Electricity	Fuel/thermal	Electricity	TOTAL
Supplied	80,473	162,391	14,888	80,221	95,109
Exported CHP	0		0		

Unit values	Energy supplied (kWh/m² GIA)		Carbon dioxide emissions (kg CO_2/m² GIA)		
	Fuel/thermal	Electricity	Fuel/thermal	Electricity	TOTAL
Supplied	68.2	137.6	12.6	68.0	80.6
Exported CHP	0.0		0.0		
Raw TM46	120.0	95.0	23.3	46.9	70.2
User Specified	151.0	85.0	29.3	42.0	71.3
Benchmark from DEC	0.0	0.0	0.0	0.0	0.0

Figure 9: Electricity consumption against benchmarks for the year to April 2015.

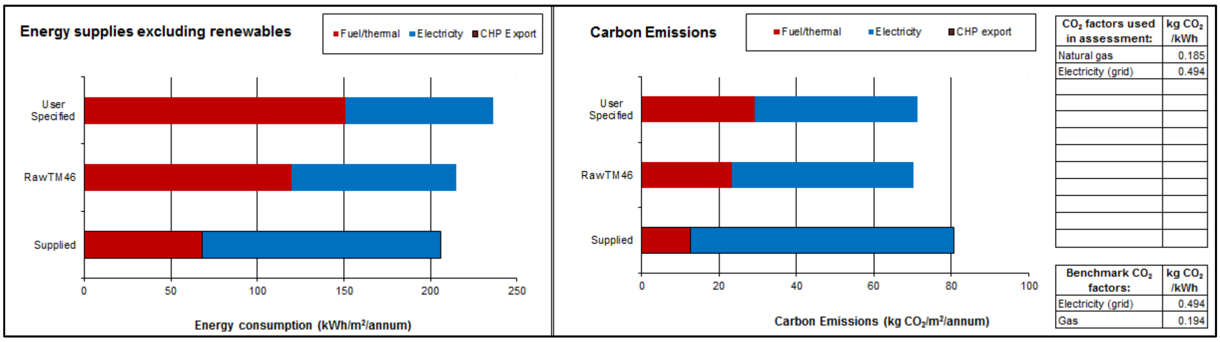


Figure 10: The energy consumption and carbon dioxide emissions graphed for the year to April 2015. Note the carbon dioxide factors used in the assessment are the same as those used for the 2011-12 analysis.

3 ENVIRONMENTAL MONITORING

Figure 11: The Tongdy Control Technologies multi-sensor in the ground floor north elevation open-plan office.

Monitoring of the building's environmental conditions for the north and south offices on both floors was carried out by Cambridge Architectural Research (CAR) from March 2013. Four internal Tongdy dataloggers measured room space temperature, carbon dioxide and relative humidity.

Owing to site constraints and internal office configurations, none of the internal dataloggers could be installed in what could be considered ideal locations. They were mostly at seated height, and visible to the occupants.

Due to cables being dislodged or units accidentally unplugged, inevitably there are some gaps in the data. CAR also reported that connection with the office network was difficult to maintain. Furthermore, it was reported by occupants that they opened windows when they saw the carbon dioxide monitor turn red at 1400 ppm.

CAR also installed temperature probes into the dynamic insulation system. All devices communicated with the web-based logging platform over the office internet facility.

An Omega Engineering EasyLog datalogger mounted outside the building monitored the external conditions. This was also unreliable, and where data are missing CAR substituted data from alternative weather stations, corrected to estimate the likely temperature at the site.

In February 2014, BSRIA installed Testo standalone dataloggers in the inlet and outlet spigots of four mvhr systems, on both floors, to measure the temperature and relative humidity conditions of the supply air into the system and the supply air to the rooms. These dataloggers provided data values across the mvhr heat recovery system for winter and summer operation. In summer the dataloggers measured values when the system is in bypass mode and air is drawn directly from outside rather than through the insulation cavity.

To avoid the need to gather and manage large datasets, data intervals for the Testo dataloggers were set at 60 minutes.

3.1 PRE-REFURBISHMENT ENVIRONMENTAL ASSESSMENT

Prior to the installation of the Jablite insulation, BSRIA carried out an analysis of the Depot's internal comfort conditions, focusing on internal temperature and relative humidity.

The data analysis in Figures 12 to 16 show:

- The weather conditions measured by the external data logger from February to June 2013
- Space temperature, relative humidity and carbon dioxide levels for a selected two-week period in March 2013(early Spring)
- Space temperature, relative humidity and carbon dioxide levels for a selected two-week period in June 2013 (early Summer).

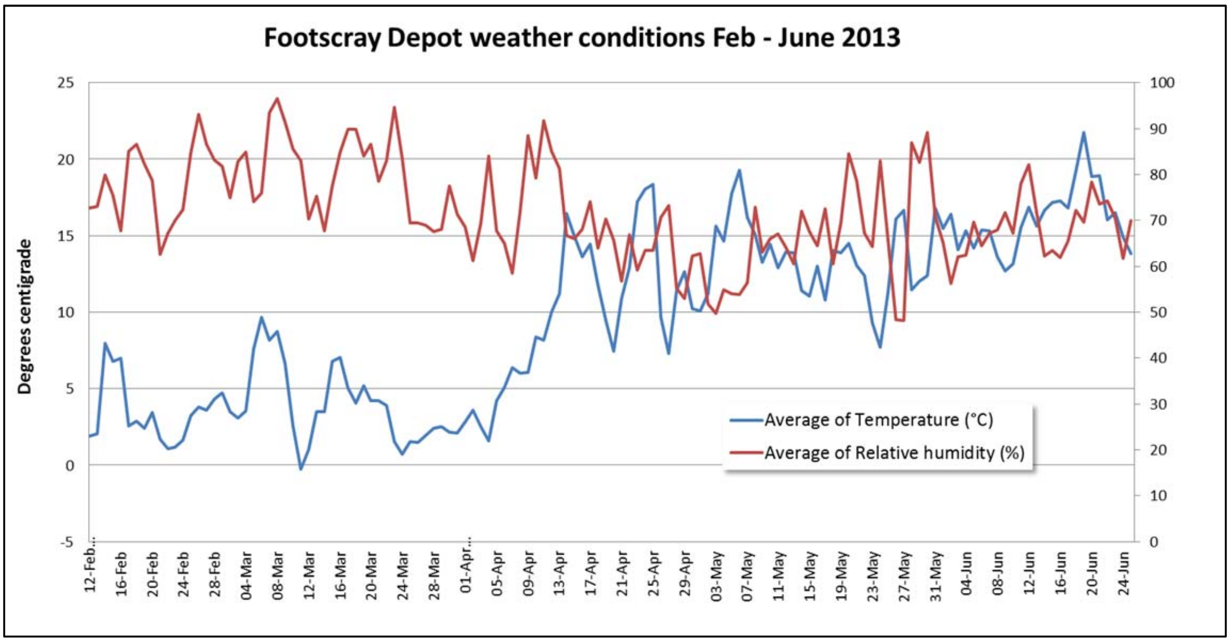


Figure 12: External temperature and relative humidity from 2 February to 24 June 2013. The data shows the mild and wet winter of 2012/13, a period of unseasonably warm weather in mid-March and mid-April and early May, followed by a period of milder weather before the onset of summer (averaged from half-hourly data).

Figure 12 shows the external weather conditions measured by the external Omega datalogger from February to July 2013. This data was smoothed and averaged from 60-second interval data. The data shows the mild and wet winter of 2012/13, a period of unseasonably warm weather in mid-March and mid-April, and a period of milder weather before the onset of summer.

Figure 13 shows that when internal temperature data is overlain on the external data, internal dry bulb temperature on the south ground floor reached 25.5°C at an external ambient of 16°C. The south side of the first floor reached a maximum of 23°C during 20-21 March. Even at weekends, internal temperatures on the ground floor south-side did not fall below 22.5°C.

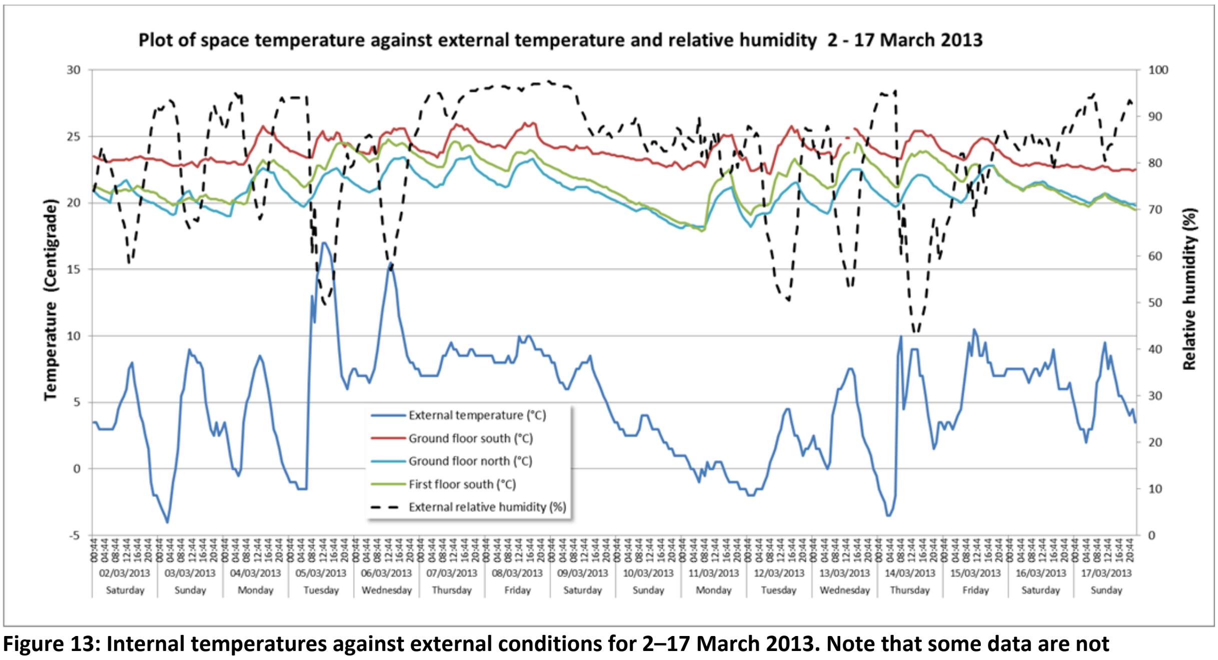


Figure 13: Internal temperatures against external conditions for 2–17 March 2013. Note that some data are not continuous owing to disturbance of CAR's Trogdy room sensors on the first floor. There is no data available for the first floor north side.

Gas consumption for March 2013 totalled 8041 kWh, so at least 4000 kWh can be attributed to the period 1-17 March given that external temperature was below 15.5°C most of the time.

The ground floor north and south offices are separated by a dividing block wall. Lower temperatures on the ground floor north offices are consistently lower, probably a consequence of being protected from the effects of direct and uncontrolled solar gain during both occupied and unoccupied periods. Figure 13 also reveals that the building did not purge itself of daytime heat at night or at weekends.

Temperatures in the south-side open-plan office and the north cellular office were broadly similar. Given that the office is adjacent to the open-plan area, and that staff were observed to keep their doors open rather than closed, it is not surprising that data readings were similar. The north side was around 1 - 1.5°C cooler.

Note that CIBSE *Guide A* (Table 1.5, Section 1.3) recommends suitable winter and summer temperature ranges and outdoor air supply rates for a range of building types. For general open-plan office buildings, the acceptable winter dry resultant temperature range is 21-23°C, and for summer a dry resultant temperature of 22-24°C. Both winter and summer values are referenced to occupant activity and clothing levels. Overheating was defined by CIBSE as the exceedance of 28°C for more than one per cent of occupied hours based on an example design summer year.

CIBSE *Guide A* overheating definitions have now been superseded by CIBSE *TM52 The Limits of Thermal Comfort: Avoiding Overheating in European Buildings* (CIBSE, 2013). *TM52* links operative temperature to a mean value for prevailing external air temperature. CIBSE TM52's mean temperature factor follows *ASHRAE Standard 55*, which uses a mean outdoor temperature for 'free running' (naturally ventilated) buildings where internal environment would be directly influenced by external conditions. The weighted average of the daily mean outdoor temperature over the previous few days is used to determine acceptable internal temperature.

