INNOVATE UK: INVEST IN INNOVATIVE REFURBISHMENT

Innovative Refurbishment, Garth House, Bicester

Final report
1204_DECC_Phase 2
Final Version – 15 January 2016

Submitted to:
Innovate UK

Prepared by:

Adrian Kite RIBA IHBC

RIDGE & PARTNERS LLP

The Cowyards
Blenheim Park
Oxford Road
Woodstock
Oxfordshire
OX20 1QR

Tel: 01993 815126
akite@ridge.co.uk

Professor Rajat Gupta and Mariam Kapsali

LOW CARBON BUILDING GROUP

Oxford Institute for Sustainable Development,
School of Architecture
Oxford Brookes University
Headington Campus
Gipsy Lane
Oxford OX3 0BP

Tel: 01865 484049
rgupta@brookes.ac.uk

Alex Towler, Nicole Lazarus and Jane Durney

BIOREGIONAL

Bioregional
BedZED Centre
24 Helios Road
Wallington
Surrey
SM6 7BZ

Tel: 020 8404 4880
alex.towler@bioregional.com

Contents

Project details

Funding:

Innovate UK: Invest in Innovative Refurbishment (formerly Technology Strategy Board)

Department of Energy and Climate Change

Period:

- August 2013 – July 2015

Project team:

Bicester Town Council

- James Porter
- Sue Mackrell

Bioregional

- Alex Towler
- Nicole Lazarus
- Jane Durney

Ridge and Partners LLP

- Graham Blackburn
- Adrian Kite
- Wayne Harper

Oxford Brookes University

- Professor Rajat Gupta
- Mariam Kapsali
- Dr Hu Du

BSRIA Instrument Solution

- Ian Orme

Contractors:

Principle Contractor: Kingerlee Ltd

- Mark Watterson
- John Clarkson

WHISCERS™ Contractor: Proteam

- Chris Cheshire
- John Wright

Acknowledgement:

We would like to thank Innovate UK's Invest in Innovative Refurbishment programme for supporting this work.

Executive Summary

Across the UK there are approximately 375,000 Listed Buildings with 110 in Bicester alone. Many of these historic buildings are being used in a non-domestic capacity such as our demonstrator building, Garth House, which now functions as offices for Bicester Town Council.

These non-domestic, heritage buildings pose a twin challenge for refurbishment programmes, which have energy efficiency drivers at their heart. Firstly, retaining the essence of these existing buildings often prevents the environmental upgrade of the building fabric using external insulation or replacement windows as altering the external appearance is generally unacceptable. Secondly, insulating internally has significant technical challenges and can be highly disruptive for building users.

The project tackled these challenges to achieve a step-change reduction in primary energy consumption and CO_2 savings by employing an innovative application of internal insulation technology, in combination with secondary glazing and a ventilation strategy. In addition to the energy and carbon savings, the significant upgrade to the environmental comfort, and consequent increase in productivity, is an attractive option for organisations operating in historic buildings.

Specifically, the project used the patented WHISCERS™ technology that had previously only been used in domestic dwellings[2] in the UK. WHISCERS™ (Whole House In-situ Carbon and Energy Reduction System) uses a laser to survey each room of the building allowing off-site cutting of the insulated plasterboard. The pre-cut pieces can then be rapidly installed as a labelled jigsaw to each internal wall. The WHISCERS™ concept is to eliminate on-site cutting of insulation creating a low mess and reduced waste process that is faster and less disruptive than traditional methods enabling users to continue to occupy their buildings throughout the refurbishment works. The following additional considerations to the standard WHISCERS™ process are required to make it suitable for a historic and non-residential application:

- To test the use of multi-skilled WHISCERS™ labour to allow the insulation teams to carry out the required complex plumbing/electrical works in non-residential buildings. This may include a requirement to test existing services for resilience prior to being concealed behind insulation.
- To provide a solution for retaining intricate architectural features, e.g. mouldings or panelling details in historic buildings.
- To develop an integrated solution for internal wall insulation and (secondary) glazing to avoid losing existing architectural features by installing secondary glazing; while improving the thermal performance of single glazed windows to avoid unnecessary heat loss and condensation issues.
- To develop an integrated insulation solution that links walls between floors, with the ground floor and roof areas to avoid unnecessary heat loss and potential condensation through uninsulated junctions.

---

[2] Between 2012-13 WHISCERS™ was used in the refurbishment of a non-domestic historic building in Vienna,

- To provide sufficient ventilation following internal insulating the building to allow good air quality in both winter and summer.
- To address the overheating issues that often results from internally insulating buildings through appropriate ventilation strategies and leaving exposed thermal mass (if available).

The project aimed to develop a holistic insulation service for historic and non-residential buildings combining internal insulation, secondary glazing and an integrated ventilation strategy. The solution was predicted to deliver about 57% annual energy savings and 37% reduction in annual CO_2 emissions. The project costs were £830/m^2 with the internal wall insulation being a relatively small proportion of this in comparison to the relatively expensive secondary glazing and ventilation elements.

Existing building performance

The case study building for the installation is Garth House, an 1830s Victorian hunting lodge. The building is located in a central park in Bicester, Oxfordshire and is of significant local importance but has no formal protection as a listed building. Typical of its era, Garth House has non-insulated construction: solid brick and stone walls on the ground floor; timber frame with vertically hung tiles on the first with a cut timber plain tile roof. Recent refurbishment of the roof has resulted in the roof being insulated to modern standards. The project team used IES (Integrated Environmental Solutions) building modelling software to estimate the energy use of the existing building. This was calibrated with actual energy consumption data of the building pre and post roof refurbishment. Historic buildings like 180-year-old Garth House usually come with high fuel bills and often, low comfort levels for building users. Building user surveys showed issues of 'chilliness' from low surface temperature walls and slow response times to heating the spaces meaning the central heating system was left on 24 hours a day throughout the heating season. Many of the windows had been painted shut reducing opportunities to opening windows leading to overheating issues in areas of the building. Therefore the building occupants were not interacting with the building very well.

The proposal

The project team, led by the building owner Bicester Town Council, met the competition scope by upgrading the building fabric of Garth House by installing an internal insulation solution that respects and retains the existing internal period features. To do this it was paramount to define where the new wall insulation would start and stop to allow the existing building features to be retained and not concealed behind insulation. These points were defined by the early placement of the window battens as to provide points for the laser survey. The insulation boards used were Kingspan K18 72.5mm. Installation of double-glazed secondary glazing / internal bay windows allows the existing features to be retained in-situ and visible to the building users while ensuring a continuous internal insulation line. To complete the thermal envelope the following measures were also installed:

- Insulated the solid ground floor with Spacetherm C; 10mm aerogel insulation bonded to 18mm chipboard, to avoid raising the floor level significantly while reducing heat loss into the ground.
- Insulated solid internal ground floor walls reducing heat loss into the ground.

- Insulated between the upper floors with mineral wool insulation to avoid gaps between wall insulation on each floor and heat loss at each floor level.
- Insulated at eaves level with mineral wool insulation to avoid gaps with roof insulation and heat loss at eaves level.

Implementing the solution

The detailed design phase of the project began in September 2013 with the construction period beginning in November 2013 and was completed on time and under budget by April 2014.

A ‘user controlled’ natural ventilation strategy was developed for the first floor that incorporated the existing sash windows with some through wall vents allowing cross ventilation into single sided rooms. A centralised MVHR (mechanical ventilation with heat recovery) replaced the original concept of through-wall individual ventilation units, significantly reducing the number of openings on the façade.

The ground floor maintained the original ‘zero occupancy’ automated ventilation strategy with automated louvres and rooflights linked to internal thermostats opening and closing with internal temperature fluctuation. This maintains a comfortable internal environment throughout the year and mitigates the risk of summer overheating, while the MVHR provides internal air changes on both floors, improving internal air quality year round.

As the building was fully occupied throughout the works, the project construction programme was divided into seven phases in order to try to ensure minimum disruption to the building occupants. However this phasing required further adjustment when additional wedding bookings affected the ground floor availability; remedial works were required to damp walls on the ground floor; supply chain issues and structural works were required to the second floor structure.

A number of project and site management issues resulted in WHISCERS™ not delivering as planned in the project intention with respect to the installation rather than the perfromnce. The principal cause of this lay in the lack of supply chain integration, difficulties in information exchange between contractors and subcontractors, and complications in project management and co-ordination.

The insulation boards installed were cut to a maximum size of 1150x1150mm which was considered optimal by the WHISCERS™ installer. The size of the boards can be limited by the size of CNC cutter size. These smaller sizes can aid in manual handling and optimising the cutting schedule. Nevertheless this represents reduction from the full-size sheet supplied by Kingspan at 2400x1200mm expected by the design and installation team, resulting in:

- Many more pieces to install and associated increase in time fixing the boards
- Many more joints between boards, reducing the risk to the continuity of insulation

- More fixings required, increasing the risk of thermal bridging and some small reduction in performance[3].

While WHISCERS™ was the project's key construction method, it required integration with the additional complexities of application to a historical and non-domestic building, including secondary glazing, floor insulation and application around historical features. The project attempted to adapt the WHISCERS™ standard operating procedure towards this aim. While the project was completed on budget and on time, these adaptions and integration had limited success in terms of quality and performance. The outcome could have been more successful had the information exchanges and supply chain integration been improved during the course of the project.

WHISCERS™ still has strong potential for historical buildings, but its efficacy is much less dependent on technical innovation but rather on standard construction sector issues of project management and procurement.

The future commercialisation of WHISCERS™ in a historical context lies with the patent holder, NEF (National Energy Foundation) and their licensing decisions. For the duration of this project the exclusive license holder was held by United House with Proteam Asset Management Limited as the sole installer.

Building Performance Evaluation summary

The study adopted a Building Performance Evaluation (BPE) approach in order to assess the energy and environmental performance of the building and occupant satisfaction *before* and *after* the refurbishment, and to measure the reduction in energy use and carbon emissions that are achieved following the refurbishment. The BPE study involved the evaluation of fabric performance through airtightness tests and thermographic surveys before and after the refurbishment, the review of the handover and occupant training, the review of performance of systems and controls, the technical review of building and equipment performance. Furthermore, it included the collection of occupant feedback through interviews and occupant satisfaction questionnaires conducted both before and after the refurbishment as well as detailed monitoring of the energy use and environmental conditions of the refurbished spaces.

As part of the study, two dynamic thermal models of Garth building were developed (IES software) to calculate the energy consumption of the refurbishment measures. Model A was developed before the refurbishment, to estimate the saving potential of the measures and Model B was developed after the refurbishment and was calibrated against actual monitoring data. The results from IES Model B indicate that improved airtightness achieves 11% annual energy savings and 7% CO_2 emissions reduction from Base Case; insulation of external walls achieves a further 22% energy saving and 16% carbon saving; and floor insulation achieves a further 33% reduction in energy and 24% carbon saving. Model B shows that the combination of all refurbishment measures achieves about 58% annual energy savings and 48% carbon savings, against a target of 57% energy savings and 37% carbon reductions.

[3] As discussed later the project still achieved the energy savings predicted

Key findings from the BPE study are summarised below:

- Post-refurbishment monitoring data showed that there is 58% reduction in overall energy and 48% reduction in CO_2 over the pre-refurbishment level. This equates to 67% reduction in annual gas consumption and 22% reduction in electricity use over the pre-refurbishment level.
- The envelope performance has very much improved after the refurbishment. The airtightness of the building improved greatly, from 20.52 $m^3/h.m^2$ @ 50Pa to 10.62 $m^3/h.m^2$ @ 50Pa. However, several air leakage paths were still identified around door and window frames, floor voids, skirtings and glazing seals. Thermal imaging after the refurbishment showed some heat loss patterns through the roof-wall junction and between floors.
- Although several minor problems have been identified during building handover, overall users are very satisfied about performance of the refurbishment, especially the indoor air quality.
- The MVHR unit is easily accessible and is easy to operate. However, the control is not intuitive and a simple User Guide would be useful. Furthermore, the system is not installed and commissioned properly. There is a large amount of leakage into ceiling voids due to the way the ceiling terminals have been installed.
- Peak electricity loads are reduced after refurbishment, as a result of the reduced usage of electric heaters. Gas usage changes greatly. Before refurbishment (winter 2014), heating was on continuously reaching a peak of 10kW at 9am. After the refurbishment a strict heating schedule is applied, with heating on only during occupancy hours.
- After the refurbishment, temperatures in most rooms range between 15-23^oC during winter and 20-26^oC during summer.
- It was observed that following the refurbishment higher temperatures can be achieved in the room during occupied hours even though the heating is on for far less amount of time than before. This is a result of the reduction of heat loss through ventilation and fabric.
- Overheating analysis using the Adaptive Comfort criteria (CIBSE TM 52) and following BS EN 15251 did not show any occurrence of overheating in any of the rooms.
- The air quality in monitored offices is very good as over 70% of occupied hours are below 800ppm CO_2 concentration. In Room G25, 2.1% of occupied hours exceeded 1400 ppm CO_2 concentration due to the large number of occupants. These findings suggest that the MVHR system is performing well.
- The moisture content of timber studs inside northwest wall of room G25, external wall of F20, southeast wall of F21 were gradually reduced from 22% to 12% over the first three months. The moisture content of external wall and floor joist stays relatively stable. They all stay below 20% moisture content above which rot does not develop.
- The overall picture of the Building Use Studies (BUS) survey conducted after the refurbishment revealed a very positive opinion of the staff members towards the building with almost all elements scoring higher than the benchmark, as opposed to the findings before the refurbishment were most factors had scored below or within the benchmarks.
- The BUS survey showed that most people find the spaces comfortable during winter and summer. Comments received during the second interviews pointed out that the comfort conditions in terms of temperature had greatly improved during both seasons, with the use of individual heater and fans greatly being reduced following the refurbishment.
- The results are better than those from the pre-refurbishment BUS survey, which showed that before the refurbishment, temperatures during both summer and winter were not considered comfortable. Temperatures were considered ‘too hot’ during summer and ‘too cold’ during winter, leading to the use of fans to promote air movement during summer and electric space heaters during winter.
- Air quality overall is also considered satisfactory, scoring higher that the scale midpoint and higher than the benchmark during both winter and summer. Results from the BUS

survey conducted before the refurbishment were significantly worse with all elements and air quality overall scoring below the benchmarks.

1 Project intention

The project combines a number of existing products and processes to provide a replicable internal wall insulation and secondary glazing solution for non-residential historic buildings that retains the historic features while ensuring a comfortable well-ventilated environment for occupants. Successful installation has been modelled to deliver a step-change in terms of energy demand specifically a reduction in primary energy use of 58% with a reduction in CO_2 emissions of 37%. In addition, by reducing the cost of installing the insulation by £35 per m^2 the product has significant roll out potential in the non-domestic market. This was predicted to produce saving of around £15,000 for this project. This builds upon the existing WHISCERS™ laser survey which has so far not been used in the UK non-residential market. At the time of the project United House was the exclusive license holder for WHISCERS™ with Proteam operating as its contractor. The patent is now held by the National Energy Foundation following a merger with the original patent holder the Sustainable Energy Academy.

1.1 The proposed technology

Product innovation: WHISCERS™ employs an innovative use of laser technology and offsite cutting to install Internal Wall Insulation (IWI) in hard-to-treat buildings whilst enabling occupants to continue to live or work in their buildings throughout the refurbishment period. It has previously been successfully used on 200 residential properties, ranging from single terraced properties to tower blocks, reducing the time taken for installation from around 5 days to 1.5 days/ room. WHISCERS™ also has the potential to reduce the performance gap by using multi-skilled trades to install the insulation and pull through the mechanical and electrical services through the insulation and by being able to measure the insulation accurately to within 3mm.

The innovation of this project is primarily in application. This is the first time the product has been applied to a non-residential building or an historic building of any tenure in the UK.

To be suitable for this new market the following challenges require the testing of critical and innovative modifications to the product:

- Many buildings both non-residential and residential buildings have intricate architectural features, e.g. mouldings or timber panelling etc. To deal with these elements an additional desk top study drawing stage was to be added to the WHISCERS™ process directly after the laser survey to make fundamental decisions about how close the insulation would be to each window / feature;

- Often the worst performing thermal element in historic structures is the glazing. However, replacing glazing units is either prohibitively expensive or can unduly effect a building’s historic character. Secondary glazing (additional windows installed on the internal face of the existing window) offers an excellent solution. This project combined internal wall insulation and secondary glazing to provide a continuous line within the building leaving the window’s architectural features intact behind the secondary glazing;

- Due to higher occupancy levels, IT equipment and lighting non-residential buildings are more prone to overheating than residential buildings. This is an even higher risk with the introduction of secondary glazing and internal wall insulation. To mitigate this risk the project tested the combination of the insulation with natural ventilation interventions. Some areas of thermal mass in the building were left un-insulated with the potential for night-time cooling. The three proposed ventilation systems are readily available in the UK market and their performance values can be calculated and guaranteed by their respective manufacturers. What is not readily available is the real in-use comparative performance data of each in the same condition performing the same task. The testing of these is an innovative step to understand the optimum condition for upgrading Listed or Historic structures. Active ventilation will significantly reduce the occurrence of overheating in an internally insulated building;

- Plumbing and electrical services in non-residential buildings are generally complex. It is therefore necessary to test the process of pulling through the building services from the inside of the insulation by a multi-skilled installer, and to check whether more complex building services leads to a reduced fit of the insulation, resulting in interstitial condensation;

- WHISCERS™ is not appropriate for floor application so *Spacetherm C* aerogel insulation from the Proctor Group was used to insulate the solid ground floor. This consisted of 10mm of aerogel on 18mm of chipboard.

1.2 Comparison table of solutions

The table below gives a broad comparison of solutions and options for the retrofit:

Area	Measures	Advantages	Disadvantages	Decision
External Walls	External Wall Insulation (EWI)	Limited disturbance to occupants. Continuity of insulation from ground to roof.	Major effect on building external appearance. Insulation not continuous at ground level.	Unacceptable solution due to loss of historic character.
	Standard Internal Wall Insulation (IWI)	Retains external character. Choice of materials from narrow boards with vapour barrier to breathable materials to receive a lime plaster.	Internal disturbance to occupants. Performance losses through joints in board and fixings. Gaps in wall insulation between floors.	Not innovative enough and too disruptive for the occupants.
	WHISCERS™ Internal Wall Insulation (IWI)	Low mess and low disturbance.	Potential performance losses through joints in board and fixings. Gaps in wall insulation between floors.	Selected to test the technology in a heritage environment while the building was continuously occupied.
Floors	No additional measures	No disturbance	Significant heat losses through ground floor. Thermographic images highlighted largest heat losses through floor at edges where internal walls go into ground.	No application would have broken the thermal envelope and would not produce the energy savings required.
	Conventional floor insulation.	Improved thermal performance	Unacceptable levels of disturbance on ground floor from excavations. Potential loss of structural integrity and heritage.	Not practicable on ground floors. Rockwool Flexi selected on upper timber floors between joists.
	Spacetherm C floor insulation. Aerogel bonded to chipboard	Very thin. No need for excavations. Relatively quick to install.	Relatively high price. Heat losses through fixings required to follow floor undulations.	Selected for performance and minimal heritage impact.
Solid Internal Walls	No additional measures	No disturbance	Heat losses through floor. Thermographic images highlighted largest heat losses through floor where	Some areas of thermal mass left uninsulated to help mitigate overheating.

Area	Measures	Advantages	Disadvantages	Decision
			internal walls go into ground.	
	Standard Internal Wall Insulation (IWI)	Choice of materials from narrow boards with vapour barrier to breathable materials to receive a lime plaster.	Internal disturbance to occupants. Performance losses through joints in board and fixings. Gaps in wall insulation between floors.	
	WHISCERS™ Internal Wall Insulation (IWI)	Low mess and low disturbance.	Potential performance losses through joints in board and fixings. Gaps in wall insulation between floors.	Selected to test the technology in a heritage environment while the building was continuously occupied.
Roof Void	Standard insulation	Cheap and relatively easy to stall	Access into confined spaces limit suitability	
	Blown Insulation	Cheap and economical. Access into confined makes it easy to install	Difficult to remove.	Selected due to difficult access to existing floor boards in roof void areas.
Glazing	Secondary Glazing	Retains existing windows in their entirety. Very good thermal performance.	Minor, loss of space internally. Some loss of internal character	Selected due to best balance of thermal performance and limited heritage impact.
	Replacement windows	Good thermal performance.	Loss of historic character.	Unacceptable solution due to loss of historic character.
	Replacement glazing	Original frames	Reconditioned sash windows are not airtight in comparison to other solutions. Difficult to prevent thermal bridging at the internal window reveals.	Many of the window panes were of considerable age and could not be lost.
Primary Energy	Low carbon heating	As well as upgrading the building fabric a low carbon energy source could be used (e.g. biomass boiler or	Limited space in the building for the plant. Such an approach can lead to profligate energy use. Fuel	This project was to investigate a fabric first approach. Such a solution is only really suitable for when the

Area	Measures	Advantages	Disadvantages	Decision
		combined heat and power).	is still required.	heritage is so valuable it should be left completely unaltered.
Ventilation	Natural Ventilation only	Minimal alterations. Reduced capital cost and disturbance.	Overheating risks are higher. No solution for rooms not in continual operation e.g. Council CChamber.	Improved throughout the building with new opening to allow cross ventilation in single sided rooms.
	Air conditioning	High level of overheating mitigation.	Very high energy. External condensers required.	Neither acceptable for a low energy retrofit nor appropriate for the overheating risks.
	Mechanical Extract Ventilation	Cheaper. Minimal ductwork.	No heat recovery. Requirement of openings in external façade.	Selected in WC where connection to the MVHR was not possible.
	Automated openings for natural ventilation	Good for rooms not in continual occupation.	Controls must be well set	Selected for council chambers and conservatory.
	Individual room MVHR	High level of user control. Very limited internal duct runs. Good air quality with heat recovery.	Increased number of openings in the external façade.	This was originally selected but removed during design development due to the impact on the external façade.
	Whole building MVHR	Cheaper than individual units. Good air quality with heat recovery. Centralised controls requiring less individual input.	Less localised user control. Increased internal ductwork.	Ultimately chosen to improve air quality through increased air changes in winter and assist the natural building ventilation in summer.

1.3 Technology readiness

The proposed solution is currently at TRL 6 - ‘System/subsystem model or prototype demonstration in a relevant environment'. Following Phase 2 activities, TRL 8 will be achieved where ‘actual system completed and qualified through test and demonstration’. TRL 9 will be achieved in the monitoring phase with ‘actual system proven through successful mission operations’.

1.4 The demonstrator building

Garth House – now used as offices by Bicester Town Council - was constructed circa 1831. The Council offices occupy the southwest end of the First Floor of the building. There is also f Registry Office on the ground Floor, a Council Chamber used for wedding receptions, Bicester Citizen's Advice Bureau and outreach charity occupying the northeast end as council tenants. The upgrade on the half of the building occupied by the Council (17 rooms) has been computer modelled. The unaffected section of the building will act as a control reference. This is a public building and the function of the building would remain unchanged by the proposed works.

The conservatory on the southeast elevation

The southwest elevation with Council Chambers on the ground floor

The front entrance - Northeast elevation

Garth House is a solid wall building with tile hanging externally on the first floor and plaster internally with areas of decorative timber panelling, built in timber shutters in windows reveals and mouldings around windows. The main linear building has two arms extending at either end in opposite directions and is laid out over three storeys (including an unused second floor attic space). The ground floor is of solid construction, with timber floors above. All thermal elements currently have little or no insulation. Notwithstanding this the building underwent a re-roofing programme in 2013 to insulate it to modern standards and prevent water ingress damaging the building interior. Single glazed sash and casement windows are installed throughout and there is a modern conservatory on the side of the Council Chambers. In addition, the building interior has original features in every room. There is timber panelling in the corridors and in most of the window reveals. There are also timber shutters and decorative mouldings around windows.

2 Existing building performance

2.1 Energy performance of the existing building

This section outlines the demonstrator buildings' current energy performance. Both measured energy consumption from bill data and the results of the dynamic building simulation using IES (predicted) have been included. The IES model for the existing building has also been calibrated with the actual energy data. Furthermore, the IES model is used to evaluate the performance of refurbishment measures. The assumptions behind the modelling are explained in appendix 3.1.

The council area of the building (where the work is proposed) is on a separate sub-meter to the other areas. Raw energy consumption data of the council part of Garth House building was obtained from actual gas and electricity bills and manual readings. The bill readings include two electricity readings on 21/07/2011 and 18/01/2012 and three gas readings on 18/02/2011, 19/05/2011 and 17/08/2011. Weekly manual readings of gas and electricity were also recorded during phase 1 of this project (26/02/2013 to 17/04/2013, seven weeks) to correlate gas consumption with heating degree days (weather). Based on data collected above, the actual energy consumption and CO_2 emissions are compared with CIBSE TM46 Energy Benchmarks. Electricity consumption from Garth House building is less than the benchmark value and gas consumption is slightly higher than the benchmark.

Energy consumption and CO_2 emissions and relevant energy benchmark	Annual Gas consumption (kWh/m^2)	Annual Gas CO_2 emission ($kgCO_2/m^2$)	Annual Electricity consumption (kWh/m^2)	Annual Electricity CO_2 emission ($kgCO_2/m^2$)
Actual consumption of Garth building	137	25	39	21
CIBSE TM46 Energy Benchmark - General office	120	23	95	50
Garth building IES base model A	159	29	70	37

The actual gas consumption was calculated based on readings on 18/02/2011 and 26/02/2013; and the actual electricity consumption was calculated based on readings on 21/07/2011 and 17/04/2013. CO_2 emission conversion factors are based on DEFRA values published in August 2011 (Electricity: 0.5246 $kgCO_2/kWh$, Gas: 0.1836 $kgCO_2/kWh$).

Natural gas is used for space heating in Garth House, apart from one small office which is heated by an electric storage heater. The relationship between weekly gas consumption and heating degree days (HDDs 15.5) is illustrated in the figure below. The equation indicates that 1 HDD increase causes 6.8 kWh gas consumption increase for this building while the R^2 value indicates a poor level of control of the heating system (which is was on for 24 hours).

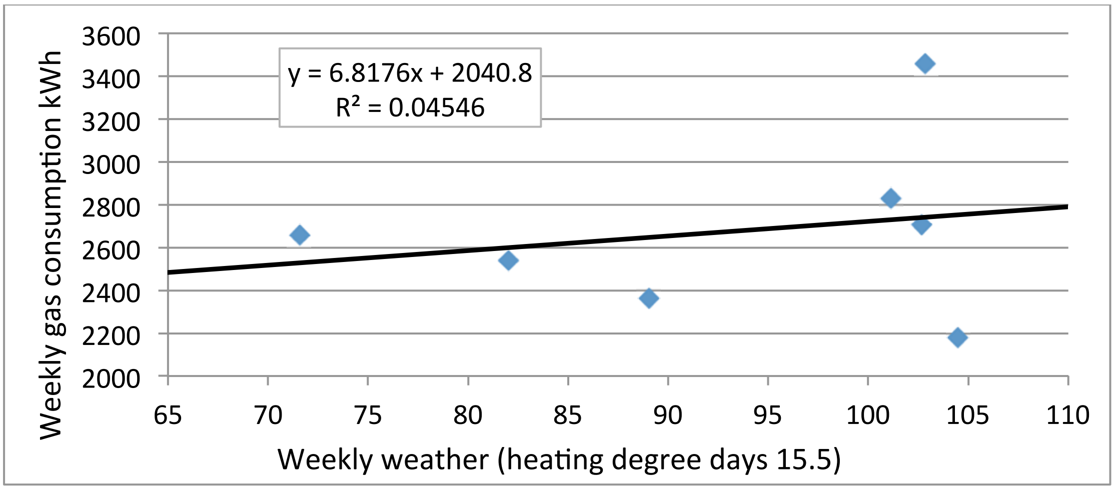


Figure 1 Relationship between weekly gas consumption & HDDs (26/02/2013 to 17/04/2013)

2.2 Summary building user analysis or feedback

A detailed evaluation of occupants' feedback (through questionnaire and interview), energy usage and environmental monitoring (conducted 15/02/2013-09/04/2013) was undertaken in this phase, key findings are described in appendix 2.2. Occupant feedback reveals their concern about a long refurbishment period and the associated disruption, which would be addressed by the proposed room-by-room refurbishment approach having much shorter timescales. The conflict between monitored high air temperature and 'cold feeling' experienced by the occupants indicates low surface temperatures of the walls and windows. The proposed approach of internally insulating the building's windows and walls will help to raise the surface temperatures and provide a better indoor environment with lower carbon emissions. This will be verified through the detailed 15-month monitoring and post-occupancy evaluation, post-refurbishment.

2.3 Issues being addressed

The issues being addressed are:

- The heat loss through the building fabric due to lack of insulation and uncontrolled air paths and the energy required to provide a comfortable internal environment.
- Lack of user interaction with the building; opening windows, adjusting radiator values or heating controls / timers.
- Intermittent occupancy on the Ground Floor leading to overheating. The Conservatory heats up in the morning and then the sun moves around the building and warms the adjacent spaces through the bay windows. Currently there is no user control and the windows are not opened to release the hot air. As a result there is a high overheating potential.

3 The proposal

3.1 No and low cost measures

An assessment of Garth House was been made by our IUK Evaluator to identify a number of no and low cost energy measures to improve the energy efficiency of the building. These are over and above the improvements expected from the proposed experimental measures and the insulation of the roof that is currently being undertaken. These are:

- Improvements to the airtightness of the building envelope by sealing service penetrations and redundant pipework; around the existing windows and any other gaps in the external fabric accessible from the inside of the building. An ATT (airtightness test), inclusive of smoke pen test to identify air leakage pathways was carried out at practical completion (10th July 2014. Remedial airtightness measures were carried out following the results of the test and 12 months later a final ATT was carried out. The airtightness was improved by 1.31 (10.62 to 9.31 $m^3.h^{-1}.m^{-2}$ at 50 Pa) as a result of these measures.

- 2. Improvement to the control of the space heating by providing zoning between floors and improving timing controls specifically to the Council Chamber on the ground floor. Following initial opening up works and mechanical assessment of the existing pipework, this was completed by installing new Evohome wireless TRV controls to all radiators in the Ground Floor Council Chambers. This allowed these Ground Floor radiators to be controlled independently from a control panel in the First Floor Kitchen while the main boiler controls services the first floor areas and entrance area.

Incorporating all the no and low cost measures has been modelled to reduce the primary energy consumption and reduce carbon emissions. In summary the impact of these measures will be a 10% reduction in energy demand.

The Evohome wireless TRV controls would not successfully interface with the main boiler controls, which disabled the boiler, blocking heating to the entire council offices. This was due to the Evohome wireless TRV's only being installed in one area of the building rather than the entire area serviced by the existing boiler.

The Evohome wireless TRV's were removed from the ground floor areas as at £7,950 it was considered too expensive to install the system throughout the building.

3.2 The proposed technology

The proposed project seeks to create an innovative methodology and approach to reduce primary energy consumption in historic buildings. The primary 'Product' is an innovative strategy to the supply and installation of the internal insulation and its integration with internal secondary glazing which will retain much of the detail and character of the period demonstrator property.

Diagram of internal wall insulation on battens

Specifically, the product consists of a series of enhancements to the patented WHISCERS™™ technology. This uses a laser to survey each room of the building allowing off-site measuring and cutting of the insulation and plasterboard. The pre-cut pieces can then be rapidly installed as a labelled jigsaw to each internal wall. As there is no cutting of insulation required on-site this is a low mess process that is faster and less disruptive than traditional methods enabling users to continue to occupy in their buildings throughout the refurbishment works.

Stages of WHISCERS™ installation, images courtesy of United House

Following the laser survey (which can be done with no disruption to building occupants) the plans provided by the laser survey can allow for a shop drawing stage to the process. This allows for the determination of where the solid wall insulation will stop and the glazing will begin. This ensures that the existing building features can be retained and not concealed behind the insulation. These measurements are then converted to a CNC (computer numeric control) cutting schedule via patented software. Following this the wall boards are accurately machined, labelled and returned to site ready for installation.

The insulation itself is 72.5mm K18 Kingspan insulated plasterboard (60mm Kingspan insulation bonded to 12.5mm plasterboard) to receive a plaster skim coat and is fitted to the internal walls on a 25mm thick treated timber battens. The insulation will then be installed using multi-skilled teams who will then pull through the plumbing and electrical services through insulation to the new inside face of the wall. There is no need for a number of trades visit and revisit the same wall to remove and re-fix services. This is a one stop shop solution that should save time, reduce disruption and allow a level of accuracy on determining areas to insulate or not.

Internal masonry walls have inherent cold surface temperature. To raise these surface temperatures and improve internal comfort levels we will secure insulated plasterboard to internal masonry walls. This will also reduce the cold bridge where internal walls meet outside walls and go into the ground.

Double-glazed secondary glazing / internal bay windows allow the existing features to be retained in-situ and visible to the building users while ensuring the internal insulation line is continuous and unbroken.

Early sketch design

The building plan in Appendix 4.2 highlights the areas of the building where works are proposed. Where decorative mouldings/ panelling are present - on the walls, around the windows and in the window reveals - careful detailing and approaches towards installation have been developed. These will continue to be developed in on-going discussed with the Town Council ahead of finalising the design. Please see the proposed details in Appendix 4.2 showing the interfaces between the internal wall insulation, secondary glazing and the internal building features.

Innovative Spacetherm C from the Proctor Group just 28mm thick (10mm Aerogel insulation bonded to 18mm chipboard) will also be used to improve fabric performance of the ground floor to reduce heat loss and raise the surface temperature on entering the building, which at present is rather chilly.

3.3 Ensuring adequate ventilation

Installing internal insulation and secondary glazing removes a source of uncontrolled air infiltration which is inadvertently provided by 'leaky' historic windows. Evidence from past projects in solid wall constructed buildings shows that significantly increasing the level of airtightness of these buildings can create a need for mechanical ventilation in order to maintain acceptable indoor air quality. Airtightness testing was not possible in Phase 1 as delays in fitting the new roof meant that there was an elevated level of air leakage. Airtightness testing was undertaken in November 2013 to understand the pre-refurbishment airtightness of Garth House. The test results were split:

- Main Building: 20 m3.h-1.m-2 at 50 Pa
- Second Floor: 45 m3.h-1.m-2 at 50 Pa

In addition, research into the performance of traditional sash windows published by English Heritage show that simply opening both sets of windows (primary and secondary) slightly to increase the background 'trickle' ventilation does not mitigate the need for further ventilation. Studies show that not only is the thermal performance benefit lost, but condensation occurs on the face of the primary glazing unless wind directions are favourable. To tackle these challenges the project will use two types of ventilation solutions:

- In the seven occupied rooms: Single room extract with heat recovery – the standalone unit will be installed to provide background ventilation (10 litres/ person/ second). The unit has a 75% heat exchanger efficiency and will 'pre-heat' incoming fresh air.

- In the three West facing offices on the first floor and the ground floor Council Chamber below: Heat dumps are proposed to allow warm air to escape in summer. There is a glass conservatory on the east side of the building that heats up in the morning; contributing to these rooms overheating in summer afternoons. There was concern that the internal insulation strategy may increase this overheating potential, so we wish to allow an improved method of letting the warm air out of the building.

Roof lights to the ground floor bay windows and louvres over the first floor windows (both on actuators linked to room thermostats) will allow heat to escape when required without action from the building occupants.

Each ventilation system will be carefully monitored to understand the overall energy consumption of the two systems, establish that they are providing a comfortable internal environment with good indoor air quality and check that the ventilation system does not contribute to the deterioration of the historic fabric by providing insufficient ventilation.

Conversations have been held with the local Conservation Officer about the installation of the ventilations system and the impact of the external building appearance, particularly with reference to minimising visual impact on the internal or external aesthetics. As a result, any external penetrations have been sited so that that appear in discreet positions i.e. not on the front elevation and have sympathetic covers / grilles that match the existing fabric.

3.4 Building user guide and training

Handover process with occupants using the building user guide

An extensive user guide and corresponding training will ensure that all users of the building understand and are confident in using the range of works and new systems. See appendix 4.6. for the full guide

3.5 Summary of the predicted energy savings of the proposed technology

The internal wall insulation will improve the U Value of the walls to 0.28W/m^{2}K from the 2.0W/m2k and the glazing with improve from 5.6W/m2K to 1.8W/m2K. This will reduce the heat loss through the fabric and improve the building airtightness.

Full details of the energy and carbon reductions achieved by these measures are described below. In summary the installation of the internal wall insulation and secondary glazing systems has been modelled to reduce energy demand by 48%, carbon emissions by 30% and fuel costs by 29%.

An IES energy model of Garth House building was developed to calculate the energy consumption of the refurbishment measures. All modelling and calculation assumptions are shown in Appendix 3.1. The energy reductions predicted by the model are shown in the following table. Base case B is for the building with the roof insulation that was installed:

Solution	**Annual Gas Consumption (MWh)**			**Annual Electricity Consumption (MWh)**				**Total**	**Sensible heating room load (MWh)**
	Gas for heating	Gas for hot water	Total	Equipment	Lighting	System	Total	**(MWh)**	
1. Base case A	59.8	0.1	60.0	12.4	12.8	1.2	26.4	86.4	53.3
2. Base case B	50.0	0.1	50.1	12.4	12.8	1.2	26.4	76.5	44.5
3. B + AirTi	46.5	0.1	46.6	12.4	12.8	1.2	26.4	73.0	41.4
4. Above+ HC	42.7	0.1	42.8	12.4	12.2	1.2	25.8	68.6	38.0
5. Above + Wall	21.3	0.1	21.4	12.1	11.8	1.2	25.1	46.5	19.0
6. Above + Glazing	12.2	0.1	12.3	12.1	11.8	1.2	25.1	37.4	10.8
7. Above + Floor	6.9	0.1	7.0	12.1	11.8	1.2	25.1	32.1	6.1
8. Above + Vent1	6.9	0.1	7.0	12.1	11.8	1.2	25.2	32.2	6.1
9. Above + Vent 2	6.9	0.1	7.0	12.1	11.8	1.2	25.2	32.2	6.1

Key: **Base case B**: base A with roof insulation; **AirTi**: increase airtightness; **HC**: improved heating control; **Wall**: internal insulation of external walls; **Glazing**: double glazing. **Floor**: floor insulation; **Vent1**: single room ventilation system; **Vent2**: Heat dumping ventilation system. The implementations of above measures in IES model are attached in Appendix 3.1.

This table shows the energy consumption, CO_2 emissions per m^2 and the annual fuel costs.

Solution	Annual Energy per m^2				Annual CO_2 emission per m^2				Fuel Cost	
	Electricity (kWh/m^2)	Gas (kWh/m^2)	Total (kWh/m^2)	Saving (%)	Electricity ($kgCO_2/m^2$)	Gas ($kgCO_2/m^2$)	Total ($kgCO_2/m^2$)	Saving (%)	Total (£)	Saving (%)
1. Base case A	69.9	158.5	228.4		36.6	29.1	65.8		£6,594	
2. Base case B	69.9	132.4	202.3		36.6	24.3	61.0		£6,136	
3. B + AirTi	69.9	123.2	193.0	**5%**	36.6	22.6	59.3	**3%**	£5,973	**3%**
4. Above+ HC	68.2	113.2	181.4	**10%**	35.8	20.8	56.6	**7%**	£5,706	**7%**
5. Above + Wall	66.3	56.7	123.0	**39%**	34.8	10.4	45.2	**26%**	£4,609	**25%**
6. Above + Glazing	66.3	32.5	98.8	**51%**	34.8	6.0	40.7	**33%**	£4,184	**32%**
7. Above + Floor	66.3	18.5	84.8	**58%**	34.8	3.4	38.2	**37%**	£3,938	**36%**
8. Above + Vent1	66.5	18.5	85.0	**58%**	34.9	3.4	38.3	**37%**	£3,947	**36%**
9. Above + Vent 2	66.5	18.5	85.0	**58%**	34.9	3.4	38.3	**37%**	£3,947	**36%**

Note that CO_2 emission conversion factors are based on DEFRA values published in August 2011 (Electricity: 0.5246 $kgCO_2/kWh$, Gas: 0.1836 $kgCO_2/kWh$). The costs are based on flat rate of 4.6 p/kWh for gas and 14.4 p/kWh for electricity.

The results indicate that improved airtightness could achieve 5% energy saving and 3% CO_2 emissions reduction from base case B, zoning of the heating controls would achieve a further 5% energy saving and 4% carbon saving wall insulation could achieve a further 29% reduction in energy. **The package with all refurbishment measures could achieve 58% energy saving and a 37% reduction in CO_2**

3.6 Summary of the monitoring strategy

A variety of monitoring devices and systems have been installed in Garth building, post-refurbishment to systematically monitor the physical, energy and environmental performance of the building:

- Orsis energy monitoring system is a web-based remote system for monitoring gas and electricity consumption, sub-metered electricity usage of MVHR and 2 electric water heaters. (5-min data start from 11/04/2014)

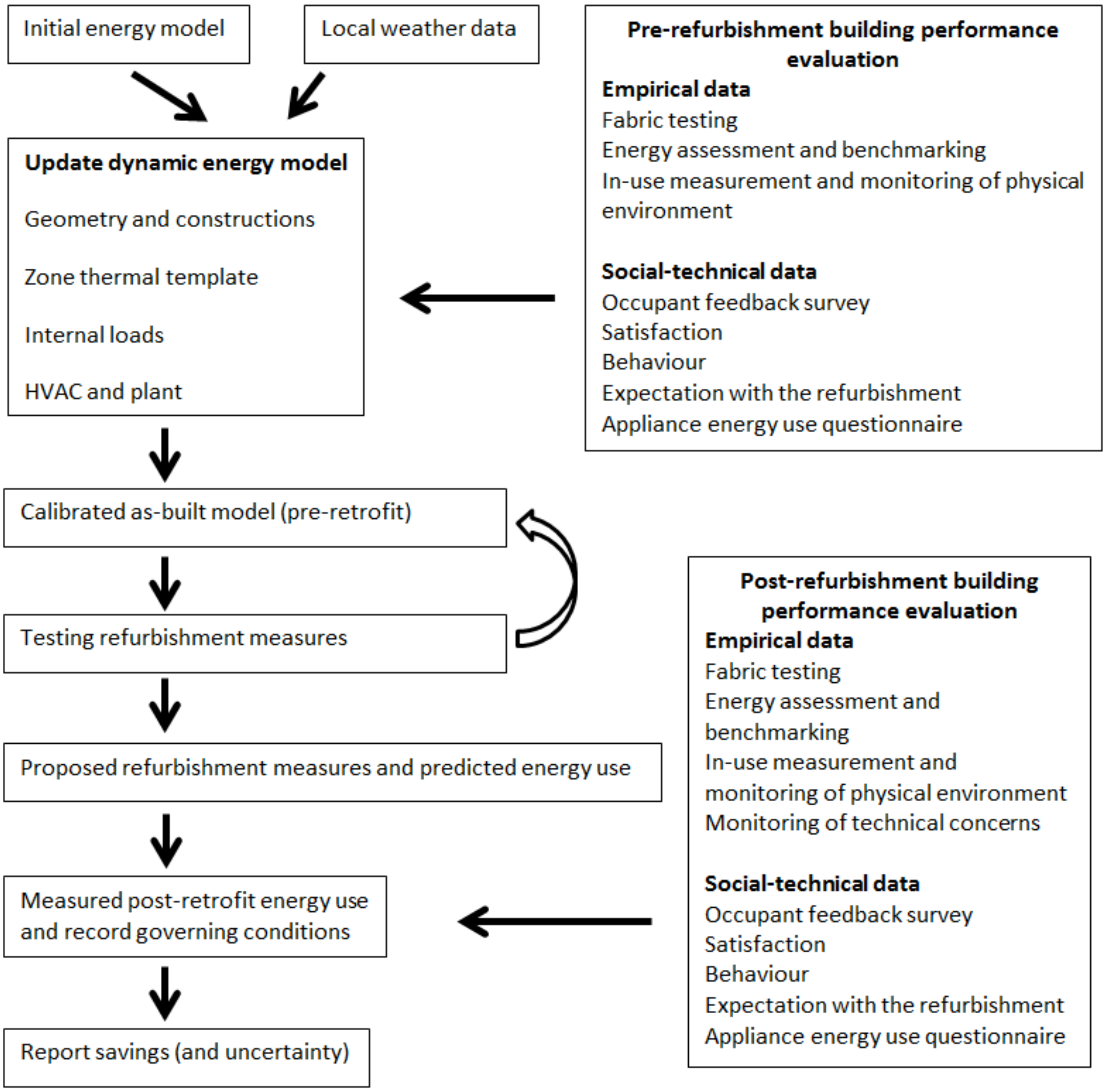
- Omnisense moisture monitoring system: This is a web-based remote monitoring system for buildings to measure temperature, relative humidity, moisture content in the cavity construction formed behind the internal wall insulation. It is used to monitor the physical performance of behind the internal wall insulation. 12nr sensors have been installed to measure moisture content of external wall, timber stud and floor joist at various locations. (5-min data start from 25/03/2014)

- Omnisense environmental monitoring system: This is a web-based remote system for monitoring indoor/outdoor air temperature and relative humidity and external solar radiation. 11nr sensors have been installed at various locations. This is assisted by 4 additional local temperature/RH data logger at the north end of the building. (5-min data start from 18/04/2014)
- CO_2 level: CO_2 data logger were installed at G25, F13, F19 and F21 to monitoring CO2 level at 5-min internal. (5-min data start from 26/04/2014)
- Window opening behaviour monitoring (door and windows opening): 15 local HOBO data loggers have been installed to measure door/windows opening at key space (main entrance, G25, F13, F19 and F21). (data start from 26/04/2014)
- Heating behaviour monitoring (heating on/off): 4 local iButton data loggers have been installed to measure the temperature of radiators at G24, G25, F13 and F21). (15-min data start from 26/04/2014)

3.7 Methodology for isolating energy savings associated with each refurbishment measure

There is no direct way to measure energy saving since instruments cannot measure the absence of energy use. However, the absence of energy use can be calculated by comparing measurement of energy use from before and after implementation of refurbishment measures. Simple comparison by subtraction of post-refurbishment energy use from the pre-refurbishment quantity does not differentiate between the energy impacts of refurbishment measures and those of other factors such as weather or occupancy. In order to access the effectiveness of the refurbishment measures alone, the influence of these other complicating factors, such weather and usage factors must be removed.