Figure 14 shows that relative humidity (rh) fell close to the 30% rh comfort threshold as defined in CIBSE *Guide A* and dropped below 25% rh on the ground floor towards the end of the graphed period. In association with the dry bulb temperature readings, it would be reasonable to presume that the occupants would suffer from poor indoor air quality, specifically dryness and stuffiness. (This is explored section X covering the results of the occupant survey.)

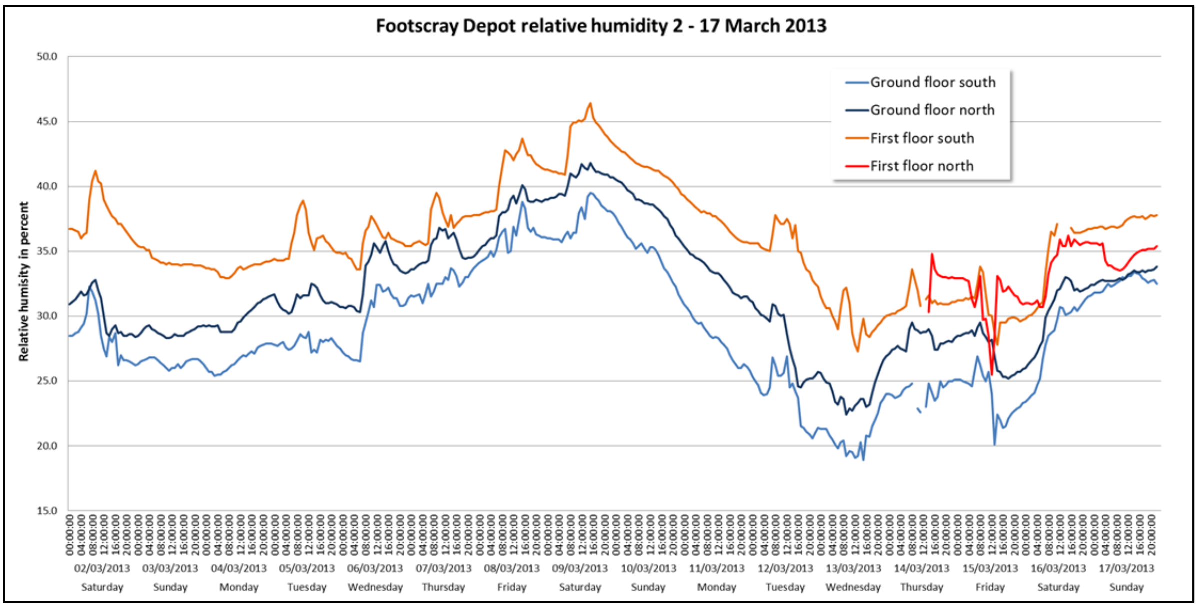


Figure 14: Internal relative humidity readings for two weeks in March 2013.

Figure 15 indicates that carbon dioxide concentration stabilises between 400-500 ppm at weekends and overnight. Concentrations climb quickly as occupants arrive at work between 08.00 h and 09.00 h, and rise to 1000 ppm and above by midday.

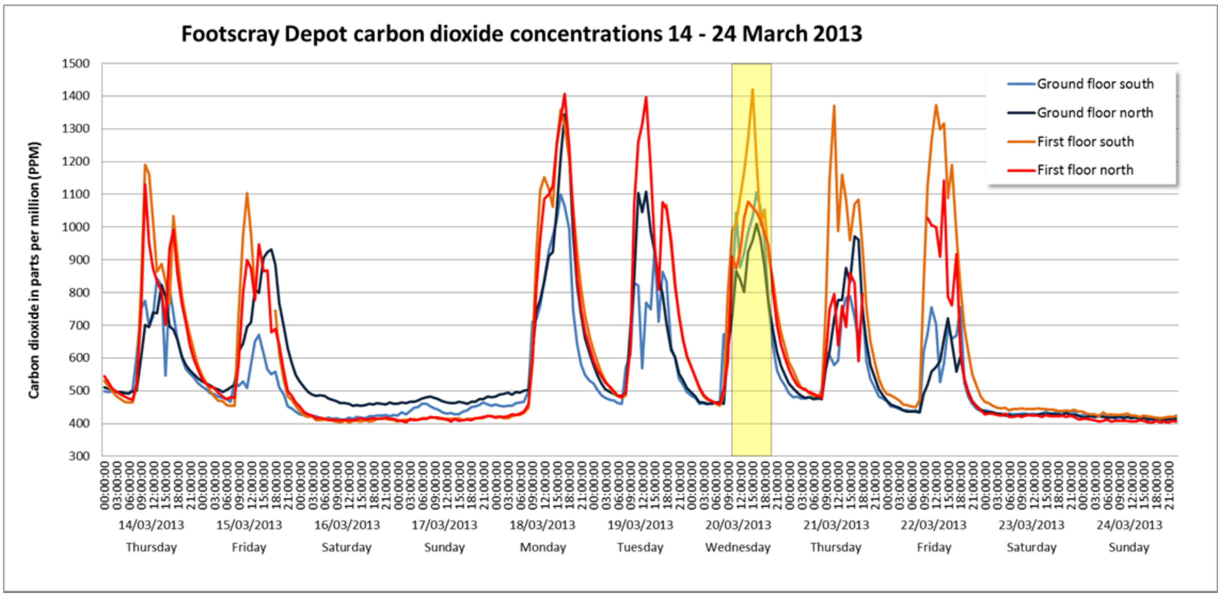


Figure 15: Internal carbon dioxide for the period 2 – 24 March 2013. Carbon dioxide peaks near 1400 ppm during weekdays. Background levels are between 400-500 ppm. The Trogdy sensor on the first floor north elevation failed to record carbon dioxide for a day towards the end of the selected period. The yellow area is the day of the BUS survey (Section 3.5).

The yellow highlighted zone represents the conditions prevailing in the building during the BUS occupant survey on 20 March. Internal conditions in the afternoon were hot and stuffy, consistent with the data shown in Figure 15.

Figure 16 shows internal temperature for a representative early summer warm spell from 1 – 16 June 2013. There is a small amount of data loss towards the end of the graphed period for the ground floor north sensor. The first floor north sensor also stopped recording data from Sunday 16 June.

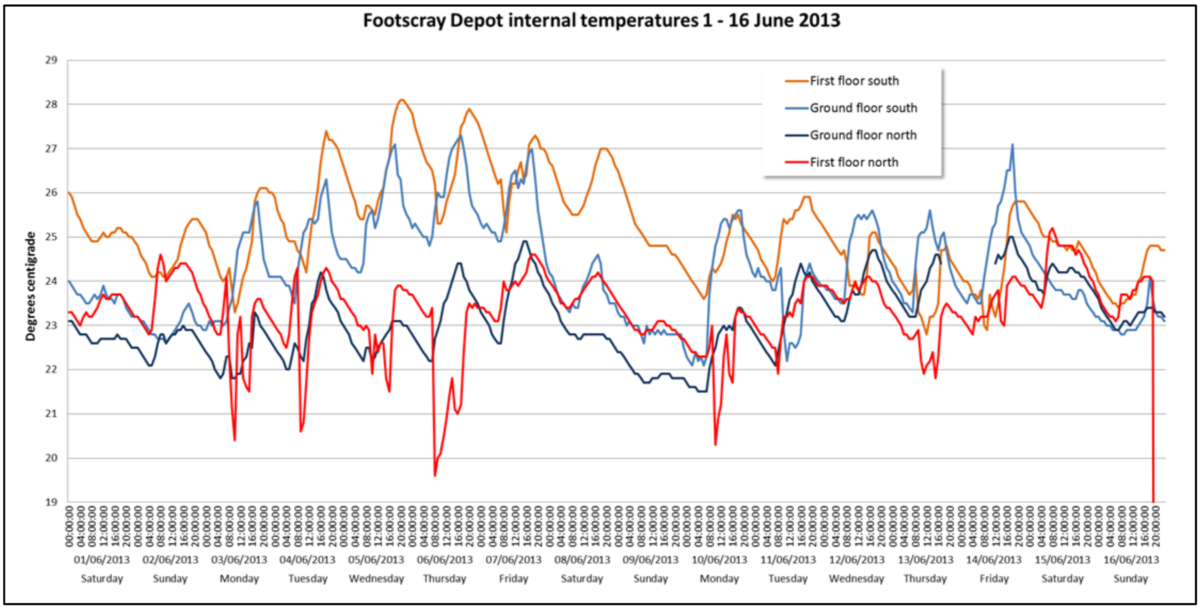


Figure 16: Internal temperatures on all floors during a two-week period in June 2013. Note data loss for the ground floor north office on 14 June. The first floor south experiences the highest temperatures, with temperatures not falling below 25.5°C at any time between 5-8 June 2013.

The south-facing offices on both floors clearly show overheating, with internal temperatures on the south side of the first floor rising to 28°C at the external temperature maximum of 20.5°C shown in Figure 13. Internal temperatures fluctuate between 24-27°C during occupied hours, and rarely drop to, or below, 22°C even on the ground floor north. This indicates that the building overheats significantly even during mild weather.

The first floor north sensor demonstrates erratic readings compared with the other sensors in the building. The author suspects this is related either to the opening of the window adjacent to the Trogdy datalogger in that office, or possibly (but less likely) the use of a mobile air-conditioning unit.

Table 1 is a summary of internal thermal and relative humidity conditions in the building during March 2013 (mid-season case) and June 2013 (prior to summer solstice).

Table1: Temperature exceedance for comparative two week periods in March and June 2013, with values for relative humidity in March. (The internal relative humidity conditions in June were within comfort guidelines.)

Location	2 - 17 March 2013			3 - 14 June 2013		
Exceedence during occupied hours	**Internal temperature <21°C**	**Internal temperature >23°C**	**Internal temperature >27°C**	**Internal temperature <21°C**	**Internal temperature >23°C**	**Internal temperature >27°C**
Ground floor south	0.0%	93.8%	39.8%	0.0%	92.3%	60.0%
Ground floor north	27.7%	12.3%	0.0%	0.0%	58.5%	0.0%
First floor south	0.0%	45.6%	0.0%	0.0%	96.9%	49.2%
First floor north	No data	No data	No data	0.0%	53.1%	0.0%
Average external temperature	12.6°C			19.6°C		
	Internal relative humidity 2 - 17 March 2013					
	Occupied hours under 30% RH			**Occupied hours over 65% RH**		
Ground floor south	71.9%			0.0%		
Ground floor north	42.3%			0.0%		
First floor south	11.6%			0.0%		
First floor north	No data			No data		

3.2 POST-REFURBISHMENT ENVIRONMENTAL ASSESSMENT

3.2.1 Dynamic insulation cavity measurements

Analysis of the Depot's post-refurbishment environmental conditions were studied by Cambridge Architectural Research (CAR) using carbon dioxide, temperature and relative humidity monitors with displays connected to communication devices. Figure 17 shows the locations of the room temperature sensors (Temp 1-4) on the ground and first floors. The following categorisation was applied and used for the graphing and analysis of the data as shown:

- Temp 1: Ground floor South (Development team)
- Temp 2: Ground floor North (Community Services)
- Temp 3: First floor South (open-plan office)
- Temp 4: First floor North (cellular office).

Owing to data drop outs and problems with internet connections, there were significant data drop-outs from both CAR's room environment sensors that reduced the contiguity of data.

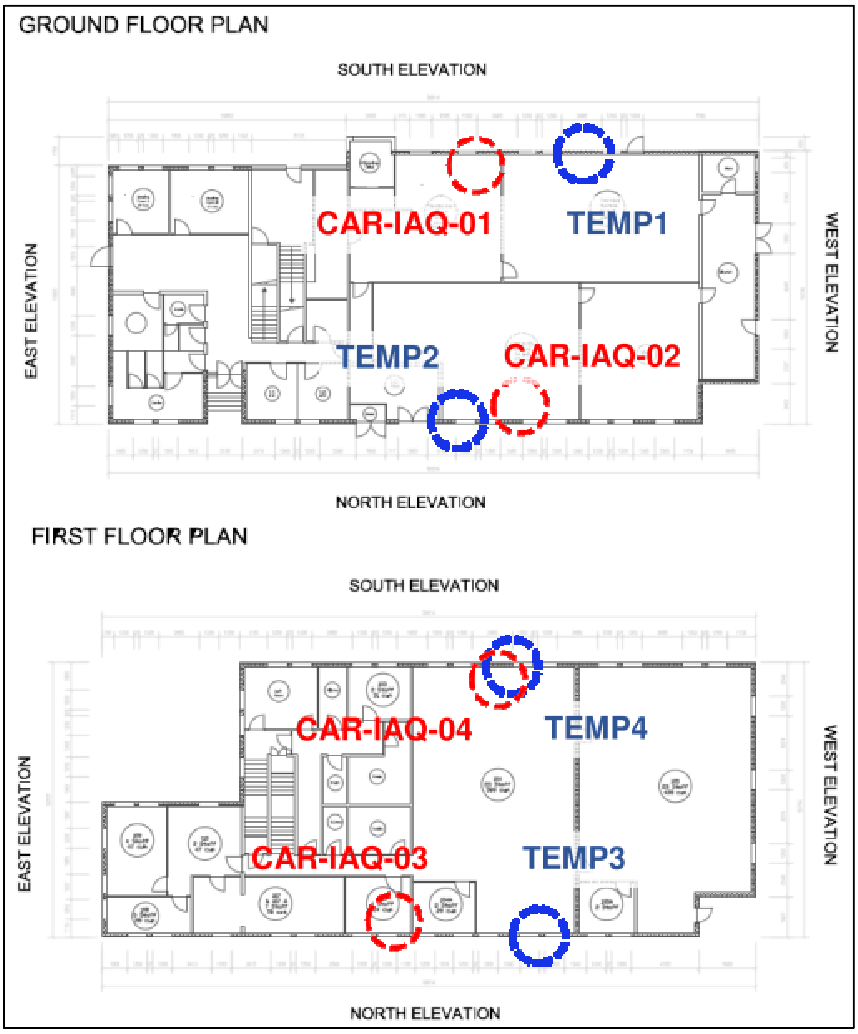


Figure 17: Location of CAR's indoor air quality sensors and room temperature sensors.

During the installation of the dynamic insulation, CAR placed eight sensors in the ventilation cavity of the insulation at locations chosen to measure the changes in the conditions of the air that pass through the cavities. Sensors were installed at the ground and ceiling level on both the ground floor and first floor (for example, TMP 1, A and B). The four locations were selected so as to place them near both the inlet ducts for air coming into the building, as well as near the internal sensors which were already in place (Figure 18).

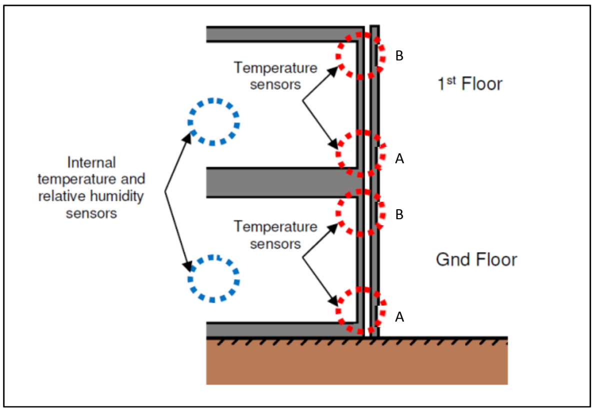


Figure 18: Location of CAR's temperature probes (labelled A and B on each elevation on each floor) were built in to the insulation system. Source: Foots Cray Depot Office Monitoring Summary Report (CAR 2015).

Owing to significant data drop-outs and other recording difficulties of the sensors embedded in the dynamic insulation (particularly for the first floor north elevation), analysis is limited to particular periods and locations.

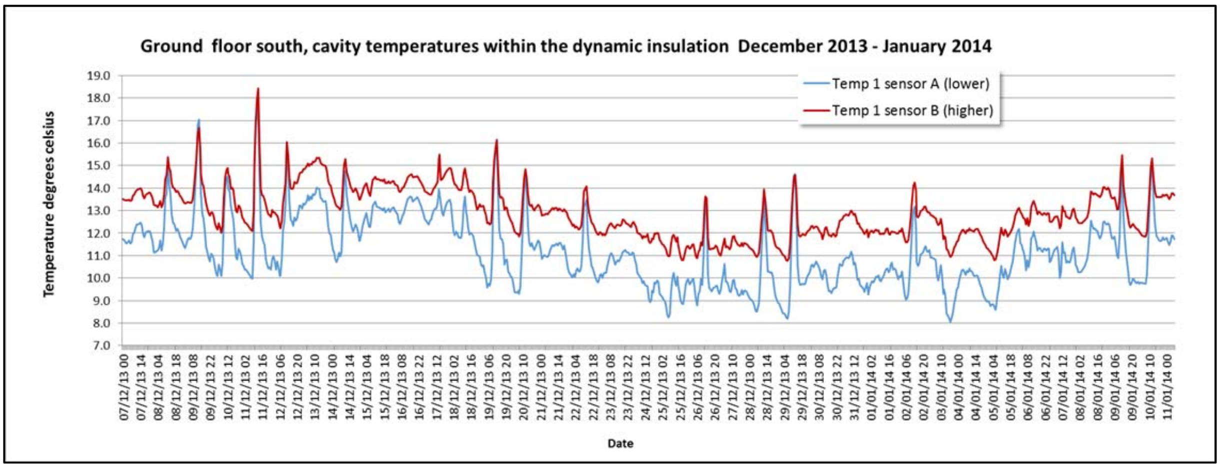


Figure 19: Cavity temperatures within the Jablite dynamic insulation on the ground floor south elevation measured on an hourly basis for December 2014 to January 2014 prior to the installation of the mechanical heat recovery system.

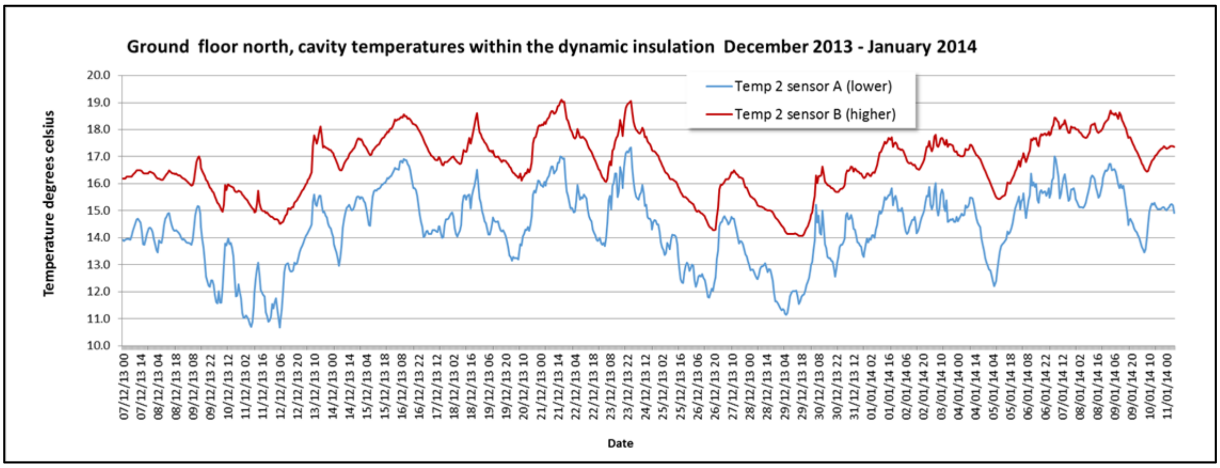


Figure 20: Cavity temperatures within the Jablite dynamic insulation for the ground floor north elevation measured on an hourly basis for December 2013 to January 2014 prior to the installation of the mechanical heat recovery system.

In figure 19 and 20, the relationship between the temperatures at the lower end of the cavities compared with values from the upper sensors is clear and suggests heat gain to the air as it flows through the cavities, potentially by heat loss from the office structure. The north elevation displays a different characteristic to the south elevation which shows a lower heat flux. The south elevation shows an average 1.8°C difference between inlet and outlet temperature, while the north elevation averages a 2.4°C differential.

Figure 21 shows the cavity temperatures for the first floor north elevation. The average heat gain across the sensors was 1.1°C, indicating warming by heat gain from heat flowing from inside the building through the building fabric to the cavity.

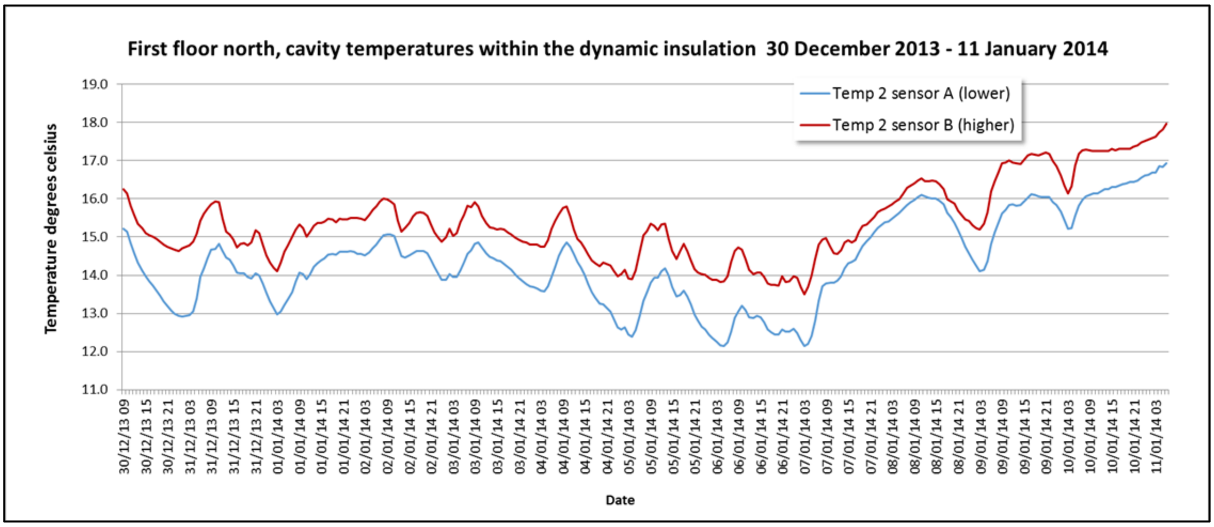


Figure 21: Cavity temperatures within the Jablite dynamic insulation for the first floor north elevation measured on an hourly basis for 30 December 2013 to 11 January 2014 prior to the installation of the mechanical heat recovery system.

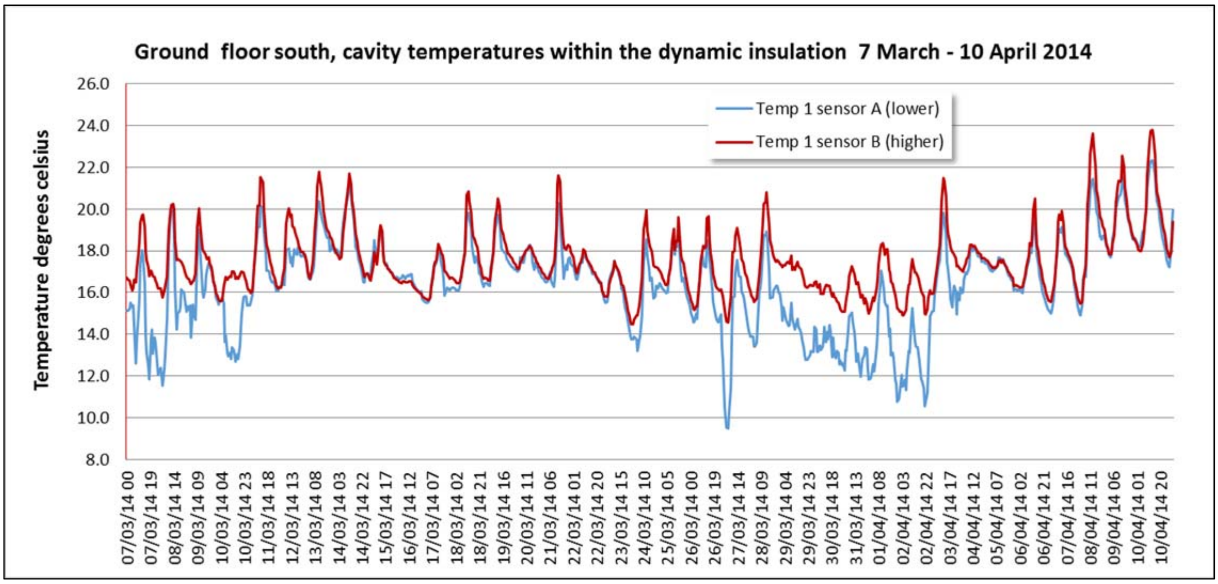


Figure 22: Cavity temperatures within the Jablite dynamic insulation for the ground floor south elevation measured on an hourly basis for 7 March – 10 April 2014 after the installation of the mechanical heat recovery system.