The same occupants will use Garth House as an office after the refurbishment, so it is assumed that there is no change in the usage. The change of weather will occur; therefore we start with defining the building energy model before and after the refurbishment and calibrated the model with monitoring data and real weather data collected through monitoring system. The following diagram illustrates how the collected monitoring data will be fed into energy modelling and calculated the energy saving.



3.8 Benefits of the product and market potential

There is significant potential for the WHISCERS™ as a main element in the non-domestic and historical retrofits.

Reduced cost of the new product will be a major factor underpinning market success. This is achieved through cost comparison with best available technologies:

- The use of WHISCERS™ technology provides a significant cost reduction for internal wall insulation. Research from WHISCERS™ indicates that the standard cost for installing internal wall insulation is £120/m2 (including fixing of mechanical and electrical services). With the use of WHISCERS™ the cost is reduced to

£85/m2[4] representing a saving of £35/m2. For a typical non-residential building such as our demonstrator building this equates to a cost reduction of £15,000.
- Reduction in time taken to measure the insulation board from the laser survey;
- Use of multi-skilled teams (i.e. teams of tradespeople with different skills) to install insulation and fix mechanical and electrical fixings reduces the installation time and the need for multiple trades on-site;
- Reduction in waste from the insulation and plasterboard as CNC machine optimises the number of pieces that fit in each board; and
- Avoiding decant costs for occupants (where this is an issue):up to ~£200/employee.

Additional benefits include: less disruptive and faster installation process, preservation of architectural features, use of multi-skilled trades reduces the performance gap, improved internal environment quality for occupants and lower risk of interstitial condensation in the building fabric.

3.8.1 Plan for commercialisation

It was intended that the project would develop a 'Turn Key' solution that can be procured and installed in any historic building with initial marketing focussed on the enterprises that typically occupy these buildings in a non-domestic capacity, including councils, schools and businesses using monitoring data from this project as evidence of benefit.

[4] For standard domestic dwellings

4 Implementing the solution

4.1 Design development

During the detailed design phase a number of developments occurred. The internal wall insulation thickness was increased from 62.5mm to 72.5mm to improve the U Values in order to comply with current building regulations. Airtightness details at the top and bottom of the walls were developed following a dew point calculation and assessment of the condensation risk to the existing wall behind the insulation.

The insulation line was amended to allow the existing porch to remain as an existing unheated uninsulated space. This allowed us to retain the existing timber boarded external door without worry that it did not fit in the frame very well and keep the original floor tiles exposed, that were covered over further into the building. The external wall insulation was omitted in this front porch lobby area and insulation was added to the floor structure above.

During the construction phase areas of the second floor were opened up to review the extent of the insulation line in the roof and determine which areas required to be insulated to avoid gaps at the junctions between wall and roof insulation. This insulation work was carried out in a traditional manner by the main contractor due to contract administration protocol and in order to complete on time.

The design of the ventilation systems were simplified during the detail design process. The original strategy was based upon ‘zero occupancy’ with localised automated background ventilation on both ground and first floors. However the project team concluded that the visual impact on the external building façade could be reduced by minimising new openings in the external walls. Therefore a ‘user controlled’ natural ventilation strategy was developed for the first floor areas that incorporated the existing sash windows with some through wall vents allowing cross ventilation in single sided rooms. A centralised MVHR (mechanical ventilation with heat recovery) replaced the individual through wall ventilation units, thus significantly reducing the number of openings on the façade. To facilitate this new strategy all of the sash windows were refurbished to allow ease of opening. A significant cost saving was achieved by this measure.

The ground floor maintained its ‘zero occupancy’ automated ventilation strategy with automated louvres and rooflights linked to internal thermostats opening and closing with internal temperature fluctuation. This maintains a comfortable internal environment throughout the year and mitigates the risks summer overheating. While the MVHR provides internal air changes on both floors improving internal air quality year round.

Overheating concerns on the ground floor were further addressed by providing automated actuators to existing windows in the conservatory to allow warm air to be released. While a solar control film was applied to the existing glass roof and sides to reduce the solar gain overheating the space.

The night cooling element had to be lost due to security concerns and insurance issues.

4.2 Implementation of the solution

Key problems in the integration of the supply chain and project team appear to have derived from early miscommunication of objectives between the project partners. This inconsistent information exchange resulted in the WHISCERS™ installer expecting to install the system as per the standard procedure rather than with the adaptations described in the preceding section.

Following the Phase 2 inception meeting it emerged that the survey intended in the 'shop drawing' stage would not be possible under the standard operation of the WHISCERS™ system. The primary reason given was that the scope of the WHISCERS™ survey was suitable solely to produce the cutting schedule. Furthermore that there would design liability not associated with a standard survey. Following discussion a laser survey was offered by the WHISCERS™ contractor yet the £2,754 quoted could not have been accommodated at that point within the project budget[5]. Furthermore a standard survey had already been carried out at this point to prevent the project becoming delayed.

These discussions were useful as they as provided an understanding of how the WHISCERS™ survey would be carried out under the standard procedure. It was advised that the windows could be surveyed and then offset 5mm to allow construction tolerance. So instead of reviewing each internal wall as a desk top study to define the edge of the insulation to be installed, (adding the shop drawing phase to the WHISCERS™ system following a detailed survey) a physical feature was placed on the walls to mark where the insulation should end. This allowed Proteam to survey the rooms and define the extent of the insulation.

Ridge developed window details for each window type in the building dependant on the position of the new window relative the existing features around the windows in each room. This allowed the principal contractor Kingerlee to complete the window surround first fix joinery prior to the WHISCERS™ survey. As the new secondary glazing windows were all bespoke they were manufactured in Kingerlee's joinery shop and fitted prior to fixing the wall insulation.

The contractual arrangement of the construction led to difficulties in procurement and site management. Due to issues of risk Kingerlee and Proteam where both appointed on two separate JCT contracts. This resulted in two separate contractors working on the same site, an unusual arrangement and usually avoided by the construction industry for a number of reasons including liability and programming. A critical result of this was split responsibilities for the site management of the WHISCERS™ installation. Issues included inadequate site supervision and a failure to control dust and disturbance to the occupants.
Some of the specific and relevant on-site issues are described below.

a) The project construction programme was divided into seven phases in an attempt to ensure minimum disruption to the building occupants. This should have allowed the users to move out of rooms before any work was carried out in them, to a completed section of the

[5] It should be noted that the underspend in the project was not known at this point.

building as phased areas and rooms became available. However three key issues disrupted this phasing:

- Late ordering of the first insulation boards
- Change in weddings scheduled
- Need for major remedial structural works on the second floor

This put pressure on the programme which was mitigated by out of hours working. However while other phases were being progressed Phase 1 was not completed to allow handover and use by the building occupants. This meant instead of moving to the other end of the building the occupants had works progress around them. Additionally dust, either from the WHISCERS system or another element of the retrofit, could not be always be contained and spread into occupied areas of the building, resulting in a degree of disruption to the users.

a) This demonstrates the importance of strong site management of the WHISCERS™ installation. It also presents challenges to the deliverability of a comprehensive retrofit using a WHISCERS™ approach while occupants are 'in-situ'. The WHISCERS™ element alone might be possible to install in an occupied room, but this is not true of the additional elements required for a holistic retrofit.

b) Due to these delays a larger amount of boards was ordered and arrived outside of the phase plan. This required greater on-site storage not in keeping with the just-in-time aspects of a standard installation. Additionally, when the insulated panels arrived on site, they were labelled to indicate the room for installation. Due to the insulation boards arriving on the same day some mix ups occurred and boards where not always installed in the correct room. This resulted in some on-site cutting and, at times, reduced accuracy.

c) The implementation of a multi-skilled workforce was not achieved. Rather than a small multi-skilled team, there were traditional isolated trades undertaking work sequentially:

- an electrical subcontractor to amend the cabling to extend the power sockets,
- a mechanical subcontractor to amend the pipework to the radiators
- a subcontractor to amend the joinery around doors and windows
- a subcontractor to secure the battens, insulation board and the plaster finish
- a subcontractor to decorate the walls

Following discussion it was clarified that a 'multi-skilled team' was provided rather than 'multi-skilled workers'. Previously, and as part of the WHISCERS™ concept, it is understood that Proteam tried to train multi-skilled workers, in this case electricians were trained to fit insulated plasterboard. However a qualified electrician carrying out batten fixing to walls is not cost effective. There are few people in the UK who have multi-skilled training such as both a plumber and electrician in a domestic environment. The non-domestic heritage environment is of greater complexity and requires increased trade specialisation. As such this project suggests that there is very limited economic scope for multi-skilled workers in projects of this nature.

4.3 Commissioning and operation

At the beginning of the construction phase an electrical survey was conducted to review the condition of the existing building services. This defined an enabling works package to make good defective items that would be concealed behind the new insulation line. Had this survey not been carried out the building occupants could have been left with a number of serious issues now inaccessible behind the new insulation. This could have been critical when extending the small power circuits through the insulation line. If power sockets are extended and they cannot be re-commissioned it would necessitate rewiring the whole circuit back to the distribution board. This would either mean new surface mounted cabling or the insulation would need to be removed to run new cables behind it.

On completion all of the mechanical services were commissioned. A comprehensive user guide and training was given to the staff during April 2014 which covered the:

- MVHR
- Rooflights with automated actuator opening in the ground floor Council Chamber
- Passivent louvres with automated actuator opening in the ground floor Council Chamber
- Conservatory actuators in the ground floor adjacent to the Council Chamber
- Evohome radiator controls
- New boiler controls

4.4 Challenges to the benefits and market potential of the proposal

During the implementation of the proposal a number of challenges emerged which in the case of this project present limits the market potential identified in the project proposal.

- Laser survey
  The laser survey has great potential to be a useful tool for the project design team, if detailed enough to record existing building features, as well as being used to produce a cutting schedule for a CNC machine. However at present due to the design liability issues discussed above only a basic survey is carried out solely to create a cutting schedule. Were the WHISCERS™ system to resolve this risk and be able to deliver this survey at a market price this potential could still be unlocked.

  As many surveying companies begin to offer similar laser surveys a third party could add this. Nevertheless this has the potential to undermine the commercialisation plan of offering WHISCERS™ as a 'turnkey' solution for an holistic historical retrofit.

- CNC cutting location
  At present there are limited CNC facilities in the UK and high capital cost associated with them. Therefore the CNC machine and cutting service for insulation boards was not offered in house by the WHISCERS™ service and instead provided by a company based in Surrey. A number of smaller trips were required to reduce on-site storage and allow for just-in-time delivery. This results in a marginal increase of the embodied energy of the application due to repeat journeys. A portable CNC would appear to offer some solutions but at present is far from economically feasible.

- CNC cutting size
  It was advised that the insulation boards being installed could be a maximum size 1150x1150mm a reduction from a full size sheet supplied by Kingspan at 2400x1200mm. It was not clear whether this was due to the size of CNC cutting machines flatbed size or in order to optimise the cutting schedule. There are advantages with the smaller sizes including easier handling, less chance of damaging edges during install and reduced wastage. However it did increase the number of connections required. The thermogrammes in section 5 show noticeable thermal bridging at the joins, yet this does not appear to have reduced the overall thermal performance.

  For market potential, it would be of interest to determine the relative advantages and disadvantages of a smaller or larger board.

- Insulation Type
  This application utilised K18 Kingspan insulated plasterboard. This is a solid phenolic insulation board bonded to 12.5mm plasterboard. The board itself has a good thermal performance and is a vapour barrier (the joints between the boards may not be). However the board is not breathable or Hydroscopic which is often required in a historical building. A WHISCRS installation in Austria with wood fibre insulation demonstrates that alternative and breathable insulation materials could be used.

- Floor insulation. It would have been possible to use the WHISCERS™ system to cut the aerogel floor insulation. This would have been technically possible and future applications could include this. This is a departure from the standard installation as an in-situ installation with occupants would not be possible.

- Cost. The WHISCERS™ system was predicted to provide a cost saving of 20-30% in comparison with a traditional application. During the project a cost comparison was conducted for additional works on the second floor. In this example there was not found to be a cost saving in comparison to a traditional application.

- Method of fixing. Proteam's preferred installation method is to secure the insulation board on 25mm thick timber. This creates an unventilated void behind the insulation board where mould growth may develop if warm moist air from the building gets into the void and condenses on the cold internal face of the external wall. Airtightness tape was applied to the base of the first floor walls and the void behind the insulation is being monitored. As discussed later in this report the monitoring results suggest there is no moisture problem as it is remaining well beneath the critical 20% moisture content.

  A 'dot and dab' method was previously explored yet this was not feasible due to the drying times associated with the plaster dabs and would slow down the process and / or increase the moisture content within the cavity.

- The critical issue for the future market potential of WHISCERS™ lies with the patent holder, NEF and the choice of licenses which is currently under consideration. At present the domestic market is being prioritised. This appears to be a major factor in the market potential in the UK non-domestic and/or historic sector.

- Were the license to be made available to a larger number of contractors the WHISCERS™ system may be more commercially widespread.

- The WHISCERS™ system is reliant on measuring and ordering the panel is in a timely manner. In this demonstrator project an error by the subcontractor resulted in insufficient lead-in times with the resulting delays affecting the project programme. The additional lead-in time of the CNC machine needs to be accurately programmed with other construction elements and processes.

- As discussed above the implementation section many issues arose leading to the implementation not fully matching the project intention. Levels of disturbance to occupants fell short of expectation despite timely completion. This was not seen to be a problem with the technical aspect of WHISCERS™ and the other systems installed. Rather the issues arise due to problems arose through insufficient information exchanges and site management difficulties – the types of difficulties long raised in the construction sector. Should these issues be overcome then WHISCERS™ is well placed for application in historical and non-domestic retrofits.

5 The energy and carbon impact

5.1 Fabric performance

5.1.1 Airtightness testing

This section presents the results of the airtightness tests carried out at Bicester County Council to determine compliance with Part L2 of the Building Regulations. Three tests were carried out: one before refurbishment and two after the refurbishment. All tests followed the same procedure and were carried out in accordance with the requirements of the ATTMA a TSL2, CIBSE TM23:2000, BS EN 13829:2001 method B, and is UKAS accredited.

The individual test areas of Bicester County Council were tested using PW5E blower door systems manufactured by Retrotec of Canada. Each system consists of one fan, mounted in an expandable aluminium frame with a canvas blanking panel, which were located within a normal door frame. Each fan contains an integral flow measuring device. The pressure differential across the building and the pressure differential across the flow measuring devices were measured using calibrated DG700 micromanometers. The results from all the airtightness tests are summarised in Table 1.

Table 1 Summary of results from airtightness tests at the Garth

	Before refurbishment	**After refurbishment**	
	26 November 2013	10 July 2014	30 April 2015
Ground and first floors $m^3/h.m^2$ @50Pa	**20.52**	**10.62**	**9.31**
Attic space $m^3/h.m^2$ @50Pa	**44.80**	**40** (estimate)	**-**

5.1.1.1 Airtightness before refurbishment

Before the refurbishment, the airtightness of the council offices was evaluated through one test on the ground floor and First floor and one test in the attic. The tests were carried out on Tuesday 26 November 2013 by BSRIA Ltd.

The target figure for the airtightness of the council offices when pressurised to 50 Pa was 10.0 $m^3/h.m^2$ @50Pa. The relevant results of the tests were as follows:

- Measured Air Permeability ground and first floor - **20.52 $m^3/h.m^2$ @50Pa**
- Measured Air Permeability council offices attic **- 44.80 $m^3/h.m^2$ @50Pa**

5.1.1.2 Airtightness after refurbishment

Test 1

This report is presented to provide the results of the air permeability pressurisation test carried out at The Garth, to determine compliance with Part L2 of the Building Regulations. Following the refurbishment, an-air permeability test was carried out on Thursday 10 July 2014, followed by a smoke pencil survey.

It was not possible to achieve sufficient pressure differential to meet the requirements for a valid test result within the Attic space.

- The air permeability of the ground and first floor was measured at **10.62 $m^3/h.m^2$ @50Pa**
- In the attic space measurements could not be taken due to sufficient pressure differential not being achieved. The minimum pressure required by CIBSE TM23 is 25Pa. The maximum pressure achieved was 16.60 Pa. This has been extrapolated to provide an estimated permeability figure at 50Pa. air permeability was estimated at **40 $m^3/h.m^2$ @50Pa**, which is similar to previous measurements prior to renovations.

During the smoke pencil survey carried out in the ground, first floor and attic space of the Garth, points of leakage were noted (Figure 1-Figure 8).

Ground and first floors: There were a number of air leakage paths into the floor void. This occurred around door frames, skirtings, the kitchen, and rooms where the floor boards were exposed. It was not determined whether this air was travelling within the floor void to other parts of the building outside the test zone, or was finding its way out of the building around gaps in the insulated plasterboard or holes in the external wall. Regarding secondary glazing, the seal between openable doors was frequently not in contact with the adjoining door and often the seals stopped short at the tops and bottoms, leaving a gap. The secondary glazing frame did not always seem to be sealed to the floor and air was drawn under the frame. On the first floor, air was drawn under the floor around the perimeter of most of the rooms.

Figure 1 Secondary glazing seals. Smoke drawn through secondary glazing.

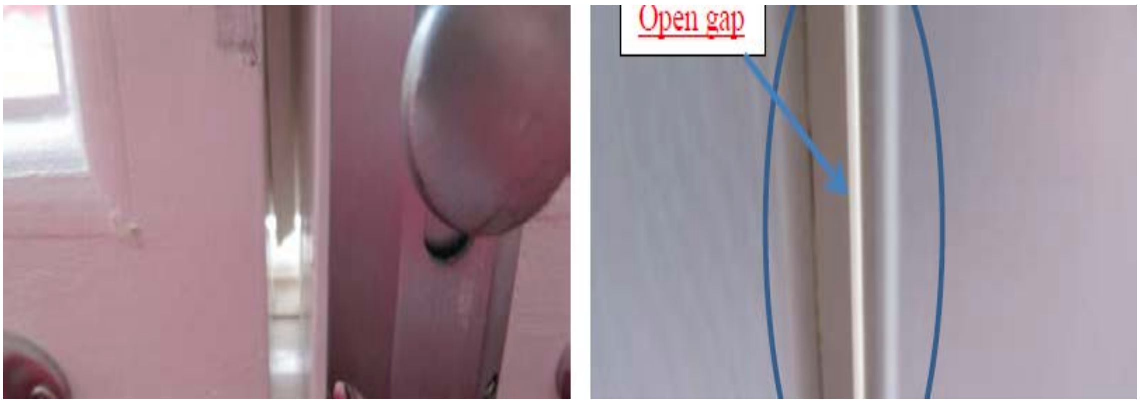


Figure 2 Secondary glazing seals. The seals between the two doors do not extend down to the bottom/sill/threshold/ step.

Figure 3 Secondary glazing frame. Air is drawn through the gap between the secondary glazing and the carpet.

Figure 4 Smoke drawn through gap between floor and skirtings.

Figure 5 Smoke drawn over top of windows. Gaps visible above windows.

Figure 6 Smoke drawn behind end of dado detail and at bottom of window reveal

Attic space: In the attic space there was a strong draw of air through all the floor boards in every room. The air movement caused by the air leakage path resulted in a rapid dissipation of smoke, as a result of which the smoke was difficult to record photographically. It is not known whether this air was traveling within the floor void and leaking into the un-refurbished area or whether there were leakage paths through the exterior fabric of the building. The cupboard where the MVHR unit was located had large holes around the penetrations for the ducting. There does not appear to be an effective air seal. It is not known whether the air seal is intended to be the floor covering or whether the floorboards should be lifted to create an air seal underneath.

Figure 7 Gaps in floor. Smoke drawn under floor.

Figure 8 Left: Smoke drawn through hole in pitched ceiling. Right: Smoke drawn through floor perimeter

Test 2

Following the results of the air-permeability and smoke pencil tests conducted in July 2014, an attempt was made by the building contractor to seal some of the air-permeability paths during a follow-up visit. This included some in-situ repairs of the frames and secondary glazing seals. Following this, a second airtightness test was conducted on 30 April 2015, in order to measure the effectiveness of these repairs. Only the ground and first floors were tested during this visit.

- The Air Permeability of the ground and first floor was measured at **9.31 $m^3/h.m^2$ @50Pa.**

The test proved that the building **passed** its envelope integrity specification as the Measured Air Permeability value is below the Design Air Permeability target.

5.1.2 Thermal imaging survey

This section details the findings from the two thermal imaging surveys conducted at the Garth: one before the refurbishment and one after the refurbishment. The surveys were undertaken by Oxford Brookes University as part of Innovate UK's Invest in innovative refurbishment for Garth building project.

The details contained in this section are in accordance with the simplified testing requirements of BS EN 13187:1998 Thermal Performance of Buildings – Qualitative detection of thermal irregularities in building envelopes – Infrared method (ISO 6781:1983 modified). In accordance with the IUK requirements all thermographic images are in the full colour rainbow-hi pallet, and the work was undertaken whilst the properties were occupied.

On both occasions a series of thermograms were taken showing the various elevations of the buildings. Images were primarily taken of the external walls and internal surface that exhibited any thermal anomalies. The environmental conditions and building fabric properties were entered into the thermal imaging reporting software and the relevant corrections were made. Both surveys were undertaken during late afternoon times and the digital images shown are for reference purposes only.

The following test equipment was used during both surveys:

- **FLIR T620 Thermal Imaging Camera**, 640x480 pixel resolution, 0.04K thermal resolution set on Rainbow colour palette
- **Vaisala HUMICAP® Hand-Held Humidity and Temperature Meter HM40 with HMP113 Probe**, ±0.2 ^{o}C, ±1.5% Accuracy

5.1.2.1 Survey before refurbishment

Environmental Conditions

The survey took place during 15:30-17:35 on 1 November 2013. No rapid / significant variations in environmental conditions were observed during the survey period. In general terms the weather could be described as a still cold winter evening with no sunshine or precipitation.

Parameter	**Measurement**
Internal Temperature	24^{o}C – F21, 20 ^{o}C – G25, 21.5 ^{o}C – G24/G23
External Temperature	13.3 ^{o}C
External RH	59.9%
Precipitation	Nil

Thermograms and Observations

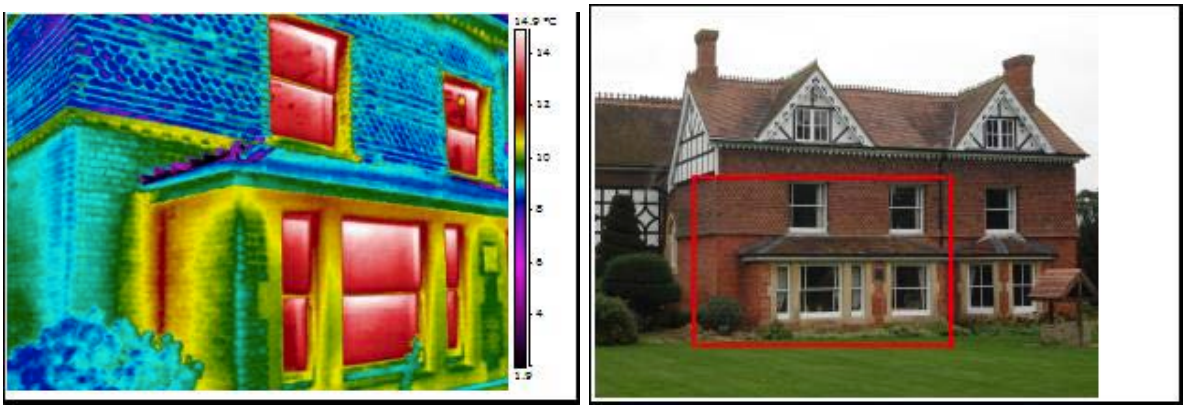


Figure 9 Southwest elevation. The image shows significant heat loss through windows and heat loss through the wall junction.

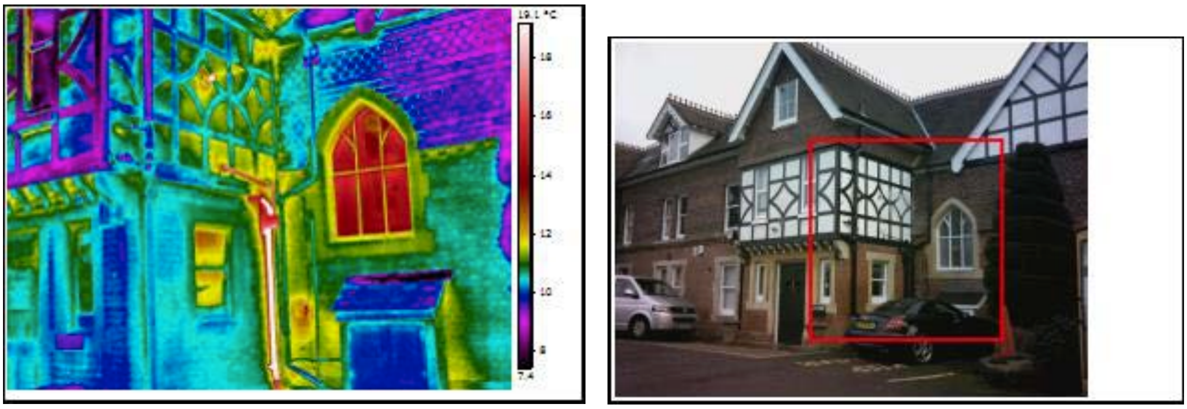


Figure 10 Front elevation (northwest). The image shows significant heat loss through windows and heat loss through white painted wall.

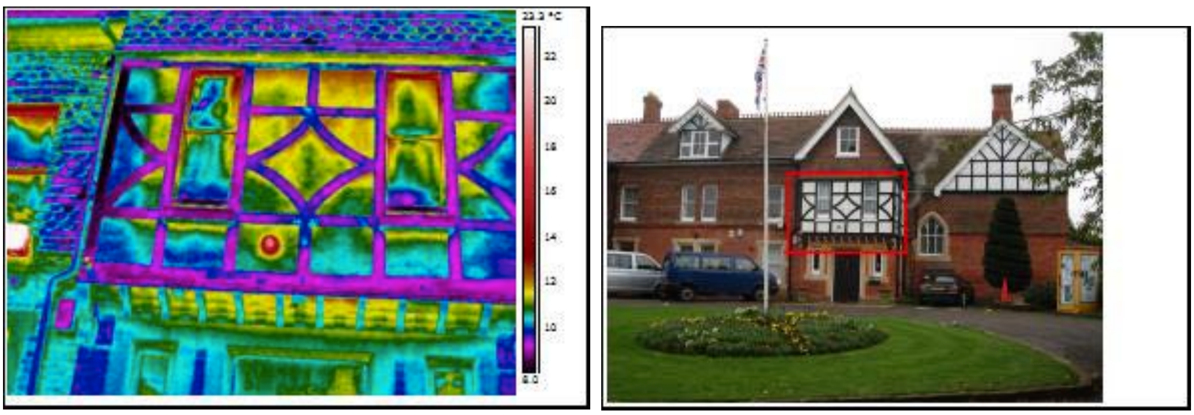


Figure 11 Front elevation (northwest). The image shows the heat loss through white painted wall. It is likely to be due to poor insulation of external wall.

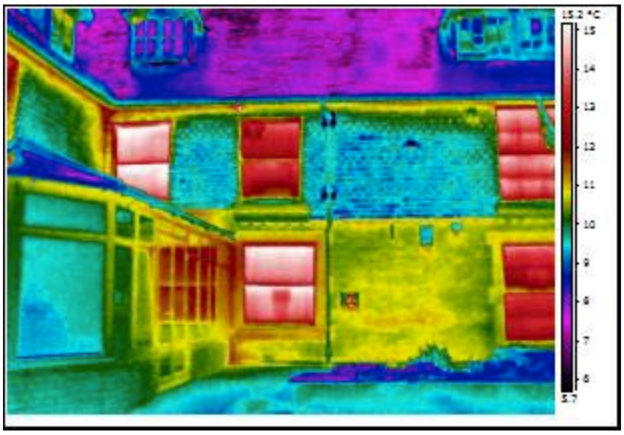


Figure 12 Back elevation (east). The image shows the heat loss through external wall at ground floor. It is likely to be due to poor insulation of external wall.

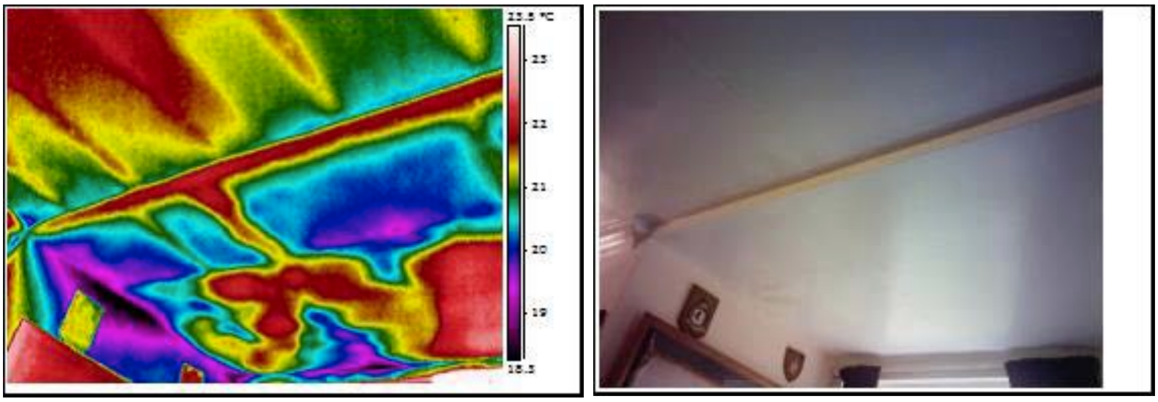


Figure 13 Room G25. The image shows thermal anomalies on the ceiling of meeting room at ground floor. It is likely to be due to poor insulation of pitched roof above windows.

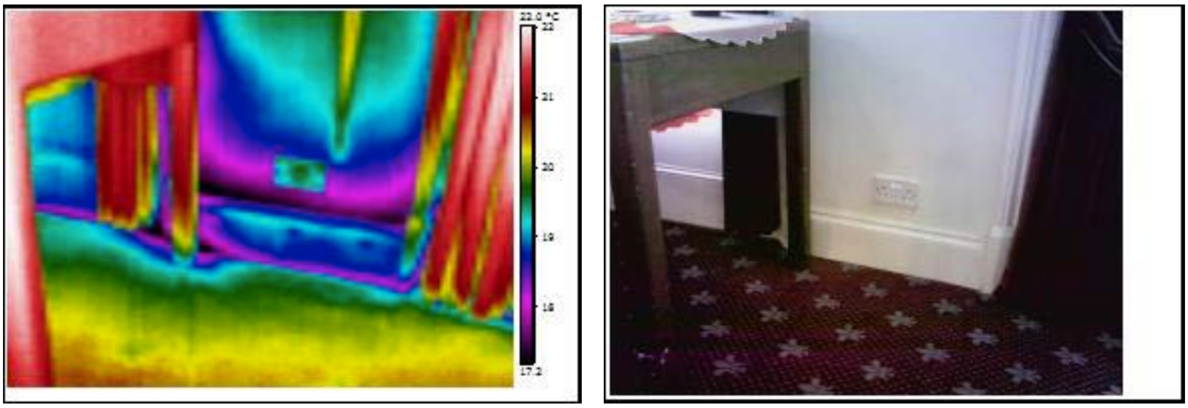


Figure 14 Room G25. The image shows the heat loss through wall-floor junction in the meeting room on the ground floor.

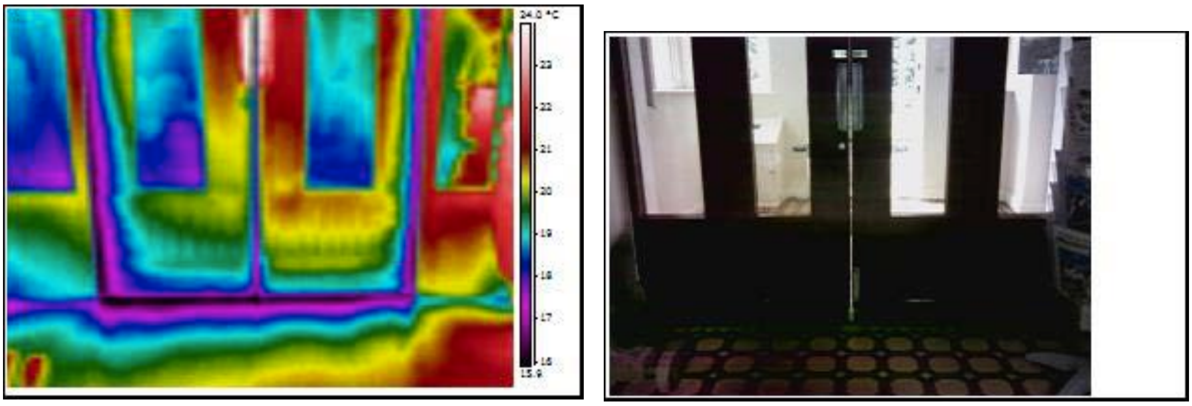


Figure 15 Room G23. Cold air leakage through the door.

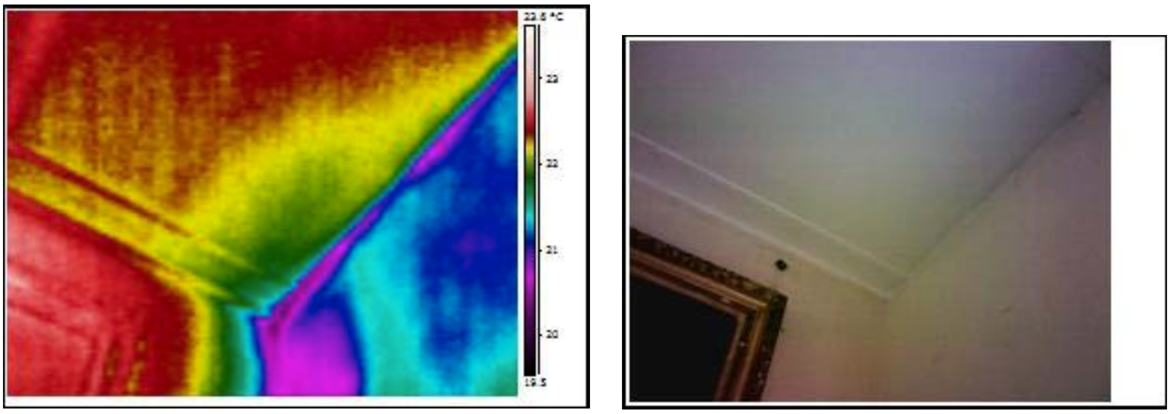


Figure 16 Room F18. Well insulated roof and poor insulated external wall.

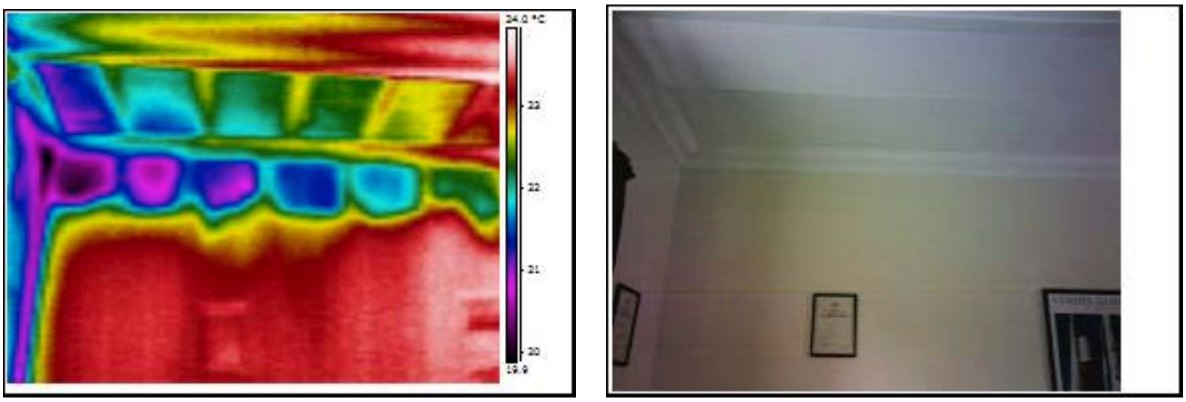


Figure 17 Room F21. The image shows thermal anomalies at the wall-roof junction in room F21 at first floor. It is likely to be due to the build process of recent roof installation.

5.1.2.2 Survey after refurbishment

<u>Environmental Conditions</u>

The survey took place during 15:30-17:30 on 11th November 2014. No rapid / significant variations in environmental conditions were observed during the survey period. In general terms the weather could be described as a still cold winter evening with no sunshine or precipitation.

Parameter	**Measurement**
Internal temperature	G25 - 21.01 ^{o}C,F19 - 21.01 ^{o}C, F13 - 23.24
External temperature	10.15 ^{o}C
External RH	90%
Precipitation	Nil

<u>Thermograms and Observations</u>

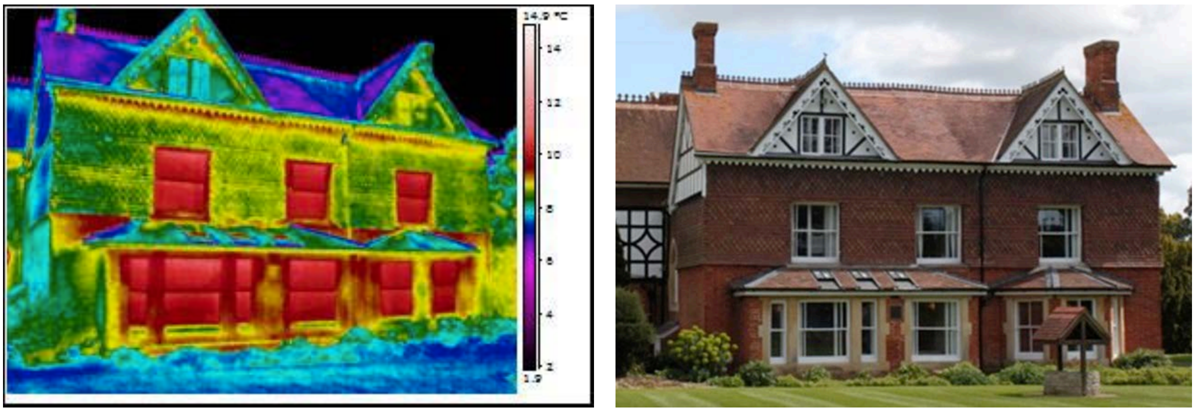


Figure 18 South elevation. The image shows the heat loss through roof-wall junction at the floor line of second floor.

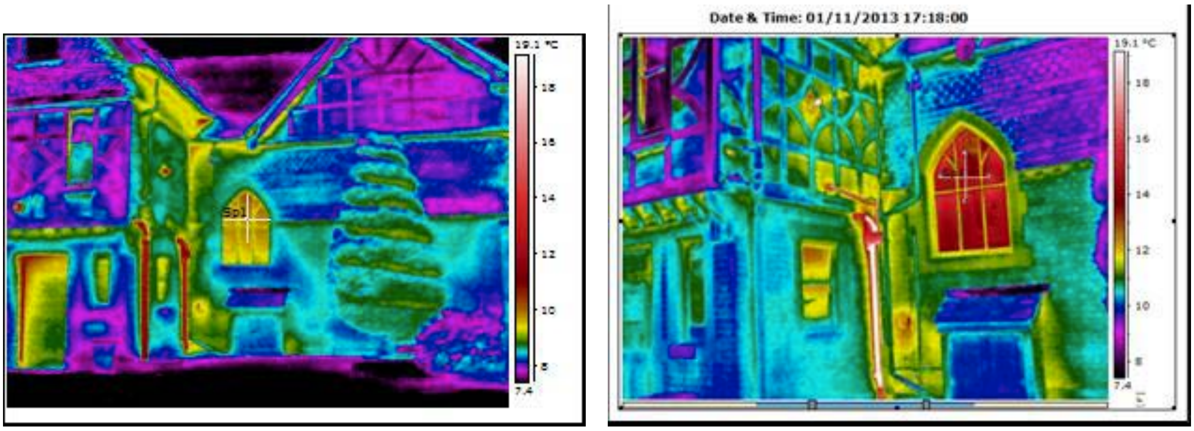


Figure 19 Left: After refurbishment (indoor 23.2 ^{o}C, outdoor 10.2 ^{o}C). Right: Before refurbishment (indoor 24 ^{o}C, outdoor 13.3 ^{o}C). The temperature at Sp1 is higher before refurbishment comparing the temperature after refurbishment. The comparison shows that the heat loss through windows after refurbishment is less than the heat loss before refurbishment.

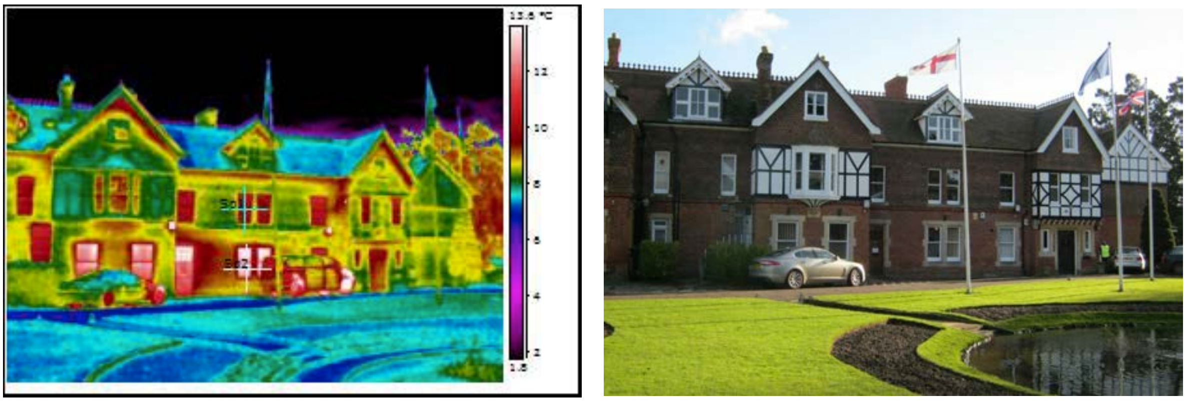


Figure 20 West elevation. The windows at ground floor are significantly warmer than the windows at first floor, as the secondary glazing is installed for windows at the first floor.