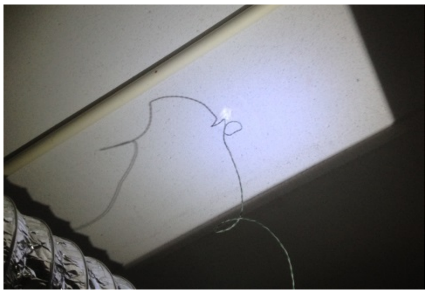
3.2.2 Ventilation system monitoring

In February 2014, BSRIA installed Testo T175 standalone dataloggers in the inlet and outlet spigots of four mechanical ventilation with heat recovery (mvhr) systems on the ground and first floors. This was to measure the temperature and relative humidity conditions of the supply air into from the dynamic insulation into the ventilation system and the supply air to the rooms.

Loggers were installed in the following locations:

- Ground floor: Community Services open-plan office (sensors 1 and 2)
- Ground floor: Technical services open-plan office (sensors 5 and 6)
- First floor: Cellular offices via room 1.10 (sensors 3 and 9)
- First floor: Open-plan office, room 1.05 (sensors 4 and 8).



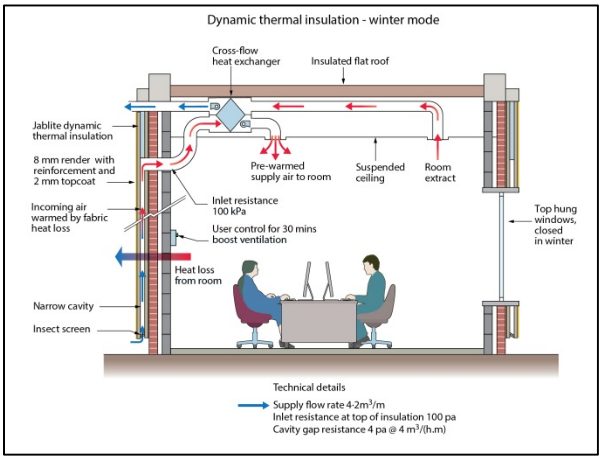


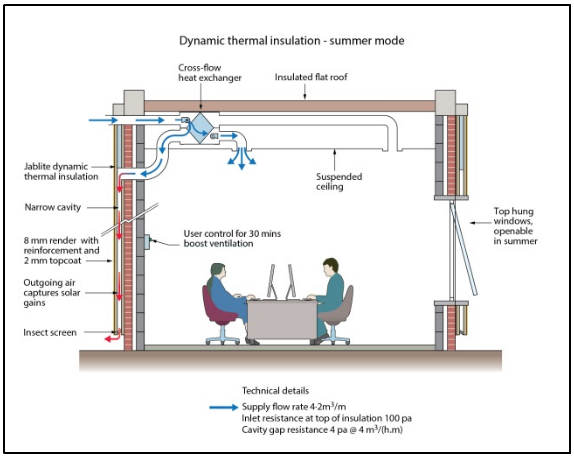
From left, Figure 23a: Dataloggers were placed downwind of the heat exchanger box. Figure 23b: An installed MHVR system. Figure 23c: A thermocouple was installed approximately 150 mm into the Aircrete slab of the south-west first floor office.

Data logging was set at 60 minute intervals. Some data gaps were caused by data logger overload and battery exhaustion, but gaps were not significant.

The data loggers provided data values across the mvhr system for winter and summer operation. In summer the dataloggers measured values when the system is in bypass mode and air is drawn directly from outside rather than through the insulation cavity. However, the precise point of switchover is not known and some interpretation of the data is needed for the summer months.

Owing to confusion over some inlet and outlet spigot locations (and a lack of labelling on the air handling units), some sensors were moved from their original locations, and then subsequently returned to their original spigots when the original location was found to be correct. An attempt has been made to correlate values to associate measurements properly to room outlet supply and room extract.





Figures 24a and 24b: The operation of the Jablite dynamic insulation system in Winter (*left*) and Summer (*right*). Note that in summer the insulation cavity is used as an extract path for vitiated air, but being automatic there is no indication as to when this control mode is in operation. The operational mode has to be determined by analysis of the temperature profiles in Section 3.3.

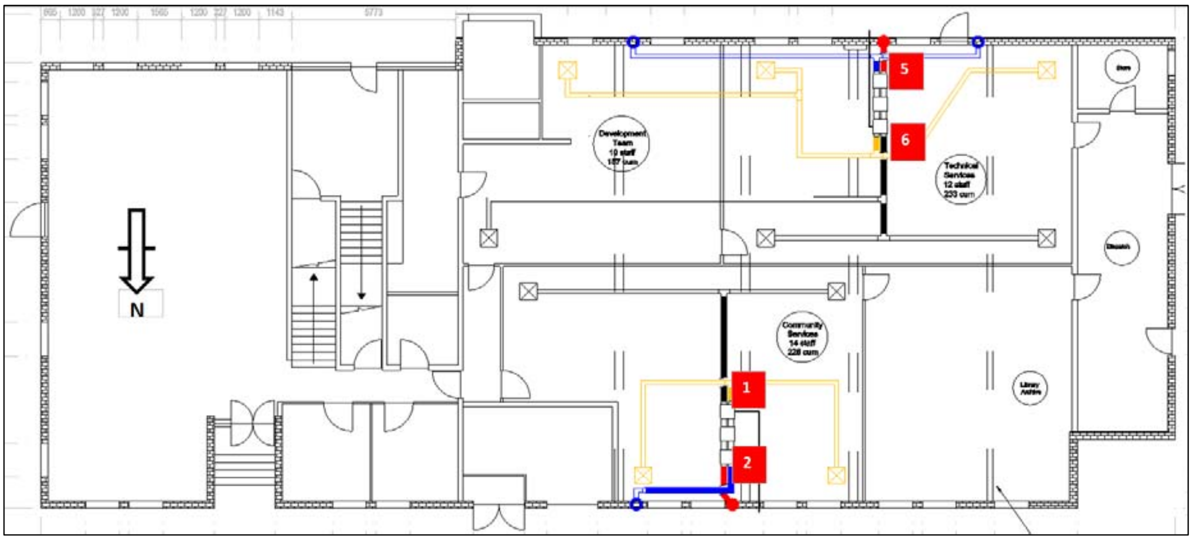


Figure 125: Locations of the ground floor MVHR system dataloggers.

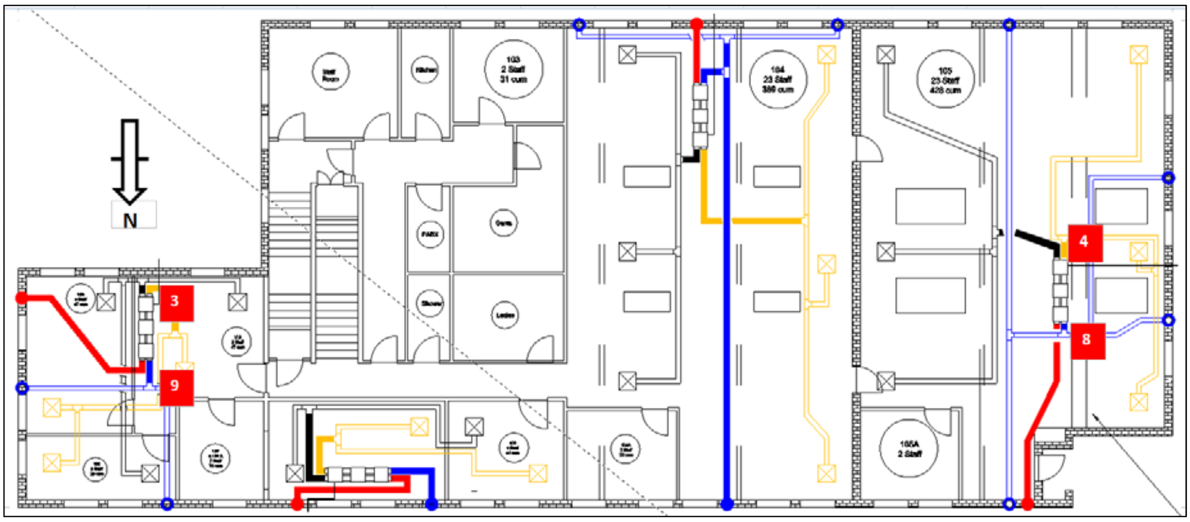


Figure 26: Locations of the first floor ventilation MVHR system dataloggers.

The bitumen-covered flat Aircrete roof slab is exposed to unobstructed solar gain. In July 2014 a surface thermocouple was installed beneath the slab to determine how the slab performs thermally. In January 2015 the thermocouple was repositioned approximately 150 mm into the slab, and in May 2015 the associated room temperature sensor was moved from the ceiling void to the underneath of the suspended ceiling. Data will be gathered during the summer of 2015 to help Bexley understand how the slab is performing thermally, and whether additional solar protection would be beneficial.

3.3 MONITORED DATA ANALYSIS

The following measurement periods for winter, mid-season and summer operation have been chosen for analysis using combined data from all sensors.

Location	Summer 2014	Autumn 2014	Winter 2014/15	Spring 2015
Ground floor north office	19 June – 3 July 2014		19 – 30 December 2014	
Ground floor south office	7 June – 1 July 2014			6 February – 6 March 2015
First floor south office	7 June – 1 July 2014	9 – 19 September 2014		6 February – 6 March 2015.
First floor west office	No data	No data	No data	No data

Attempts were made to combine internal temperature values with external weather data. Initial analysis for June to July 2014 for the south ground-floor elevation showed extreme variation in data obtained for the external Omega data logger. Values above 35°C were obtained on several occasions suggesting that the data logger was exposed to direct solar gains. This means the data are of questionable value during daylight hours.

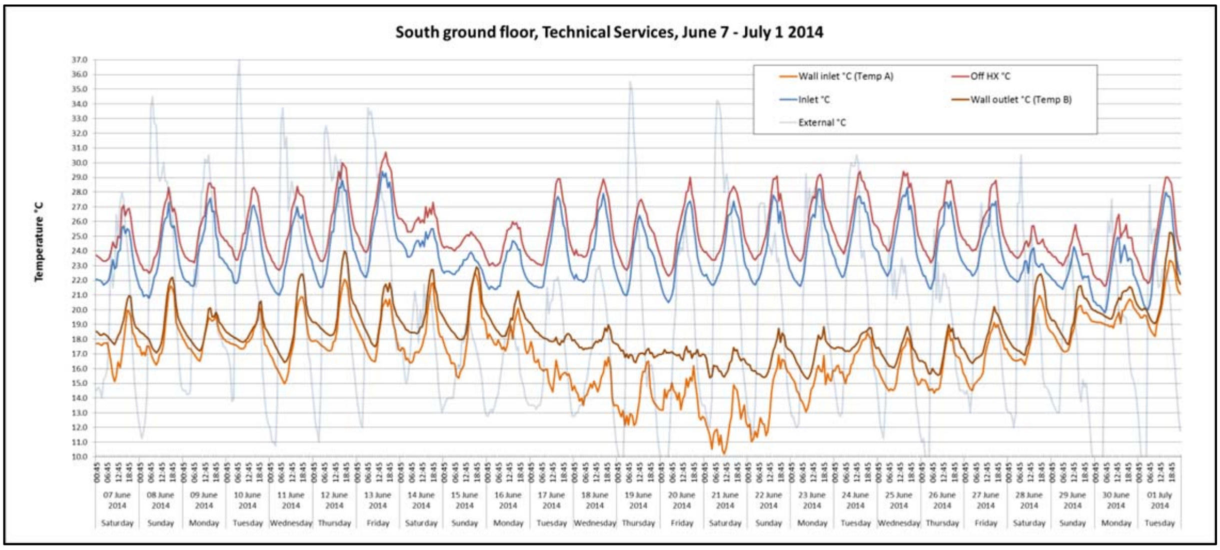


Figure 27: Temperature profiles for the summer conditions the south-facing ground floor offices. The red and blue lines show the temperatures across the mechanical ventilation system, with temperatures peaking between 27-30°C during working hours. External temperatures are shown as a faint blue line. Note that the mechanical ventilation system operates constantly, and shows that inlet temperatures never fall below 21°C, even at weekends. The Wall inlet and outlet (cavity) temperature profiles match, but the 3-4°C or greater differential between the top of the cavity and the inlet temperature to the mechanical ventilation system is considered to be dubiously large.