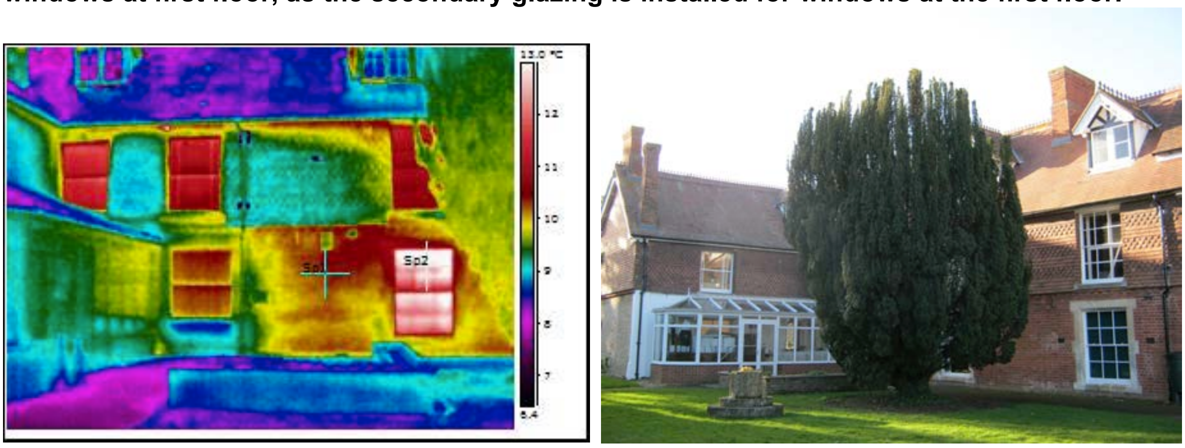


Figure 21 East elevation. The registry office is not insulated as part of this project. The image shows significant higher heat loss through windows and external wall of the registry office.

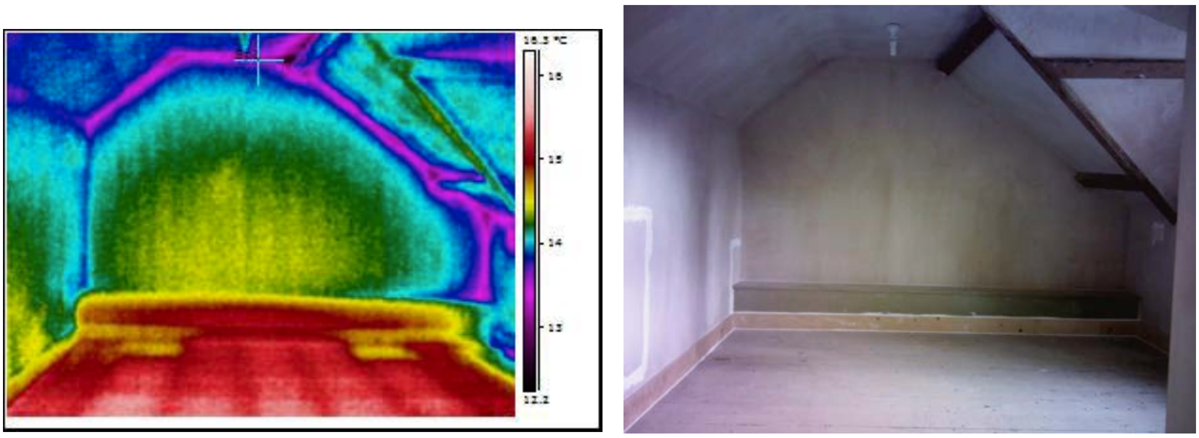


Figure 22 Room S19, attic space. The image shows thermal bridges at the junctions between the external wall and roof in the second floor.

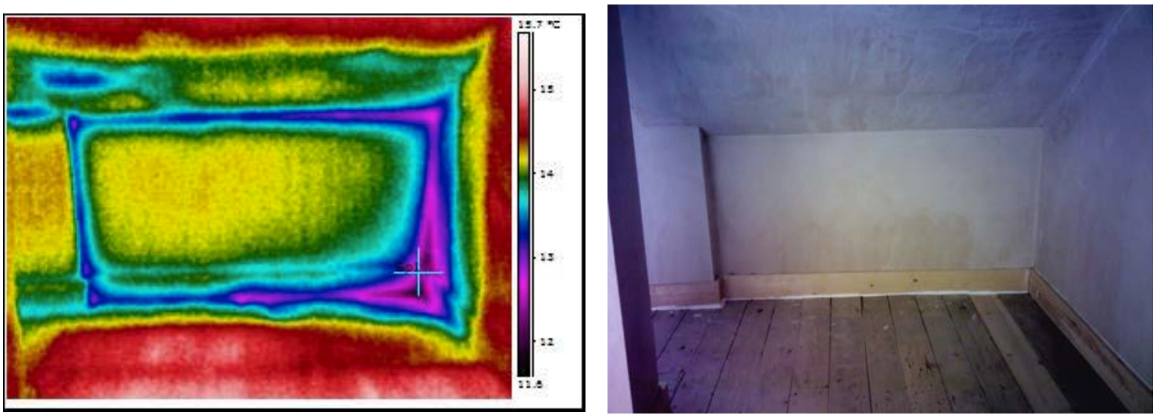


Figure 23 Room S18, attic space. The image shows thermal bridges at the junctions between external wall and roof in the second floor.

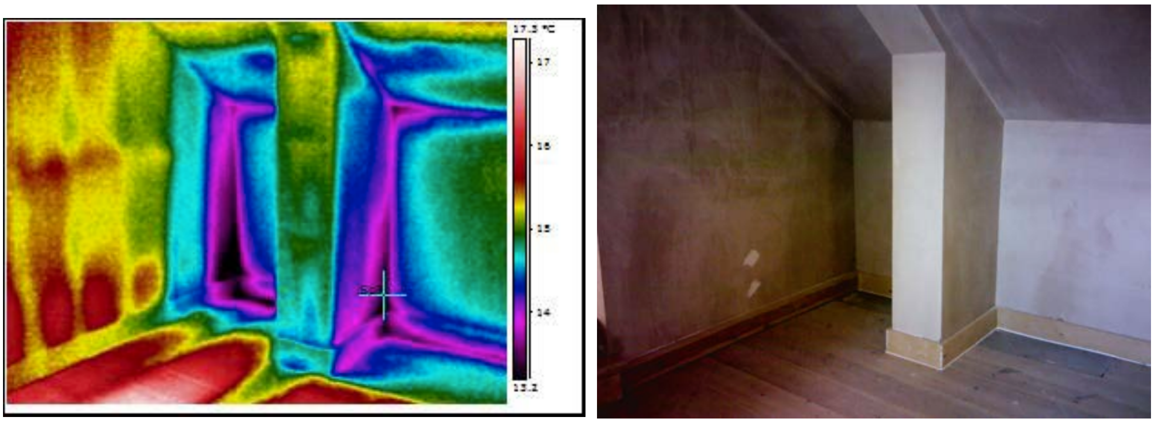


Figure 24 Room S18, attic space. The image shows thermal bridges at the junctions between external wall and structural beam in the second floor.

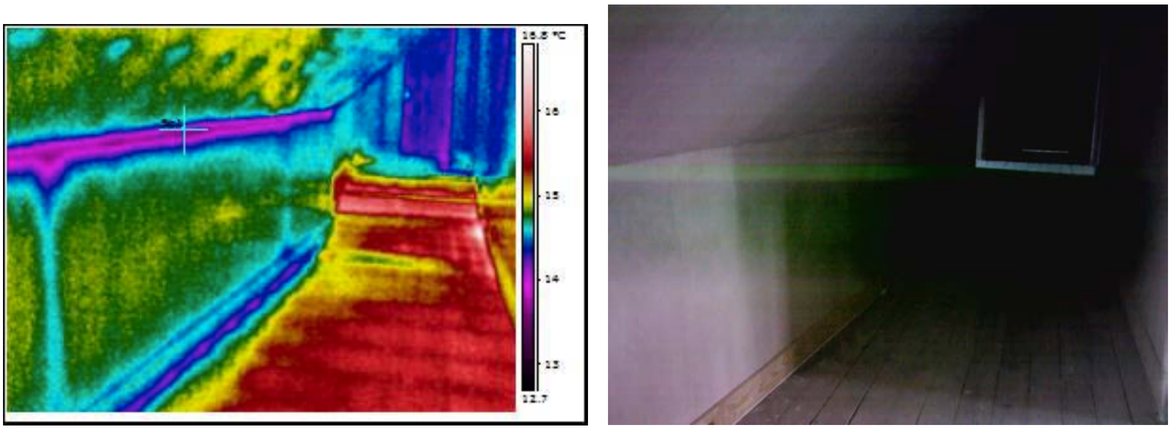


Figure 25 Room S12, attic space. The image shows thermal bridges at the junctions between wall and roof in the second floor.

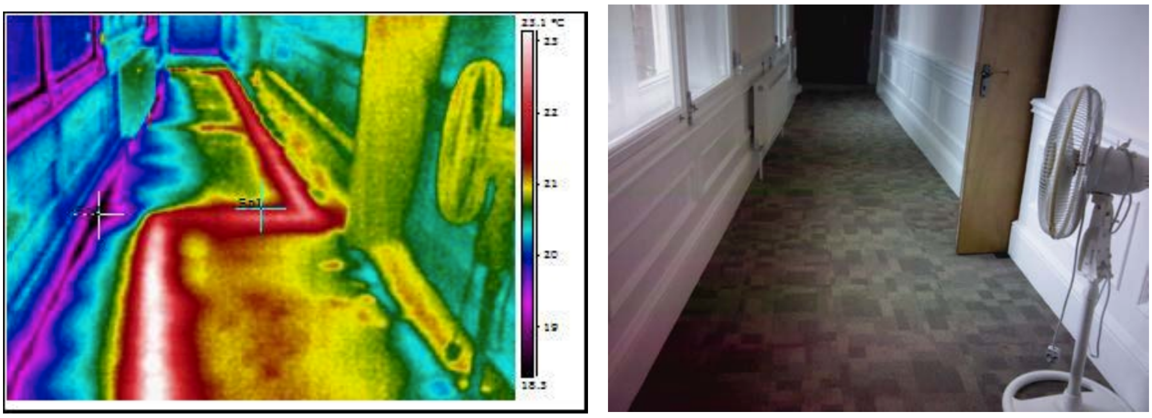


Figure 26 Room F09, First floor corridor. New heating pipe (underfloor) for radiator in F10. The image also shows the thermal bridges at the junction of external wall and first floor line.

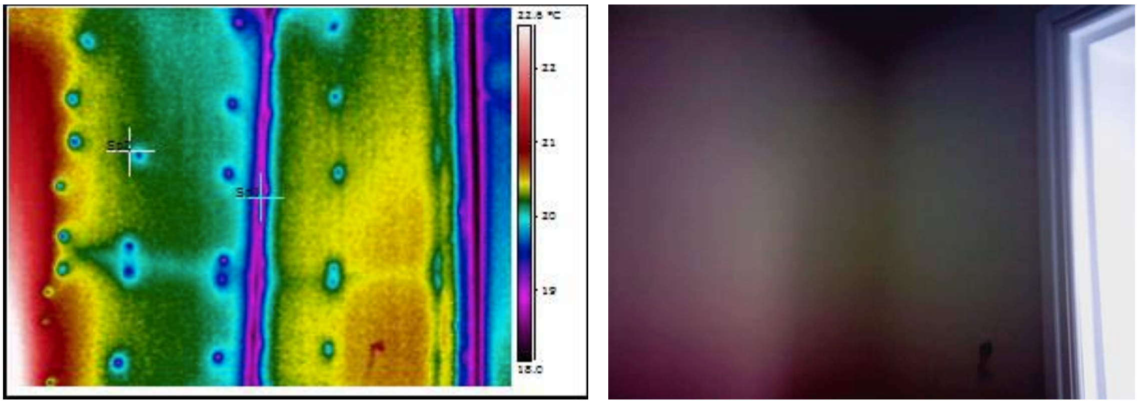


Figure 27 Room F10. First floor office. Thermal bridge at the junction of the external wall. It also shows the fixing points of the insulation panels. This pattern can be found all over the building.

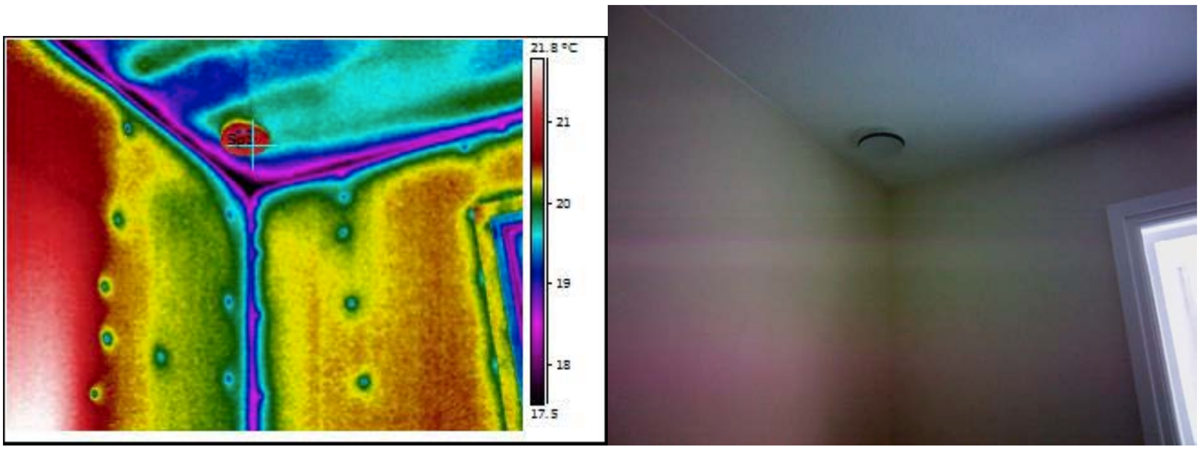


Figure 28 Room F10, First floor office. The red point shows the air outlet for MVHR system.

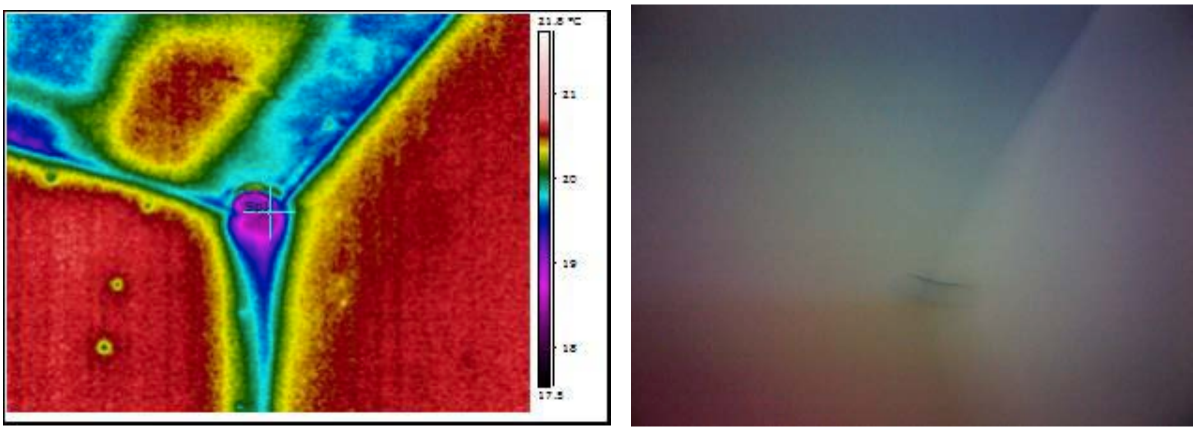


Figure 29 Room F10, First floor office. The purple point shows the air inlet of MVHR system. The temperature of fresh air is generally 2-3 ^{o}C lower than the temperature of indoor air.

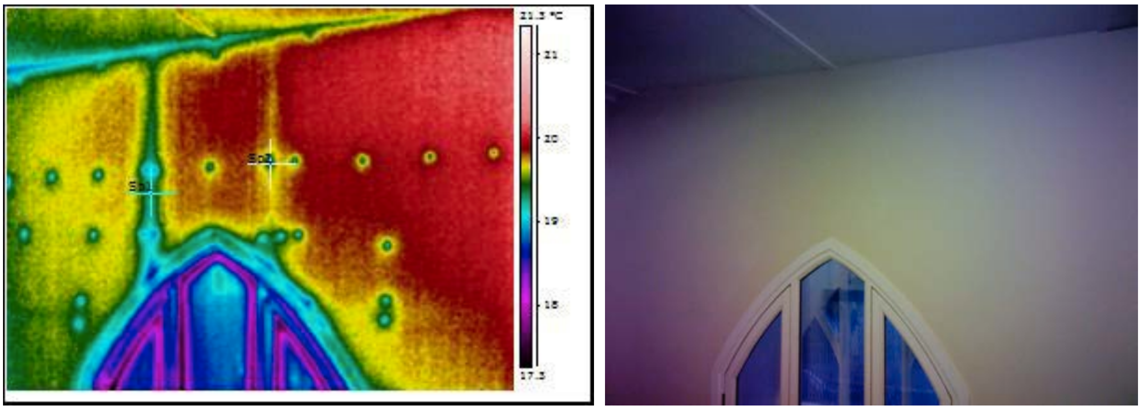


Figure 30 Staircase hallway. The image shows the thermal bridge at the gap between insulation panels. It also shows the fixing points of insulation panels. This pattern can be found all over the building.

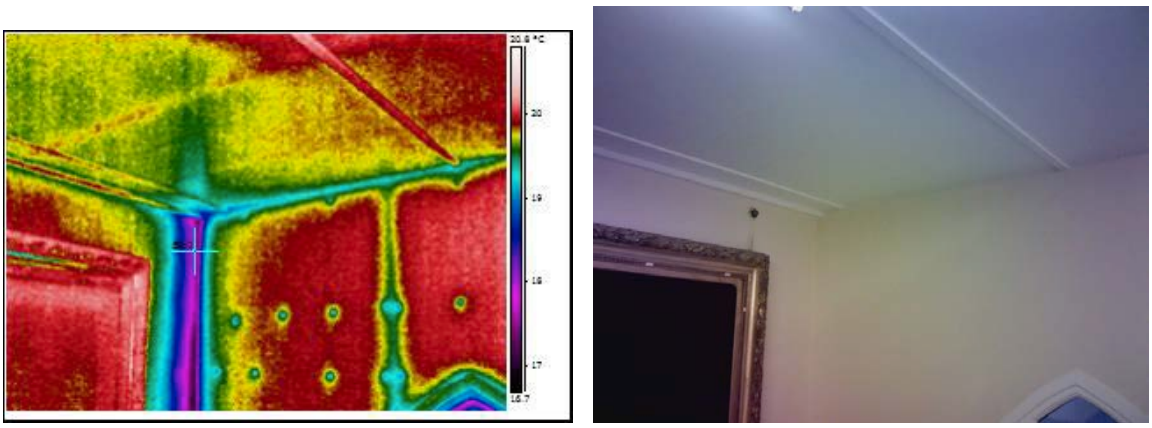


Figure 31 Staircase hallway. The image shows the thermal bridge at the junction of internal wall and external wall. Because the building is internally insulated, it is expected to see such a thermal bridge. It also shows the fixing points of insulation panels. This pattern can be found all over the building.

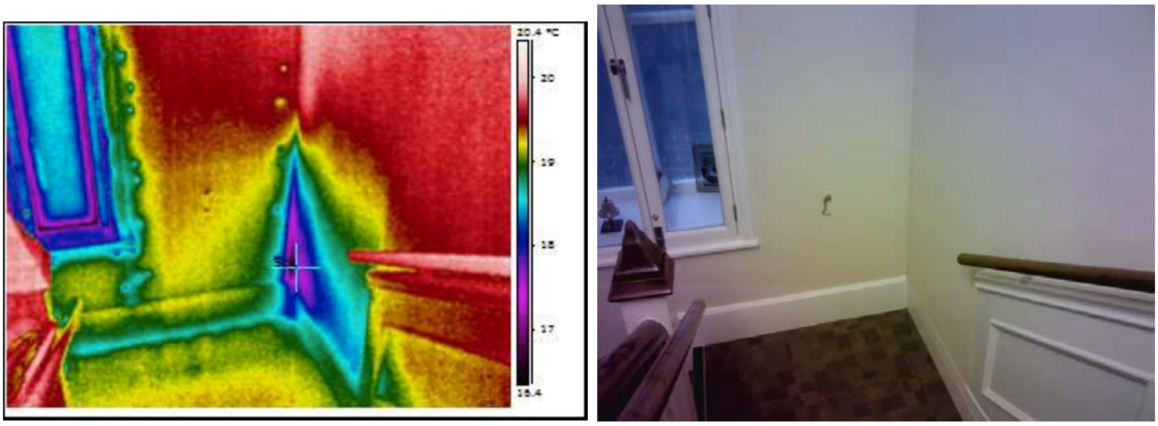


Figure 32 Staircase hallway. The image shows the thermal bridge at the junction of internal wall and external wall.

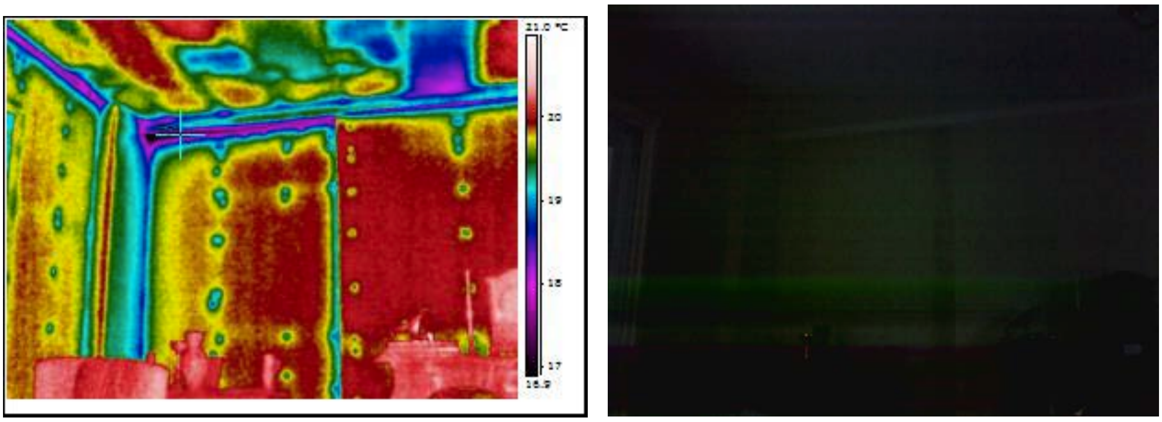


Figure 33 Room F21. The image shows the fixing points of insulation panels and thermal bridge at the junction of first floor ceiling line and external.

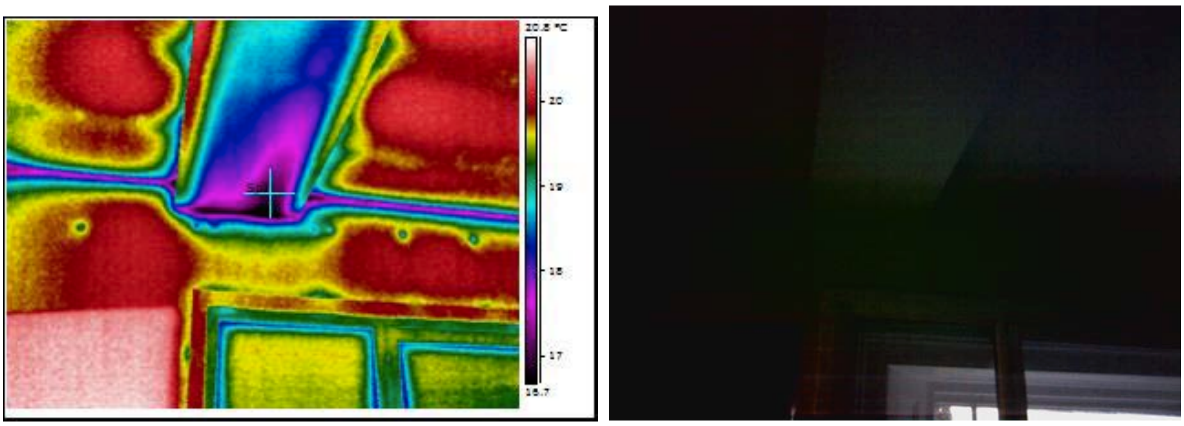


Figure 34 Room F21. The image shows heat loss through the structural beam in the ceiling of first floor.

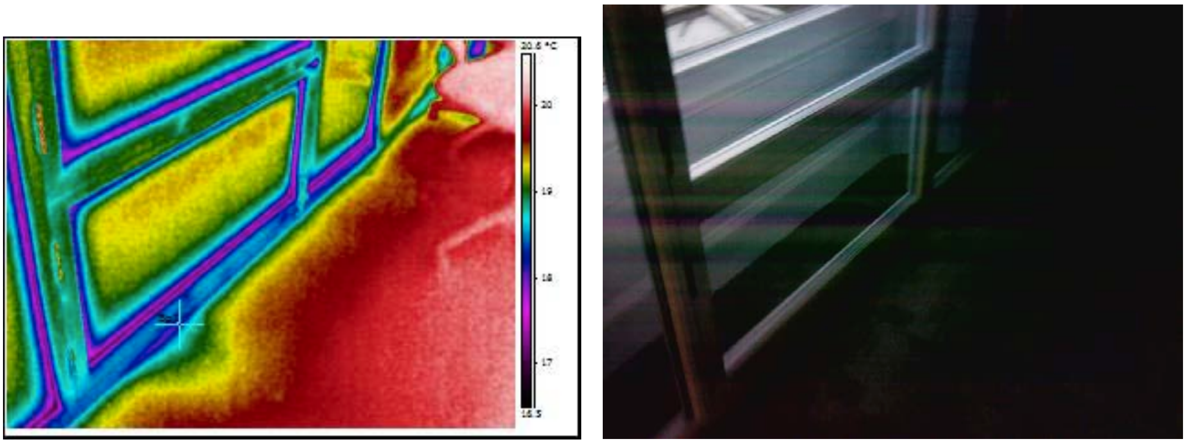


Figure 35 Room F21. The image shows heat loss through the edge of secondary glazing. The smoke test also shows the smoke drawn under the secondary glazing.

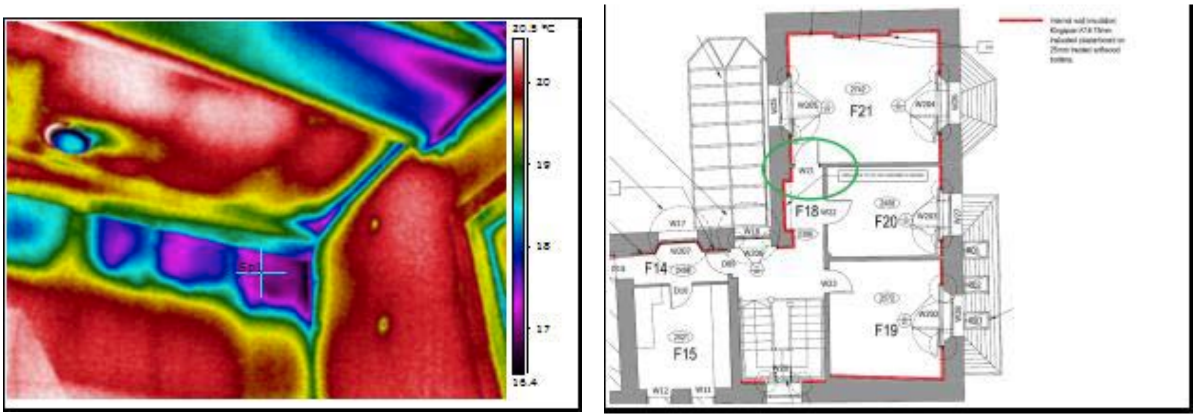


Figure 36 Room F21. The image shows heat loss through the edge of secondary glazing. It also shows the air inlet of MVHR next to the door in room F21.

Figure 37 Room F18. The image shows thermal bridge at the junction of first floor floor line and external wall.

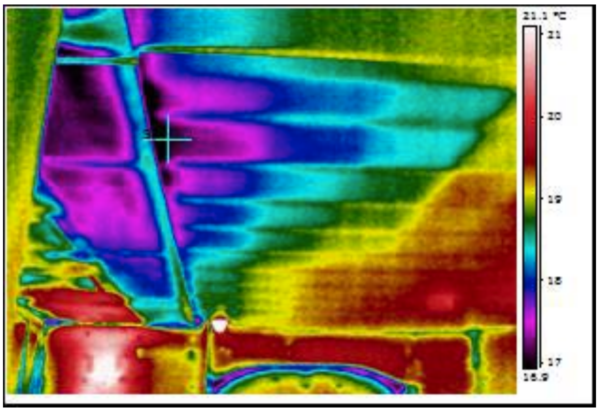



Figure 38 Room G25. Ground floor Council Chamber. The image shows thermal anomalies on the ceiling of the Council Chamber. It is likely to be due to poor insulation of pitched roof above windows.

5.2 Handover review and occupant training

This section describes the approach and findings from the review of the handover and commissioning processes of the Garth building.

5.2.1 Background and methodology

A review of a building's handover process and commissioning aims to tackle any issues faced during the early stages of occupation of the building and intents to enable building users and building managers to understand, manage and operate their building effectively from its initial operational phase. Efficient operation of a building is expected to result in lower running costs and reduced CO_2 emissions. The building is also expected to provide good level of thermal comfort for occupants and achieve users' satisfaction and improvement in productivity.

The Handover review involves a survey, interviews and evaluation of different aspects of a building's handover including:

- Managing the delivery of design intent.
- Arrangements for seasonal commissioning, aftercare and maintenance.
- Evaluation of handover data, including building logbook, O&M manuals, user guides for occupants.
- What aspects of handover worked and what could have been improved leading to recommendations on improving handover processes for future learning.

This report provides a detailed overview of the issues and key findings following the review of the handover process and commissioning of the Garth building in Bicester and presents the feedback and recommendations given to the Garth building - IIR project team in order to improve management of the building activities and improve handover processes of future developments.

The effectiveness of handover process in Garth building has been evaluated through analysis of data obtained via the following method:

- Desktop research included a thorough review of the existing handover documentation.

- Structured interviews were conducted with all parties involved in the design, construction and maintenance of the building (Owner/occupant, architect, contractor). The structured interviews aimed at gathering contextual information on each party's role during the different phases of design and construction and their understandings of the design intent.
- Handover Questionnaire survey was conducted to gather quantitative data on the handover, as well as help trigger further discussion within the review meeting.

- Handover questionnaires were distributed to all parties involved in the design, construction and maintenance of the building (Owner/occupant, architect, contractor). The questionnaire survey aimed at mapping each party's role during the different design and construction phases and their contribution during and after the building's handover.
- The responses obtained through the handover review questionnaires were analysed and illustrated through graphs that reflected the overall views on the project's handover aspects.
- The Handover Review workshop played a major role in the review of handover process and commissioning. The workshop was organised by the BPE evaluators on 4 July 2014 and gathered together all parties involved in the design, construction and handover process.
- Finally the information collected by the above survey process was analysed in order to present a detailed report on evaluation of handover process and commissioning.

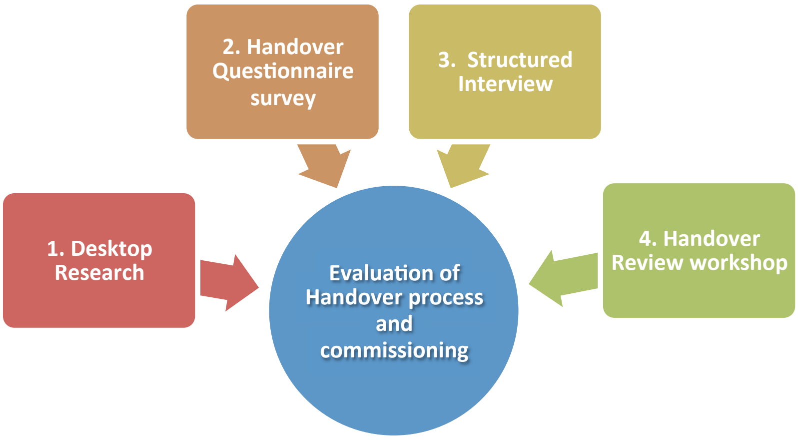


Figure 39 Methodology schematic of evaluation of handover process and commissioning.

5.2.2 Familiarisation and training of occupants and management

It is very important to familiarise the building occupiers and facilities manager with the building features and its operation during initial aftercare period. The building handover was done by Kingerlee (contractor), Bioregional (project coordinator) and Ridge (designer) with Bicester Town Council (Owner and end user).

Bicester Town Council (owner) received the following training on using and managing the mechanical systems:

- Training and instruction was given to the Town Council manager team at the time of handover.
- The handover documentation delivered to building owner included mechanical services files, building user guide, record drawings and incomplete building manual.

- A building user guide is explained to building users on how the improved building will work and to ensure users know how to keep the temperature inside the building comfortable all year around. Demonstrations of building services and controls took place during the building handover.
- During handover there was demonstration of boosting MVHR, control of roof light and control of window opening.
- There is a very good communication established between designer and building users who aim to familiarise other users with their findings regarding the function of building services.
- Observation shows that occupants have understood the ventilation strategy and when they should open windows. The outstanding training is the heating control and the use of radiator valve which is scheduled after the installation of system.

5.2.3 Review of arrangements for seasonal commissioning, aftercare and maintenance

According to available handover documentation which has been reviewed by the BPE team, there is no written information about commissioning report and maintenance procedures. This is partly due to the building being designed with low maintenance strategies and partly due to the refurbishment project rather than a new build project. The issues highlighted by BPE team are:

- There is no commissioning report of MVHR system.
- There is no airtightness test report after refurbishment.
- There is no written information about maintenance schedule.
- The role of Facilities Manager and his/her responsibilities should be identified by the organisation management team

According to the interview with designer team, Ridge and Kingerlee was responsible for re-inspecting the building and M&E installations during the 12 month Defects Liability Period. This requires:

- Evidence of inspection of the M&E installations should be provided to the building owners at that time
- All seasonal commissioning to be checked at six months after Practical Completion.
- The contractor has re-balanced the heating system after the first seasonal change.

5.2.4 Evaluation of handover data: O&M manuals, log book, user guides for occupants

5.2.4.1 Evaluation of handover data

The soft copy of Building Manual and Building User Guide were available to Bicester Town Council after the handover meeting. However, building users have rarely used the documentation partly due to the fact that document is incomplete and difficult to read, partly because the building had been occupied for a very short period after the refurbishment.

A checklist of handover documentation is presented in Table 2. The BPE team understand that the checklist is for a new building project, and it is used to compare against what is available to the building users.

Table 2 Handover documentation checklist (up to 2 July 2014)

Name of the handover documentation	Available on site (✓)
Legal contract, project description, consultants and construction details	?
Health and safety file	x
Architectural, civil & structural, electrical and mechanical drawings	✓ soft copy
Project/building fabric specifications, structural information, risk assessments and method statements	x
Mechanical services O&M manuals	✓
Electrical services O&M manuals	✓
Ventilation system specifications	✓
Commissioning records	x
Building Logbook	x
Strategy for energy and metering	x
Building User guide	✓
Energy assessment documents	x

According to the review of handover documentation the BPE team have noticed that:

- The building manual is incomplete.
- It is unclear whether the building had a Health and Safety File and Cleaning and Maintenance guide previously. What is the plan to change the situation?
- There is no building logbook.
- There are no architectural, structural, electrical and mechanical drawings in hard copy format, however soft copies are available to building users.
- Strategy for energy and metering is not provided as this is a simple building. Only one gas and one electricity meter are installed on site.
- O&M manual provides mainly guidance on installation and operation of the electrical and mechanical services.
- There is no energy assessment document.
- There is a lack of written information about maintenance procedures.
- During the defect period, building design and contractor team are expecting direct communication with building users regarding the problems of the building.

- Although hard copies and CDs of the building O&M manuals and Health and Safety File were issued and provided to the client, the uptodate/complete version should be issued again in due course.

5.2.4.2 Evaluation of handover process by the building project team

According to the results of handover review questionnaire survey obtained by the BPE team:

- Overall the building meets users' expectations at a very good level and provides suitable facilities/environment in relation to primary purpose/function, while key stakeholders have perceived the handover process generally well (Figure 40 and Figure 41).
- The changes of design (windows/ventilation) make the building better.
- The handover process was quite satisfactory.
- Communication between building owner and designer/ contractor are vital for this project as this is a live building and occupants are working on site.
- The Facility Managers have been provided with more detailed information on existing handover documentation on-site.
- It would be key to involve all stakeholders in the handover process in order to ensure correct implementation of building management and commissioning, aftercare and maintenance procedures.

A few problems were identified through questionnaires:

- The heating system should be re-commissioned in the autumn.
- Some of the control systems were not yet installed. This limited the amount that could be covered in the handover.
- The design intent changed over the period of the project with significantly more user control being included in the scheme. This increased user control meant that a greater amount of training was necessary. However the changes of design (windows/ventilation) make the building better.
- Internal handover could have been far more refined. Changes in staff may have negative impacts on the building operation without internal handover.
- More user-friendly and better organised handover documentation could have been provided.
- Familiarisation with available handover documentation and training of FMs on how to use the provided O&M manuals could improve the building maintenance and management process.
- Graduated handover is necessary for smooth running of the building – including a programme of induction sessions.
- Delays in the delivery of insulation material did occur, however this had only a minor impact on the handover process.

Figure 40 Average ratings of handover process aspects

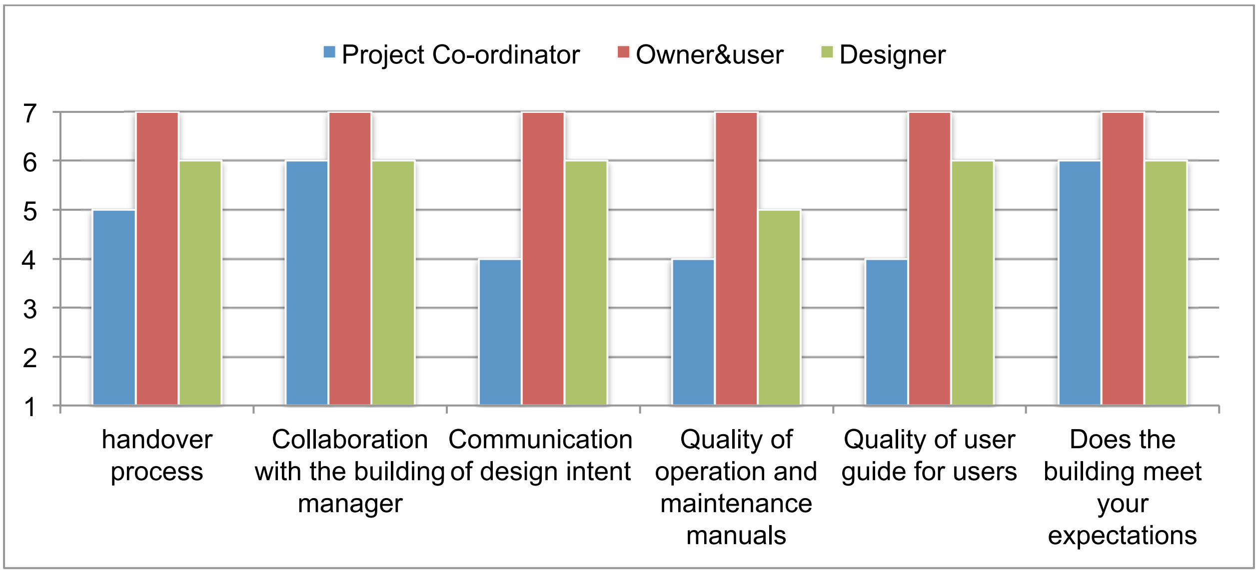


Figure 41 Rating of aspects of handover process by key stakeholders

5.2.5 Feedback/recommendations to IIR project team and wider communities

The review of handover process for Garth revealed several issues faced after the practical completion of the project. Valuable conclusions have been drawn that also form precious recommendations for future similar developments.

a. Design intent

- Effective communication is a very important element:
  - Ensure good communication between building owner and designer. It is important to build confidence in the design team. The change of design intent should be fully discussed with the building owner.
  - Ensure strong links between contractors and subcontractors have been established not only before, but also after the end of defects period.

  - Good communication between building manager and contractors is important in order to tackle any building defects quickly and effectively and receive further information on building services when required.
  - End users should also be able to communicate their perception of the building ranging from its physical layout all through suitability of systems (e.g. heating, ventilation etc.) and controls. Feedback should be provided to the building manager by users in order to improve sustainable performance of the building.

- End-user requirements should be carefully considered during design stage.
  - The building should fit for purpose and thus satisfy the end users criteria.
  - Users should be able to comment on the actual building performance and express their needs according to type of activities they undertake in the building.

b. Seasonal commissioning and aftercare

- Seasonal commissioning of building services would improve building performance and identify any under-performing controls.
- Dedicated handover on how to maintain low energy buildings should be included in the handover session.

c. Training and familiarisation of occupants

- Organising demonstrations and training in videos would be an excellent way of informing future employees and would strengthen the internal handover process.
  - Most key stakeholders agreed that video demonstrations and repeated live training is a preferred option over advising the O&M manuals only.
  - Beware technical language used during communication with building users. Users may forget or not understand the technical terms used by building professionals.
  - Videos and training handover could have acted as internal transition of information.
  - There should be an opportunity or a way where building user can actually come back to the technicians.
- Demonstrations of building systems and controls should be scheduled to take place more than once when new operators join the building management team.
  - Further emphasis should be given on ventilation strategies in both summer and winter which are the key factor determining thermal comfort and energy saving.
- Complete knowledge is an essential feature of building handover.
  - A specialist should exist among the building team that has knowledge of all systems and controls.
  - Building manager is key in running the building efficiently, therefore building manager would be desirable to demonstrate a certain level of experience in maintaining/operating similar buildings.
  - One person should be responsible in receiving an holistic training and demonstration of building services.
  - All information received though training and demonstrations should be properly documented for future reference.

d. Handover documentation

- O&M manuals

- Handover documentation should be carefully organised in order to provide the required information which should also be easy-to-find within the O&M manuals.
- Although the full set of O&M manuals is not required for refurbishment projects, it would be a good opportunity to fill the missing documents which are important to building operation, such as building log book.

- User guide is a very important part of handover documentation
  - A short overview of building systems (e.g. formed in a 2-3 paragraph statement for each system that would summarise how the system works, who designed it and who to contact in case of a problem) would simplify the interaction of users with O&M manuals.
  - User guide should be available on site to inform end users about building systems and controls. Otherwise users may not be satisfied by building performance due to lack of knowledge of how to operate it.
  - User guide is proposed to organise information for each building feature under the titles: Intent - Strategy - Residual Risks – Guidance.

In addition, during the handover review workshop the BPE team made substantial reference to BSRIA's Soft Landings framework (Figure 42) as an exemplar procedure that would ensure improved operational readiness and performance in use (UBT, 2009). The Soft Landings recommend the review of buildings' handover process as a unique opportunity to achieve a greater involvement of the whole project team - designers, constructors, operators and end users.

Therefore, a building handover should involve:

- Support in the first weeks of occupation from the building design and contractors team.
- Demonstration of operation and maintenance of controls and technologies for the building users (windows, taps, heat controls, check meters, etc.).
- Technical guidance to the facility manager and building manager in a clear, simple manner.
- Provision of handover documentation (Logbook, O&M manuals, User guides for occupants and management).
- Arrangements for aftercare, operation management and maintenance.

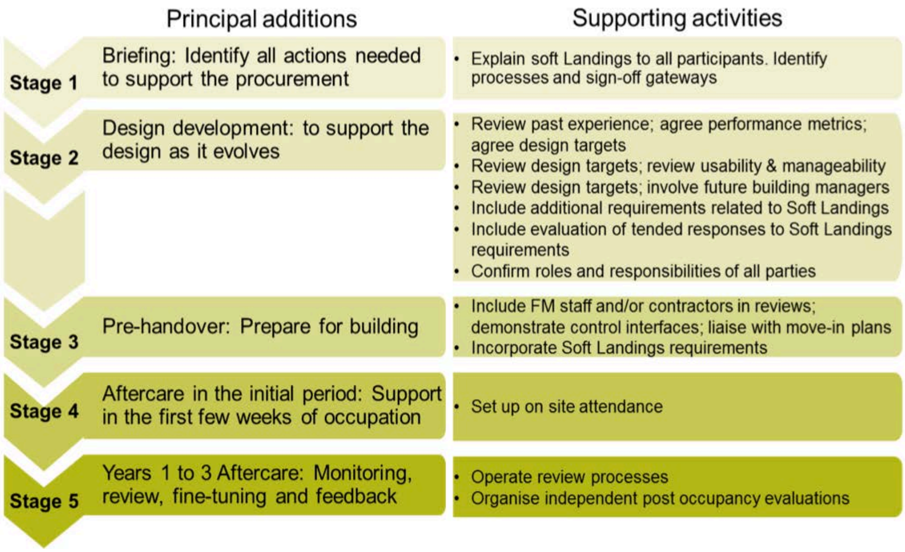


Figure 42 Diagram illustrating BSRIA Soft Landings work steps. Source: BSRIA, 2009.

Finally, following the evaluation of the available handover information, documentation and handover review workshop at the Garth building, there are a number of recommendations for future projects to ensure a successful transition from design of buildings to in-use:

- Include building or building manager in the pre-construction design meetings.
- Tailor a bespoke move-in support plan with the user and owner from the project start – including a programme of induction sessions.
- Consider Techniques: Soft Landings residency, walkthroughs, photo survey, discussions with occupants and site manager, energy logging and energy workshops.
- Make sure that facility managers and building end users attend handover sessions.
- Organise internal handover if necessary.
- Involve caretakers and facilities teams in the planning process to clarify roles and responsibilities.
- Develop a Welcome Letter to aid staff in taking ownership of the building and explain normal teething issues before inductions begin.

Messages to wider communities

- Designers have to start thinking about how small organisations work because many of historic buildings are in the hands of the individual small organisations that simply don't have the capacity and resources to have a full-time facility manager. What they have is an operation manager who has to look after everything indoor and outdoor.
- Handover should be an on-going process to allow building users to understand how to run the building.
- The estimate of maintenance costs should be given to building users, so they can start budgeting ahead for replacement and servicing costs.
- The maintenance schedule should be highlighted in the user guide.
- The principle of cutting off-site, bringing it to site and installing it was right, however the application and delivery on this project is not appropriate because of the involved additional time of cutting and cost of transportation. It will be quicker for a high-rise block that has a number of rooms with the same layout. It doesn't work in a bespoke setting. If the supplier, such as Kingspan, have the CNC machine and laser survey technology, it would be very effective way of working.

5.3 Performance of systems and controls

5.3.1 MVHR testing

This section provides an overview of the key findings relating to a site inspection of the heat recovery ventilation system (Renovent) installed at The Garth – Bicester Town Council's offices as part of the refurbishment project. This review focuses on the installation processes and commissioning procedures of the mechanical ventilation system that may have a bearing on performance. The review was completed by Four Walls Ltd on 20 May 2015 and was commissioned by Oxford Brookes University.

5.3.1.1 Ventilation observations

Air distribution valves are mounted onto the plasterboard ceiling in all ventilated areas. As Figure 43 shows, the air valves for both supply and extract were found to be 'unlocked', i.e. the nut on the metal adjusting rod was not tightened to 'lock' the commissioned valve settings. As there are no volume control dampers elsewhere on the system, the only possible adjustment to the air flow distribution will be via these valves. It is essential that these are adjusted and commissioned correctly.

Figure 43 i) top left-diffuser showing untightened locking nut. ii) top right-an example of a gasketted flange spigot. iii) bottom left-gap between duct end and ceiling. iv) bottom right-oversized cut outs in plasterboard.

The spring fixing lugs on the valve in Figure 43 i) are intended to be inserted within the duct. However, the duct finishes short of the plasterboard by approximately 1cm (Figure 43iii)). The result is that the valve is not fully engaged with the duct, and that there is significant air flow that bypasses the valve, flowing directly into the ceiling void. It should be noted that not all air valves were inspected to the degree illustrated by the Figure above.

Flanged spigots should be inserted into the aperture to 'bridge' the gap between the short duct and the ceiling. These are widely available in most commonly available duct sizes, and an example is given in Figure 43 ii), which shows a gasketted version. This type will allow an air tight seal and needs only access from below. This will need to be fixed (mechanical, or bonded) to the plasterboard ceiling. However, as Figure 43iv) shows, local ceiling repairs may be required, as these have been cut too large in some cases. Checks will need to be made to ensure the ceiling valves are compatible with the flanged spigots.

There was found to be a general mix up of ceiling valves selected for supply and extract air. In 8 out of 9 instances, supply air valves have been used on extract terminals. In 7 out of 9 instances, extract air valves have been used on supply air terminals. The Passivent drawings show the room terminals: the positions of which have broadly been followed. However, Figure 44 i), which is an extract from the Passivent drawings, shows that blue terminals are intended as supply, and red are intended as extract. Whilst the positions have been maintained, the blue is in fact extract, and red is supply. Despite this change (reason unknown), the terminal valves types have been fitted, generally in accordance with the drawing, e.g. extract terminals fitted in the right place according to drawing, although the duct is a supply duct.

Figure 44 i) top left-excerpt from Passivent drawing. Ii) top right-a supply air valve used as extract.

Figure 44 ii) shows a typical location of an extract air terminal with a supply air valve attached

There are three locations (meeting room, Council Chamber and Bioregional office) where the ceiling terminal has been fitted too close to the wall. Not only will this create a local vortex (affecting effective air distribution), it is very difficult to commission correctly, as any hood for air flow instruments cannot engage with the surrounding ceiling. Supply air devices closer than 500mm to vertical surfaces should be fitted with blanking segments inserted inside the valve to deflect air flow to the room (away from the wall). These have not been fitted.

There are two options available to correct the air flow distribution. The desired approach would be to reconfigure the supply and extract ducts serving the manifold plenums, which should be fairly straight forward (see next section). Alternatively, the room ceiling valves could be swapped over and blanking segments installed where terminal is close to a wall. This is a less favoured approach, as the locations for the supply air, as designed (i.e. diagonally opposite entrance door), is optimal, with extract being nearest the door.

The kitchen is shown to be served by the MVHR unit on the Passivent drawings, but it was observed that these had not been installed. The Bioregional office is not shown to be ventilated on the Passivent drawings, but this room is served with supply and extract terminals, connected to the MVHR unit.

The WC areas that lead off the kitchen have been fitted with intermittent extract fans, activated by an occupancy sensor. These are not shown on the drawing, but these units are not part of the Passivent design. It is not normally recommended to mix ventilation strategies, particularly when heat recovery is core to the main ventilation strategy.

5.3.1.2 MVHR unit and ductwork

The MVHR unit is located in an unoccupied area on the second floor, approximately central to the ventilated zone. The unit is a Renovent Excellent 400 unit, having a maximum air flow setting of 400 m^3/hr (110 l/s).

Figure 45 Supply and extract ducts (rigid) serving the supply (top) and extract (bottom) plenum manifolds

The installation, including ducting is of a general, good standard, and proprietary components appear to be have been used throughout. Bends on the flexible ducting, used for supply and extract distribution, employ large radii, which is good practice for minimising system resistance. The unit appears to run satisfactorily, and fan speed control (4 position switch in kitchen) functions correctly.

As discussed in the previous section, the supply and extract terminals have been installed incorrectly (compared to the design intent), which has resulted in the wrong diffusers being used and the air distribution locations being incorrect. The easiest remedy to this situation would be to swap over the supply and extract mains feeds to the supply and extract manifold.

The intake an exhaust ducts are insulated, 180mm dia flexible ducts. These run within the cold loft and terminate in roof slate ventilator tiles. The size of the intake and exhaust tiles (free area) could not be ascertained during the survey, but the measured air flows (see next section) suggest these are sufficiently sized. As the ducts pass between the cold loft and the second floor ceiling, air gaps are present, which will contribute to the overall air leakage of the building – see Figure 46 i).

Figure 46 i) Left – intake and exhaust duct – air leakage around ceiling penetrations. ii) Middle – supply and extract ducts to office accommodation below – uninsulated in cold zone and unsealed at head of riser.

Air distribution to and from rooms is via flexible, 75mm dia. plastic ducts, connected in a radial arrangement to each room via two manifold plenum units (one for extract, one for supply). It was noted that the ducting serving the Chief Officer's office were uninsulated as they passed into the cold loft and, further, that the head of the riser was not sealed, as Figure 46ii) shows.

All distribution ducting run within unheated zones (e.g. cold loft) should be insulated. Any air gaps between the heated and unheated zones (around ducting penetrations) should be sealed. As part of the swapping over of the supply and extract ducts, the connection to the top manifold should be correctly and permanently sealed.

The filter alarm was found to be on, and the condition of the filters suggested that they needed cleaning or changing. The maintenance provision for the system is unclear – no maintenance log was available.

5.3.1.3 Air flow measurements

Air flow measurements were taken at fan speeds 1 to 3, and are tabulated below (Figure 50Table 3). In the MVHR unit controller, the fan speeds are set as follows for the various fan speed settings (controller located in kitchen): 0. 50 m_3/hr, 1. 100 m^3/hr, 2. 200 m^3/hr, 3. 3000 m^3/hr

Table 3 Summary of air flow measurements

	Air distribution balance by rooms				Acutal measured figures at given fan speeds (as found)							
All figures in l/s	Design (low)		Design (high)		Speed 1		Speed 2		Speed 3		Speed 0*	
Room type	Supply	Extract	Supply	Extract	Supply	Extract	Supply	Extract	Supply	Extract	Supply	Extract
Chambers 1	N/P	N/P	N/P	N/P	2.7	1.3	5.2	3.9	7.2	6.1	N/M	N/M
Chambers 2	N/P	N/P	N/P	N/P	3.3	3.6	6.5	5.8	7.7	9.2	N/M	N/M
Chambers 3	N/P	N/P	N/P	N/P	3.6	1.2	6.5	3.7	8.9	5.8	N/M	N/M
Meeting Room	N/P	N/P	N/P	N/P	3.1	2.1	6.5	4.6	9.3	5.5	N/M	N/M
Operation Man. Office	N/P	N/P	N/P	N/P	2.8	4	6.2	7.1	8.7	10.6	N/M	N/M
Chief Officer Office	N/P	N/P	N/P	N/P	3.7	4.1	7.3	6.4	10.1	10.5	N/M	N/M
Reception	N/P	N/P	N/P	N/P	2.3	3	5.7	5.7	7.7	8.8	N/M	N/M
Records office	N/P	N/P	N/P	N/P	0.7	2.9	5.5	4.6	7.8	5.4	N/M	N/M
BioRegional Office	N/P	N/P	N/P	N/P	3.2	1.7	5.4	2.7	8.3	3.7	N/M	N/M
Totals:	0	0	0	0	25.4	23.9	54.8	44.5	75.7	65.6		
Balance deviation from supply/					-6.09		-20.75		-14.30			
Total in m³/hr	0	0	0	0	91	86	197	160	273	236		
Readinggs on Unit:												
INTAKE (m³/hr)					99		201		301		48	
EXHAUST (m3/hr)					100		200		300		74	
IMBALANCE SETTINGS (%)					0		0		0		0	
Supply Fan Pressure (Pa)					16		33		105		39	
Extract Fan Pressure (Pa)					0		0		58		2	
Bypass					22°C							
Bypass Hysteresis					2°C							
Bypass Setting					Auto							
RH Sensor					Disabled							

Design values were not available for the given fan speeds (N/P = not provided), but for offices CIBSE Guide B, 2.3.2 recommends a minimum ventilation rate of 8 l/s per person. This would suggest that, even set at speed 3, the MVHR unit would not provide all of the recommended minimum ventilation rates in the Chamber, meeting room and reception office. It was noted that the unit operated noisily (sound level measurements not taken) in fan speed 3 – according to occupants, fan speed 1 is the 'normal' setting.

The minimum recommended ventilation rate may be achieved by the opening of windows in the summer months to supplement the ventilation system, although this is not likely to happen in winter.

It is recommended that the occupants use settings 2 or 3 in winter, and that the system, when re-commissioned (required after ductwork alterations have been made), is set to higher air flow rates for these two settings. It is acknowledged that a balance needs to be struck between system noise and ventilation rates.

System balance is reasonable in speed setting 1 (<10%), but is out of balance in higher settings. The system has an intelligent controller to allow an imbalance (set electronically). This was found to be set at 0%. In practice this needs to be adjusted to account for slight difference in resistance between the supply and extract ducts. This should be addressed during re-commissioning. It was noted that the RH sensor has been disabled, perhaps intentionally. Given the simplicity of the controls, it may be worth enabling this sensor such that the system boosts during higher humidity conditions.

5.3.2 Review of the performance and usability of controls

5.3.2.1 Review of design intentions for controls - heating, ventilation, lighting

A review of design intentions for controls was conducted by reviewing the User Guide and O&M Manuals provided after the refurbishment. According to the User Guide, the building's response to heating and cooling was expected to change after the refurbishment and good occupant control would be of significant importance in order to achieve comfortable conditions throughout the year. The Guide provides useful information regarding the design intentions for some of the new controls and their location (Figure 47). The O&M manual contains useful information regarding the use and installation of all the new controls.

Space heating and hot water

The building is heated by a gas boiler and radiators. The existing gas boiler was retained and a new control system was installed. According to the User Guide, heating can be controlled through the boiler's thermostat and timer and space temperatures can be controlled using the radiator valves (TRVs). An additional EvoHome smart control system allows for the Council Chamber to be controlled remotely from a control panel in the kitchen or from a laptop or smart phone.

According to the Project Initiation Document the building was required to be as eco-friendly as possible using renewable energy sources where applicable. Additionally the design and detailing of the building (including controls interfaces) should mitigate the impacts of vandalism. The Building Performance Specification document states that the (heating and hot water) control panel system shall have a user-friendly interface with clear and straightforward operational procedures indicated.

Ventilation

During winter the new secondary glazing is closed to keep the building warm and draft proof. To ensure fresh air is supplied to the offices a mechanical ventilation system with heat recovery (MVHR) has been installed. This system extracts the warm stale air from the rooms, and supplies pre-warmed fresh air through vents in the ceiling.

During summer occupants are advised to keep the windows open to remove hot air and prevent the building from overheating. The original windows were refurbished to make them easier to open. To promote cross ventilation circular vents have been inserted through the main reception office and adjoining office walls. When the windows are open in both the corridor and office, cool air can cross the width of the building. The Council Chambers are cooled by automatic louvres and roof-lights that open when the temperature rises beyond a certain point. This can be manually overridden when required. During the mild and warm months ventilation is provided by opening the windows.

Figure 47 Location of controls (Source: User Guide)

5.3.2.2 Forensic survey for assessing performance and usability of controls

A forensic survey for assessing the performance and usability of the controls in The Garth was conducted on 10 November 2014. Key findings are:

- The space heating control strategy is confusing as there are several controls installed in the building and the override strategy is not clear: the Honeywell thermostat on the first floor, the old thermostat on the ground floor and the boiler control panel.

- Occupants do not find the touch screen Honeywell thermostat intuitive and are not able to control the temperatures effectively. There is not a good indication of system response and the users are not sure whether the control is actually connected to the boiler. The fact that the old thermostat control has not been removed after the refurbishment creates further confusion and occupants are not sure whether this control is still in operation.
- The degree of fine control provided by the Honeywell thermostat is good but the building is not zoned so one temperature setting applies for all spaces.
- The individual radiator valves in the first floor offices are easy and intuitive to use. The wireless Honeywell radiator valves that had been placed on the ground floor radiators were recently removed but have not yet been replaced by another type of valve, thus limiting control in these spaces.
- The electric panel is well labelled but the labelling of the electricity meters does not provide information as to which part of the building they correspond.
- The number of electrical sockets might not be sufficient for the needs of the building as highlighted by the presence of several plug extensions throughout the building.
- The presence of some old plugs that are no longer in use creates confusion to the occupants as they are not aware of their purpose.
- The control interfaces of the smoke and security alarms are both easily accessible but not intuitive and guidance is needed in order to operate them.
- In two of the toilets the hot water tap is not operable but no indication is provided creating some confusion to new users. Instead, hot water is provided via an additional electrical water heater.
- The new double glazing casement windows that were fitted after the refurbishment are easy to use and fully openable allowing good access to the original single glazing sash windows. The casement windows open towards the inside and in some rooms opening is prevented by furniture placed in front of them.
- Electrically controlled windows, such as roof lights and conservatory windows are easy to operate but are not visible from the position of their respective control interface thus limiting good control.
- Some of the traditional shutters are still operable but are not being used for additional night insulation.
- The MVHR unit is easily accessible and is easy to operate. However, the control is not intuitive and a simple User Guide would be useful.
- The MVHR boost is located in the kitchen but its purpose is not clear and there is no indication of system response. The grilles are not locked in fixed positions. This could potentially undermine the system balance.

Heating and hot water controls

The gas boiler is located in the women's toilet on the first floor but the thermostat is located in one of the offices The boiler control is not intuitive as the control strategy and override settings are not clear. Instructions placed on the boiler aim to prevent users from changing the boiler settings. Occupants do not find the touch screen Honeywell thermostat intuitive and are not able to control the temperatures effectively. There is not a good indication of system response and the users are not sure whether the control is actually connected to the boiler. In addition, the fact that the old thermostat control has not been removed after the refurbishment creates further confusion. The degree of fine control provided by the Honeywell thermostat is good but the building is not zoned so one temperature setting applies for all spaces. The individual radiator valves in the first floor offices are easy and intuitive to use. The wireless Honeywell radiator valves that had been placed on the ground floor radiators were recently removed but have not yet been replaced by another type of valve, thus limiting the degree of fine control in these spaces.

Boiler Control

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

Comments

The boiler is located in the women's toilet and is accessible by all staff and even visitors. Instructions provided aim to prevent users from using the boiler control and point out that space heating should be controlled by a touch screen located in a different part of the building. A smaller control connected to the boiler is located on the wall but is not labelled and its purpose is not clear. Overall, the boiler control is not intuitive as the control strategy and override settings are not clear.

Heating Control Panel / Thermostat (New)

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

Comments

The panel was originally placed in the kitchen (as shown in the User Guide), but the wi-fi signal in there was weak and the panel was moved to the chief officer's room. As a result, it is not easily accessible by staff members when the office is closed. The control was positioned close to a radiator, possibly affecting the thermostat sensor. The screen provides useful labelling and is easy to use. The users, however, do not find it intuitive and were not able to use the control effectively. Also, as there is not a good indication of system response, the users are not sure whether the control is actually connected to the boiler. Issues with the wi-fi connection were reported undermining the reliability of the control. Furthermore, the fact that the old thermostat control has not been removed after the refurbishment creates further complications.

The control allows for different setting on a daily and weekly basis but does not provide any zoning.

Heating Control Panel / Thermostat (Old)

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

Comments

The old thermostat has not been removed after the refurbishment and is located in the ground floor entrance, easily accessible by staff and visitors alike. This creates confusion as it is not clear whether this control is still in operation. Occupants were told that the control has been disconnected but it still appears to be calling for heat. The system provides good degree of fine control with six different settings for every day of the week but is not intuitive to use.

Radiator valves

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

Comments

The radiator valves in the first floor offices are easy and intuitive to use. The scale is from 0 to V and provides good degree of fine control. Most valves were found to be set at III.

Wireless radiator valves: EvoHome smart control system

Criteria	Poor				Excellent
Clarity of purpose		■			
Intuitive switching		■			
Usefulness of labelling		■			
Ease of use				■	
Indication of system response	■				
Degree of fine control					■
Accessibility					■

Comments

Wireless Honeywell radiator valves had been installed in the ground floor but were subsequently removed as they were not properly connected to the EvoHome smart control system. The valves have not been replaced yet, thus limiting the option of automated control in the ground floor rooms. The controls did not seem intuitive to use.

Gas meter

Criteria	Poor				Excellent
Clarity of purpose				■	
Intuitive switching					
Usefulness of labelling				■	
Ease of use					
Indication of system response					
Degree of fine control					
Accessibility					■

Comments

The gas meter is located outside the building, next to the main entrance and is easily accessible.

Windows and doors

The new double glazing casement windows that were fitted after the refurbishment are easy to use and fully openable allowing good access to the original single glazing sash windows. One issue that was identified was that, contrary to a sash window, the casement windows require some space in order to be opened and in some rooms this is prevented by furniture placed in front of them. However, when fully opened they do not take up any space. Hinges are provided on the walls to secure the window in an open position. Electrically controlled windows such as rooflights and conservatory windows are easy to operate but are not visible from the position of the control interface thus limiting good control. Doors are easy to use and some of them are fitted with an equally easy to use stopper. Some of the traditional shutters are still operable but are not being used for additional night insulation. Interview with the occupants would be helpful for gaining a better understanding of the daily and seasonal use of windows.

Main entrance

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

Comments

There are three locks and their purpose is not clear. The door is easy to open and close.

Internal doors

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

Comments

The internal doors are easy to operate. Door stoppers are also easy to operate and well labelled allowing for good fine control. Not all doors have fitted door stoppers and some occupants use small wood stoppers.

Ground floor entrance windows

Clarity of purpose					[dark green]
Intuitive switching				[light green]	
Usefulness of labelling					
Ease of use	[red]				
Indication of system response					
Degree of fine control			[yellow]		
Accessibility					[dark green]

Comments

The reviewer could not open the window in the ground floor entrance. The window, even though easily accessible, is not easy to operate. This could create problems in the ventilation of the space especially during the summer months.

Ceremony room windows

Criteria	Poor				Excellent
Clarity of purpose					■
Intuitive switching				■	
Usefulness of labelling					
Ease of use	■				
Indication of system response					
Degree of fine control			■		
Accessibility			■		

Comments

The windows in the ceremony rooms are often blocked by the furniture of the space and cannot be opened.

First floor rear office windows

Criteria	Poor				Excellent
Clarity of purpose					■
Intuitive switching				■	
Usefulness of labelling					
Ease of use		■			
Indication of system response					
Degree of fine control			■		
Accessibility				■	

Comments

The new windows are easy to operate but as they open towards the inside they take up much of the useful space when semi-opened. They allow good access to the old sash window. As a result of the design of the new windows, the openable area has not been reduced allowing for good ventilation of the offices.

First floor corridor windows

Criteria	Poor				Excellent
Clarity of purpose					■
Intuitive switching				■	
Usefulness of labelling					
Ease of use			■		
Indication of system response					
Degree of fine control			■		
Accessibility				■	

Comments

The windows in the corridor are quite large. Despite this, they can be fully opened without taking up any of the corridor space. Good access to the sash window.

First floor front office - bay windows

Criteria	Poor				Excellent
Clarity of purpose					Dark green
Intuitive switching				Green	
Usefulness of labelling					
Ease of use	Red				
Indication of system response					
Degree of fine control		Orange			
Accessibility	Red				

Comments

The opening of the window is blocked by the furniture. The depth of the bay window makes it difficult to reach the old sash window.

Conservatory electric windows

Criteria	Poor				Excellent
Clarity of purpose	Red				
Intuitive switching			Yellow		
Usefulness of labelling		Orange			
Ease of use				Green	
Indication of system response	Red				
Degree of fine control			Yellow		
Accessibility				Green	

Comments

The control is located in the ceremony room and its purpose is not clear The electric windows are not visible from the position of the control. Despite this the control is intuitive.

Rooflights

Criteria	Poor				Excellent
Clarity of purpose			Yellow		
Intuitive switching				Green	
Usefulness of labelling			Yellow		
Ease of use				Green	
Indication of system response			Yellow		
Degree of fine control			Yellow		
Accessibility					Dark green

Comments

The control is located in the ceremony room, is easy to operate. The purpose of the control is not very clear. Indication of system response is achieved by the sound of the windows opening, but the windows are not visible from the position of the control.

Shutters

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

Comments

The original shutters of the sash windows are still operable in some of the windows on the ground floor, but are not being used by the occupants. Night shutters could help prevent heat loss to the outside by increasing the insulation of the windows. The shutters are easy to operate and do not take up any space when folded.

Ventilation controls

Ventilation is provided through Mechanical Ventilation with Heat Recovery (MVHR). The MVHR unit is easily accessible on the second floor and is easy to operate. However, the control is not intuitive and a simple User Guide would be useful. The MVHR boost is located in the kitchen but its purpose is not clear and there is no indication of system response. The supply and extract grilles located in the offices are placed in the corners of the rooms and do not seem to undermine the use of the spaces. The Passivent system located in the ceremony room can be easily controlled by a simple interface.

MVHR unit

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

Comments

The MVHR unit is located in a spacious cupboard on the second floor and is easily accessible. The control is easy to operate but is not intuitive. Users need guidance in order to operate the unit. A technical manual is located next to the unit but a simplified user guide would be more useful.

MVHR boost

Criteria	Poor				Excellent
Clarity of purpose	■				
Intuitive switching				■	
Usefulness of labelling		■			
Ease of use					■
Indication of system response	■				
Degree of fine control			■		
Accessibility				■	

Comments

The MVHR boost is located in the kitchen next to the door. Its purpose is not clear as there is no labelling. No indication of system response. There are no MVHR grilles in the kitchen.

Supply/Extract grilles

Criteria	Poor				Excellent
Clarity of purpose			■		
Intuitive switching					
Usefulness of labelling					
Ease of use				■	
Indication of system response		■			
Degree of fine control				■	
Accessibility					■

Comments

There is an MVHR supply and extract grille in each of the office rooms. The position of the grilles is good, not directly above desks. It is not clear which is the supply and which is the extract. The grilles are not locked in fixed positions.

Passivent control

Criteria	Poor				Excellent
Clarity of purpose			■		
Intuitive switching				■	
Usefulness of labelling				■	
Ease of use					■
Indication of system response				■	
Degree of fine control			■		
Accessibility				■	

Comments

This control is located in the ground floor ceremony room and is easily accessible. It is well labelled and easy to use. System response is determined by the noise generated by the ventilation system.

5.4 Technical review of building and equipment performance

5.4.1 Site survey to identify energy wastage

A site survey was undertaken to identify any areas of potential energy wastage. The occupants have certain awareness of their energy use and take great care in ensuring lights and electrical appliances are switched off when no one is in the room. Plain light bulbs are used in some spaces. Replacing them with Compact Fluorescent lamps (CFLs) or light emitting Diodes (LEDs) could save about £3 per year per bulb.

The key equipment energy consumption was established through a walkthrough inside the Garth building in order to spot and measure the energy consumption of the different equipment and devices. The data analysis was done using one of the aspects of CIBSE TM22 v2.17 (Figure 48).

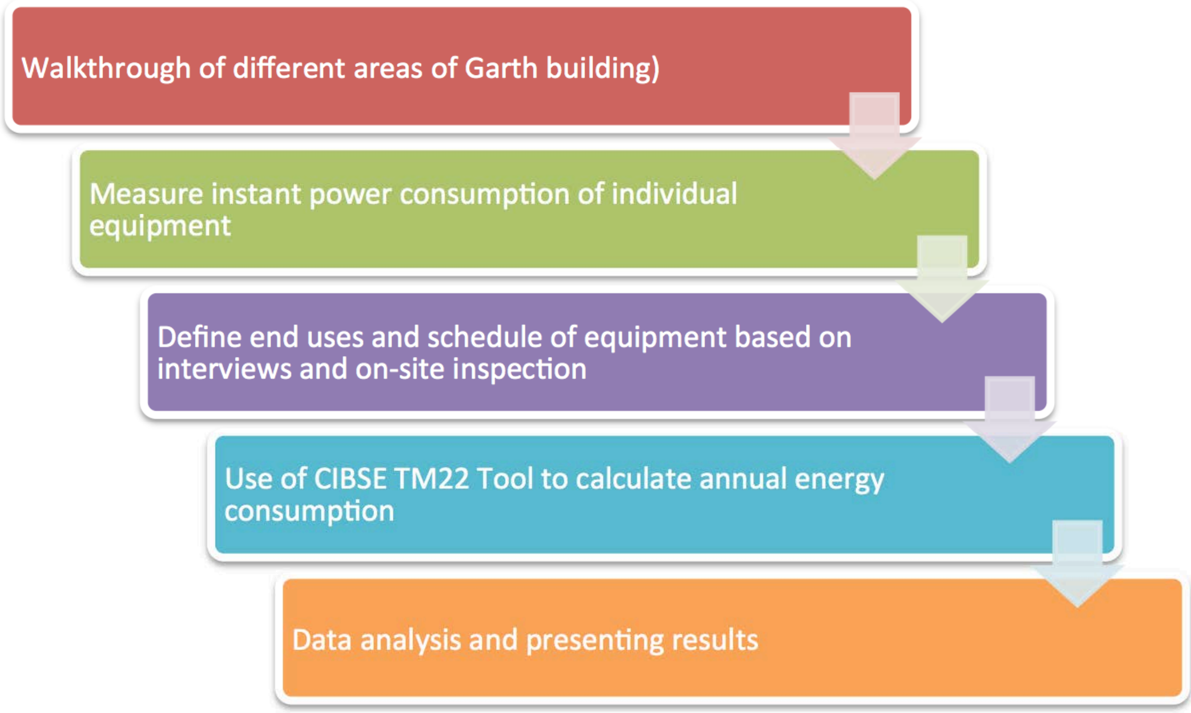


Figure 48 Calculation of key equipment energy consumption schematic

5.4.2 Measure key equipment energy consumption using true power meters

A list of equipment energy consumption was compiled with on-site observations noted during the walkthrough. The power rating of running appliances was measured using a portable true power meter. The operation schedule of each device was defined and the data were entered in the CIBSE TM22 v2.17 tool. Note that it was not possible to measure the true power rate of some appliances due to its usage, such as internet server, CCTV system (

Figure 49) and UPS (Figure 50).

The calculation of equivalent full load hours (Table 4) is calculated for each season as follows: Equivalent full load hours = Seasonal hours available (from profile) x Usage Factor x

Load Factor x Seasonal usage factor. The equivalent full load hours for each of the three seasons are then added together to determine the annual total.

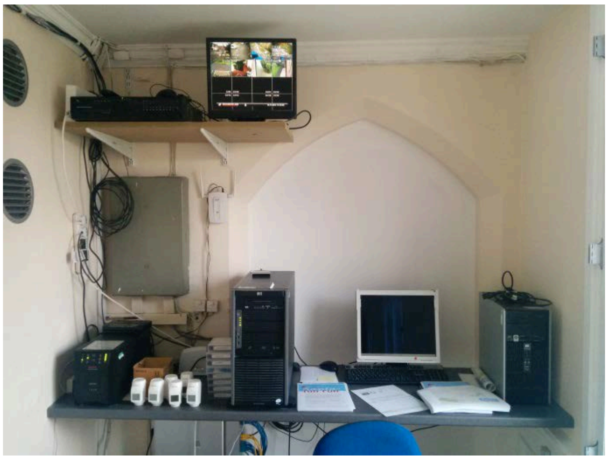


Figure 49 CCTV System

Figure 50 APC Smart-UPS Table 4 Calculation of annual energy consumption for small power equipment using CIBSE TM22 tool

Location	Item description	end use category	y consumption kWh/y	Select Profile	plate rating - kW per	Load Factor	lent full load
F09	CCTV monitoring PC	ICT Equipment	700.8	24h flat 100%	0.1	0.8	7008
F09	router	ICT Equipment	262.8	24h flat 100%	0.01	1	8760
F09	tape recorder	ICT Equipment	788.4	24h flat 100%	0.09	1	8760
F09	UPS	ICT Equipment	1760.8	24h flat 100%	0.67	0.3	2628
F09	light	Lighting (Internal)	205.9	Monday - Friday 9 to 5	0.035	1	1961
F10	laptop	ICT Equipment	50.1	Monday - Friday 9 to 5	0.03	0.8	1669
F10	light	Lighting (Internal)	137.2	Monday - Friday 9 to 5	0.035	1	1961
F10	heater	Space Heating	625.7	Monday - Friday 9 to 5	2	1	313
F11	light	Lighting (Internal)	68.6	Monday - Friday 9 to 5	0.035	1	1961

Location	Item description	end use category	y consu mption kWh/y	Select Profile	plate rating - kW per	Load Factor	lent full load
F12	fax	ICT Equipment	438.0	Monday - Friday 9 to 5	0.7	0.1	209
F12	PC	ICT Equipment	333.7	Monday - Friday 9 to 5	0.1	0.8	1669
F12	printer epson	ICT Equipment	18.4	Monday - Friday 9 to 5	0.022	0.2	417
F12	light	Lighting (Internal)	274.5	Monday - Friday 9 to 5	0.035	1	1961
F12	shredder	Small Power	198.1	Monday - Friday 9 to 5	1.9	0.5	104
F13	PC	ICT Equipment	667.4	Monday - Friday 9 to 5	0.1	0.8	1669
F13	light	Lighting (Internal)	274.5	Monday - Friday 9 to 5	0.035	1	1961
F14	light	Lighting (Internal)	68.6	Monday - Friday 9 to 5	0.035	1	1961
F15	fridge	Cooled Storage	876.0	24h flat 100%	0.25	0.4	3504
F15	hot/cold water	Hot water	700.8	24h flat 100%	0.1	0.8	7008
F15	dish washer	Small Power	449.5	Monday - Friday 3 to 4	4.31	0.8	104
F15	kettle	Small Power	1470.4	Monday - Friday 12 to 2	3	1	245
F15	microwave	Small Power	208.6	Monday - Friday 12 to 2	0.8	1	261
F15	toaster	Small Power	521.4	Monday - Friday 12 to 2	1	1	261
F16	1st floor water heater	Hot water	104.3	Monday - Friday 9 to 5	0.5	0.1	209
F19	PC	ICT Equipment	166.9	Monday - Friday 9 to 5	0.1	0.8	1669
F19	light	Lighting (Internal)	137.2	Monday - Friday 9 to 5	0.035	1	1961
F20	PC	ICT Equipment	166.9	Monday - Friday 9 to 5	0.1	0.8	1669
F20	printer epson	ICT Equipment	9.2	Monday - Friday 9 to 5	0.022	0.2	417
F20	light	Lighting (Internal)	137.2	Monday - Friday 9 to 5	0.035	1	1961
F21	printer	ICT Equipment	1251.4	Monday - Friday 9 to 5	1.5	0.4	834
F21	router	ICT Equipment	70.1	24h flat 100%	0.008	1	8760
F21	switchboard	ICT Equipment	57.8	24h flat 100%	0.0066	1	8760
F21	light	Lighting (Internal)	411.7	Monday - Friday 9 to 5	0.035	1	1961
F21	heater	Space Heating	625.7	Monday - Friday 9 to 5	2	1	313
G25	Grd floor water heater	Hot water	260.7	Monday - Friday 11 to 3	2.5	0.1	104
G25	hot/cold water	Hot water	700.8	24h flat 100%	0.1	0.8	7008
G25	light	Lighting (Internal)	651.5	Monday - Friday 11 to 3	0.035	1	886
S15	MVHR	Fans	87.6	24h flat 100%	0.01	1	8760
External	External lighting	Lighting (External)	986.0	INV 7 day 12h shift	0.3	0.5	1643

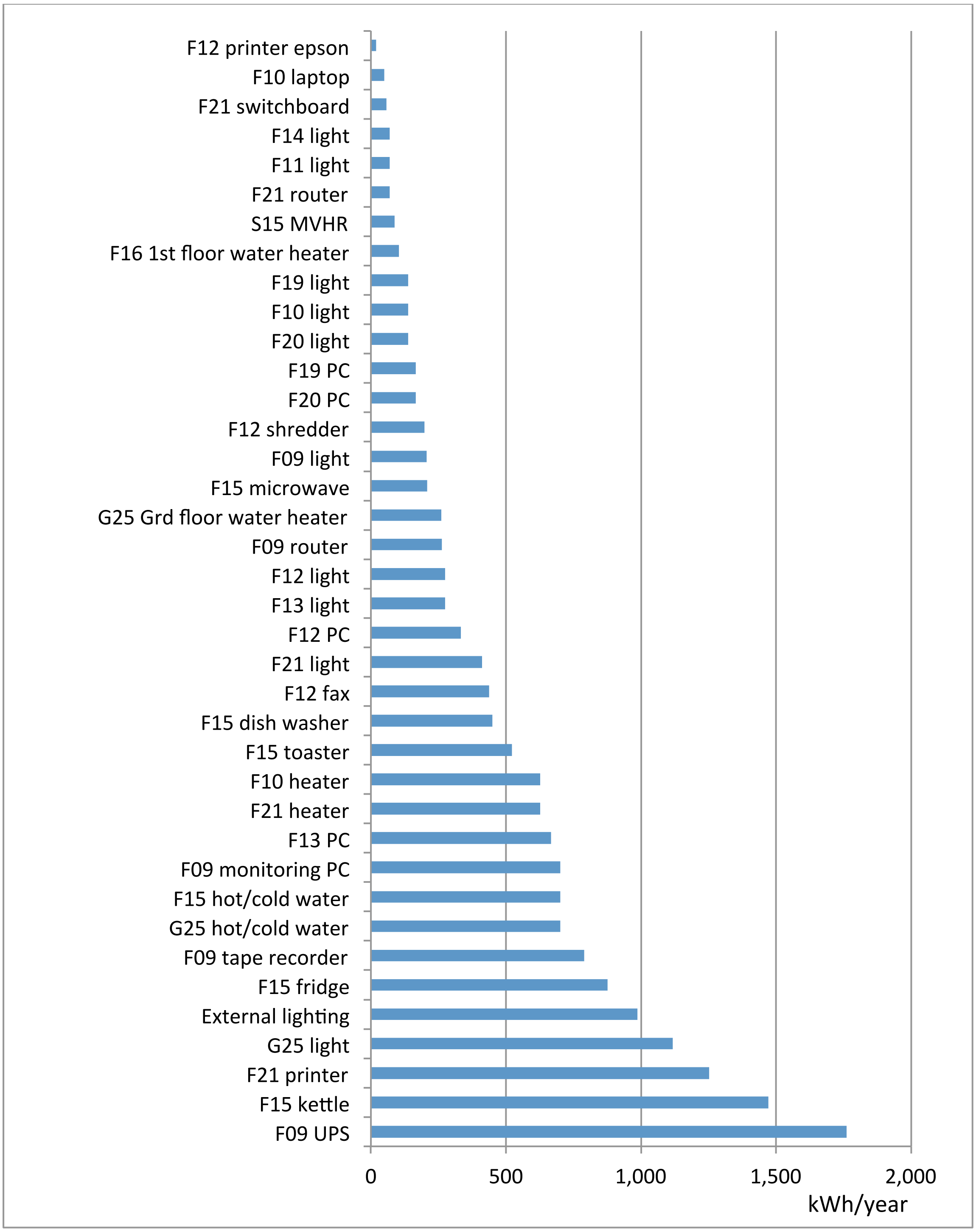


Figure 51 Appliances annual energy consumption breakdown (kWh/year)

The annual energy consumption breakdown of the appliances showed that the UPS, kettles, printers and fridges consume the largest amounts of electricity. It is to be noted that due to lack of measured data it is assumed that the UPS has power rate of 670 W with 0.3 load factor. Other kitchen and office appliances such as PCs, fax, dish washer, toaster, electricity hot water heaters, cold/hot water machines were found to consume reasonable amount of energy in range of 400 - 700 kWh annually. MVHR unit, Wireless router, EPSON printers in F20 and F21 consume less than 100 kWh of electricity annually.

The ICT equipment consumes 40% of total electricity in the building. Small power equipment and lighting consume 17% and 14% of the electricity respectively (Figure 52).

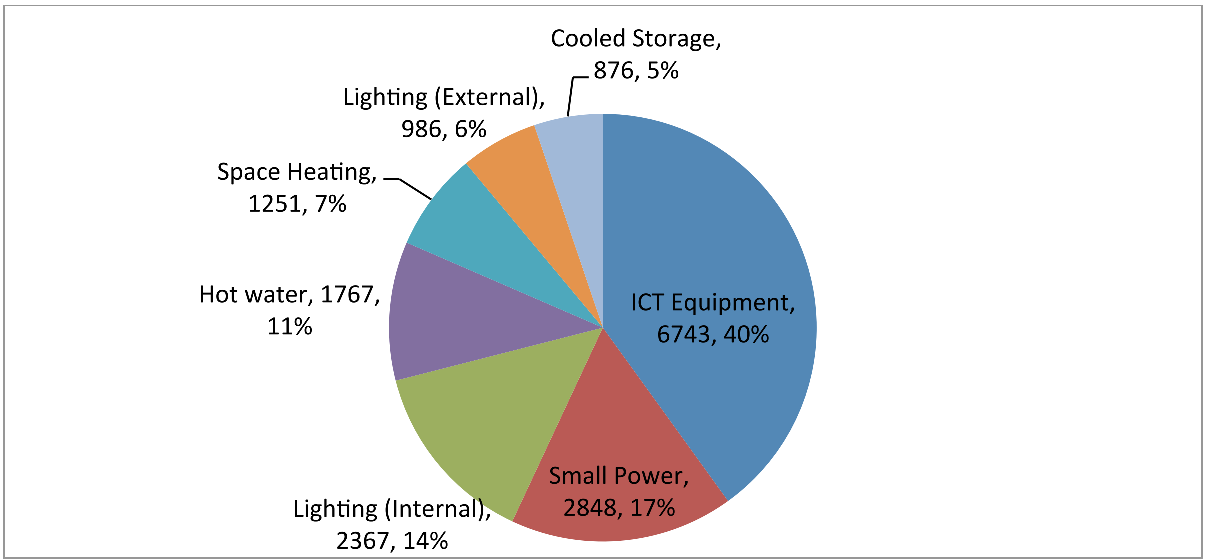


Figure 52 Annual electricity consumption distribution by end use category

The annual electricity consumption at each room is shown in Figure 53. Kitchen (F15) and east corridor (F09) consume 25% and 22% of the total electricity respectively. This is mainly due to small appliances in the kitchen and the CCTV system in east corridor.

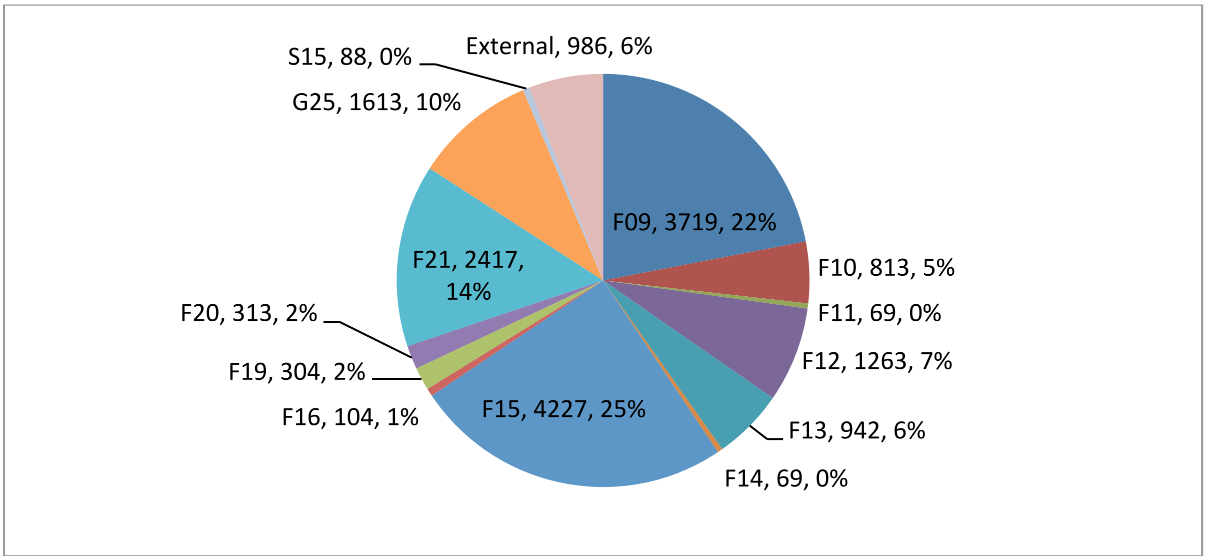


Figure 53 Appliances annual electricity consumption distribution by location

- The UPS, kettles, printers and fridges consume the largest amounts of electricity.
- The ICT equipment consumes 40% of total electricity in the building. This shows how ICT equipment is becoming a key end use of energy in sustainable buildings.
- Small power equipment and lighting consume 17% and 14% of the electricity respectively.