It is surmised that the flatter profile of the cavity readings between Monday 16 June and Friday 27 June may coincide with a period of stagnant air where no air was being drawn through the cavity, commensurate with summertime operation. It is therefore possible that the thermocouples were recording fabric temperature including conductive losses at night.

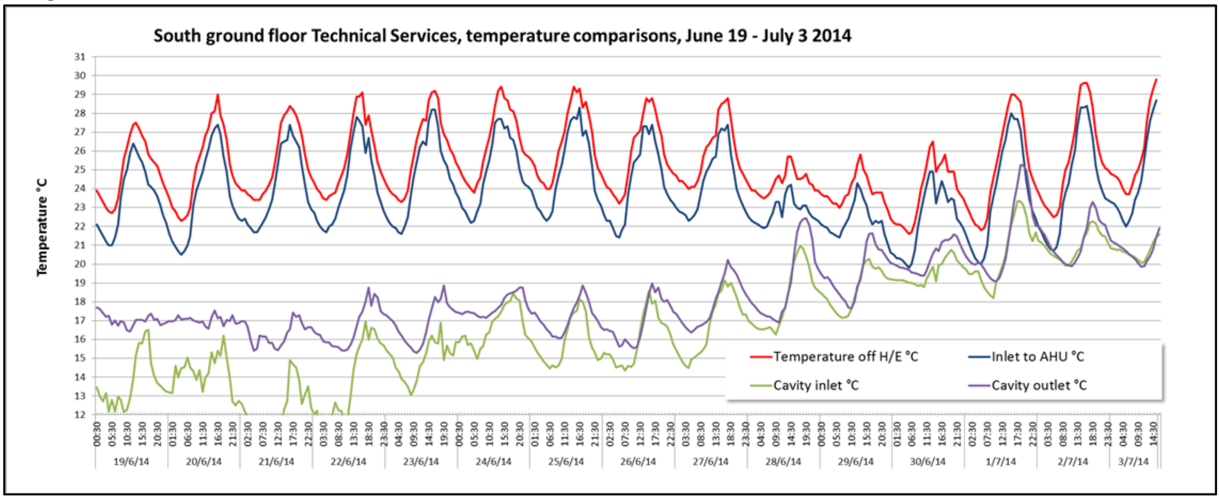


Figure 28: Temperature profiles for the summer conditions the south-facing ground floor offices for the short period of 19 June – 3 July 2014. The graph shows the difficulties experienced with relating temperature readings from sensors embedded in the insulation cavity with temperatures recorded within the mechanical ventilation inlet and room supply. (There is also a 20 minute offset between measurement sets that have not been normalised.)

Temperatures measured within the air handling system are far higher than the values obtained from the insulation sensors. However, the data show that whatever is happening inside the cavity (ie: the cavity being used as an exhaust path in summer – see Figure 24b), air temperatures inside the building regularly exceed comfort conditions except for

the weekend of 29-30 June 2014 when internal temperatures drop to the lowest value of 20°C. The implication is the south ground floor is not purging itself of heat at night, and rapidly increases in temperature during occupied hours through a combination of external and internal gains. The flat curve for the cavity outlet suggests no air movement, and the data for the cavity inlet conforming more to external ambient.

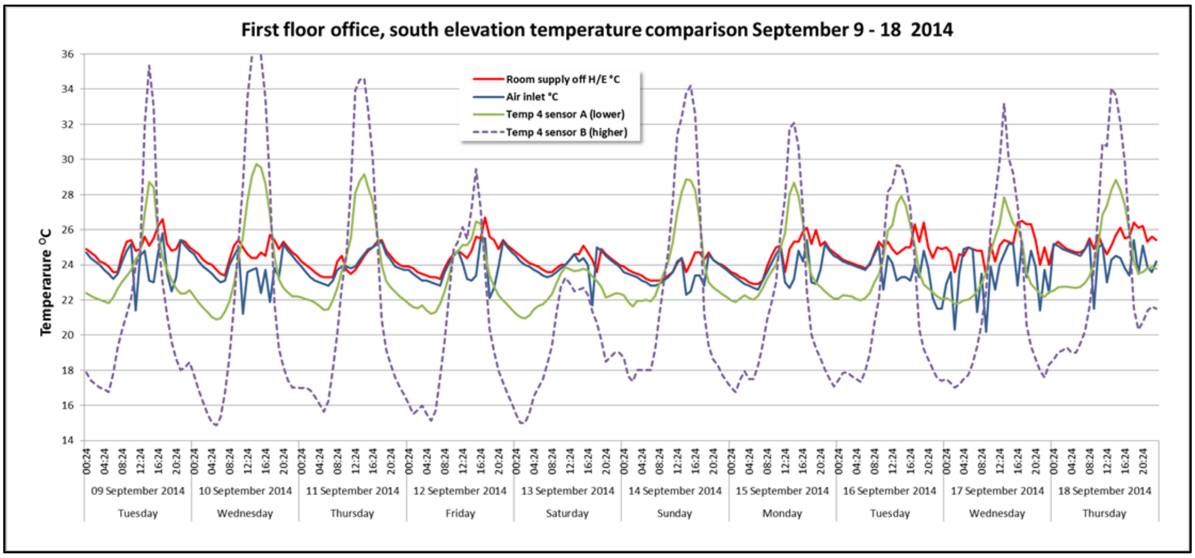


Figure 29: Temperature profiles based on hourly data for the south-facing first floor offices during 9 – 18 September 2014. The values for the upper cavity sensor, shown as a dotted line, may conform more to an external temperature reading, suggesting a static condition where the air flow temperatures may be influenced by external of surface temperature conditions. Values for the lower cavity sensor shown in green conform better with temperatures measured within the mechanical ventilation system (inlet to fan box and outlet from heat exchanger). The maximum Delta T between inlet to MVHR and supply to room is 3.8°C, and the average value 0.8°C.

Note that temperatures in the system (including upper cavity thermocouple) are consistently at or above 21°C, day and night, and peak above 26°C. The data should therefore be compared with Figure 16 and the occupants' perceptions of temperature and air quality in the BUS summary charts (Figure 40).

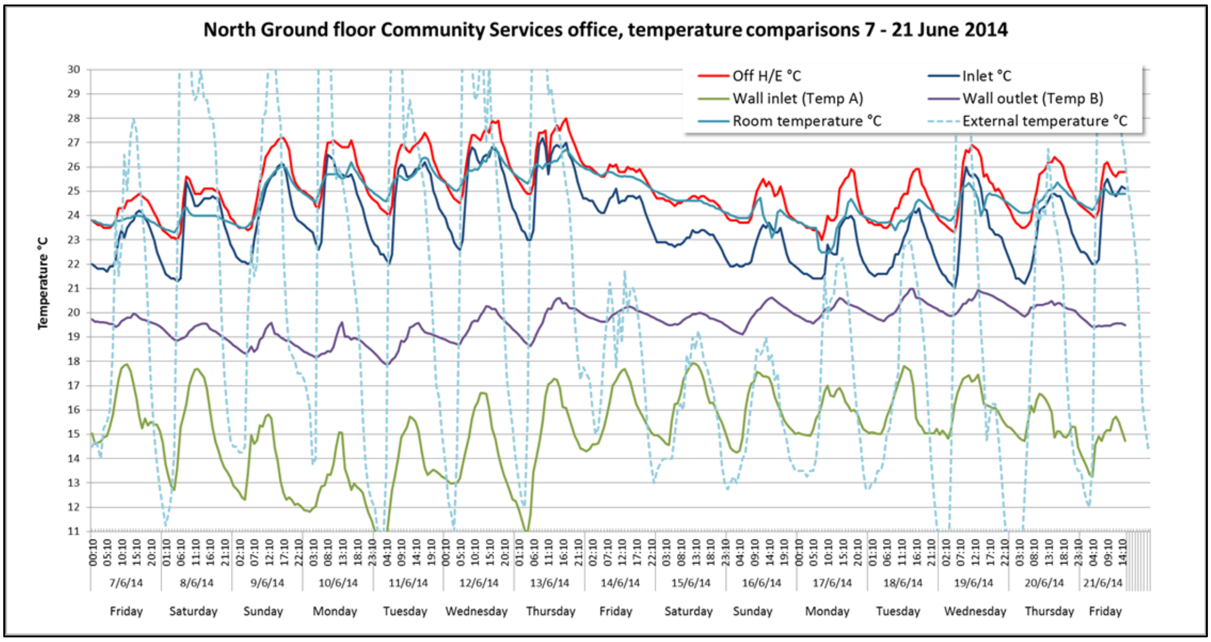


Figure 30: Temperature profiles for the ground floor office on the north side. The data includes CAR's internal temperature measurements shown in light blue, and the (questionable) external weather data in dotted blue. The internal data conforms closely to the outlet temperatures for the MVHR system, which are slightly higher due to room mixing of supply air with room air. Notably the wall outlet temperature for the period shows an average delta T of 4.1°C and a maximum of 8.1°C over MVHR inlet temperature, while the delta T between cavity sensors is an average of 4.5°C

and a maximum of 7.7°C for the period. This suggests a gain on average of over 4°C as the air moves up the cavity. Note that internal temperatures for weekday occupied hours (08:00 h – 18:00 h) was 25°C with a Tmax of 26.8°C.

If it is assumed that the maximum air temperature on the north side of the building is represented by the supply air temperature measured by the lower cavity thermocouple (no higher than 18°C), and the average internal temperatures for the period were 24.7°C (with a Tmax of 26.8°C), the average delta T between external conditions and internal temperatures can be held to be 9.6°C with a maximum of 14.3°C. Therefore it is reasonable to presume heat loss across the building envelope and therefore regain to the insulation cavity on the north elevation, even during summer.

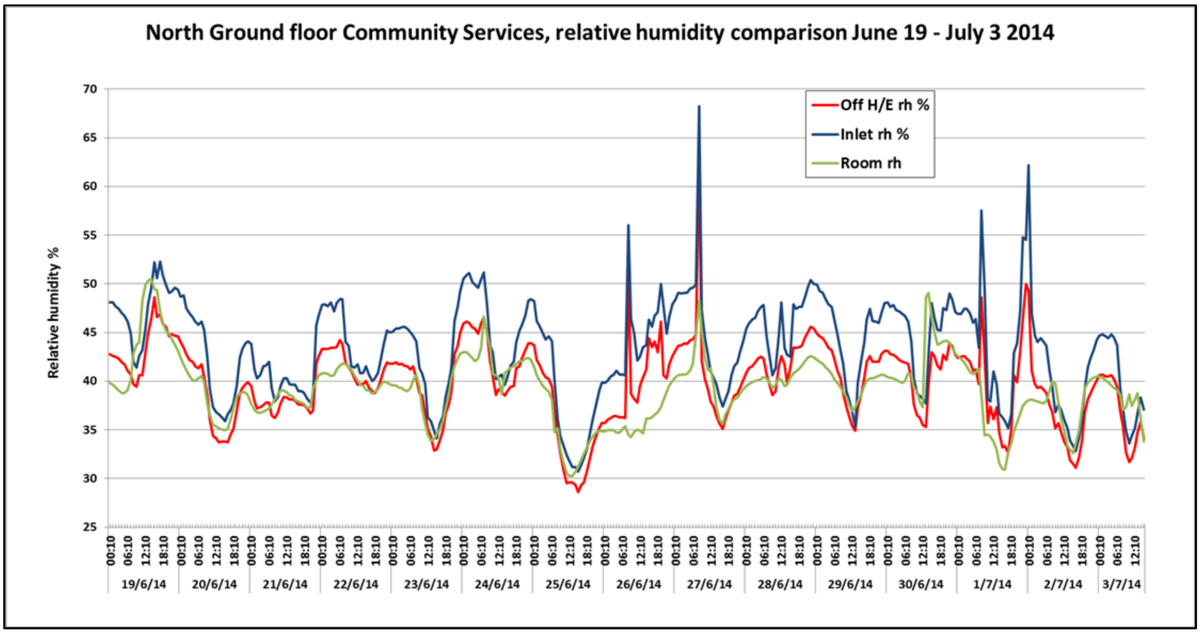


Figure 31: Room relative humidity readings for the ground floor office on the north side. Other than unusual peaks at various times (possibly coinciding with periods of heavy rainfall), room RH rarely rises above 50% and commonly falls to 40% and regularly below during mid to late afternoon. This corresponds with complaints of dry air and static electricity reported by the occupants of the Community Services office.