- Kitchen (F15) and east corridor (F09) consume 25% and 22% of the total electricity respectively. This is mainly due to small appliance in kitchen and CCTV system in east corridor.
- Some building spaces are illuminated by traditional light bulb. Replacing a traditional light bulb with Compact Fluorescent lamps (CFLs) or light emitting Diodes (LEDs) could save its electricity consumption.

5.5 IES Modelling and prediction of performance

5.5.1 Summary of the predicted energy savings of the proposed technology

Full details of the energy and carbon reductions achieved by all refurbishment measures are described in this section. Two IES energy models of The Garth building were developed to calculate the energy consumption of the refurbishment measures. Model A was developed before the refurbishment, to estimate the saving potential of the measures and Model B was developed after the refurbishment and was re-calibrated against actual monitoring data. The calibration of Model B against monitoring data from before and after the refurbishment is shown in Table 5.

Table 5 Calibration of IES model B against actual data

	Estimated Gas use (kWh)	Estimated Electricity use (kWh)	Actual gas use (kWh)	Actual Elec use (kWh)	Deviation of Gas use(%)	Deviation of Elec use (%)
S1_Base Case /Before refurbishment	64,331	17,217	64,223	16,981	0.2	1.4
S9_Final Case /After refurbishment	21,191	13,700	21,165	13,222	0.1	3.6
Total Reduction(kWh)	**43,140**	**3,517**	**43,058**	**3,759**		
Reduction (%)	**67**	**20**	**67**	**22**		

All modelling and calculation assumptions are shown in Appendix 3.1. The internal wall insulation improved the U Value of the walls to 0.28W/m^{2}K from the 2.0W/m^{2}K and the glazing U Values improved from 5.6W/m^{2}K to 1.8W/m^{2}K. These changes, along with the reduction of infiltration levels, helped in reducing the heat loss through the fabric and improve the building airtightness.

The energy reductions predicted by Model B are shown in Table 6. The methodology followed to calculate these savings is explained in Appendix 3.1. This table shows the energy consumption, CO_2 emissions per square metre and the annual fuel costs (Model B)

Table 6 Energy use, CO2 emissions and annual fuel costs (Model B)

	Annual Energy per m^2				**Annual CO2 emissions per m^2**				**Fuel Cost**	
	Gas kWh/m2	Electricity kWh/m2	Total kWh.m2	Reduction (%)	Gas kgCO2/m2	Electricity kgCO2/m2	Total kgCO2/m2	Reduction (%)	Total (£)	Saving (%)
S0_No Roof Insulation	183.3	45.5	228.8		33.6	23.9	57.5		1498	
S1_Base Case	170.0	45.5	215.5		31.2	23.9	55.1		1437	

S2_Airtightness	147.2	45.5	192.7	**11**	27.0	23.9	50.9	**7**	1332	**7**
S3_Insulation of external wall	100.1	45.0	145.2	**33**	18.4	23.6	42.0	**23**	1109	**23**
S4_Insulation of internal wall	97.5	44.8	142.4	**34**	17.9	23.5	41.4	**24**	1094	**24**
S5_Floor insulation	75.1	44.8	119.9	**44**	13.8	23.5	37.3	**32**	991	**31**
S6_Secondary Glazing	61.3	44.8	106.1	**51**	11.2	23.5	34.8	**36**	928	**35**
S7_Thermostat settings	55.8	44.8	100.7	**53**	10.2	23.5	33.8	**38**	903	**37**
S8_MVHR	54.7	44.8	99.6	**54**	10.0	23.5	33.6	**39**	898	**38**
S9_No Heaters (Final Case)	56.0	35.0	91.0	**58**	10.3	18.4	28.6	**48**	762	**47**

Note that CO_2 emission conversion factors are based on DEFRA values published in August 2011 (Electricity: 0.5246 $kgCO_2/kWh$, Gas: 0.1836 $kgCO_2/kWh$). The costs are based on flat rate of 4.6 p/kWh for gas and 14.4 p/kWh for electricity.

The results from Model B indicate that improved airtightness achieves 11% energy saving and 7% CO_2 emissions reduction from Base Case, insulation of external walls achieves a further 22% energy saving and 16% carbon saving, floor insulation achieves a further 33% reduction in energy and 24% carbon saving. **Model B shows that the package with all the refurbishment measures achieves a 58% energy saving and a 48% carbon savings.** Model A prediction was similar, as the energy savings were also estimated at 58%, and carbon savings were estimated at 37% (See Section 3.5). This discrepancy in carbon emissions is due to the fact that in Model A, the effect of the reduction of use of electric heaters and fans had not been taken into account. As documented through the BPE study, the use of electric heaters and fans was greatly reduced after the refurbishment, thus positively affecting the carbon footprint of the building. Estimates from both IES models match the actual 58% reduction calculated from the monitoring data (See Section 5.6.1).

Table 7 shows a breakdown of the energy use and reductions for gas and electricity, for each of the refurbishment measures and strategies.

Table 7 Energy consumption (kWh)and reduction achieved through each scenario (Model B)

	Estimated Gas use (kWh)	Reduction in Gas use	Reduction in Gas use (%)	Estimated Elec use (kWh)	Reduction in Elec use	Reduction in Elec use (%)
S0_No Roof Insulation	69,351			17,217		
S1_Base Case	**64,331**	5,020		**17,217**	-	-
S2_Airtightness	55,691	8,640	13	17,217	-	-
S3_Insulation of external wall	37,893	26,438	41	17,032	185	1.1
S4_Insulation of internal wall	36,900	27,431	43	16,971	246	1.4
S5_Floor insulation	28,409	35,922	56	16,971	-	-
S6_Secondary Glazing	23,184	41,147	64	16,971	-	-

S7_Thermostat settings	21,118	43,213	67	16,971	-	-
S8_MVHR	20,707	43,624	68	16,971	-	-
S9_No Heaters (Final Case)	**21,191**	43,140	**67**	**13,700**	3,517	**20**
Total Reduction (From S1 to S9)		**43,140**			**3,517**	

5.6 Monitoring data analysis

5.6.1 Energy data

5.6.1.1 TM22 Assessment and benchmarking

The following simple assessment of energy usage in Garth building covers the period from 26 February 2013 to 12 February 2014 (351 day). The period provides the closest estimation of annual energy usage of Garth building before refurbishment. Grid electricity and gas are supplied to the Garth building. The annual electricity consumption from 26 February 2013 to 12 February 2014 was 16,981 kWh (51.3 kWh/m^2/year) which equates to carbon dioxide emissions of 22.8 kg CO_2/m^2/year. The annual gas consumption is 64,223 kWh (194.0 kWh/m^2/year) which equates to carbon dioxide emissions of 35.7 kg CO_2/m^2/year (Figure 54). Gas comprised 79% of total energy consumption and 61% of carbon emissions.

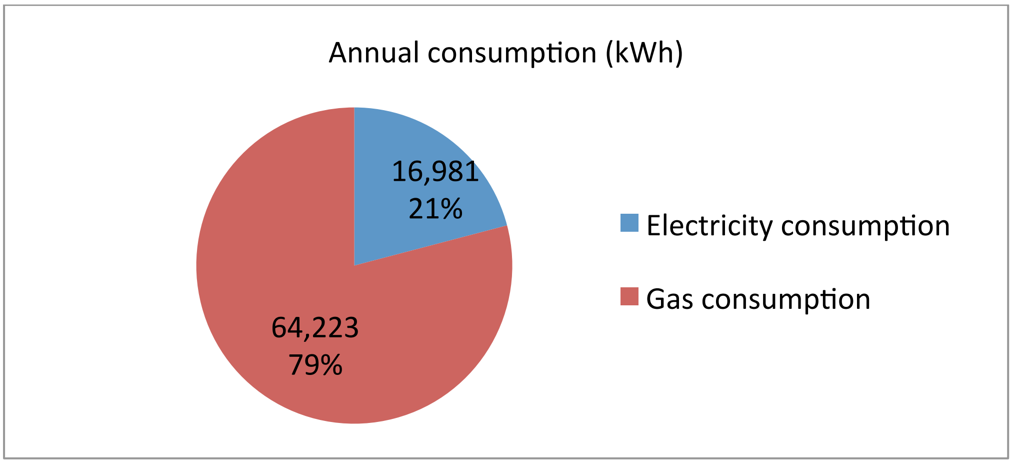


Figure 54 Annual energy consumption of Garth building (annualized from the meter readings on 26 February 2013 and 12 February 2014)

Garth buildings' annual energy usage per square metre and carbon dioxide emissions during the monitoring period (a year from 26 February 2013) are compared with ISO 12 ECON 19 Good practice, typical benchmark and TM46 in Figure 55 and Figure 56. The supplied energy in Garth building is 14% more than the TM46 benchmark, 48% more than ISO 12 ECON 19 typical benchmark, 2.7 times of ISO 12 ECON 19 Good practice benchmark. The overall carbon emission of Garth building is 11% less than the TM46 benchmark, 4.5% more than ISO 12 ECON 19 typical benchmark, 84% more than ISO 12 ECON 19 Good practice benchmark. The carbon factor for electricity is 0.445, and the factor for gas is 0.184. (Carbon Trust).

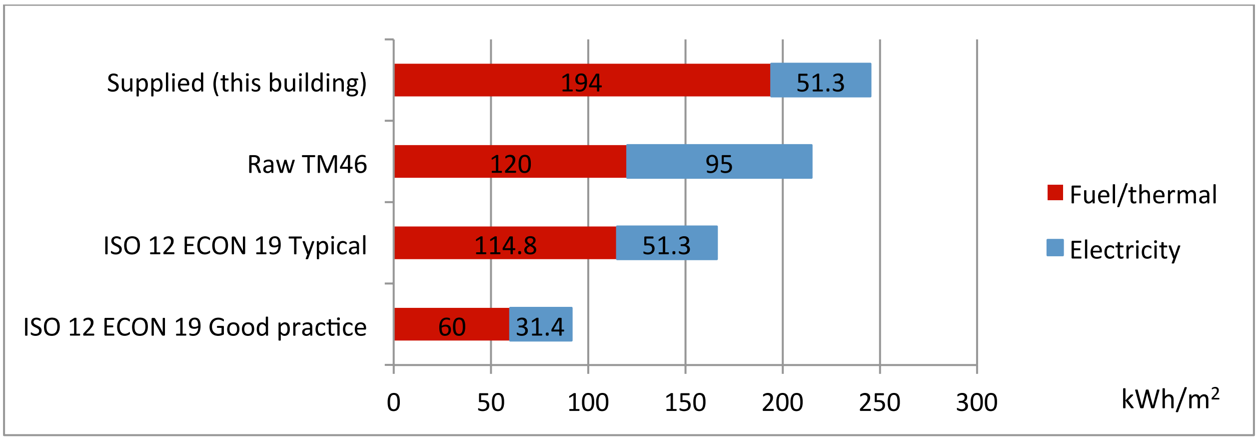


Figure 55 Energy supplies and comparisons with energy benchmarks

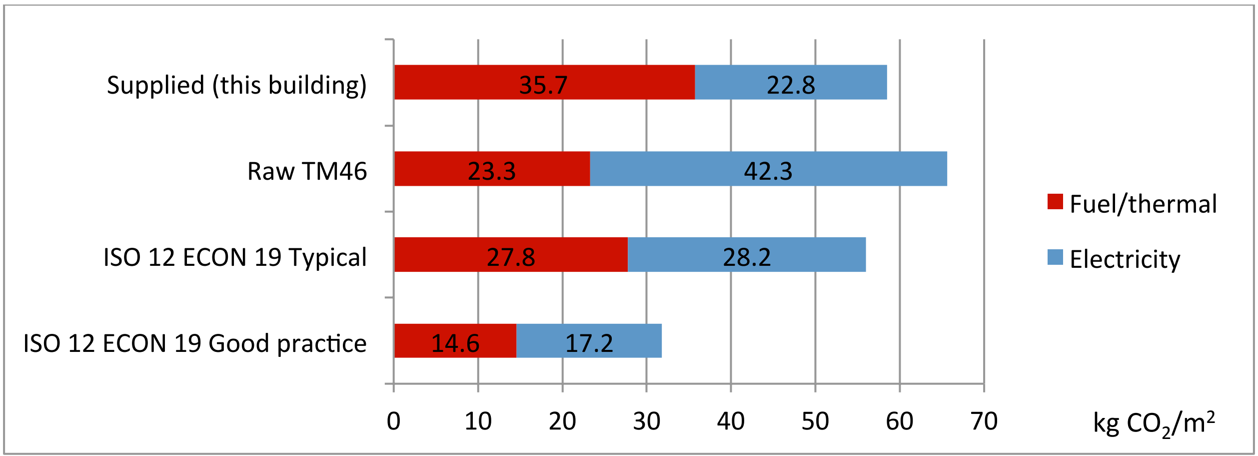
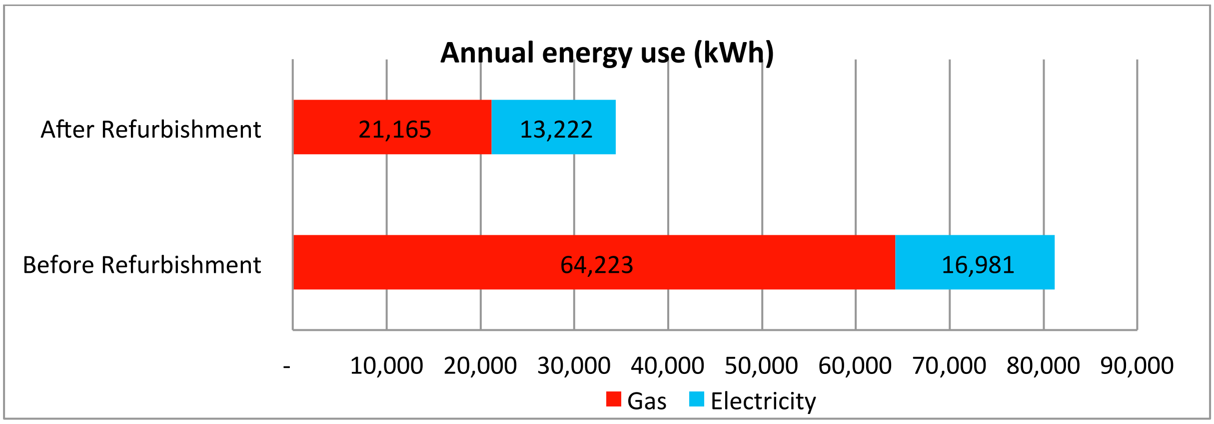


Figure 56 Carbon emissions and comparisons with carbon benchmarks

5.6.1.2 Brief comparison of energy usage before/ after refurbishment

The refurbishment of Garth building took place during November 2013- April 2014. The energy usage data after refurbishment were taken between 01/05/2014 and 30/04/2015; the energy usage data before refurbishment were taken between 26/02/2013 and 12/02/2014. Annual gas and electricity consumption in 2013 (before refurbishment) and 2014 (after refurbishment) were calculated from the meter readings. The results show that after the refurbishment there is a 58% reduction in overall annual energy savings and a 48% reduction in carbon savings. As shown in Figure 57, this equates to 67% reduction in gas consumption and 22% reduction in electricity.



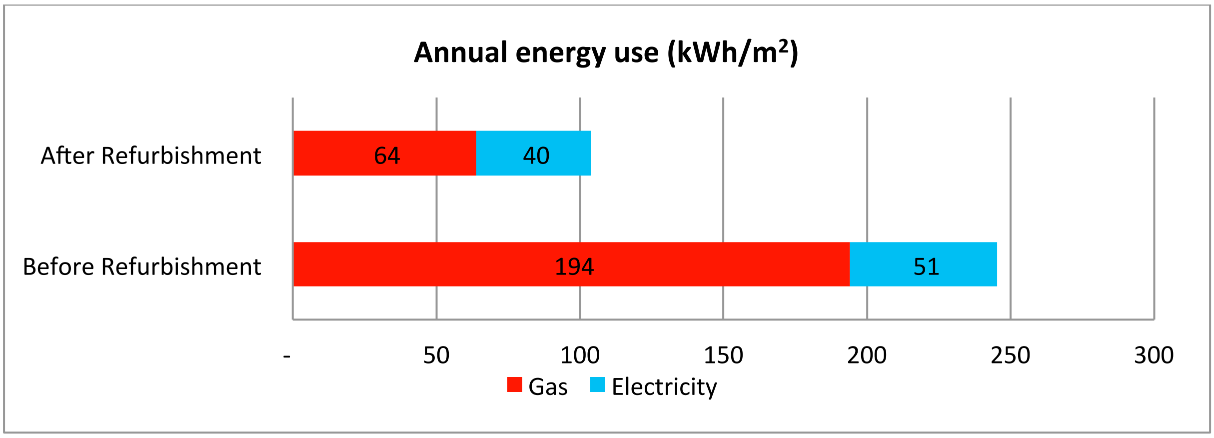


Figure 57 Gas and electricity consumption before and after refurbishment

5.6.1.3 Energy usage profile after refurbishment

Monthly electricity of the Garth building during monitoring period (May 2014-April 2015) stays relatively constant between 700 kWh and 1200 kWh (Figure 58). Gas consumption increases dramatically from 16 kWh in September 2014 to 4000kWh in January 2015 due to the drop of external temperature. Gas use is 62% of the total energy use of the building (Figure 59). Daily electricity and gas use during the one-year monitoring period are shown in Figure 60.

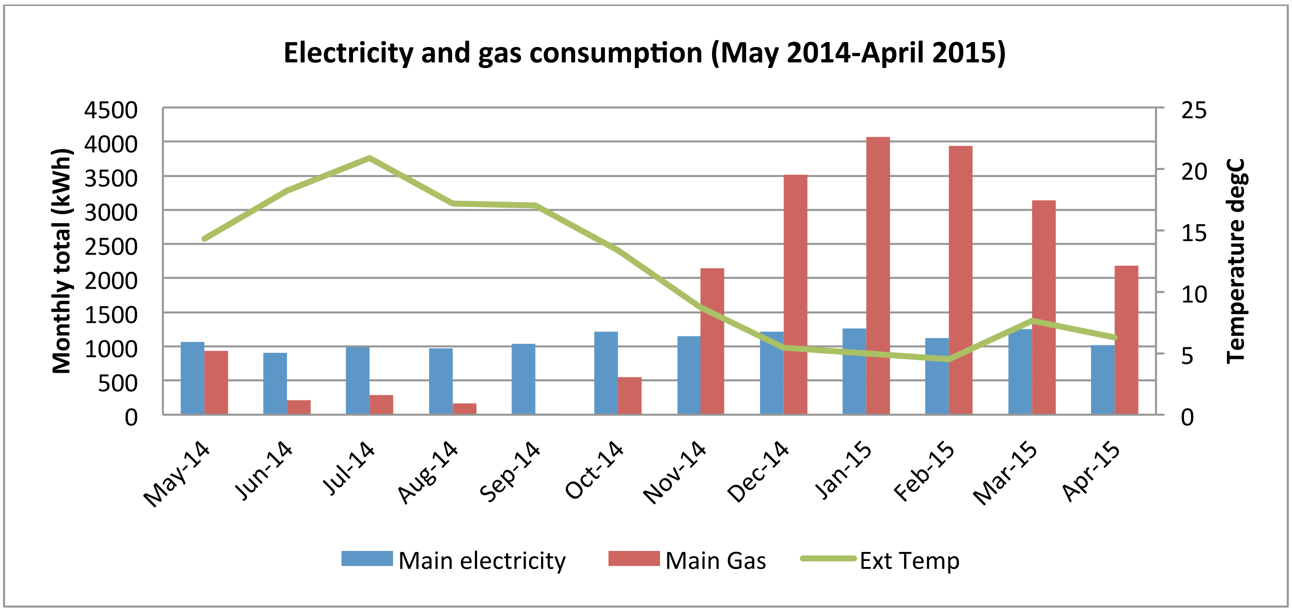


Figure 58 Monthly gas and electricity consumption of the Garth building (May 2014 –April 2015)

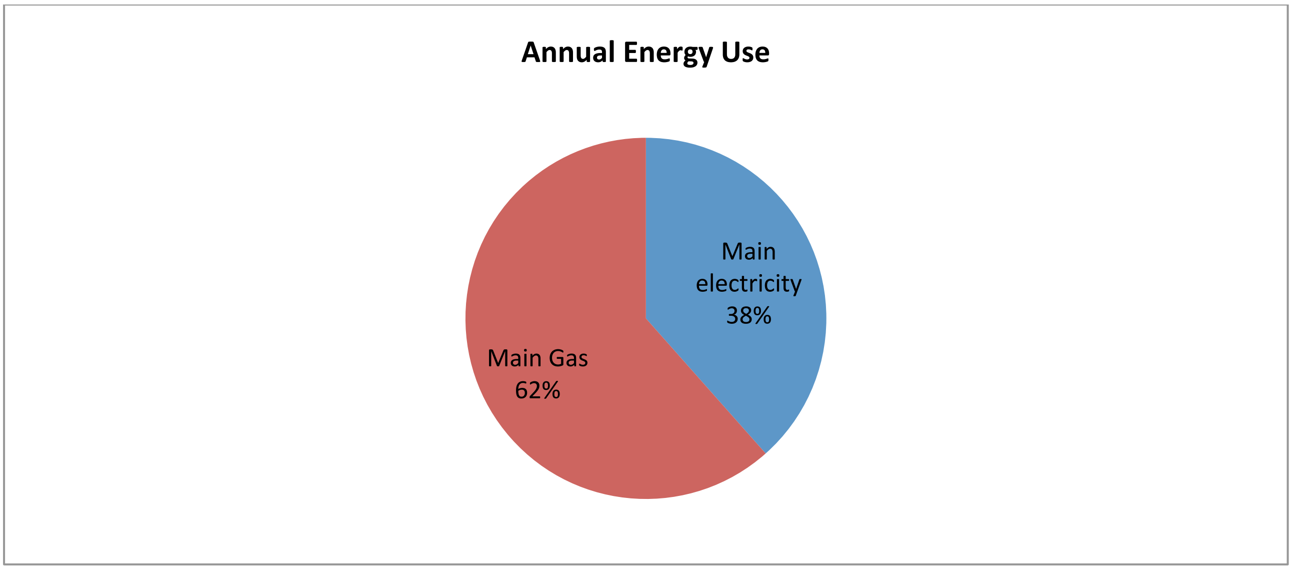


Figure 59 Annual energy consumption of Garth building (May 2014-April 2015)

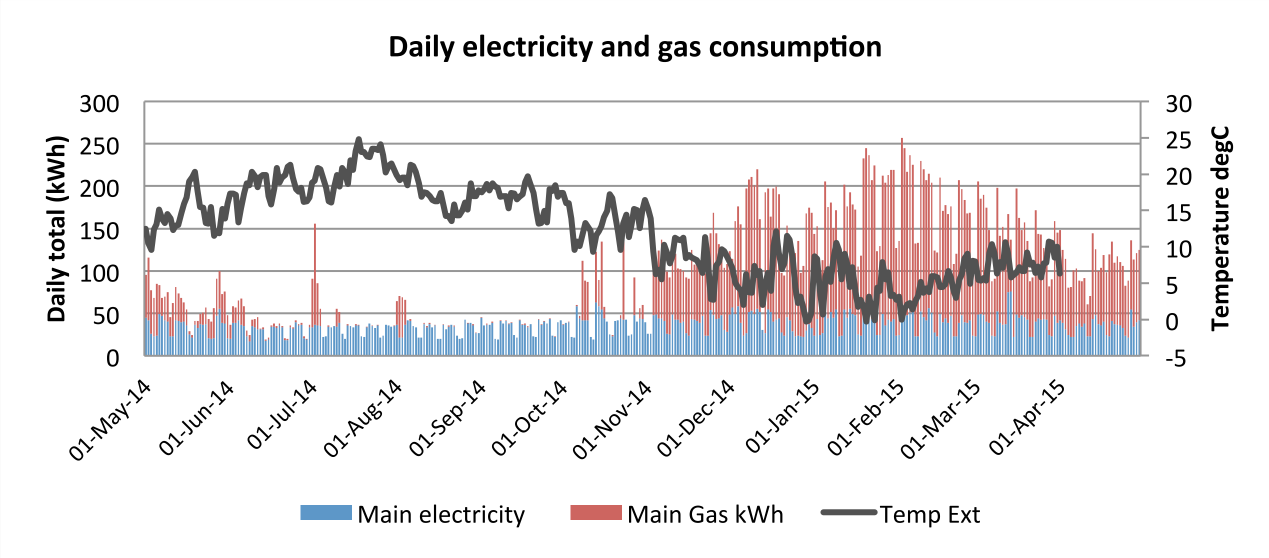


Figure 60 Daily electricity and gas consumption (May 2014-April 2015)

Figure 61 shows the daily electricity and gas use during a week. During weekdays, gas usage ranges between 58-60 kWh and electricity usage ranges between 39-42 kWh. Energy use drops during weekends.

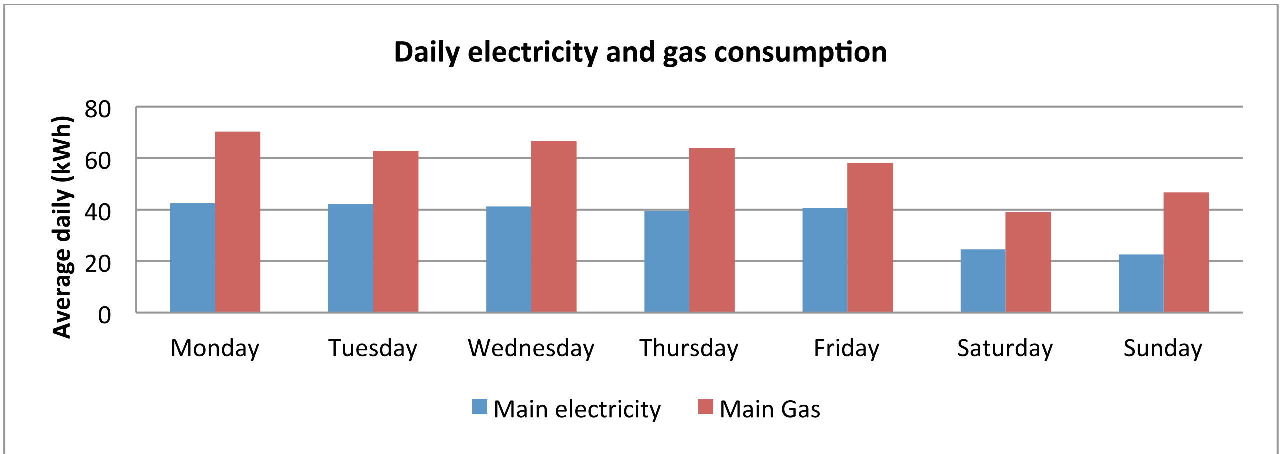


Figure 61 Daily electricity and gas consumption per weekday (May 2014-April 2015)

Two electric water heaters and MVHR unit are monitored individually in order to identify the electricity used for hot water and ventilation. The monitoring data shows that MVHR unit consumes 5 to 10 kWh electricity per month (Figure 62). The electric water heaters consume less than 5 kWh electricity each month. In general, the electricity consumption for ventilation and hot water is small comparing to the total energy consumption.

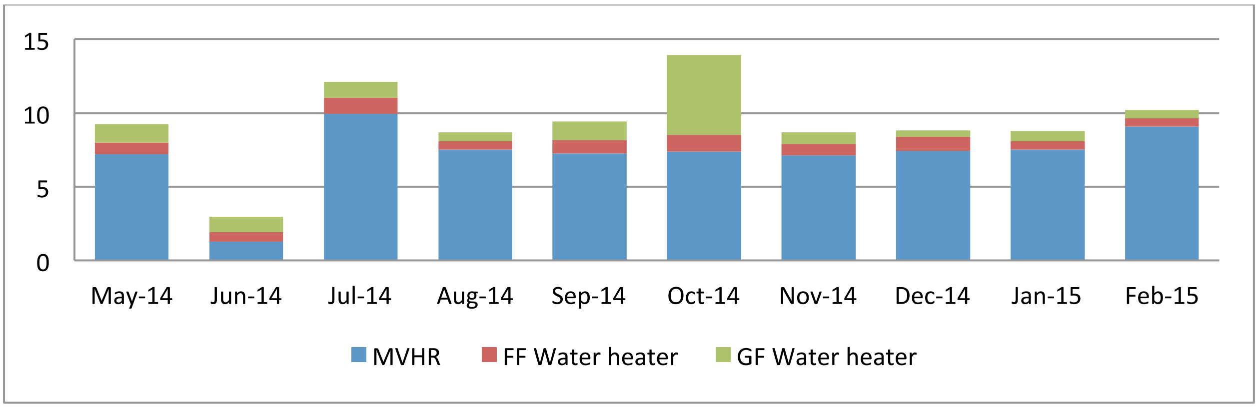


Figure 62 Monthly electricity consumptions of MVHR unit and electric water heaters at ground and first floor (May 2014-February 2015)

The average daily profile of electricity usage on winter weekdays and weekends before and after refurbishment are shown in Figure 64 and Figure 64 respectively. Peak electricity loads are reduced after refurbishment, as a result of the reduced usage of electric heaters. Gas usage changes greatly. Before refurbishment (winter 2014), heating was on continuously reaching a peak of 10kW at 9am. After the refurbishment a strict heating schedule is applied, with heating on only during occupancy hours. Gas use peaks again at 10am, reaching 17kW.

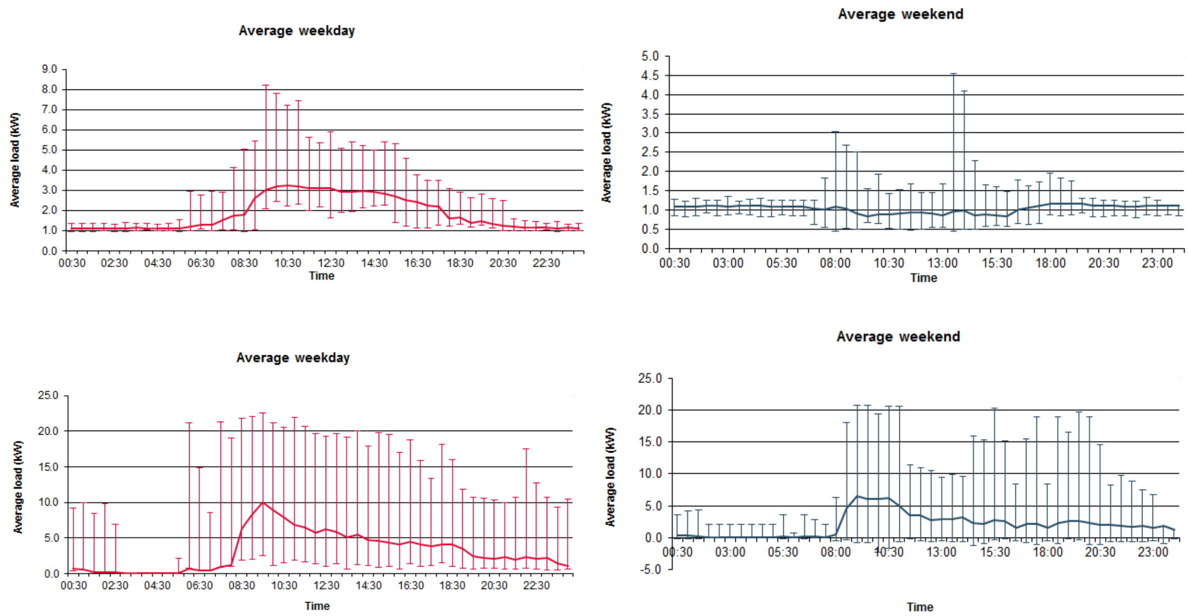


Figure 63 Average weekday/weekend electricity profile during winter 2014 (before refurbishment). Top: Electricity use, Bottom: Gas use

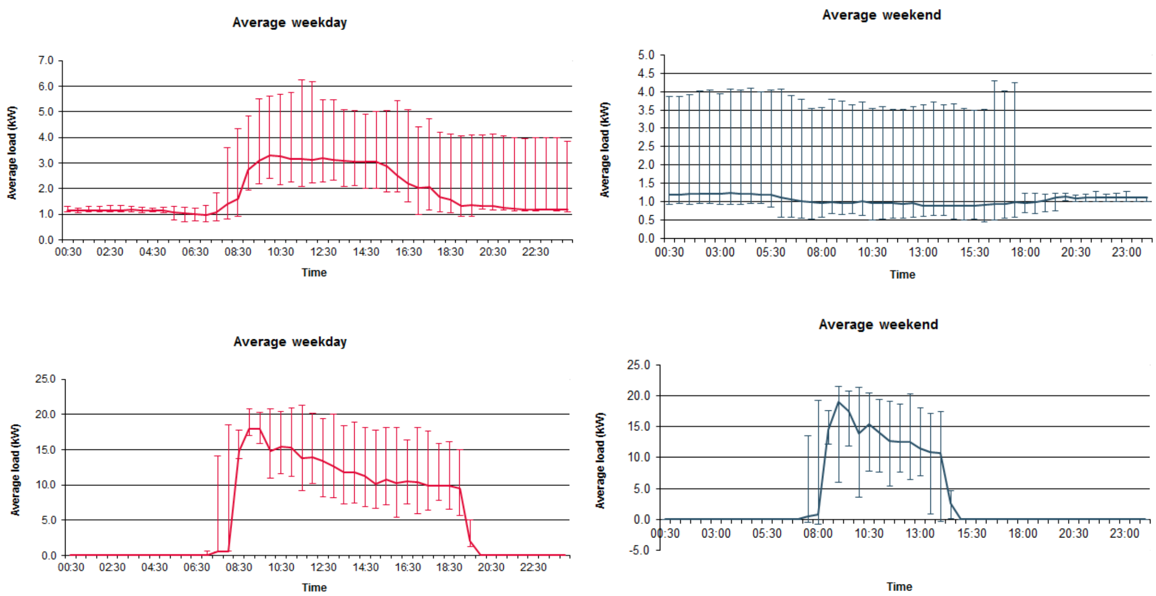


Figure 64 Average weekday/weekend electricity profile during winter 2015. Top: Electricity use, Bottom: Gas use

5.6.2 Environmental data

5.6.2.1 Temperature

Figure 65 shows the average daily temperatures recorded in the Garth building after the refurbishment during the 1-year monitoring period from April 2014 to March 2015. Temperatures seem to follow the external temperature variations throughout the year. Temperatures in most rooms range between 15-23oC during winter and 20-26oC during summer. Room G25 is an exception to this as it appears to be the coldest room throughout the year. Room F13, that accommodates the largest number of occupants is the warmest during winter, whereas the highest summer temperatures are recorded in southwest facing rooms F20 and F21.

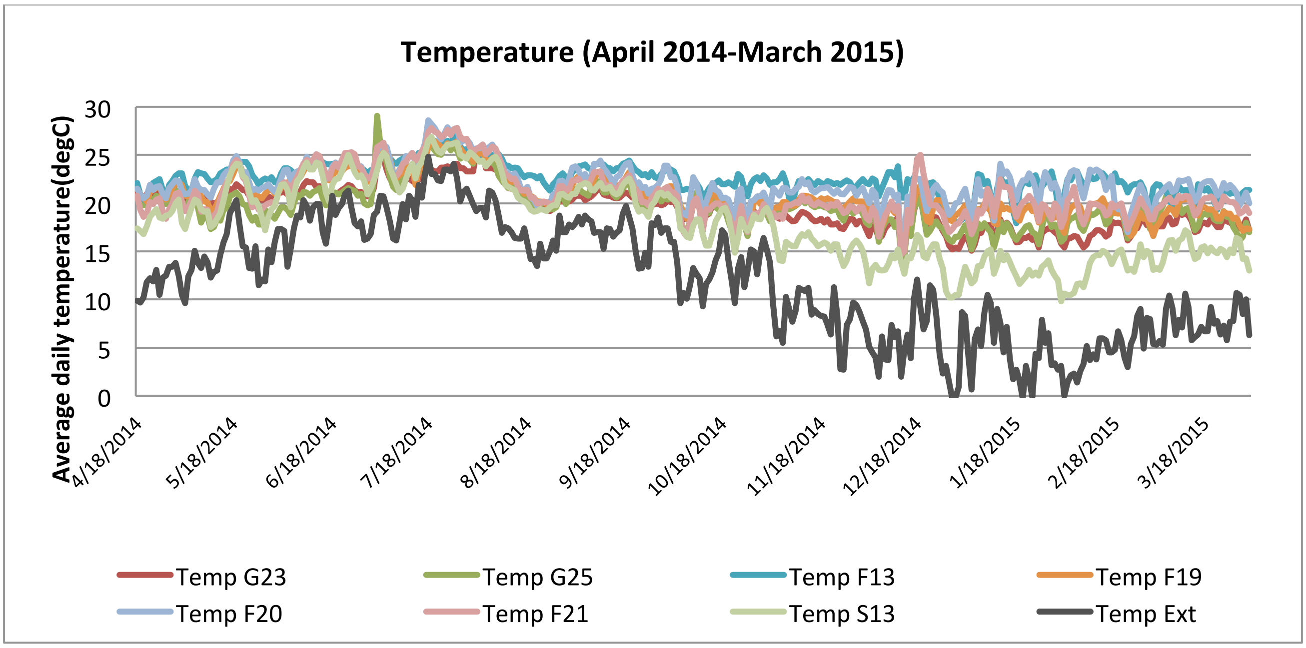


Figure 65 Average daily temperature after refurbishment (April 2014-March 2015)

Figure 66 shows the average hourly temperatures recorded in the Garth before the refurbishment during the period from February to April 2013. It should be noted that the heating was on continuously at that time. As a result temperatures range from 18-26°C in most rooms, even when rooms are not occupied and throughout the night. These patterns and high temperatures explain the high gas use before the refurbishment.

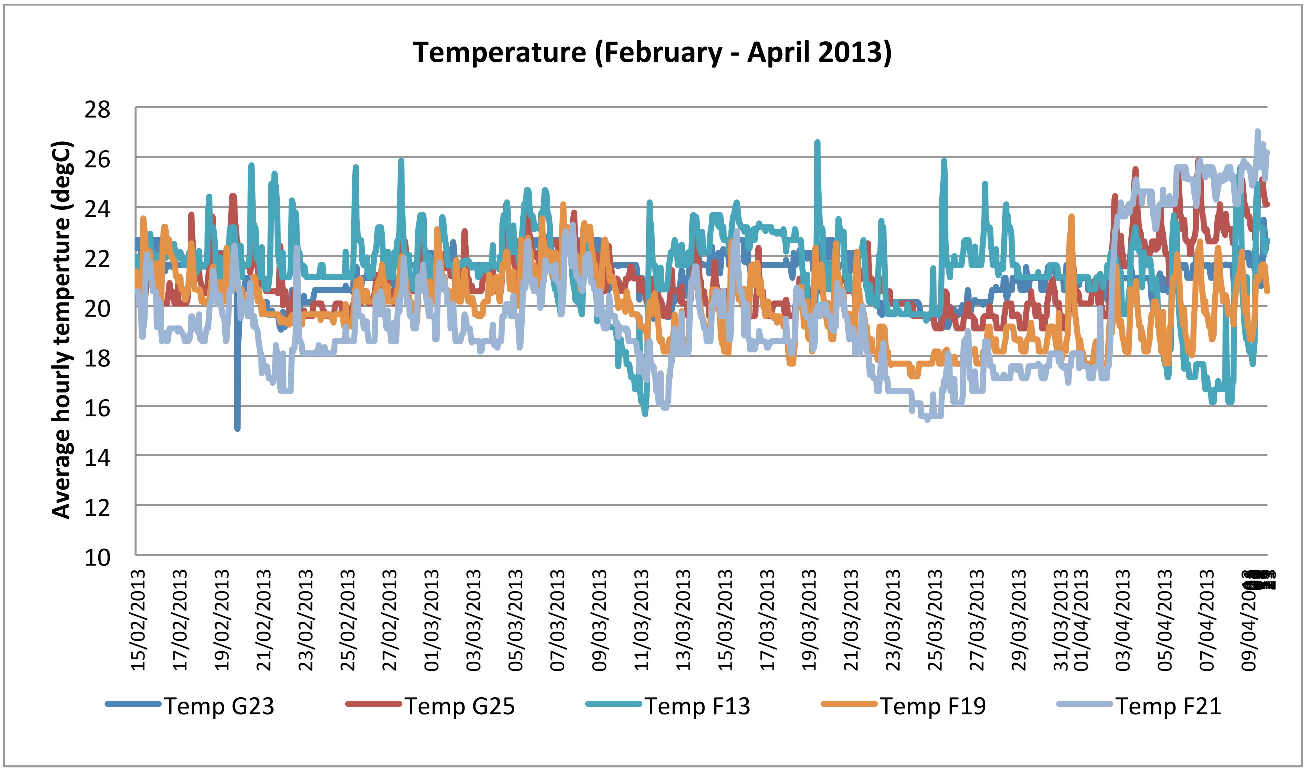


Figure 66 Average hourly temperatures before refurbishment (February-April 2013)

To investigate temperature stability, the daily average temperature, maximum temperature and minimum temperature of room G25 (wedding room), F13 (reception room), F19 (Chief Officer's room) are illustrated in Figure 67, Figure 69, Figure 71 respectively. They show that the temperatures of offices are generally between 20-26°C during occupied hours. The temperatures of Room G25 vary from 14 to 28°C.

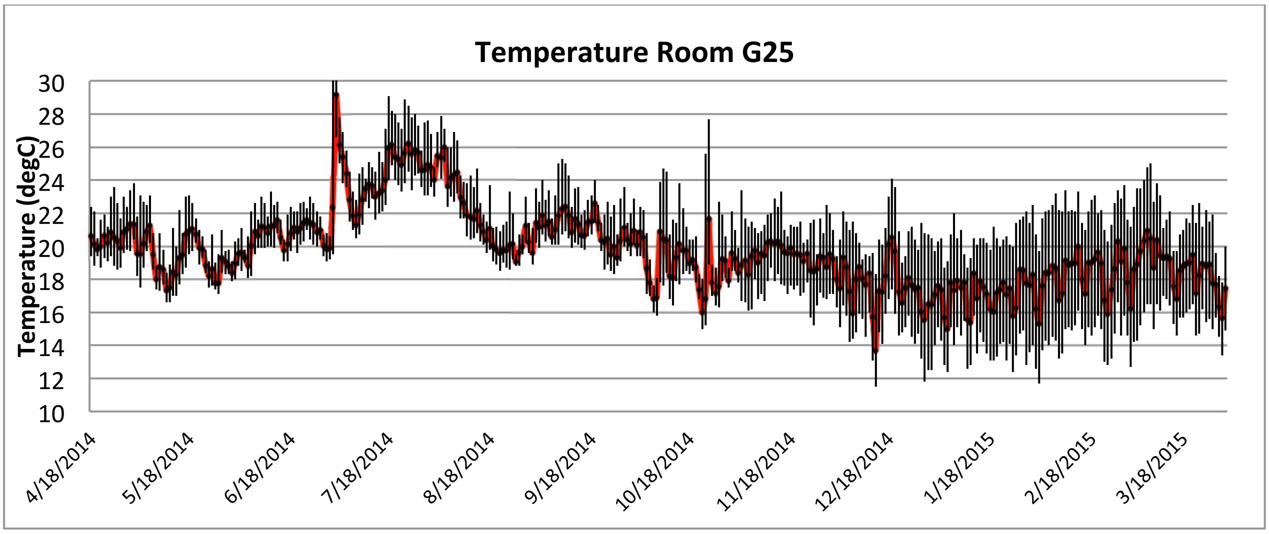


Figure 67 Maximum, minimum and average temperature of G25 (April 2014-May 2015)

Figure 68 shows a comparison between indoor temperatures recorded before and after refurbishment in Room G25 during the months of February and March (2013 vs 2015). Some discrepancy in external temperature can be observed between the two winter seasons, with winter 2015 being slightly warmer than winter 2013. Despite this, indoor temperatures in Room G25 present a much greater fluctuation after the refurbishment usually ranging from 15 to 23°C throughout the day. Before the refurbishment, indoor temperatures ranged between 20-25°C. These patterns are directly related to the heating schedule profiles used before and after the refurbishment, and have a direct effect on energy use.

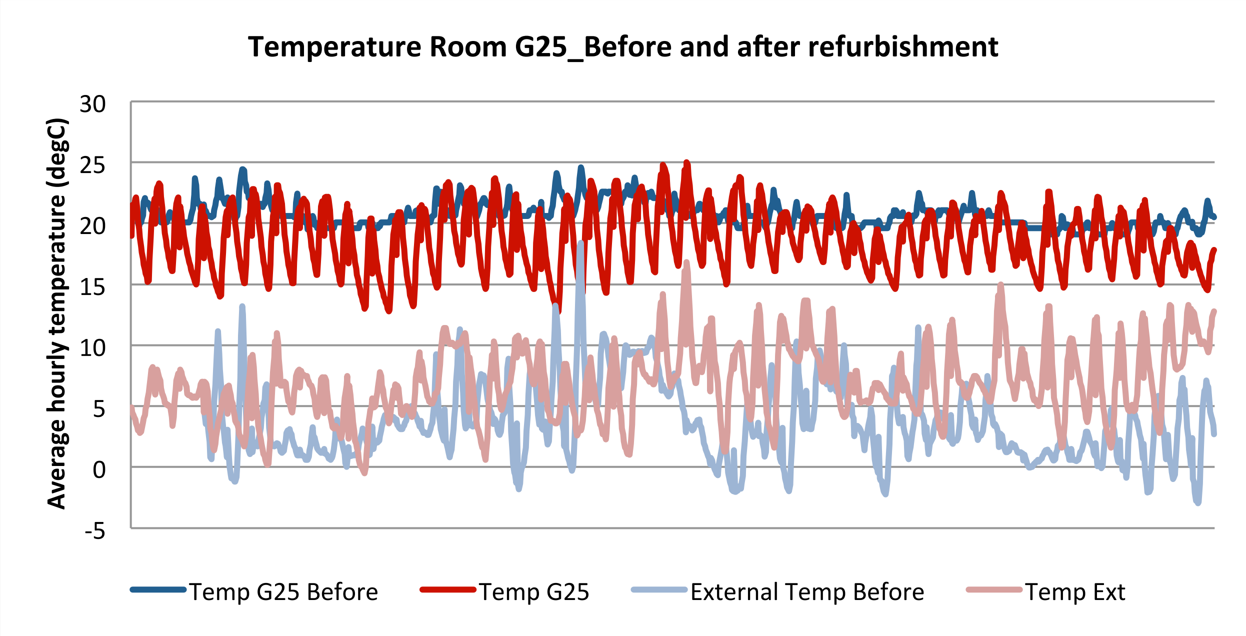


Figure 68 Comparison of average hourly temperature in Room G25 before and after refurbishment during winter months (February-March 2013 vs February-March 2015).

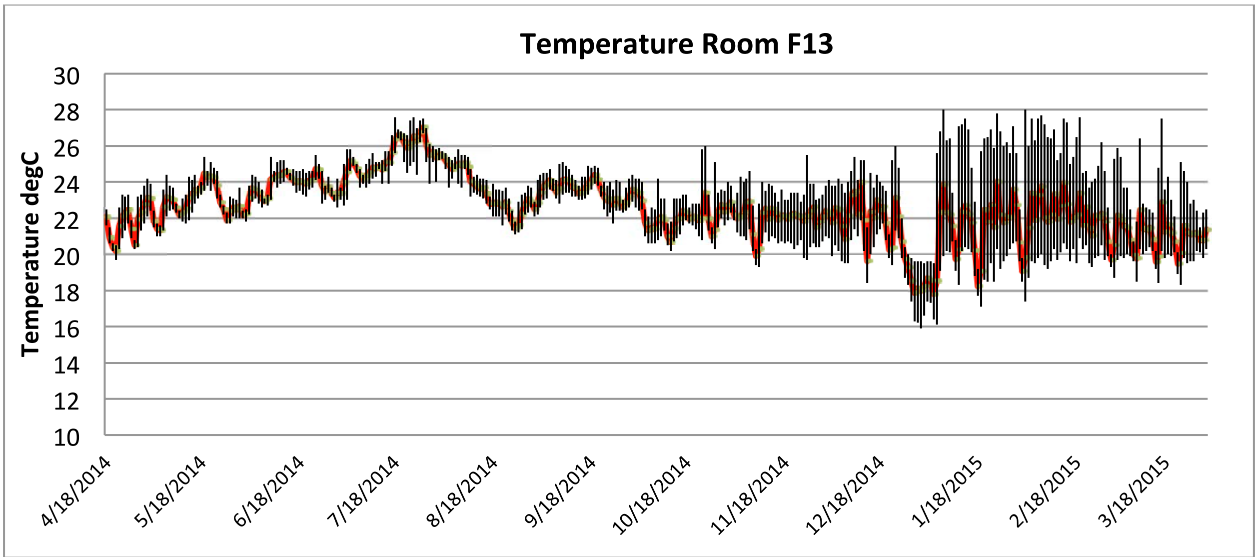


Figure 69 Maximum, minimum and average temperature of F13 (reception) (April 2014-March 2015)

Figure 70 shows a comparison between indoor temperatures recorded before and after refurbishment in Room F13 during the months of February and March (2013 vs 2015). As in the case of Room G25 shown above, indoor temperatures in Room F13 also present a much greater fluctuation after the refurbishment. Temperatures after the refurbishment range from 20 to 26°C, whereas before they used to range between 21-24°C (heating on continuously). It can be seen that following the refurbishment higher temperatures can be achieved in the room during occupied hours even though the heating is on for far less amount of time than before. This is a result of the reduction of heat loss through ventilation and building fabric.

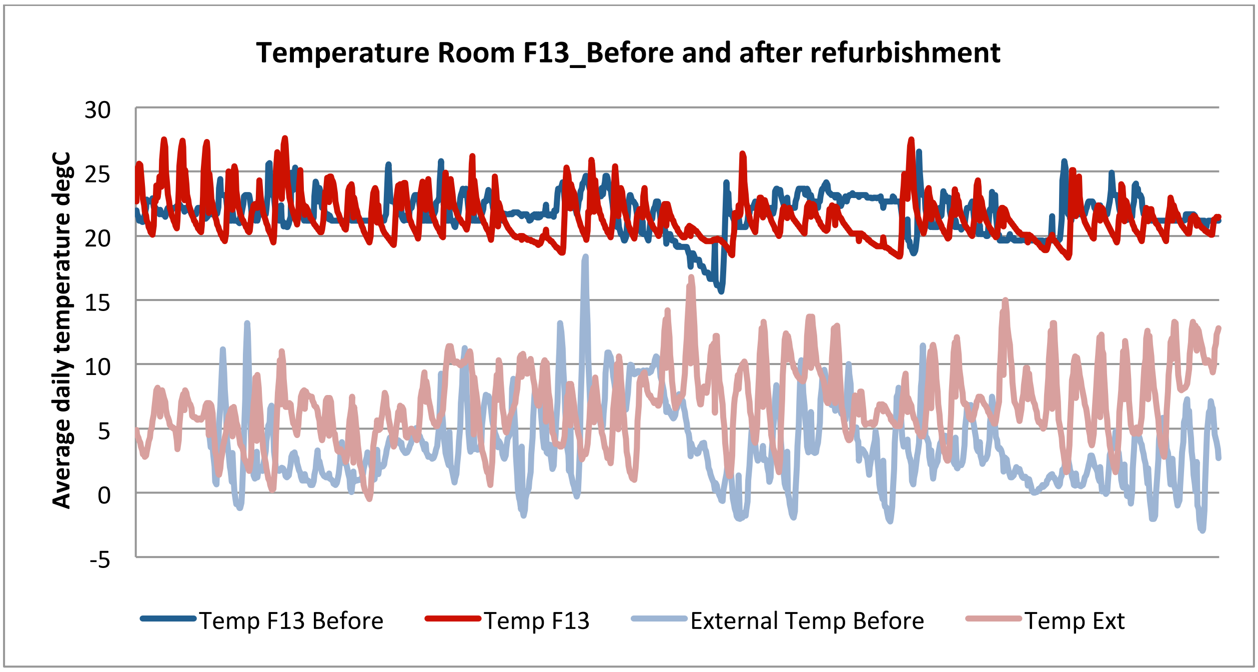


Figure 70 Comparison of average hourly temperature in Room F13 before and after refurbishment during winter months (February-March 2013 Vs February-March 2015).

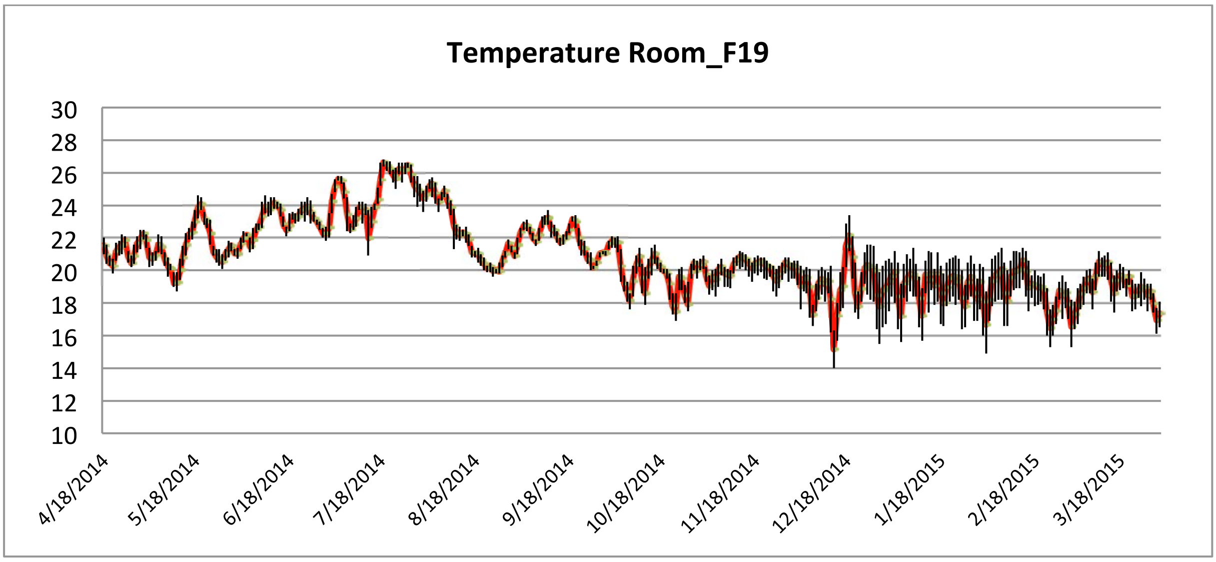


Figure 71 Maximum, minimum and average temperature of F19 (Chief Officer's office) (April 2014-March 2015)

Figure 72 shows the temperature distribution during occupied hours from May to September 2014. The red box in Figure 72 highlighted the percentages within CIBSE operative temperature ranges. Note: 'occupied hours' are 9am – 6pm of weekdays. It shows that:

- Over 36% of occupied hours in room F13, F19 and F20 are within CIBSE Guide A temperature recommendation.
- 38% of occupied hours in room F13 are between 24-26°C and 5% are between 26-28°C.

- South facing rooms at first floor have more chance of experiencing higher temperature, e.g. 9% of occupied hours in F20 and 10% of occupied hours in F21 are within temperature of 26-28°C.
- 1% of occupied hours during monitored period in office F20 have exceeded the overheating CIBSE Guide A criteria (28°C). No other room shows instances of overheating.
- Lower temperatures are recoded in Room G25 because it is not always occupied.

Overheating analysis using the Adaptive Comfort criteria and following BS EN 15251 did not show any occurrence of overheating in any of the rooms.

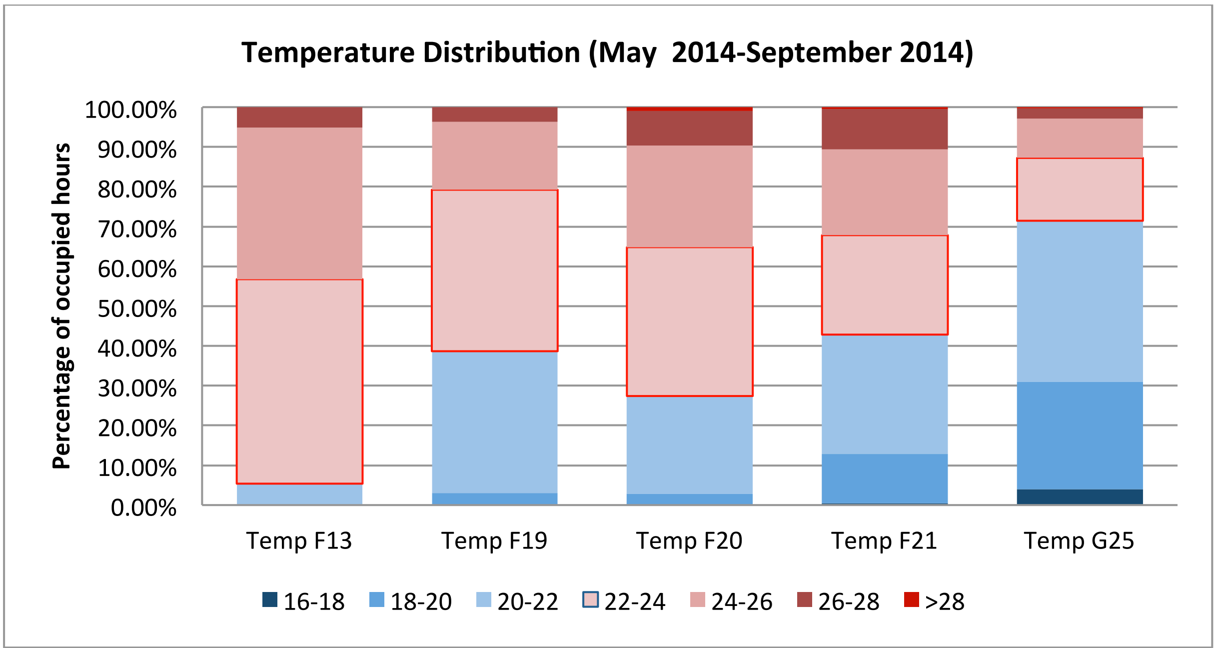


Figure 72 Percentage of occupied hours at a given temperature during May-September 2014 (red borders indicate recommended temperature 22-24°C in summer by CIBSE Guide A)

Figure 73 and Figure 74 show the daily variation of average hourly temperatures after the refurbishment during a winter and a summer day respectively. During winter, temperatures follow the external temperature fluctuations and range from 18-22°C in most rooms, with the exception of room S13, that is located on the second floor and is not heated. During summer temperatures during the day remain relatively steady ranging around 24°C in Room F13 and 21°C in Room G25.

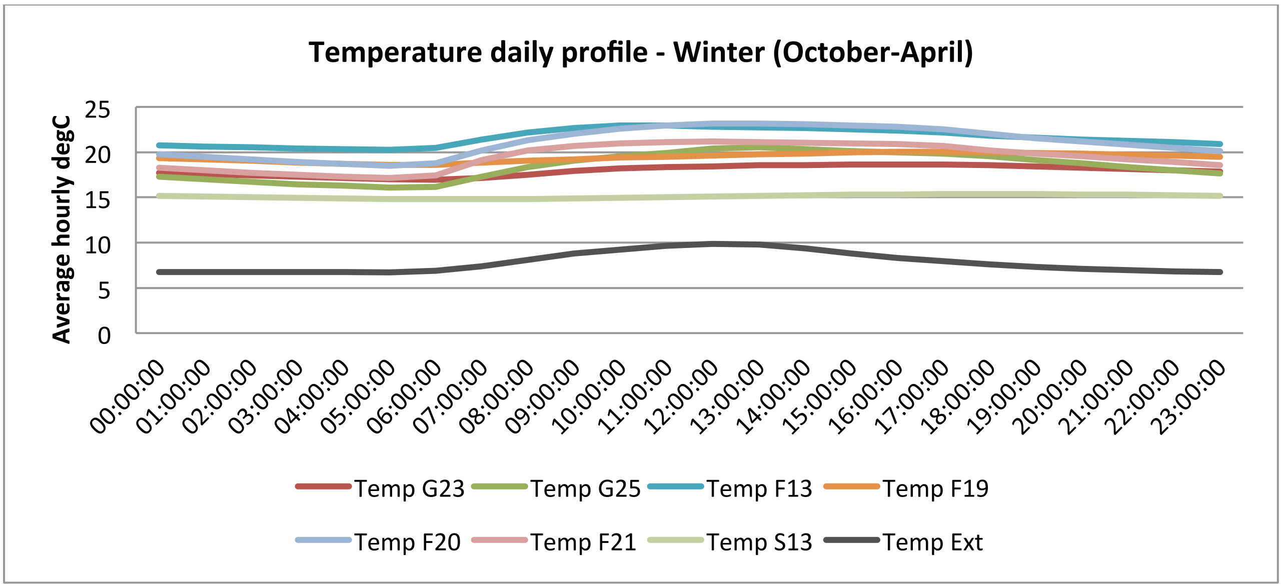


Figure 73 Daily variation of average hourly temperatures after refurbishment (October-April)

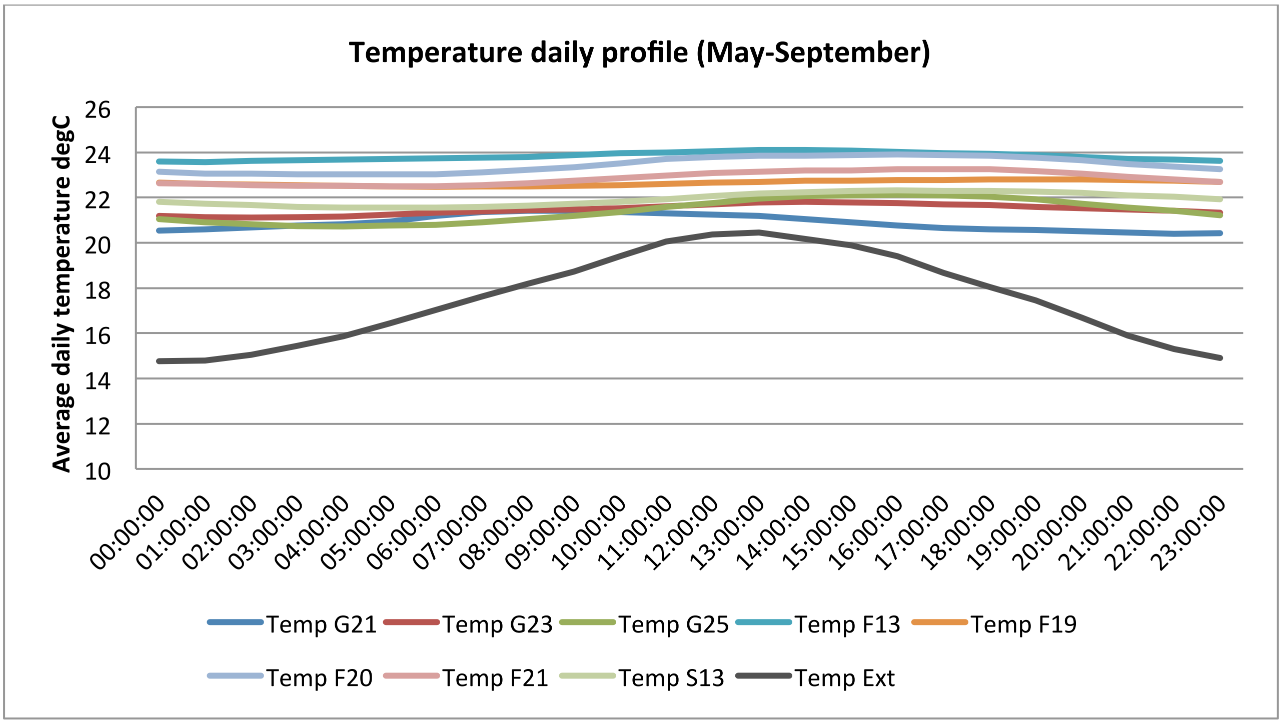


Figure 74 Daily variation of average hourly temperatures after refurbishment (May-September)

Temperature in a hot week

The hourly indoor/outdoor temperature at the hottest week in 2014 is plotted in Figure 75 and it was compared with the adaptive thermal comfort range defined by CIBSE TM 52. Temperatures in F13 on 17, 18 and 23 July have exceeded the upper limit of adaptive thermal comfort zone for category II occupancy group (Normal level of expectation, used for new buildings and renovations).

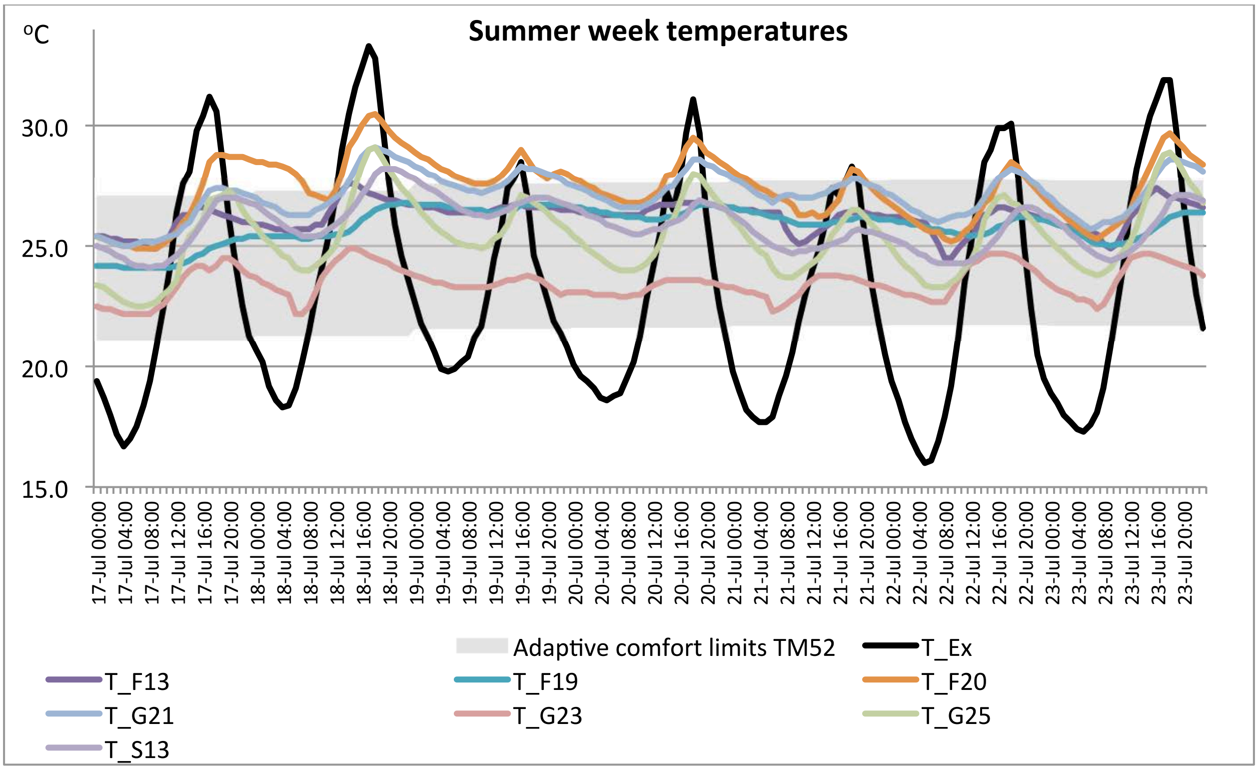


Figure 75 Indoor temperature at the hottest week in 2014

5.6.2.1.1 Temperature in a cold week

The hourly indoor/outdoor temperature at the coldest week in 2014 (by 10 November 2014) is plotted in Figure 76 and it was compared with comfort range defined by CIBSE TM 52 (20-26°C). F13 is hottest room in winter due to its high internal heat gain from equipment and people. The registry office (G23) is the coldest room because it is not insulated as part of this project. It is a ‘control’ room (for comparison).

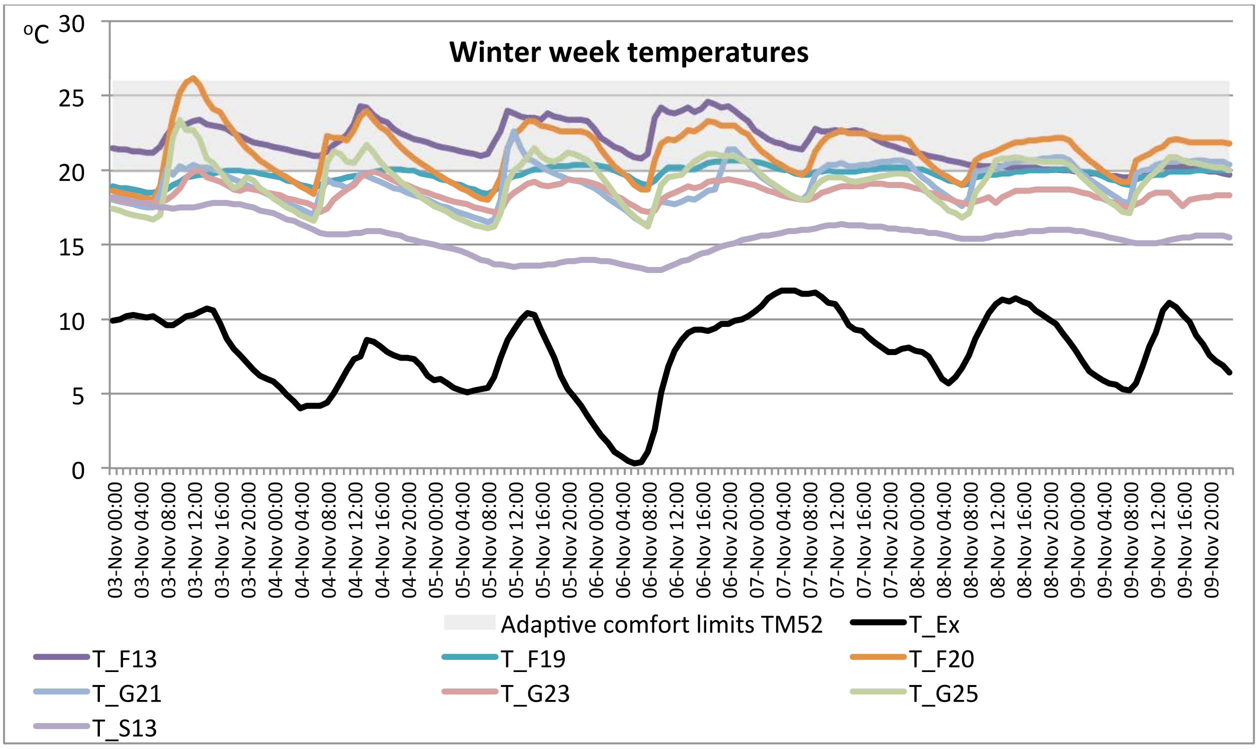


Figure 76 Indoor temperature at the coldest week in 2014 (by 10th November 2014)

Figure 77 shows the temperatures recorded before the refurbishment during a winter week. In Figure 78 these temperatures are compared against indoor temperatures recorded after the refurbishment during a winter week in January 2015 with similar external temperature. Temperatures after the refurbishment are higher in all rooms during occupied hours. In Rooms F13 and F20, temperatures during occupied hours range between 22-27^{o}C and between 18-21^{o}C in Room F19. This discrepancy is due to the fact that the occupant in Room F19 has set the radiator valve at a lower setting. During weekdays temperatures do not fall below 18^{o}C even during the night hours, as a result of the improved fabric. Before the refurbishment temperatures recorded were significantly lower during occupied hours despite the heating being constantly on.

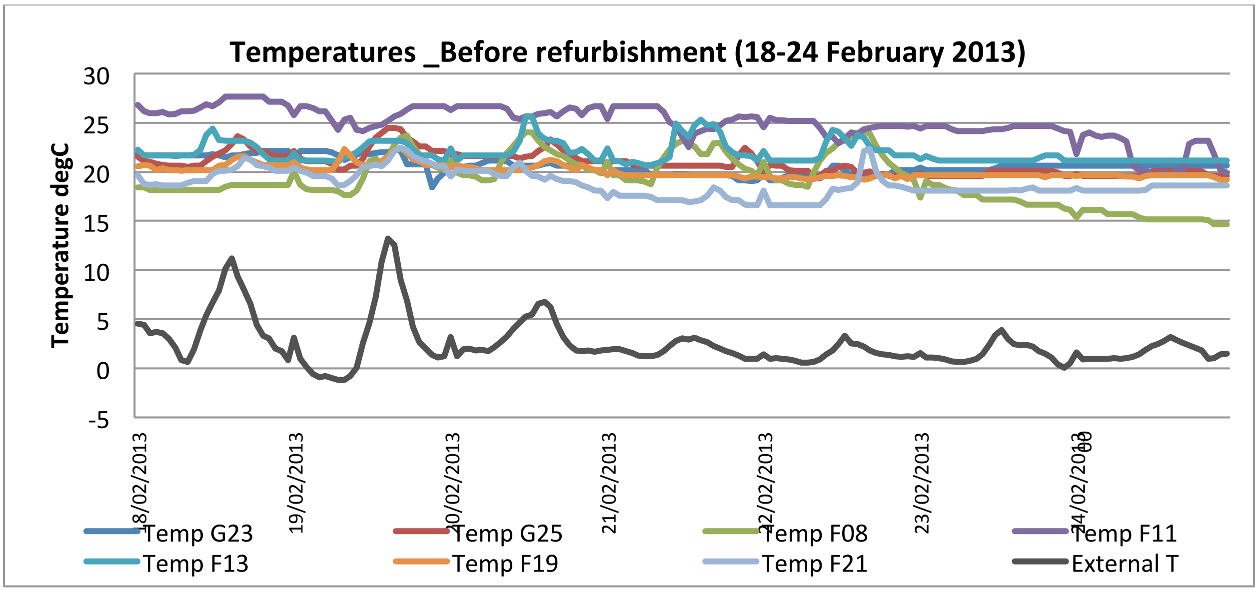


Figure 77 Indoor temperatures during a winter week in 2013 before refurbishment

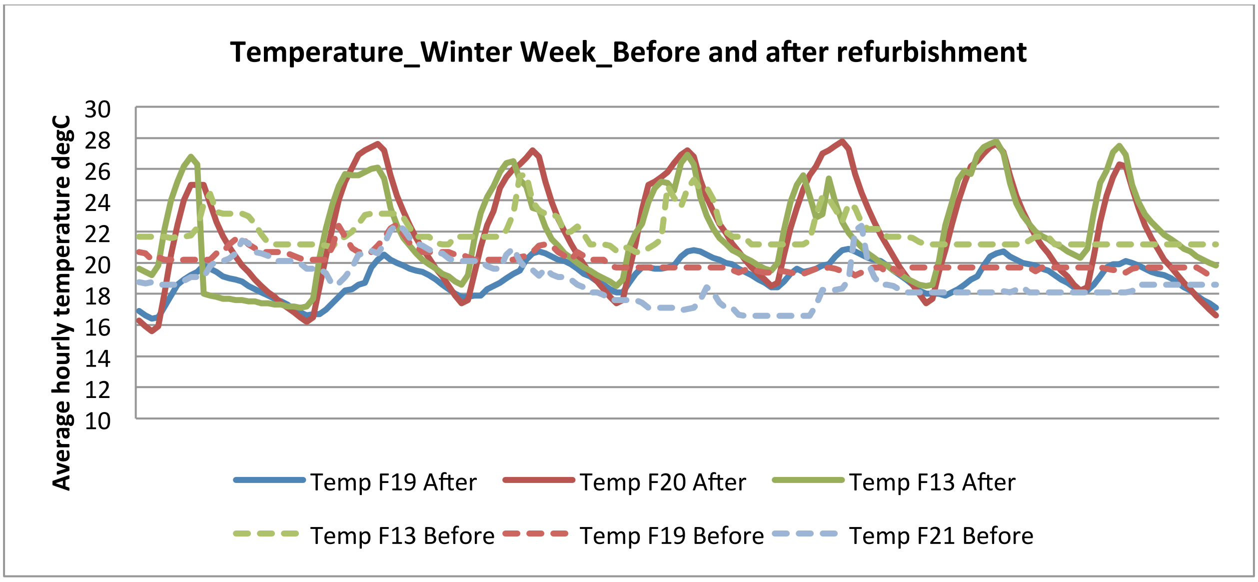


Figure 78 Comparison of average hourly temperatures before and after refurbishment during a winter week (Mon-Sun) in February 2013 and in January 2015. The week in January 2015 was picked in order to achieve a good match between the external temperatures recorded during the two weeks, to allow for a more accurate comparison.

5.6.2.2 Relative humidity

Figure 79 shows the average daily RH levels recorded in the Garth building after the refurbishment during the 1-year monitoring period from April 2014 to March 2015. RH levels in most rooms range between 35-55% during winter and 45-65% during summer. Room F13, that is the warmest during winter, has the lowest RH levels ranging between 30-50% during winter. Room S13 is neither occupied nor heated.

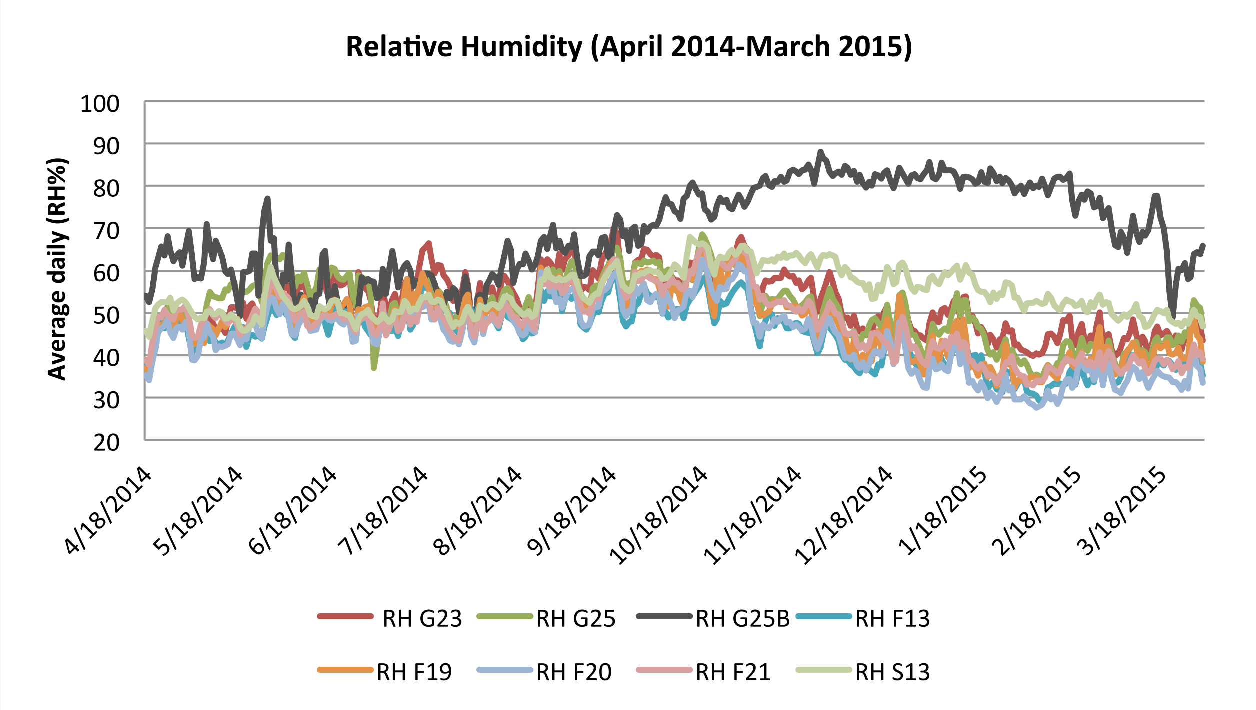


Figure 79 Average daily RH levels after the refurbishment (April 2014-March 2015)

As shown in Figure 80, RH levels during winter before refurbishment were low, ranging between 20-40%, as a result of continuous heating. After the refurbishment, and with the help of the MVHR system, RH levels during winter range between 30-40% in Room F13 and 35-55% in Room G25, values that are closer to the CIBSE recommended limits of 40-70% (Figure 81).

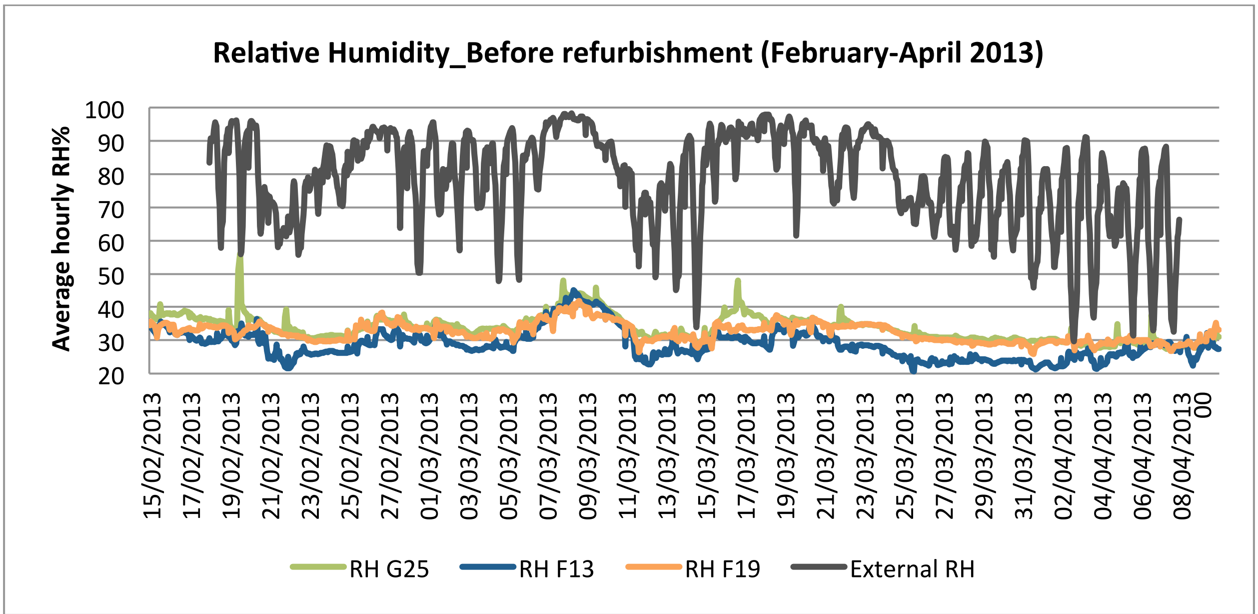


Figure 80 Average hourly RH levels before the refurbishment (February-April 2013)

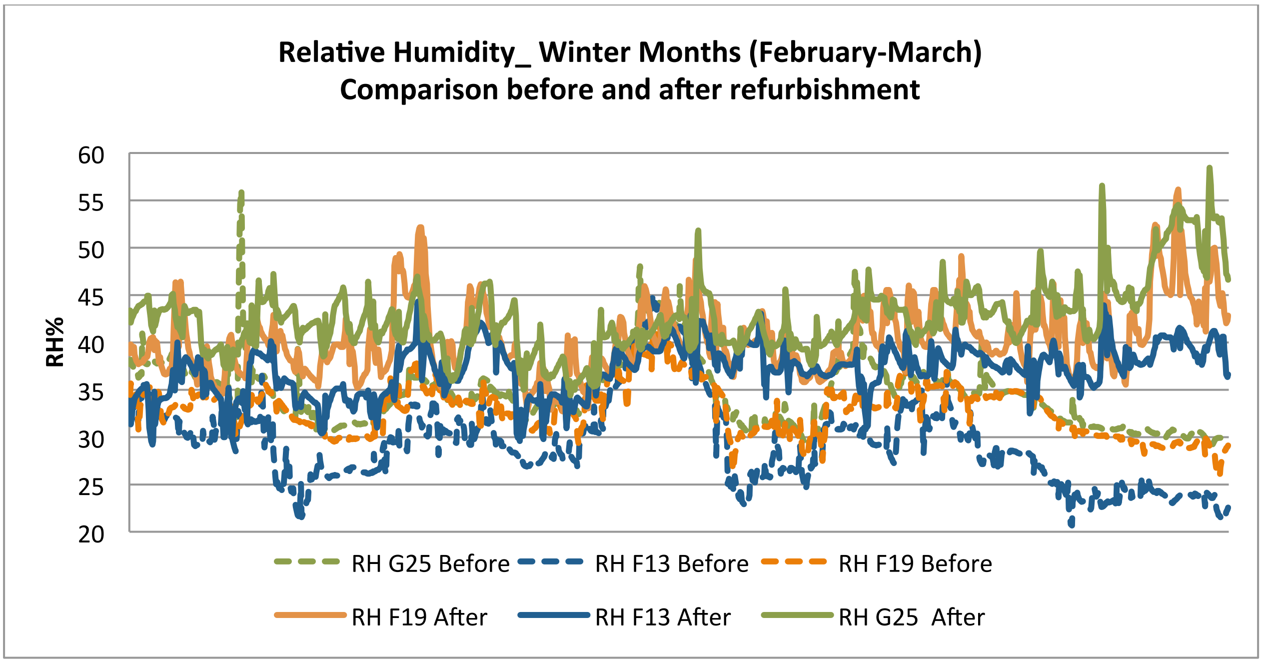
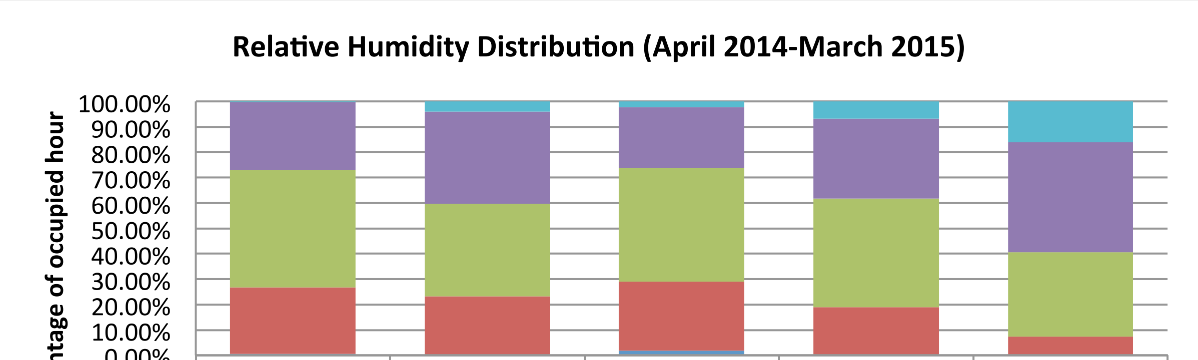


Figure 81 Comparison of RH levels during winter months before and after refurbishment (February-March 2013 Vs February-March 2015).

As shown in Figure 82, more than 70% of occupied hours are within relative humidity range of 40%-70% which is recommended by CIBSE. Relative humidity levels follow the indoor temperature levels, with the lowest levels recorded in the warmer rooms (F13, F20).