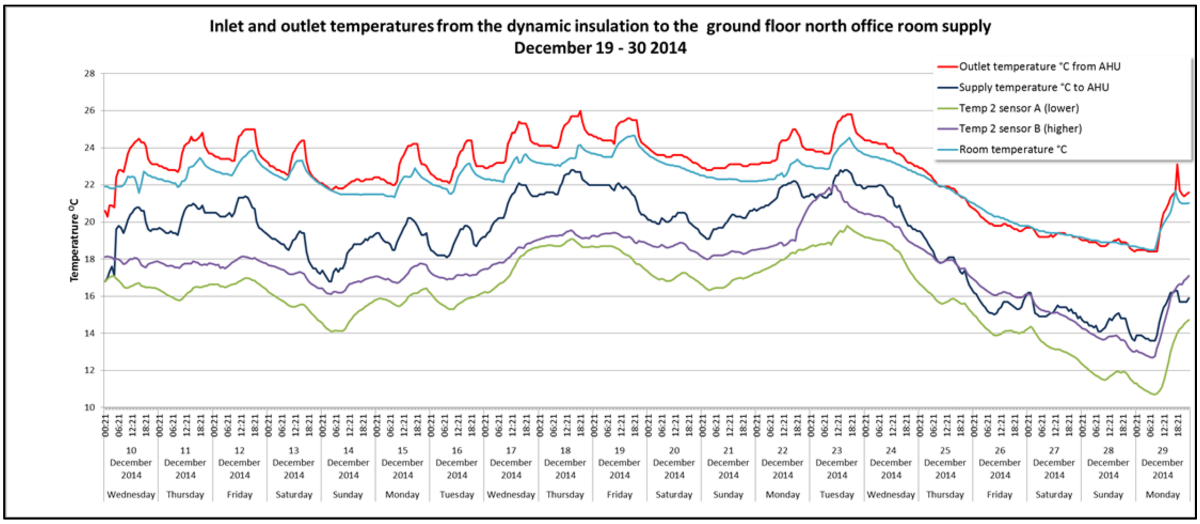


Figure 32: Temperature profiles for the ground floor office on the north side for 19 – 30 December 2014. The relationship between the values across the cavity sensors, the MVHR loggers and the room temperature logger shows strong comformity, with the possible exception of the outlet temperature values which may be due to the data logger being placed erroneously in the room extract duct rather than the room supply duct. This would account for the average temperature difference between the room temperature and the outlet temperature of 0.9°C over the period (excluding the Christmas break where heat gains from equipment and occupants were absent). Note that during occupied weekday periods internal temperatures did not drop below 22°C and peaked at 26°C. There is also the possibility that (warmer) air

supplying the air handling unit is being drawn from other areas of the cavity insulation not measured by the cavity sensors.

The drop in all temperatures over the Christmas break 2014 strongly indicates that the cavities do gain heat from inside the building to the cavity sensors. By definition, it is possible to say that during occupied periods the cavity sensors are picking up heat from inside the building and reintroducing that lost heat via the MVHR system. The data for the north office demonstrates this far more clearly than any previous data samples from other times and elsewhere in the building.

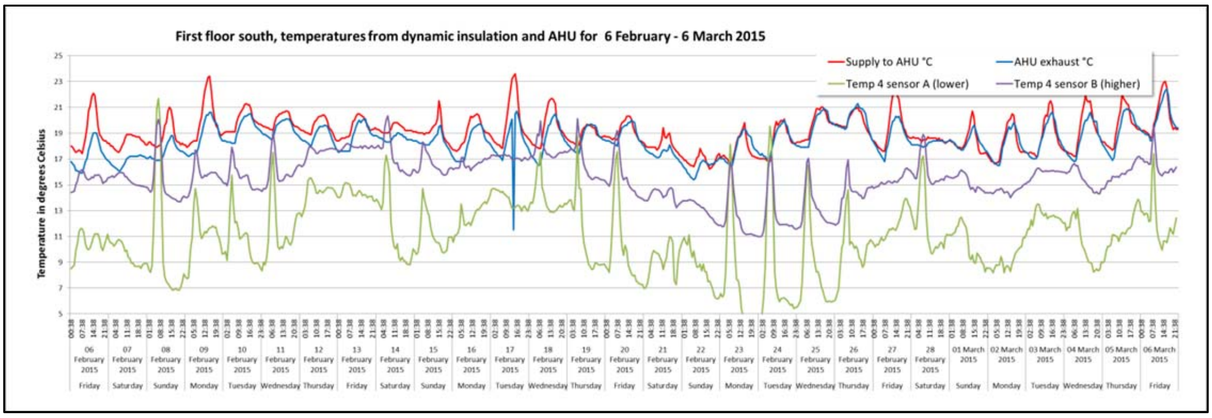


Figure 33: A month of winter monitoring in 2015 for the first floor south-facing open-plan offices suggests an average delta T of 4.7°C and a maximum of 7.1°C between the two cavity sensors over the period. This data should be compared to the results graphed in Figure 32. It is unknown whether the thermocouples are accurately located in the cavity and reading void (air) temperatures or structural temperatures, either partially or wholly. The south-facing first floor is equipped with openable windows and clerestory roof lights, although the latter are rarely used due to local control problems.

Figures 34a and b: Local control over ventilation via the clerestory windows is compromised by some winding handles being trapped behind shelving.

3.4 CONCLUSIONS

The following conclusions can be drawn from analysis of the monitoring:

- Temperature sensors placed within or near to the insulation cavity show an increase in air temperature from the bottom to the top of each cavity, broadly in line with expectation that heat loss from the building can be captured by the dynamic insulation and the warmed air re-introduced to the occupied spaces via the MVHR system.
- The MVHR dataloggers show a consistent increase in temperature across the MVHR system
- Room temperature readings (where available) are consistent with readings obtained from the MVHR dataloggers

- The delta T between the cavity sensors, and between the top cavity sensor and the MVHR inlet dataloggers, is often of several degrees Celsius, suggesting heat regain from unidentified sources (such as solar gains, and possibly room regain into the air handling system), or from voids in the insulation not in the air path of the cavity thermocouples.

- Room temperatures in all occupied spaces rarely drop below 21°C and often rise to 28°C and above, particularly in the south-facing offices. The over-heating characteristic was evident both prior to and after the addition of external dynamic insulation and is corroborated by the results from the occupant satisfaction surveys.

- The characteristic of the building to retain heat at nights and at weekends is evident of the building's inability to purge itself of daytime heat gain from solar energy, electrical equipment, and the occupants. The building's inherent good thermal performance, evident from the pre-retrofit energy and environmental data, suggests that the building has ventilation shortcomings that the background MVHR system cannot address. However, this was not the purpose, nor the goal, of the system.

The following caveats need to be considered in respect of the monitoring results:

- The precise location of the cavity sensors is unknown. Their installation was not witnessed nor photographed *in situ*, so considerable doubt exists as to whether the data obtained from the thermocouples is reading cavity temperature or structural temperature. If the thermocouples are in contact with the insulation or the building structure, (i.e. sitting halfway between the wall and the duct, located under plaster or buried in the render), the values obtained cannot be said to reflect air temperatures.

- The lack of contiguous data from cavity sensors and internal room temperature sensors has limited the amount of data analysis to specific periods.

- The external temperature sensor may be influenced by direct solar radiance, elevating the temperatures way above actual air temperature.

- The summer/winter switchover point of the MVHR system (whereby supply air is drawn directly into the system bypassing the heat exchanger, and extract air blown down the insulation cavity) is unknown, and cannot be inferred from the monitored data.

- In the absence of air flow sensors in the insulation cavity, it is not certain when the air is flowing up the cavity, or down the cavity, or merely stagnant. This is important to know, as it would indicate when the MVHR system is in winter mode or summer mode.

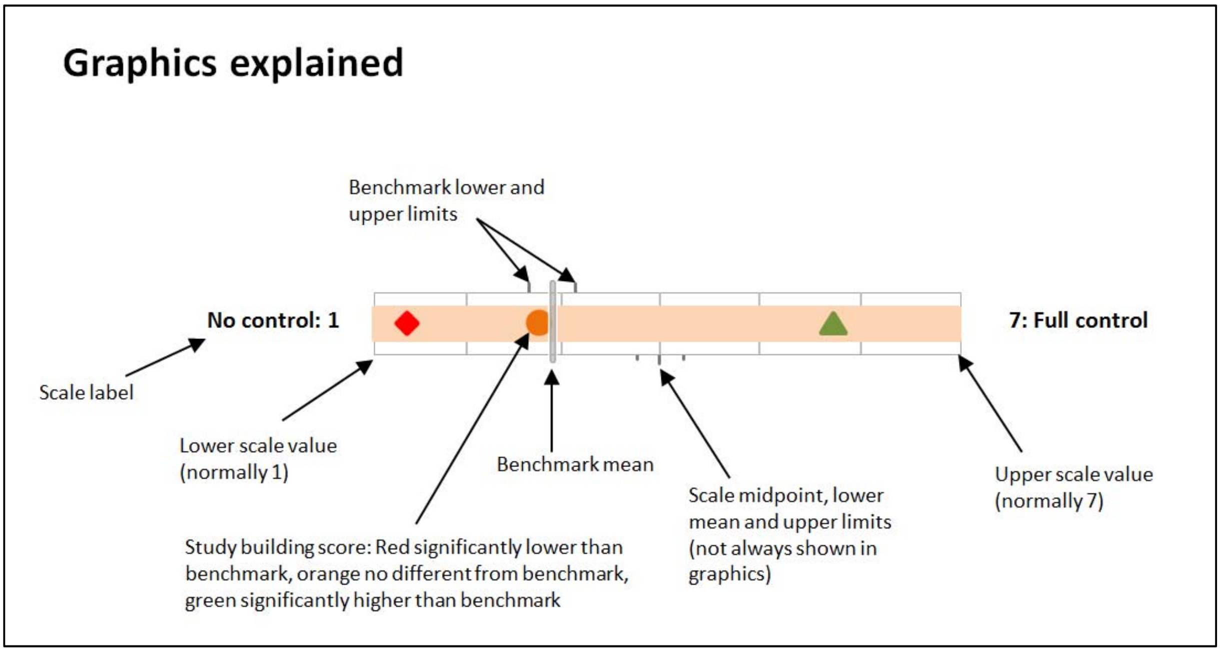
- Some data from the cavity thermocouples suggests stagnation (particularly in summer) where the fabric heat recovery system may be in reverse flow mode, or even stagnant. If so, the lower cavity values may be more representative of thermal conduction, and on the south elevation by direct solar gains.

- Local boost controls operated by the staff will increase the air flow rate and reduce heat gain into the air. The actual air flow rates have not been measured and nor is there any mechanism whereby times of boost control can be plotted against the monitored data.

- Some dataloggers in the MVHR may have been recording room extract rather than room supply. This was due to uncertainties in the installation of the system, and a lack of rigorous labelling of the MVHR boxes.