	RH F13	RH F19	RH F20	RH F21	RH G25
60-70	0.15%	4.09%	2.17%	6.85%	16.05%
50-60	26.77%	36.10%	24.05%	31.34%	43.44%
40-50	46.26%	36.54%	44.81%	42.75%	33.18%
30-40	26.24%	23.10%	27.06%	19.05%	7.29%
20-30	0.57%	0.15%	1.92%	0.00%	0.00%

20-30 30-40 40-50 50-60 60-70

Figure 82 Percentage of occupied hours at a given relative humidity ranges during 18th April – 2nd November 2014 indicate recommended RH 40-60%)

As shown in Figure 83 and Figure 84, RH levels remain steady throughout the day, during both winter and summer, always remaining well within the recommended limits of 40-70%.

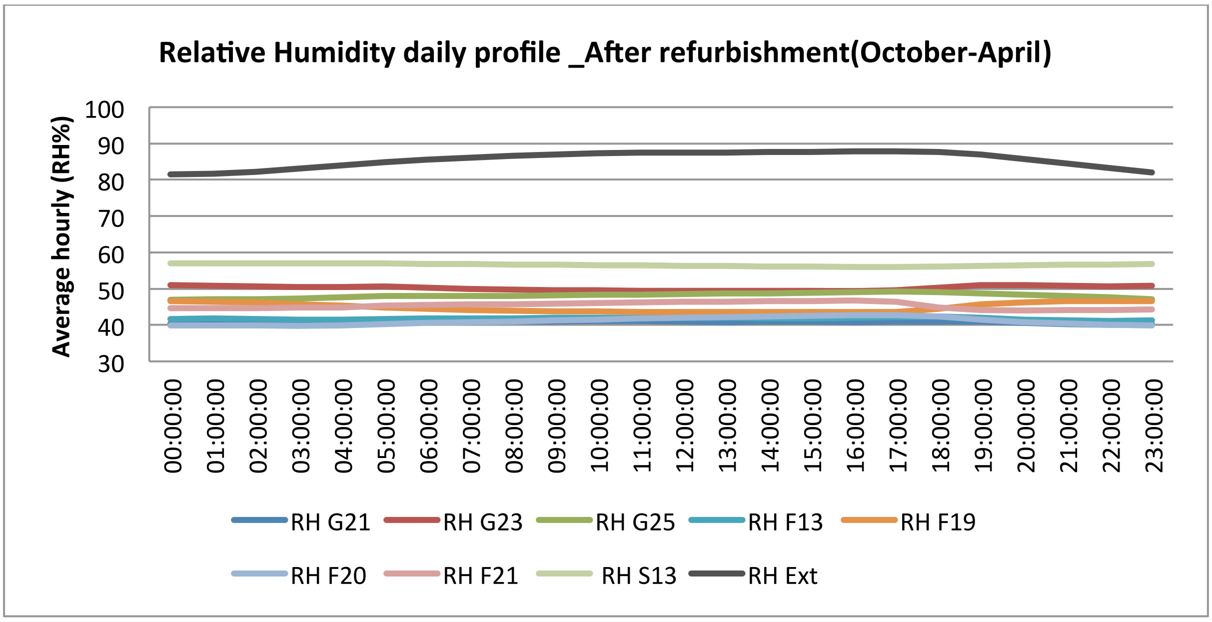


Figure 83 Daily variation of average hourly RH levels during winter months (October-April) after the refurbishment

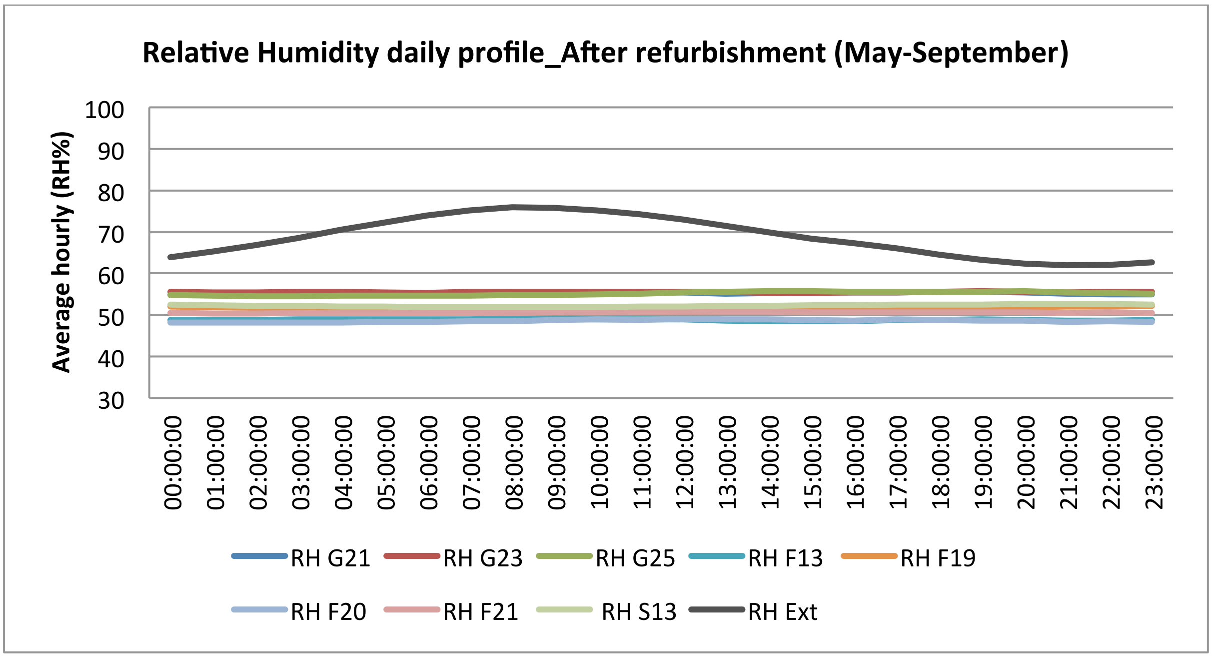


Figure 84 Daily variation of average hourly RH levels during summer months (May-September) after the refurbishment

Figure 85-Figure 88 show the environmental conditions in Room G25, Room F13, Room F19 and F21 respectively, during a winter and a summer month after the refurbishment. In Room G25 (Council Chamber), that is not occupied continuously and is used for council meetings and marriage ceremonies, average hourly temperatures range between 12-22°C in winter

and 20-29°C in summer. Maximum temperatures recorded were as high as 33°C, but these occurred very few times. RH levels are similar during both seasons, remaining within the 40-70% recommended band. In Room F13, average hourly temperatures range between 16-28°C in winter and 23-27°C during summer. RH levels in winter range between 30-50%, whereas in the summer they are higher as a result of frequent window opening. Similar patterns can be observed in the other two rooms.

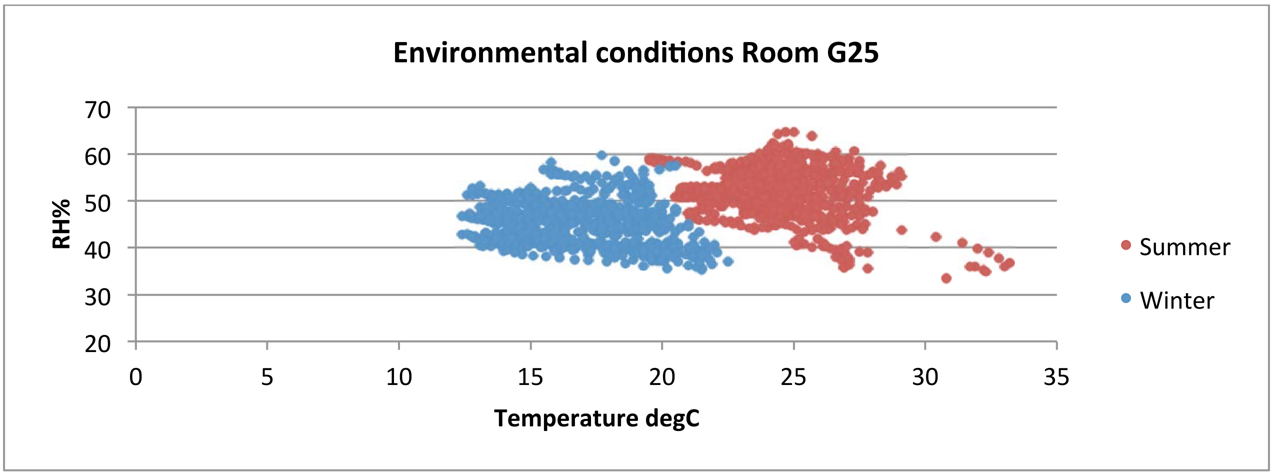


Figure 85 Environmental conditions in Room G25 during a winter (January) and a summer(July) month after the refurbishment

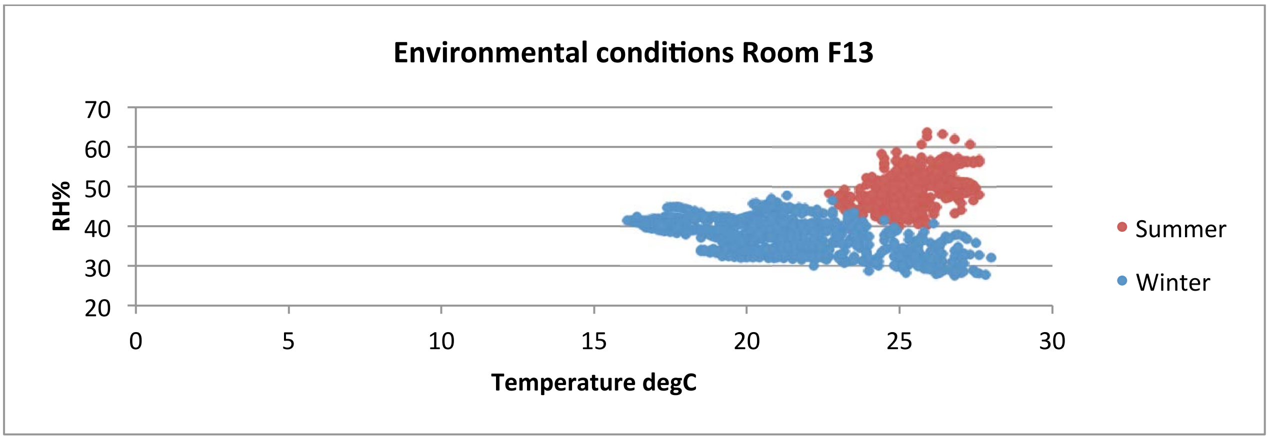


Figure 86 Environmental conditions in Room F13 during a winter (January) and a summer (July) month after the refurbishment

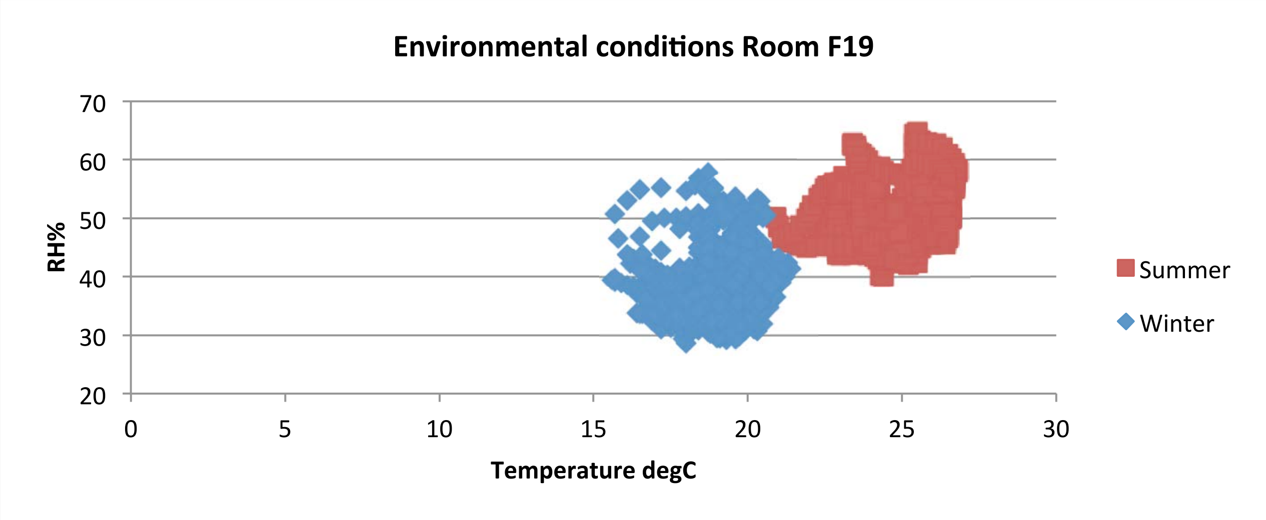


Figure 87 Environmental conditions in Room F19 during a winter (January) and a summer (July) month after the refurbishment

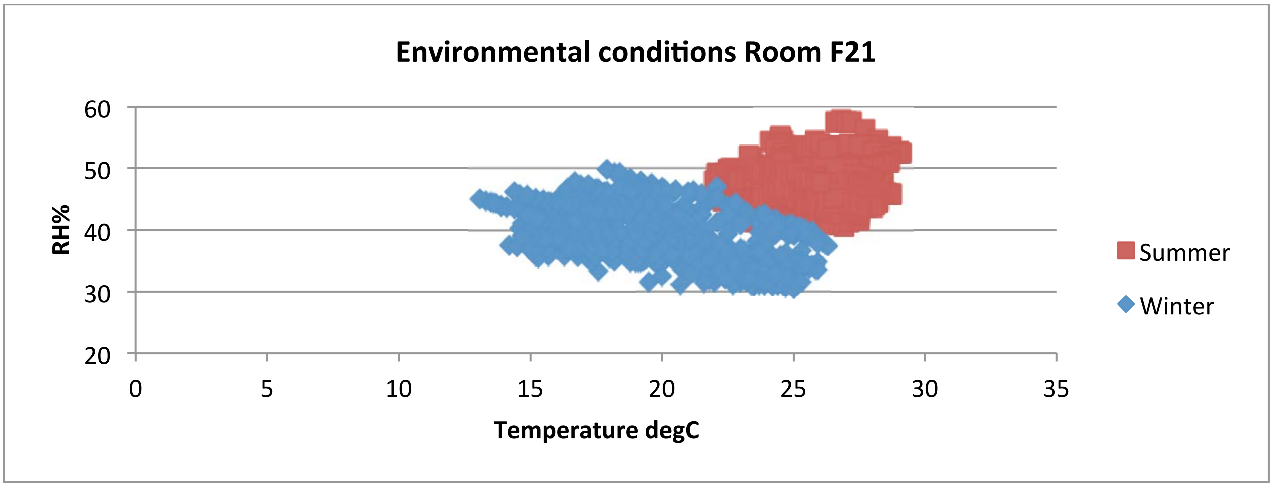
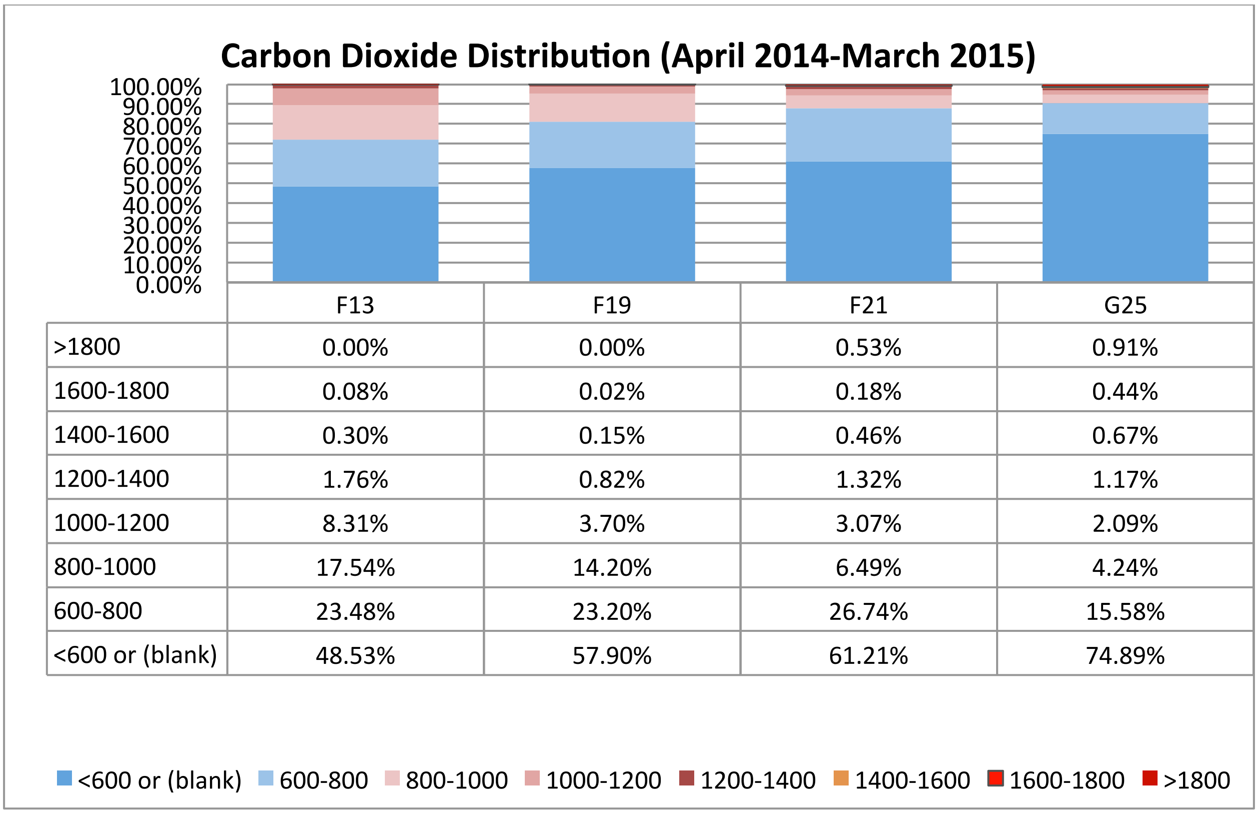


Figure 88 Environmental conditions in Room F21 during a winter (January) and a summer (July) month after the refurbishment

5.6.2.3 CO_2 concentration

As shown in Figure 89, the air quality in monitored offices is very good as over 70% of occupied hours are below 800ppm CO_2 concentration. In Room G25, 2.1% of occupied hours exceeded 1400 ppm CO_2 concentration due to the large number of occupants. These findings suggest that the MVHR system performing well.



	F13	F19	F21	G25
>1800	0.00%	0.00%	0.53%	0.91%
1600-1800	0.08%	0.02%	0.18%	0.44%
1400-1600	0.30%	0.15%	0.46%	0.67%
1200-1400	1.76%	0.82%	1.32%	1.17%
1000-1200	8.31%	3.70%	3.07%	2.09%
800-1000	17.54%	14.20%	6.49%	4.24%
600-800	23.48%	23.20%	26.74%	15.58%
<600 or (blank)	48.53%	57.90%	61.21%	74.89%

Figure 89 Percentage of occupied hours at a given CO_2 concentration range during 26 April – 30 June 2014

Figure 90 shows a comparison between CO_2 levels recorded during the months of February and March before and after the refurbishment in Room F13. It should be noted that the number of occupants remained unchanged. CO_2 levels before the refurbishment appear to be slightly lower. This is probably due to the high air-permeability levels of the old fabric.

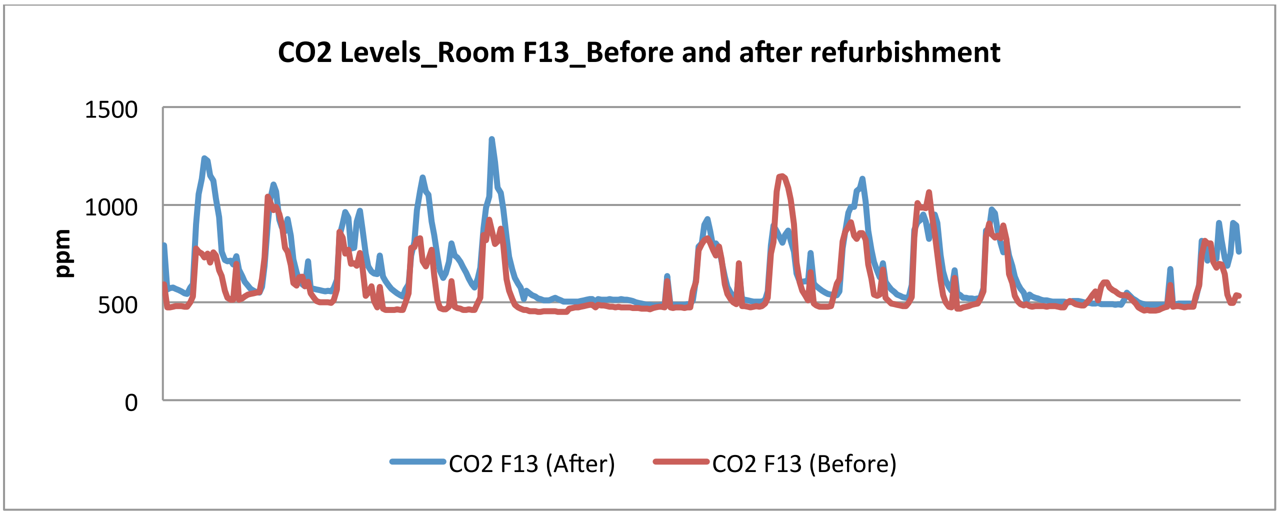


Figure 90 Room F13. CO_2 levels before and after refurbishment during winter (February-March 2013 Vs February-March 2015).

The CO_2 concentrations in a typical summer week (the starting at 13^{th} July 2014) and a winter week are illustrated in Figure 91 and Figure 92. They show that CO_2 concentrations reach peaks on Thursday evening and Saturday afternoon in the Council Chamber due to meetings. And the CO_2 concentrations in winter are generally higher than the concentrations in summer.

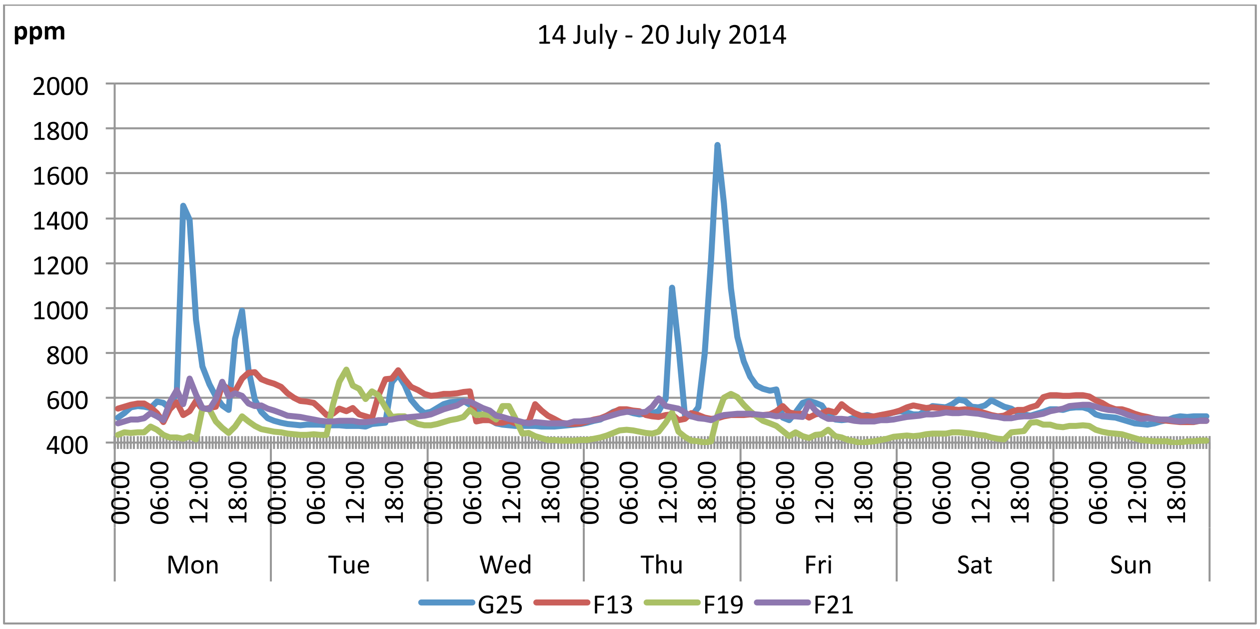


Figure 91 CO_2 concentration (ppm) in a summer week

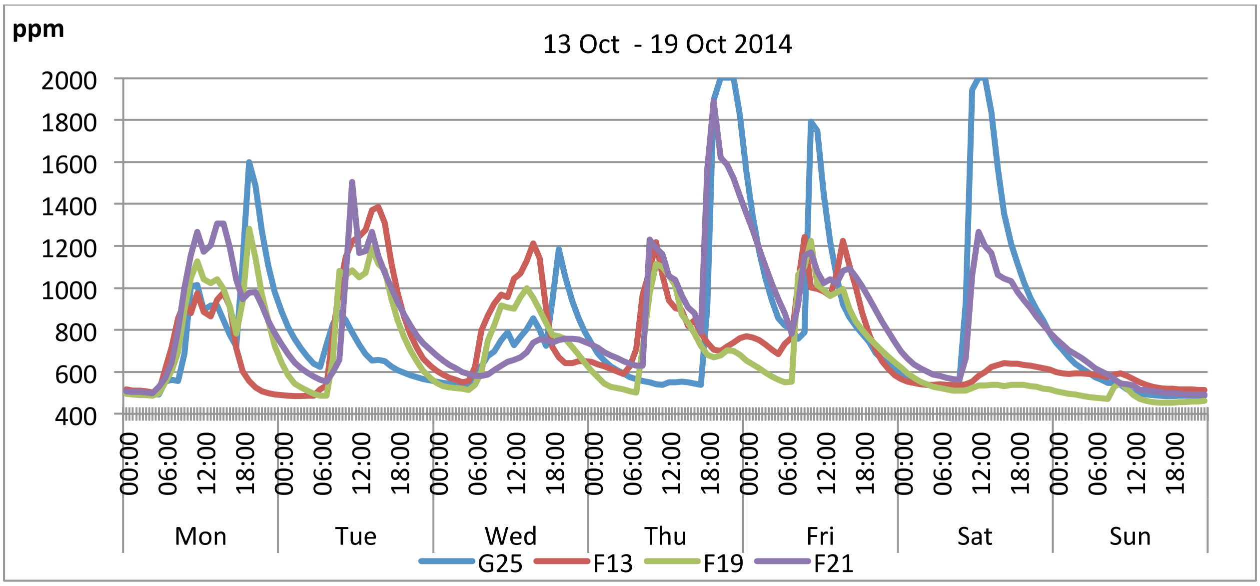


Figure 92 CO_2 concentration (ppm) in a winter week

5.6.2.4 Window opening

Monitoring data from window opening are cross-related with indoor temperatures in Figure 93-Figure 97 for the period of May to September. As noted by occupants windows mostly remain closed during winter. With the exception of Room G25 where window opening is automatically controlled, window opening occurs during occupancy hours. As can be seen in the graphs, indoor temperatures remain within comfortable levels and appear to drop when windows are opened.

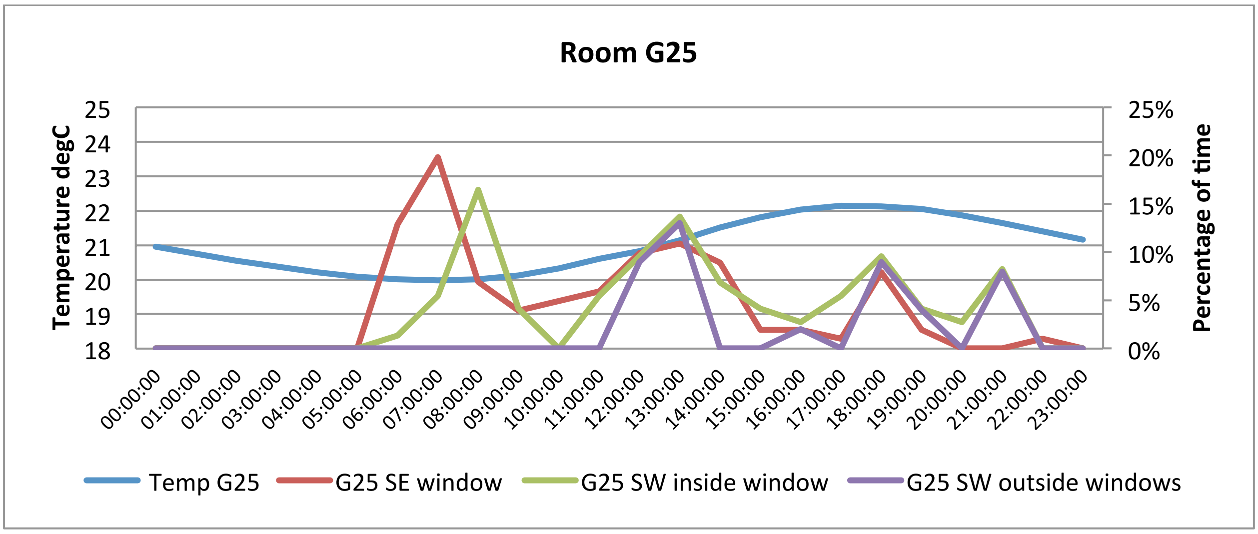


Figure 93 Room FG25. Window opening and indoor temperatures (May-September)

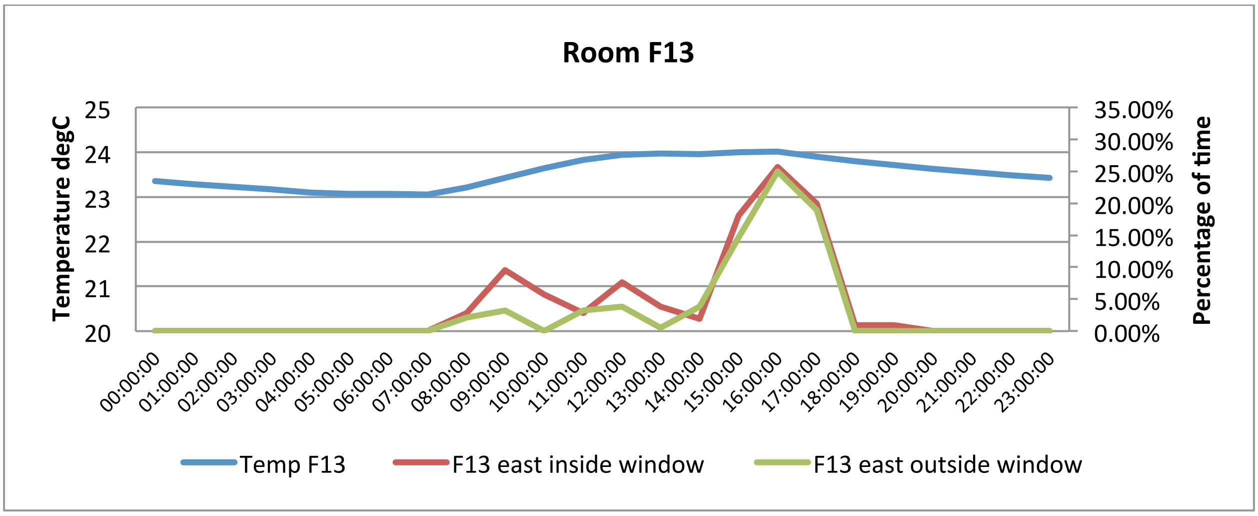


Figure 94 Room F13. Window opening and indoor temperatures (May-September)

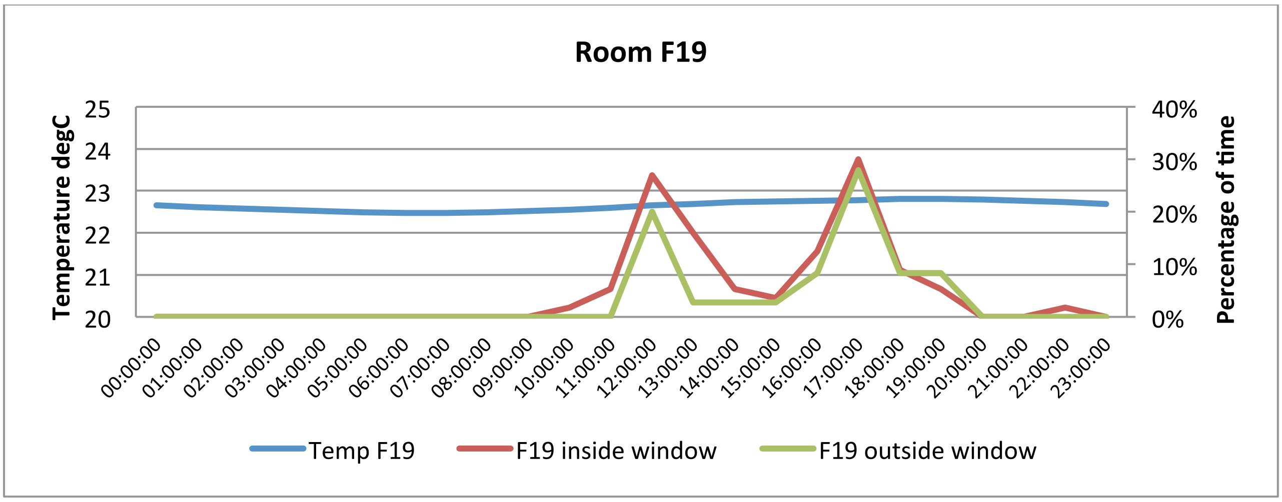


Figure 95 Room F19. Window opening and indoor temperatures (May-September)

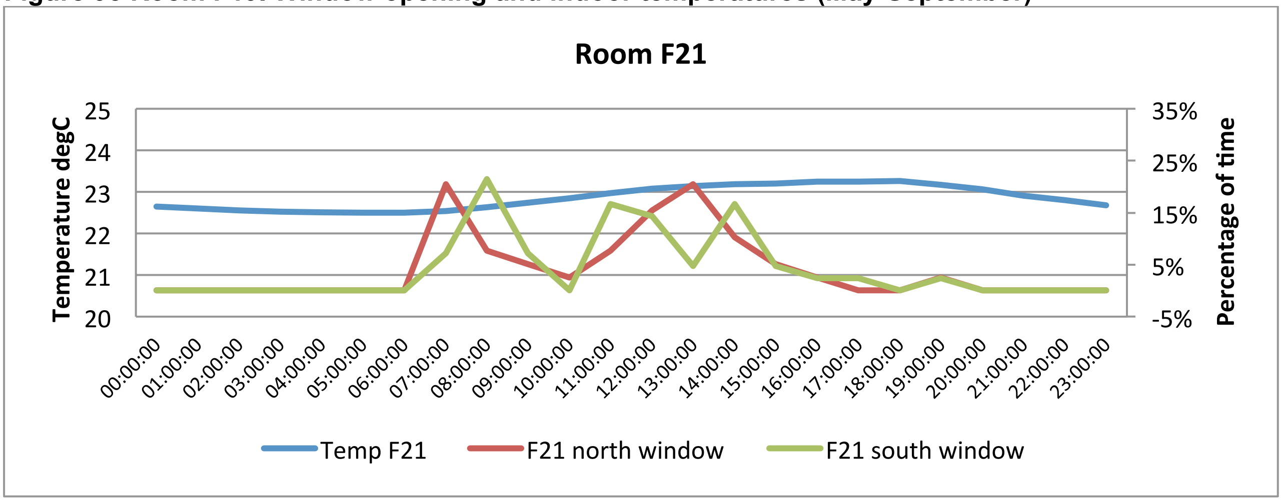


Figure 96 Room F21. Window opening and indoor temperatures (May-September)

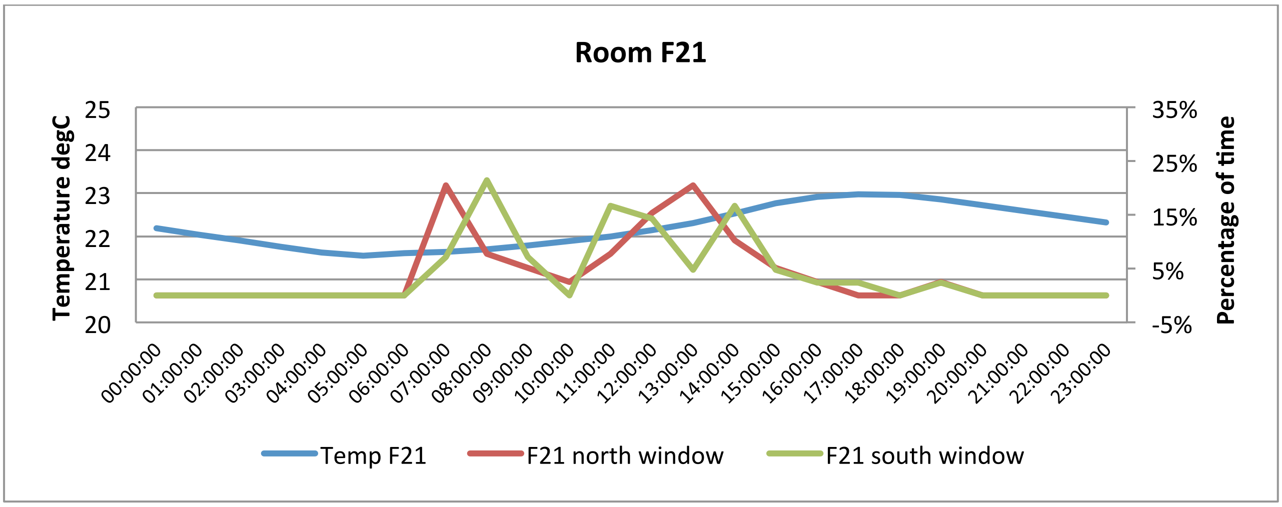


Figure 97 Room F21. Window opening and indoor temperatures (May-September)

5.6.2.5 Moisture level inside building fabric

In addition to the standard environmental building monitoring system, Omnisense moisture monitoring system, a web-based remote monitoring system for buildings, is installed to measure temperature, relative humidity, moisture content (also known as Wood Moisture Equivalent or WME) in the cavity construction formed behind the internal wall insulation. It is used to monitor the physical performance of behind the internal wall insulation. Sensors were installed to measure moisture content of external wall and timber stud at various locations

The moisture content of timber studs inside northwest wall of room G25, external wall of F20, southeast wall of F21were gradually reduced from 22% to 12% over the first three months (Figure 98). The moisture content of external wall (Figure 99) and floor joist (Figure 100) stays relatively stable. They all stay below 20% moisture content above which rot does not develop. Note that wood does not feel damp below 30% moisture content (at round 97% or 98% relative humidity).

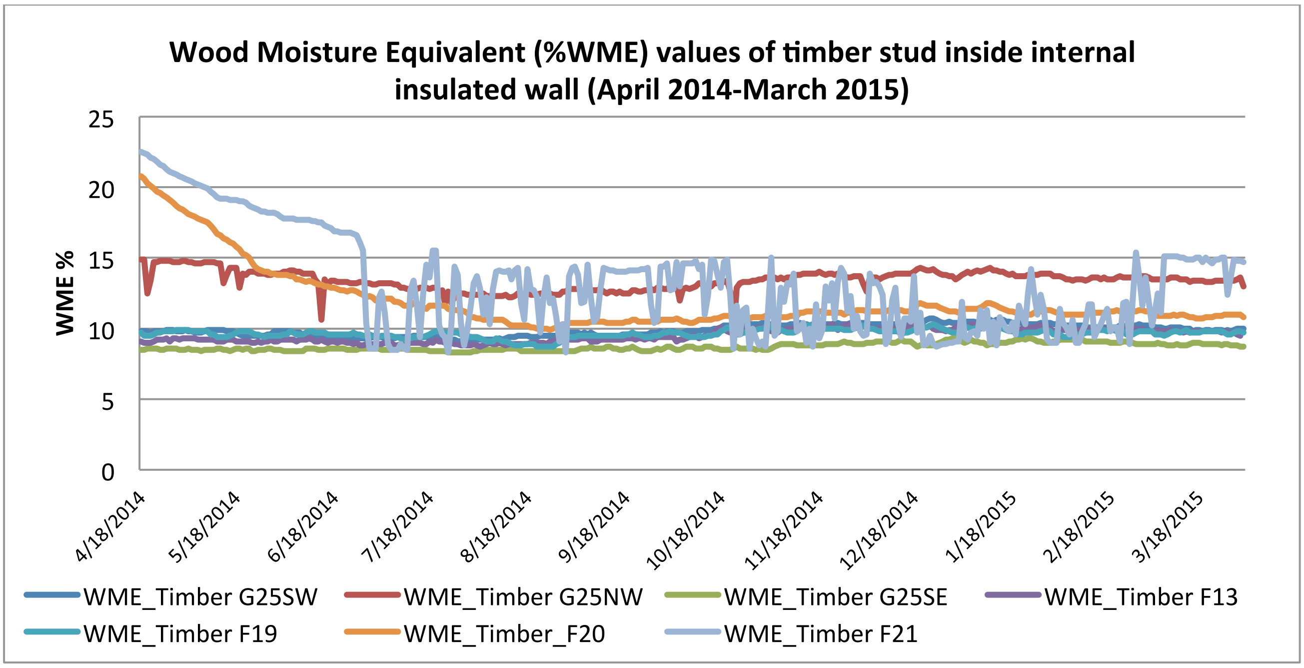


Figure 98 Wood Moisture Equivalent (%WME) values of timber stud inside internal insulated wall

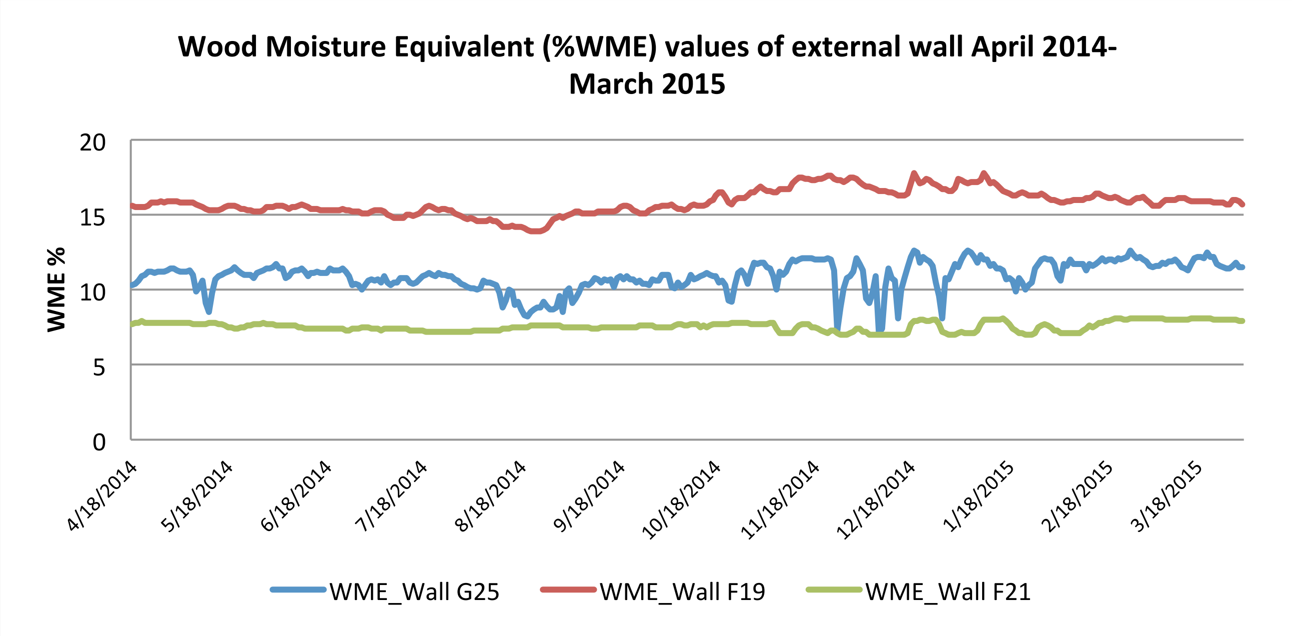


Figure 99 Wood Moisture Equivalent (%WME) values of external wall

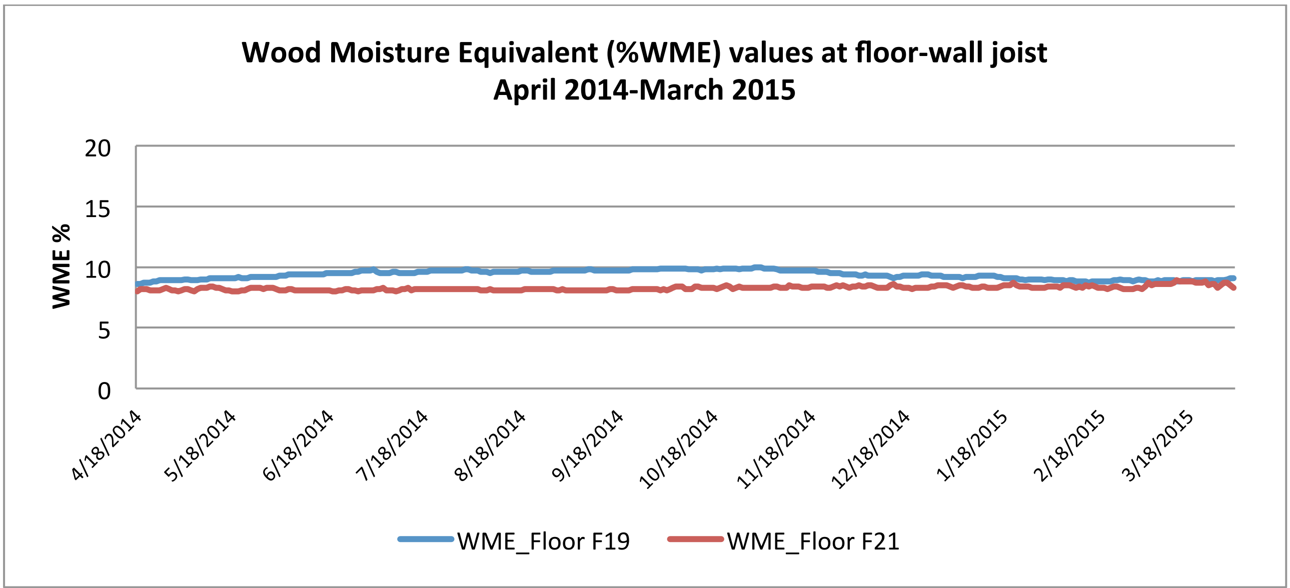


Figure 100 Wood Moisture Equivalent (%WME) values at floor-wall joist

5.7 Occupant feedback through BUS surveys and semi-structured interviews

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

The BUS questionnaire method was used to map the office staff reactions on whether the building meets their needs, including comfort and control. A BUS survey was undertaken twice in the Garth building: once before the refurbishment (November 2012) and once following the refurbishment (May 2015). The same number of responses (n=6) was collected in both occasions, during which building users filled the questionnaires and returned them in the same day.