3.5 OCCUPANT SATISFACTION SURVEYS

Two BUS surveys were carried out. The first survey was conducted prior to refurbishment works in March 2013 in order to establish the occupants' base-line perceptions of the building's environmental conditions. The second survey was conducted in May 2015 to gauge the occupants' perceptions of the comfort conditions 12 months after the installation of the dynamic insulation and background ventilation. Both surveys were conducted on a single day, by a researcher handing out BUS survey questionnaires in the morning and gathering up completed questionnaires in the afternoon.



3.5.1 Pre-refurbishment survey

The questionnaires were handed out to 64 permanent and regular adult workers in the depot on the day of the survey. The response rate to the survey (the percentage of people available to be surveyed and who filled in a survey form) was estimated at 98 per cent. Only one survey questionnaire was unable to be retrieved.

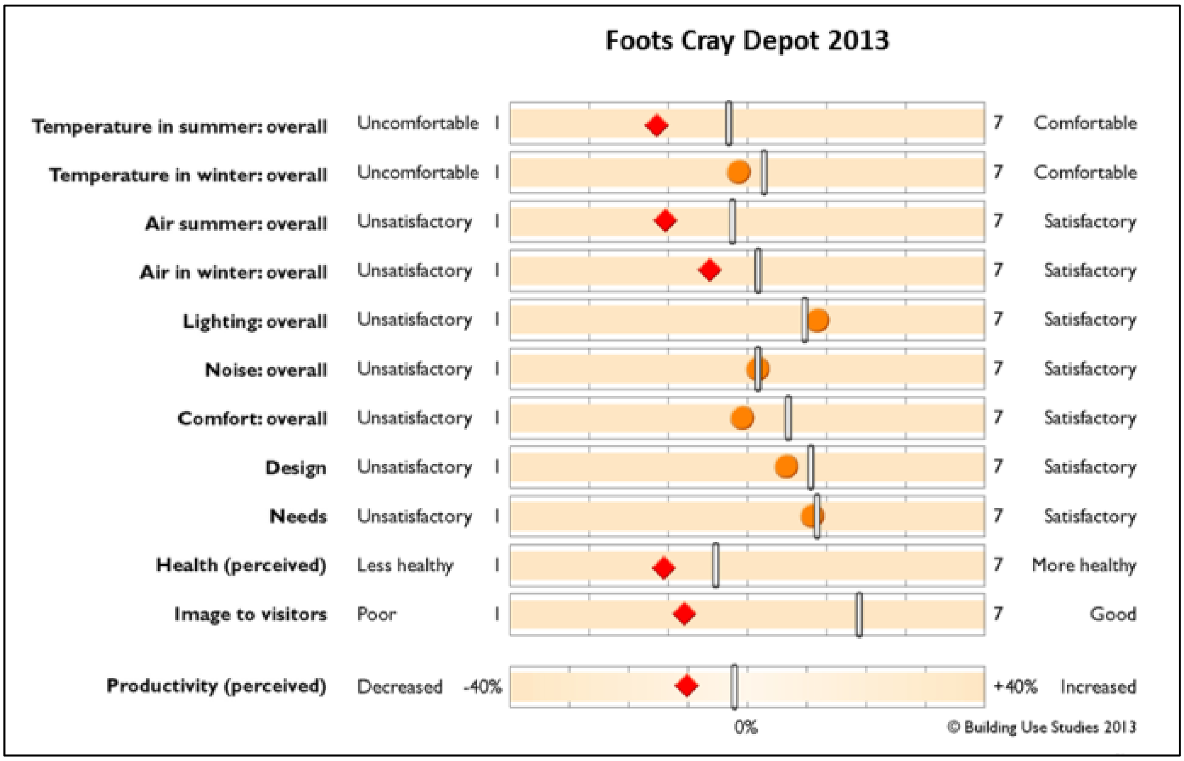


Figure 35: The BUS occupant survey results pre-retrofit for 2013. Vertical lines through each variable show the benchmark mean of naturally ventilated UK offices. (Note scale confidence limits are not shown.)

The survey respondents possessed the following characteristics, and should be borne in mind when interpreting the 2013 survey results:

- 64 people surveyed (estimated 98% response rate)
- 52 per cent of the Foots Cray Depot occupants were female
- 81 per cent were aged 30 or over
- 46 per cent sat next to a window
- 90 per cent had worked in the building for a year or more.

While over 30 comfort variables are measured in the BUS survey, this report focuses on those variables most relevant to the Jablite innovation: the occupants' perceptions of winter and summer indoor air quality and indoor temperature.

The headline scores for the main comfort variables are shown in Figure 35.The building scored lowly on temperature and air quality in summer, while winter air quality was also significantly below the benchmark. The building is perceived to be less healthy.

The occupants report a negative effect on their perception of productivity. The survey results for lighting and noise are not statistically different from the benchmark reference, indicating that the occupants' views of these comfort variables can be said to be typical compared with the benchmark database.

Analysis of the detailed occupant survey results revealed the specific problems with high temperatures in the building in winter and summer. Figure 36 shows that occupants found the building to be too hot in both summer and winter.

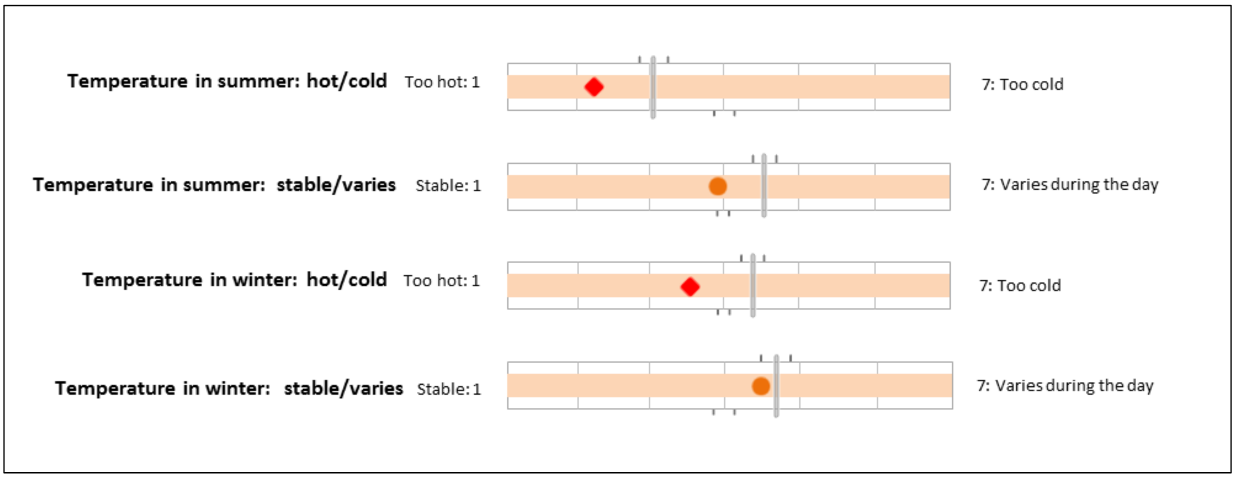
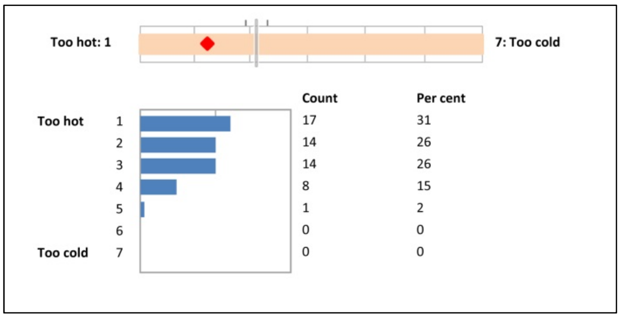
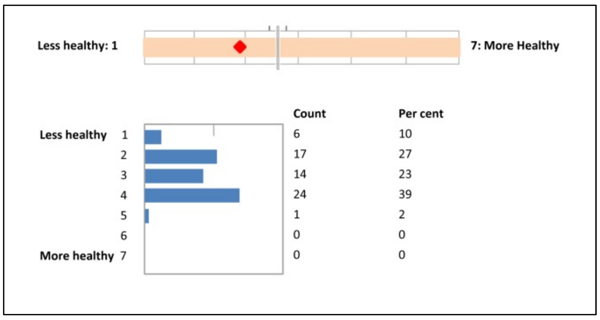


Figure 36: The summary temperature variables for the 2013 BUS survey. Scale midpoint confidence limits included.





Left, Figure 37: The individual responses in head count and per cent for summertime internal temperature. Right, Figure 38: The individual responses in head count and per cent for health

A short selection of the anecdotal responses (*verbatim*, in italics) on temperature put the results into context:

Not too comfy. Heating/ventilation system is poor.

Sometimes it is unbearably hot even during the winter months. The summer months are far worse as nothing cools the staff.

The building is hot, noisy, airless and uncomfortable and the lighting is awful too.

The BUS survey enables analysis at the individual level. Figures 20 and 21 show actual responses and percentage distribution.

Figure 39: The summary indoor air quality scores for the 2013 BUS survey at Foots Cray Depot.

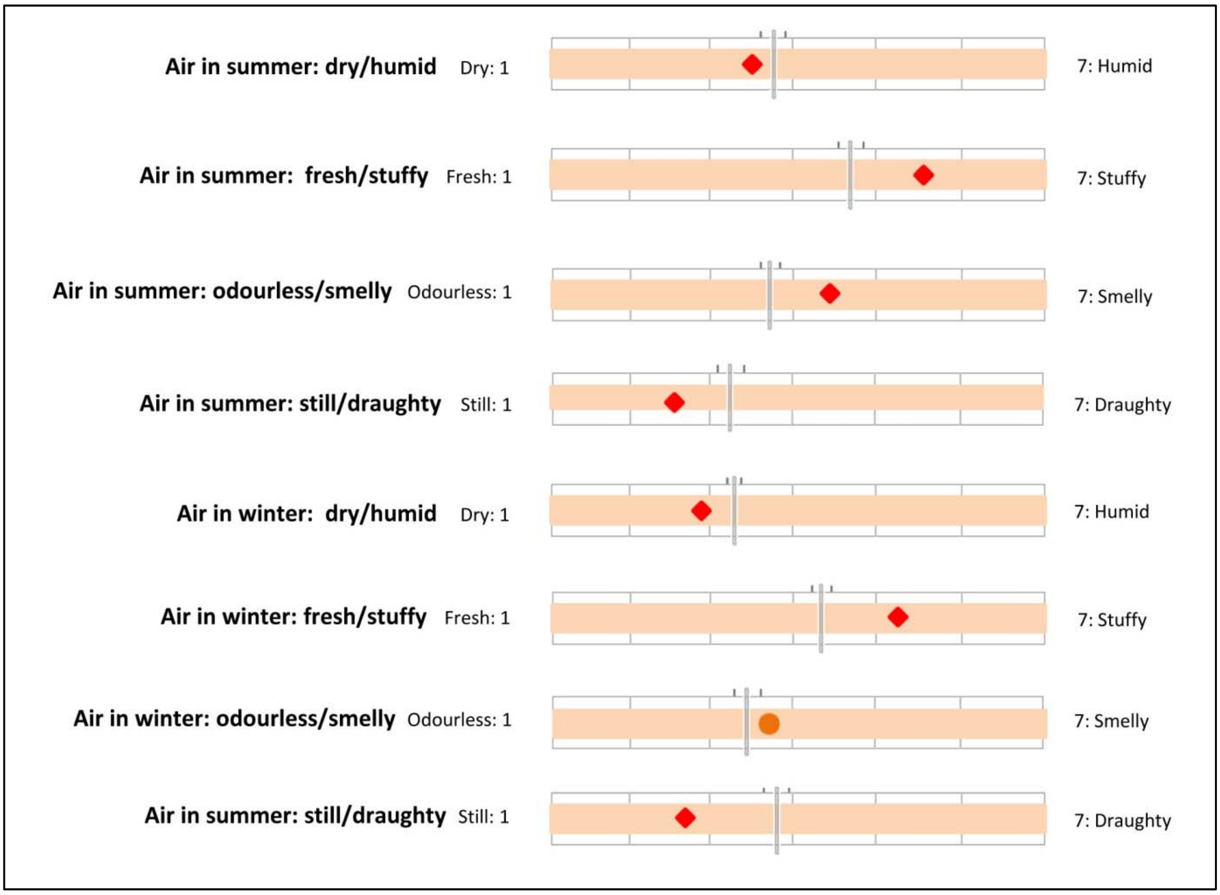


Figure 39 shows revealed that occupants' found their working environment in 2013 dry, stuffy, still and smelly.

Given the relative humidity measurements in March, the author deduces that the occupants find the air to be too dry rather than too humid. A short selection of the anecdotal comments on air quality (*verbatim*, in italics) put the statistics into context:

Temperature and stuffiness are major issues.

Poor air quality at times – skin is very dry, not great for asthmatics.

Temperature variations and too hot/too stuffy conditions give me regular headaches.

The Depot was perceived to be unhealthy by most occupants compared to the reference benchmark (Figure 35). Over a third rated the building at the far end of the "less healthy" scale. A majority of occupants at the Depot perceived their productivity to be decreased, with 60 per cent of them saying between -10 and -40 per cent. However, 38 per cent said their productivity was unaffected by the conditions.

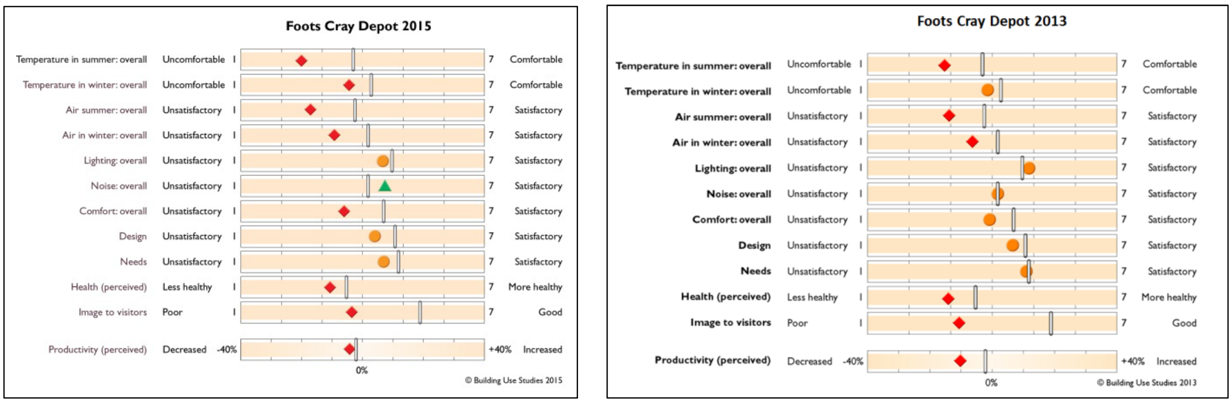
3.6 POST-REFURBISHMENT SURVEY

The second survey was carried out on 19 May 2015, 14 months after the installation of the dynamic insulation. Completed BUS questionnaires were retrieved from 69 permanent and regular adult workers in the Depot on the day of the survey. As with 2013, the response rate to the survey (the percentage of people available to be surveyed and who filled in a survey form) was estimated at 98 per cent. One survey questionnaire was discounted from the results owing to irregularities.

For ease of comparison, Figure 40 shows the summary results from 2015 next to the 2013 results. As can be seen, most of the comfort variables have declined since 2013, while some are about the same, and a couple (noise and perceived productivity) have slightly improved, along with a small change in perceptions of overall comfort. Most people can agree on extremes of temperature and air quality, but while some can put up with noisy office environments others cannot.

The change in the non-temperature and air-related variables may be due to a significant difference in the people filling in the survey in 2015 compared with 2013. The Foots Cray Depot is known to have a highly mobile population. Only 27 of those who filled in the 2015 questionnaires could be reliably linked to the 2013 survey. The actual number may be slightly higher as some people in both surveys chose to remain anonymous. However, while 12 people chose not to be identified in the 2013 survey only with four did so in 2015, so the difference can only be a maximum of 16 people (leaving aside name changes due to marriages).

Figure 40 (left): The summary comfort variables chart for the 2015 survey against the 2013 summary chart (right).



The survey respondents possessed the following characteristics, and should be borne in mind when interpreting the 2015 survey results (2013 data in parenthesis):

- 69 survey forms returned with an estimated 98% response rate (64)
- 54 per cent of the Foots Cray Depot occupants were female (52)
- 91 per cent were aged 30 or over (81)
- 42 per cent sat next to a window (46)
- 93 per cent had worked in the building for a year or more (90).

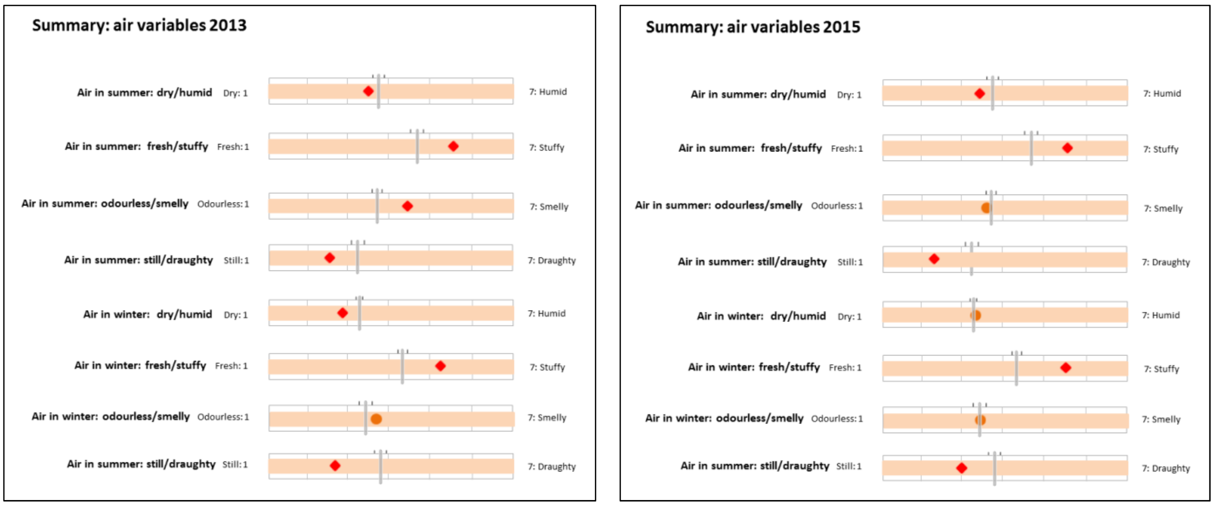


Figure 41: The 2015 air quality results compared with 2013. Air is perceived to be slightly less smelly in both winter and summer, and less dry than in 2013. However, the perceptions are significantly below scale midpoint (4) in most instances.

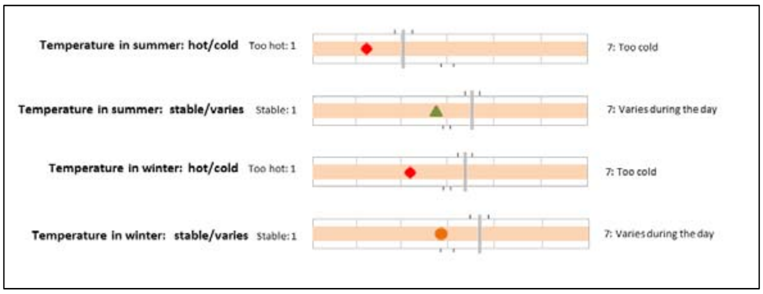
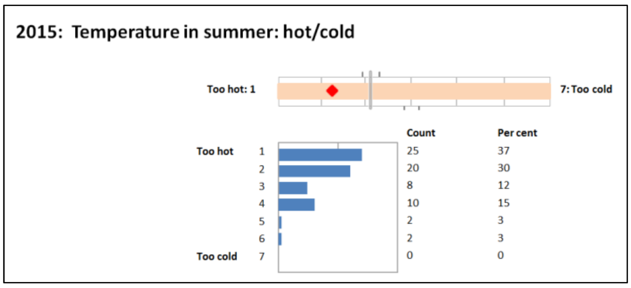
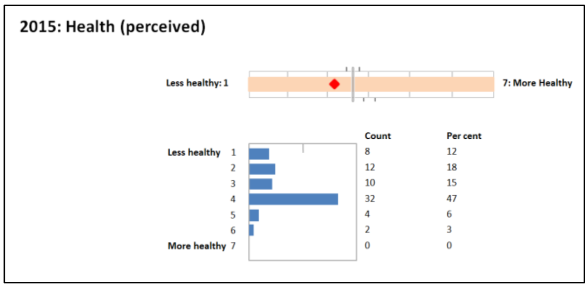


Figure 42: The stability of temperature in summer has improved from being within the scale midpoint confidence limits. Stable, however, is not necessarily good, as the building is still perceived to be significantly too hot in summer and winter.





Left, Figure 43: The individual responses in head count and per cent for summertime internal temperature. A higher percentage perceive the building to be too hot compared with 2013. Right, Figure 44: The individual responses in head count and per cent for health. A higher percentage report less healthy conditions than in 2013, although a far higher percentage score the building at the scale midpoint.

A short selection of the high number of anecdotal comments made on temperature, air quality and overall comfort condition (*verbatim*, in italics) put the statistics into context:

Always too hot and stuffy

Atmosphere too stuffy and heavy unless I can sit near an open window

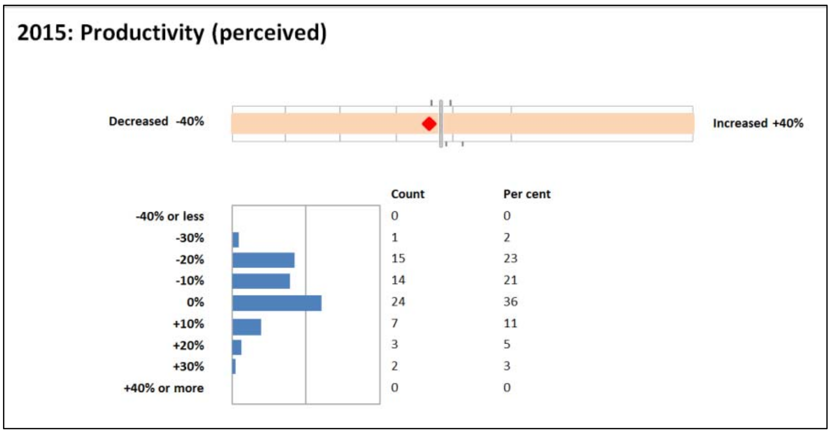
Building is often too hot on this side, no air and it's often noisy

In general it's uncomfortable during the summer months at my workstation

Temperature is a big issue as it makes it very uncomfortable to work for long periods of time
Often feel sleepy - not alert!

It is now so hot and stuffy in here that it's unbearable in summer

Lack of fresh air; high room temperatures, noise from colleagues, too many interruptions, inability to alter environmental factors to suit my individual needs, all impact upon the quality of work.



Left, Figure 45: Perceived productivity (an outcome variable of many other comfort variables) is slightly better than the 2013 survey but still significantly below both scale midpoint confidence limits and benchmark. Essentially, people do their work despite the internal conditions rather than because of them.

3.7 CONCLUSIONS FROM THE OCCUPANT SURVEYS

The following conclusions can be drawn from both surveys:

- The occupants report hot stuffy and uncomfortable internal conditions both before and after the retrofit works. A higher percentage of occupants perceive the building to be too hot compared with 2013 and that air quality in winter and summer is poor. This correlates with the physical monitoring results.

- While conditions in winter were typical against benchmark prior to the refurbishment works, conditions are now significantly below both scale midpoint and the benchmarks. This correlates with the physical monitoring results.

- Air is perceived to be slightly less smelly in both winter and summer, and less dry than in 2013.

- A higher percentage of occupants reported less healthy conditions in 2015 compared with 2013, although a far higher percentage scored the building at the scale midpoint

- Perceived productivity is slightly better in 2015 compared with 2013, but still significantly below both scale midpoint confidence limits and benchmark.

4 APPENDIX A: DATA TABLES

See separate attachments.

5 APPENDIX B: COMMENTS

See separate attachments.