The BUS analysis method is a quick and thorough way of obtaining feedback data on building performance through a self-completion occupant questionnaire; the results of which can be compared against a national benchmark database. The questionnaire prompts the respondents to comment on the building's image and layout, occupant control, and daily use of the building features and any general changes they have noticed since using the building. The BUS uses 'effectiveness' scales but also provides space for additional comments, if needed. The questionnaire variables are compared with their respective scales midpoint and BUS benchmarks to provide a slider showing the mean score across the 6 responses using green/amber/red lights depending on where it sits within the upper and lower limits of the scale midpoint and benchmark. The benchmark used is the UK non-domestic benchmark which forms of multiple non-domestic buildings in the UK.

In addition to the BUS survey, semi-structured interviews with occupants and walkthroughs also took place before and after the refurbishment, in order to further investigate any underlying issues with regards to the building's performance and overall user experience. All of the employees who participated in the BUS study and were interviewed had been working in the building for more than one year and have a good knowledge of the building. Therefore their responses are essential to understanding the building.

5.7.1 The building overall

The overall picture of the BUS survey conducted after the refurbishment revealed a very positive opinion of the staff members towards the building with almost all elements (with the exception of lighting and productivity) scoring higher than the benchmark (Figure 101). The design, image to visitors and response to occupant needs are the most appreciated elements. During the last interviews all occupants commented on how nice the building looks from the inside after the refurbishment and pointed out that this is a much nicer environment to work in. Also, office users mentioned that many visitors who were familiar with the old building are pleasantly surprised with the new environment and comment positively about it. Comments made during interviews report that 'The appearance of the building is smarter now. It's more welcoming as an employee and as somebody coming to visit the offices here' and '(following the refurbishment) it is a much nicer building to work in' and that 'The refurbishment has made the building look better and feel better'. Most occupants also reported that the outcome of the refurbishment has greatly exceeded their expectations. 'It looks a lot tidier, a lot smarter, a lot welcoming for people coming to council offices, it's a nice atmosphere for the staff to work in.'

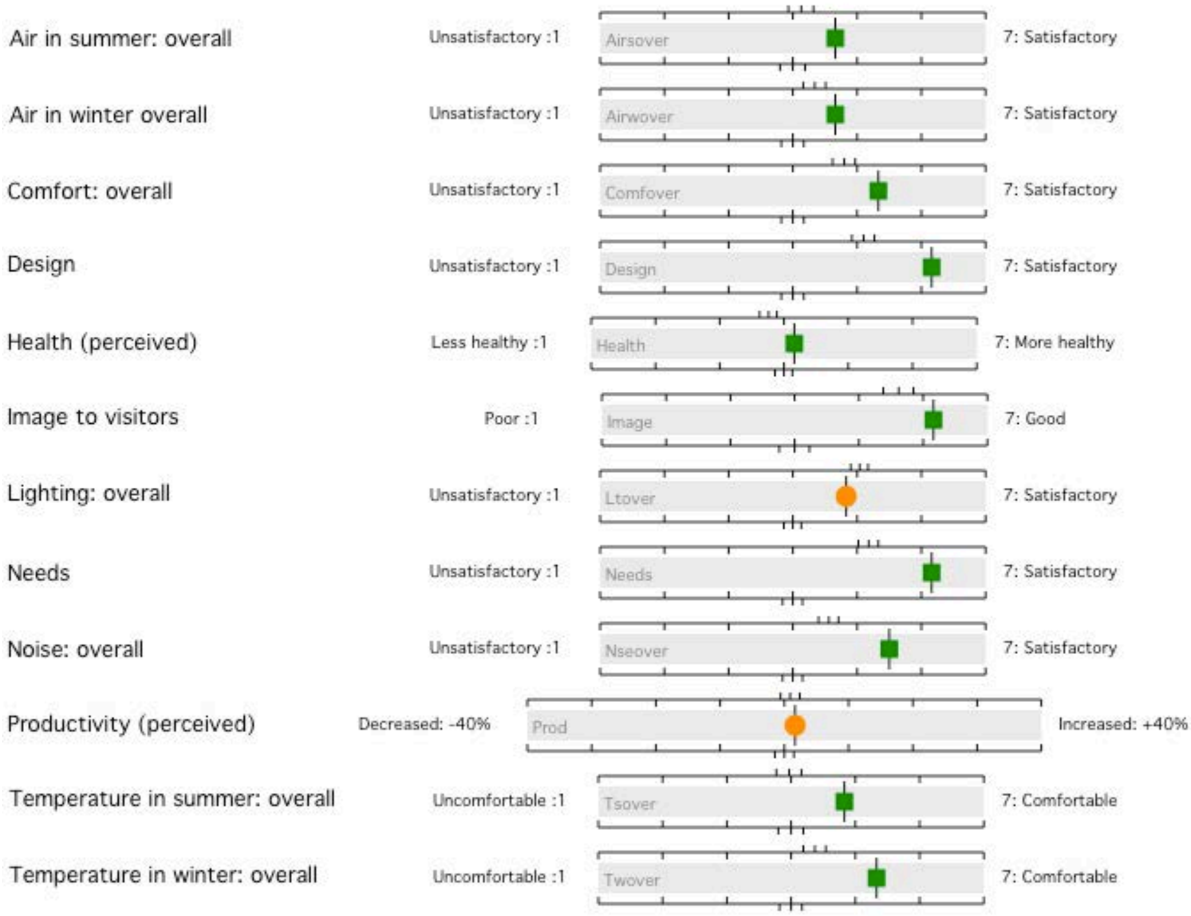


Figure 101. The building overall: after the refurbishment

It is interesting to compare these results, with the results of the BUS survey conducted before the refurbishment. Figure 102 shows an overall view of key factors of occupants' satisfaction about the Garth Building, where it can be observed that the overall view is not positive by the dominance of amber and red markers. As can be seen, the only element that scores above the benchmark is noise. All the other factors score within or below their respective benchmarks. Occupants find temperature and air quality unsatisfactory. This would relate strongly to the information gathered from the in-use monitoring (See Section 5.6.2). Interviews with occupants conducted before the refurbishment also revealed that occupants find the air in the building to be stuffy. As well as that, productivity is considered to be below the benchmark. Interestingly, during the second interviews (May 2015) when asked about the effect of the refurbishment on their productivity levels, occupants reported that their productivity levels had not changed: 'It has had no effect on my productivity although it is a nicer atmosphere to work in'; 'I don't think it has affected productivity. We all work very hard. But it's a much more pleasant environment which should help with productivity I suppose'; 'I haven't noticed that I've been more productive or less productive. It's more pleasant because it looks better'. However, the comparison of the two BUS results shows an increase in the rating of productivity. It can be argued that the positive effects of the refurbishment on comfort, makes the occupants more positive in their responses in general.

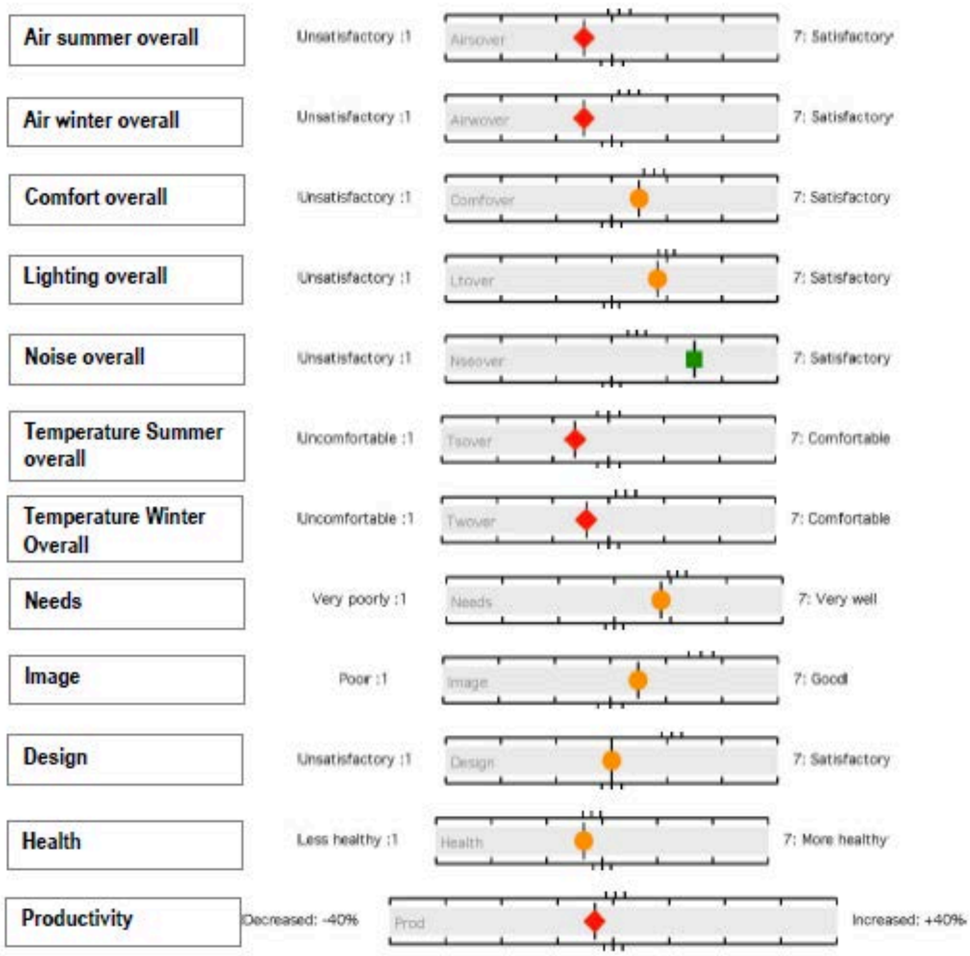


Figure 102 The building overall: before the refurbishment

5.7.2 Comfort

The staff members were asked about their comfort perception within the building relating to the air temperature and quality, noise, lighting, ventilation and level of personal control of these elements. All the participants (6 out of 6) felt that the building was comfortable overall, with comfort scoring higher than the upper end of the benchmark confidence limit (Figure 103).

The overall design of the building was highly rated with all of the respondents (6 out of 6) feeling satisfied and stating that the provided facilities met their needs very well. Both elements scored close to the higher end of the scale and higher than the benchmark. Positive comments were received during interviews regarding the rearrangement of the desks in the shared office room (F13) after the refurbishment.

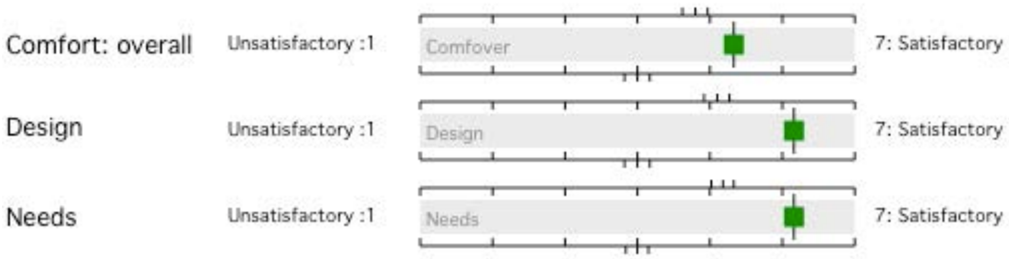


Figure 103. Overall comfort, design and needs: after the refurbishment

5.7.3 Temperature

The BUS questionnaires revealed that most people find the spaces comfortable during winter (5 out of 6 participants) and summer (6 out of 6) (Figure 104 and Figure 105). Comments received during the second interviews pointed out that the comfort conditions in terms of temperature had greatly improved during both seasons, with the use of individual heater and fans greatly being reduced following the refurbishment. Occupants commented: ‘In the past we nearly all had an electric heater. We don’t need them as much, at all now. And the heating thing has been fixed, I may not need one this winter. Before there was at least one heater per person, so probably about 4 and now there’s probably one’, ‘In the summer we used to get fans out to move the air around whereas with this summer we did notice quite a difference with opening the window. We all had a fan each (before)’. Indoor temperature monitoring data also shows that spaces are within the comfort limits during occupancy hours (See Section 5.6.2). Results regarding the ‘hot/cold’ element of temperature are rated below the benchmark during both winter, however, a closer look reveals that only 1 out of 6 respondents considers temperatures to be ‘too cold’. Instead, the majority of respondents rated temperatures as ‘neutral’ (scale midpoint) during both seasons.

Comments received during interviews mention that ‘The refurbishment has succeeded in making the building warmer and less draughty’ and that ‘In winter it used to be very cold and this winter was much more comfortable in terms of extremes in temperature and obviously there’s not the draught through the windows’ and also that ‘In the winter, yes we have noticed warmer conditions. The radiators are not used on full power all the time and the heating system is not being worked as heavily as it should so we have noticed a big impact.’ One of the interviewees reported a localised problem that affects their comfort: ‘I feel cold at my desk area as I sit right under the MVHR inlet and away from the radiator.’ The occupant pointed out that they achieve comfort by wearing extra layers of clothing. This localised issue had not been reported to the management. Occupants reported that summer temperatures were also more comfortable: ‘In the summer it’s been much nicer because we have those (new) vents so we can open the windows at the back and open the windows in our office, so it was lovely breeze coming through’. No overheating issues were reported.

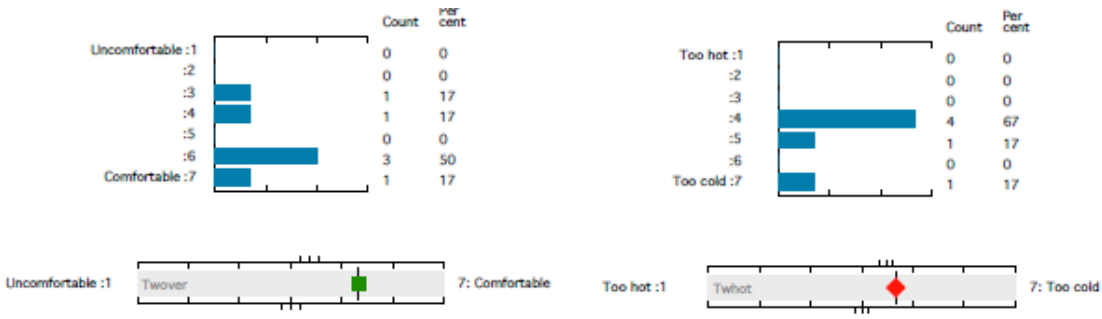


Figure 104 (Left) Temperature in winter overall. (Right) Temperature in winter: hot/cold. After the refurbishment

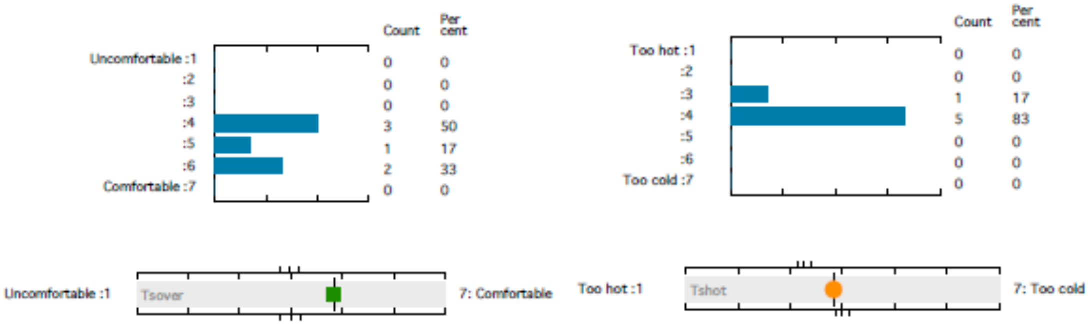


Figure 105 (Left) Temperature in summer overall. (Right) Temperature in summer: hot/cold. After the refurbishment

Results from the first BUS survey show that before the refurbishment, temperatures during both summer and winter were not considered comfortable (Figure 106), with the elements scoring below the respective benchmarks. Temperatures were considered ‘too hot’ during summer and ‘too cold’ during winter, leading to the use of fans to promote air movement during summer and electric space heaters during winter. The use of these appliances, as well as the use of continuous gas heating during winter to achieve comfort, reflected on the annual energy use of the building.

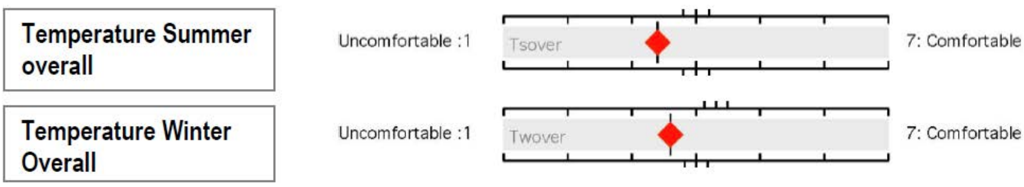


Figure 106 Temperature in winter and summer: before the refurbishment

5.7.4 Air quality

Air quality overall is considered satisfactory, scoring higher that the scale midpoint and higher than the benchmark during both winter and summer (Figure 107).

However, air is considered somewhat ‘smelly’ by the majority of the respondents (5 out of 6) during both seasons (Figure 108). Also, 2 out of 6 respondents find the air ‘still’, but only 1 out of 6 find it ‘stuffy’, during winter and summer. Most comments collected during the interviews point out that air quality has improved. The manager mentioned that ‘The air quality is much better than it used to be. The MVHR has improved the air quality considerably from the way it used to be in both winter and summer. No draughts or noise issues have been reported to me'.

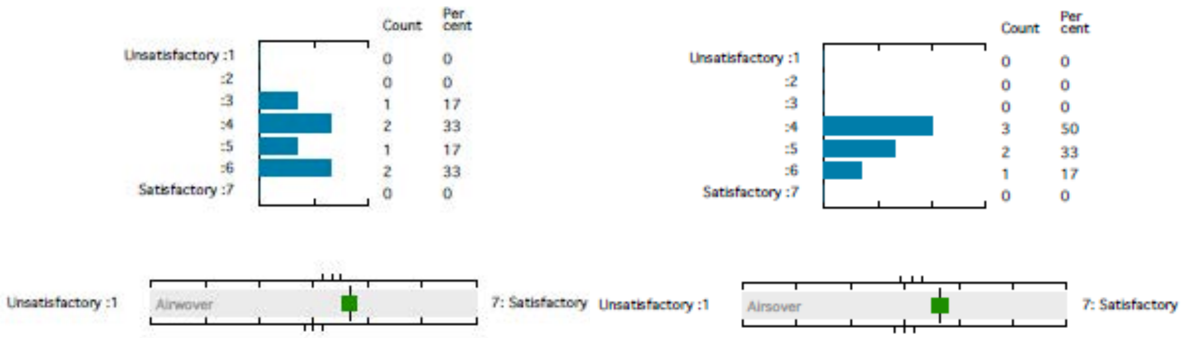


Figure 107 (Left) Air in winter overall. (Right) Air in summer overall. After the refurbishment

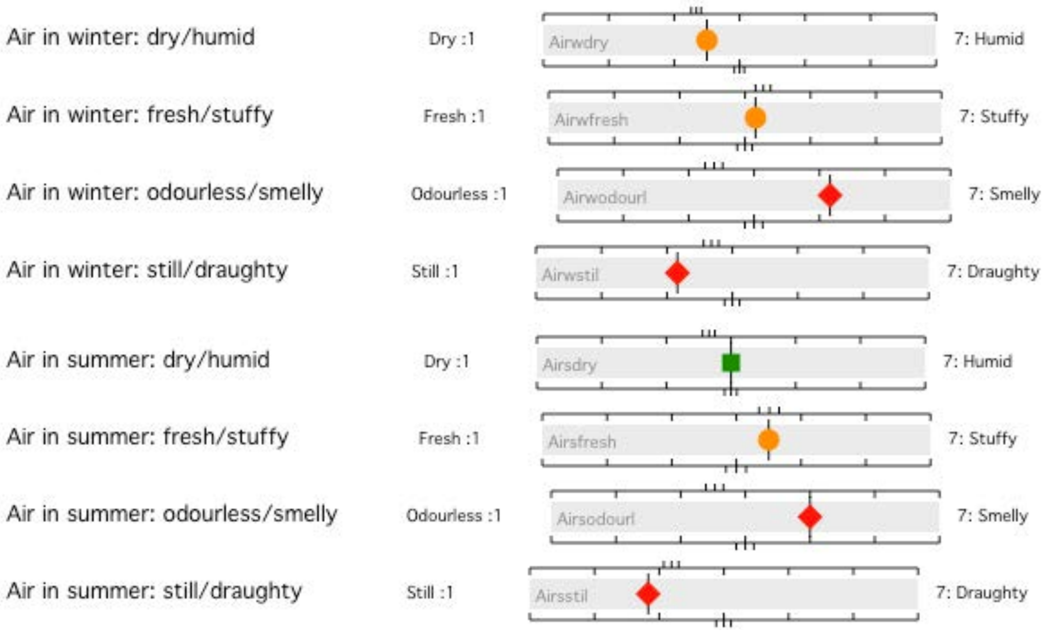


Figure 108 Air quality parameters: after the refurbishment

Results from the BUS survey conducted before the refurbishment were significantly worse (Figure 109 and Figure 110), with all elements and air quality overall scoring below the benchmarks. Occupants had commented that 'The building can smell at times. An old fusty smell from the age of the building.' and 'The more people in the building, the more musty it becomes.'

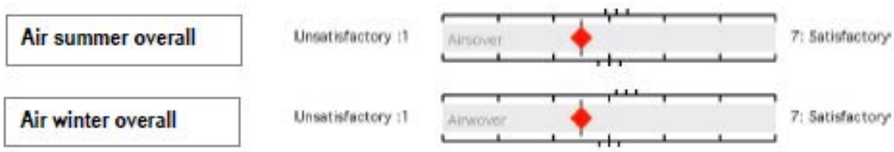


Figure 109 Air quality overall during winter and summer: before the refurbishment

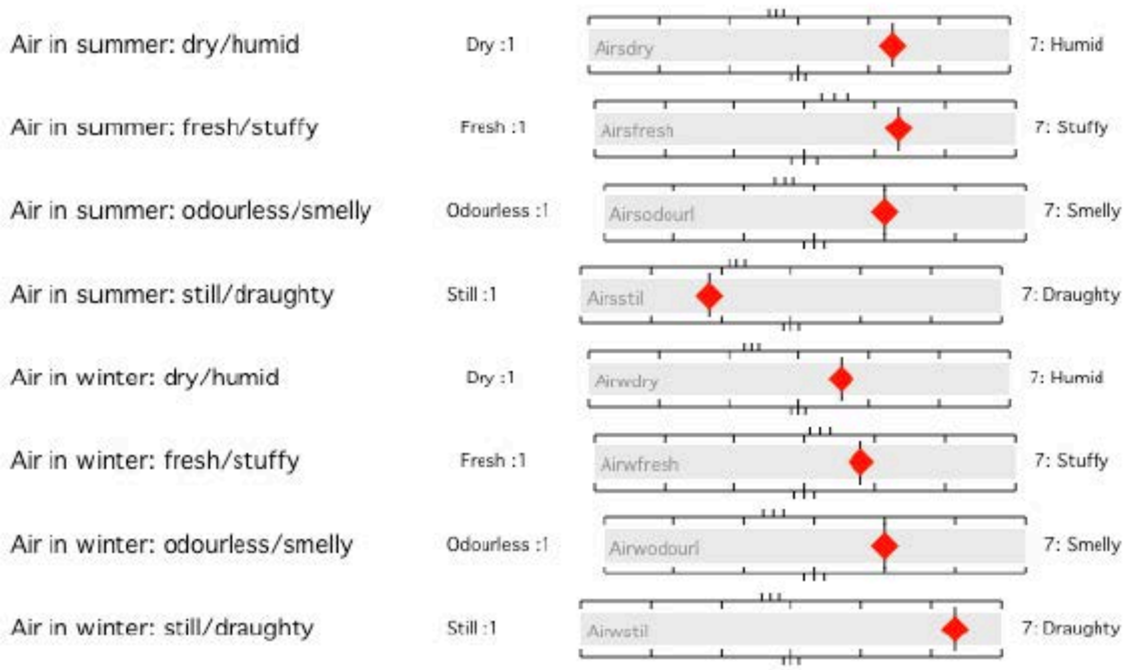


Figure 110 Air quality parameters: before the refurbishment

5.7.5 Lighting

Lighting overall scored similar to the benchmark and above the scale midpoint (Figure 111). These results are similar to the ones collected during the pre-refurbishment BUS survey, which was expected, as the refurbishment did not involve any measures regarding lighting. As shown in Figure 112, artificial lighting scored below the benchmark and towards the ‘too much’ end of the scale, however, 4 out of 6 respondents find artificial lights to be satisfactory. Natural lighting also scored below the benchmark, with 2 out of 6 respondents finding it ‘too little’. One respondent added in the BUS comments that ‘Can find overhead lighting a little too bright. Unable to switch off individual lights. Colleague has had light bulbs removed from lights above her.’ The same was reported during interviews: ‘The light in our office is a big issue because before each strip of light had its own switch and now they are all controlled by one switch, so the one close to the window we took the bulb out because we don’t want that light on. Very rarely do we want that on especially when it’s sunny’.

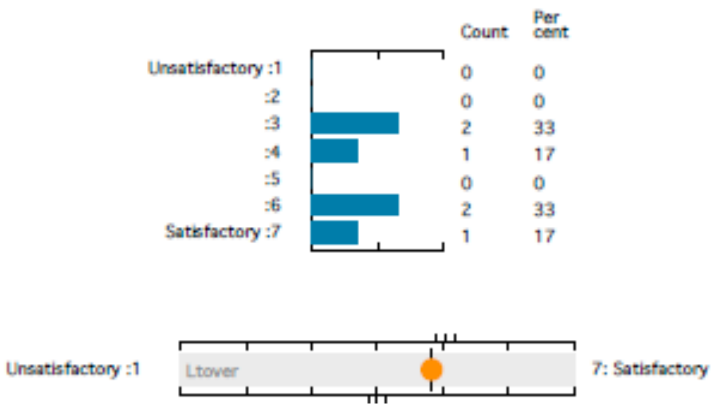


Figure 111 Lighting overall

Figure 112. (Left) Artificial lighting. (Right) Natural lighting

5.7.6 Control

Control over heating and cooling scored above the benchmark and above the scale midpoint (Figure 113). The majority of the respondents (4 out of 6 and 5 out of 6) feel they have good control over heating and cooling respectively. Control over lighting, noise and ventilation scored within the benchmark. During the last interviews, occupants reported that they do not control the heating thermostat (which is controlled by the manager), but do control the radiator valves. Despite the positive rating however, it was revealed during the interviews that the manager was not very familiar with the operation of the thermostat. Furthermore, the other member of staff involved in the operation of the building was mistaken about the location of the new thermostat control. As mentioned in Section 5.3.2, the old thermostat control (located in the Ground Floor) has not been removed thus creating some confusion among building users.

Interviewees reported being satisfied with their control over the windows and point out that the internal layer of double-glazing installed provides them with more adaptive opportunities. Also, positive comments were made about the air vents installed on the wall between Room F13 and the corridor. Occupants reported that these allow for good cross ventilation during the summer, improving comfort levels and reducing overheating. 'We open the windows regularly in my room (F13) but not so much in the winter. But sometimes, occasionally when it gets a bit stuffy we will open the windows. We open the inner one to cool down the room. In the summer, we open them throughout the day on both sides and if it gets warm (like this) it stays open, we don't shut them at night either. In the room with the vents, we open the corridor windows and we can feel the breeze in there'

As shown in Figure 114, before refurbishment, control over cooling had scored lower. However, control over lighting had scored higher. This is related to the fact that after the refurbishment lights in room F13 are only controlled by one switch, which creates some control issues and conflict among office users, as reported above.

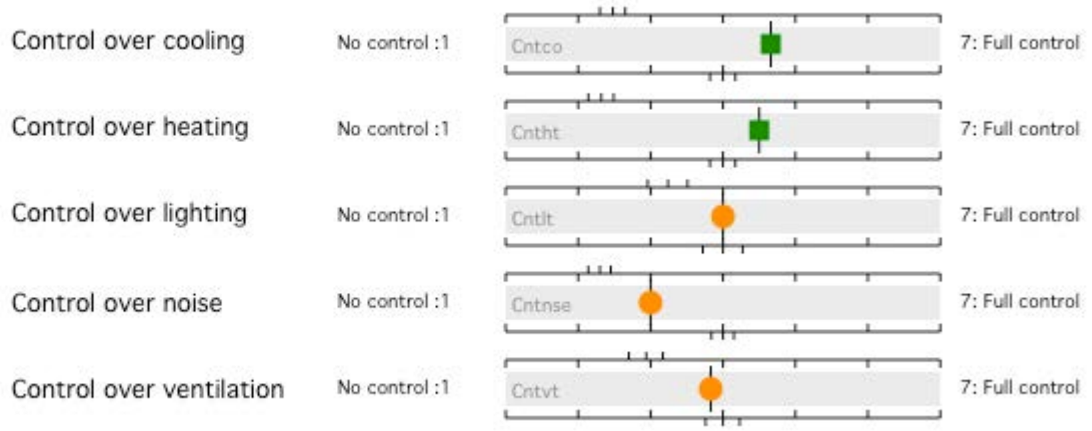


Figure 113 Control after the refurbishment

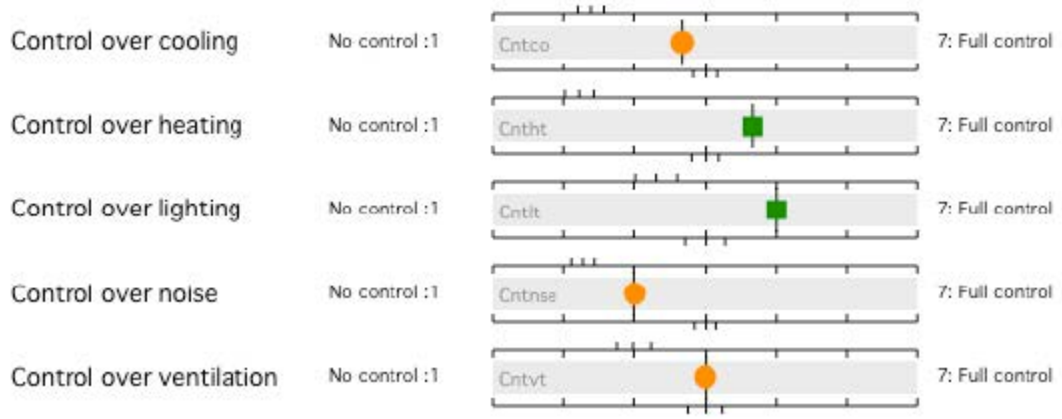


Figure 114 Control before the refurbishment

5.7.7 Facilities management

Elements related to cleaning, furniture and perceived health all scored above the benchmark (Figure 115). The same applies for elements such as space in the building and storage space available. Space at desk scored below the benchmark, falling towards the high ('too much') end of the scale. The administration staff sharing Room F13 reported that: '(The refurbishment) made us utilise the space better. I wouldn't say that I feel we've got more or less space' and 'We gained a little bit of space in our room. We fit in a bit better. Where I was sat before wasn't ideal but now it works better'.

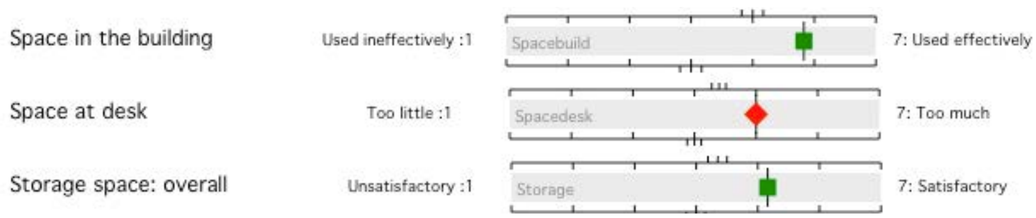


Figure 115 Facilities management elements: after the refurbishment

5.8 Conclusions and key findings

5.8.1 Fabric performance

- Before the refurbishment Air Permeability was measured at 20.52 $m^3/h.m^2$ @50Pa on the Ground and 1st Floor and at 44.80 $m^3/h.m^2$ @50Pa on the Attic. After the refurbishment air permeability on the Ground Floor and First Floor was reduced at 10.62 $m^3/h.m^2$ @50Pa. Several air leakage paths were identified around door and window frames, floor voids, skirtings and glazing seals.
- Thermal imaging after the refurbishment showed some heat loss patterns through the roof-wall junction and between floors. Despite this, the envelope performance has very much improved after the refurbishment. The heat loss through windows after refurbishment is less than the heat loss before refurbishment. Some thermal anomalies were also identified.

5.8.2 Handover and occupant training

- Although several minor problems have been identified during building handover, users are very satisfied about building's performance and available facilities that fit for purpose.
- The issues identified were automatic windows in conservatory, heating control and valve.
- Regular communication, building user guide and handover meeting tremendously helped building user understand the design intend and how to operate the building effectively.
- O&M manuals are incomplete.
- A building logbook does not exist on-site and any maintenance schedule is documented in the building manual.
- Feedback and recommendations are also provided to the Garth building project team so as to improve management of the building activities, and inform handover processes of future developments. These include:
- Design intent: End-user requirements should be carefully considered during design stage. In addition, effective communication among contractors, facility manager and users is a vital element for ensuring smooth operation of the building.
- Seasonal commissioning and aftercare: Seasonal commissioning of services after defects period would improve building performance and identify any under-performing systems and controls.
- Training and familiarisation of occupants: Videos of demonstrations and training would make knowledge transfer easier. Furthermore, demonstrations of building systems and controls should be scheduled to take place more than once when new operators join the building management team.
- Handover documentation: Although the full set of O&M manuals is not required for refurbishment projects, it would be a good opportunity to fill the missing documents which are important to building operation, such as building log book. User guide is also very important part of handover documentation and should be available on-site to inform users about building systems and controls.

5.8.3 Performance of systems and controls

- The MVHR system is not installed and commissioned properly. There is a large amount of leakage into ceiling voids due to the way the ceiling terminals have been installed. This issues needs to be fixed before re-balancing the system.
- Supply and extract terminals used are mixed up and supply air terminals positions on the drawing are, in fact extract air, and vice versa.
- The air flow on each fan setting is below the stated performances, and the system is out of balance. This issue needs to be addressed.
- The User Guide provides useful information regarding the design intentions for some of the new controls and their location. All the controls are accompanied by operation and installation manuals that were included in the O&M manual.
- The space heating control strategy is confusing as there are several controls installed in the building and the override strategy is not clear: the Honeywell thermostat on the first floor, the old thermostat on the ground floor and the boiler control panel.
- Occupants did not find the touch screen Honeywell thermostat intuitive and were not able to control the temperatures effectively. There was not a good indication of system response and the users were not sure whether the control is actually connected to the boiler. The control panel was subsequently removed due to poor connection with the boiler, and heating is controlled directly from the boiler thermostat located at the First Floor WC. The fact that the old thermostat control has not been removed after the refurbishment creates further confusion and occupants are not sure whether this control is still in operation.
- The individual radiator valves in the first floor offices are easy and intuitive to use. The wireless Honeywell radiator valves that had been placed on the ground floor radiators were recently removed but have not yet been replaced by another type of valve, thus limiting control in these spaces.
- The presence of some old electrical sockets that are no longer in use creates confusion to the occupants as they are not aware of their purpose.
- The new double glazing casement windows that were fitted after the refurbishment are easy to use and fully openable allowing good access to the original single glazing sash windows.
- The MVHR unit is easily accessible and is easy to operate. However, the control is not intuitive and a simple User Guide would be useful.
- The MVHR boost is located in the kitchen but its purpose is not clear and there is no indication of system response. The grilles are not locked in fixed positions. This could potentially undermine the system balance.

5.8.4 IES modelling

- The results from IES Model B indicate that improved airtightness achieves 11% energy saving and 7% CO_2 emissions reduction from Base Case, insulation of external walls achieves a further 22% energy saving and 16% carbon saving, floor insulation achieves a further 33% reduction in energy and 24% carbon saving. Model B shows that the package with all the refurbishment measures achieves a 58% energy saving and a 48% carbon savings.
- IES Model A prediction was similar, as the energy savings were also estimated at 58%, and carbon savings were estimated at 37%.

5.8.5 Energy data

- The annual electricity consumption from 26 February 2013 to 12 February 2014 was 16,981 kWh (51.3 kWh/m^2/year) which equates to carbon dioxide emissions of 22.8kg CO_2/m^2/year. The annual gas consumption is 64,223kWh (194.0 kWh/m^2/year) which equates to carbon dioxide emissions of 35.7 kg CO_2/m2/year (Figure 54). Gas took 79% of total energy consumption and 61% of Carbon emission.

- After the refurbishment monitoring data show that there is 67% reduction in gas consumption and 22% reduction in electricity.
- Peak electricity loads are reduced after refurbishment, as a result of the reduced usage of electric heaters. Gas usage changes greatly. Before refurbishment (winter 2014), heating was on continuously reaching a peak of 10kW at 9am. After the refurbishment a strict heating schedule is applied, with heating on only during occupancy hours. Gas use peaks again at 10am, reaching 17kW.

5.8.6 Environmental data

- After the refurbishment, temperatures in most rooms range between 15-23^{o}C during winter and 20-26^{o}C during summer.
- Indoor temperatures in Room G25 present a much greater fluctuation after the refurbishment usually ranging from 15 to 23^{o}C throughout the day. Before the refurbishment, indoor temperatures ranged between 20-25^{o}C. These patterns are directly related to the heating schedule profiles used before and after the refurbishment, and have a direct effect on energy use.
- Indoor temperatures in Room F13 also present a much greater fluctuation after the refurbishment. Temperatures after the refurbishment range from 20 to 26^{o}C, whereas before they used to range between 21-24^{o}C (heating on continuously). It can be seen that following the refurbishment higher temperatures can be achieved in the room during occupied hours even though the heating is on for far less amount of time than before. This is a result of the reduction of heat loss through ventilation and fabric.
- Overheating analysis using the Adaptive Comfort criteria and following BS EN 15251 did not show any occurrence of overheating in any of the rooms.
- RH levels during winter before refurbishment were low, ranging between 20-40%, as a result of continuous heating. After the refurbishment, and with the help of the MVHR system, RH levels during winter range between 30-40% in Room F13 and 35-55% in Room G25, values that are closer to the CIBSE recommended limits of 40-70%
- The air quality in monitored offices is very good as over 70% of occupied hours are below 800ppm CO_2 concentration. In Room G25, 2.1% of occupied hours exceeded 1400 ppm CO_2 concentration due to the large number of occupants. These findings suggest that the MVHR system is performing well.
- As noted by occupants windows mostly remain closed during winter. With the exception of Room G25 where window opening is automatically controlled, window opening occurs during occupancy hours. Monitoring data shows that indoor temperatures remain within comfortable levels and appear to drop when windows are opened.
- The moisture content of timber studs inside northwest wall of room G25, external wall of F20, southeast wall of F21 gradually reduced from 22% to 12% over the first three months. The moisture content of external wall and floor joist stays relatively stable. They all stay below 20% moisture content above which rot does not develop.

5.8.7 Occupant feedback

- The overall picture of the BUS survey conducted after the refurbishment revealed a very positive opinion of the staff members towards the building with almost all elements (with the exception of lighting and productivity) scoring higher than the benchmark.
- The design image to visitors and response to occupant needs are the most appreciated elements.
- Before the refurbishment results were very different and overall view is not positive. The only element that had scored above the benchmark was noise. All the other factors score within or below their respective benchmarks. Occupants found the temperature and air

quality unsatisfactory. This would relate strongly to the information gathered from the in-use monitoring

- The BUS questionnaires revealed that most people find the spaces comfortable during winter (5 out of 6 participants) and summer (6 out of 6).Comments received during the second interviews pointed out that the comfort conditions in terms of temperature had greatly improved during both seasons, with the use of individual heater and fans greatly being reduced following the refurbishment.
- Results from the first BUS survey show that before the refurbishment, temperatures during both summer and winter were not considered comfortable, with the elements scoring below the respective benchmarks. Temperatures were considered ‘too hot’ during summer and ‘too cold’ during winter, leading to the use of fans to promote air movement during summer and electric space heaters during winter.
- Air quality overall is considered satisfactory, scoring higher that the scale midpoint and higher than the benchmark during both winter and summer.
- Results from the BUS survey conducted before the refurbishment were significantly worse with all elements and air quality overall scoring below the benchmarks.
- Lighting overall scored similar to the benchmark and above the scale midpoint. These results are similar to the ones collected during the pre-refurbishment BUS survey, which was expected, as the refurbishment did not involve any measures regarding lighting.
- Control over heating and cooling scored above the benchmark and above the scale midpoint. The majority of the respondents feel they have good control over heating and cooling respectively
- Interviewees reported being satisfied with their control over the windows and point out that the internal layer of double-glazing installed provides them with more adaptive opportunities. Positive comments were made about the air vents installed on the wall between Room F13 and the corridor. Occupants reported that these allow for good cross ventilation during the summer, improving comfort levels and reducing overheating

6 Learning from work on this project

6.1 Approach to Project

The best practice approach to low energy refurbishments, and particular in a historical context is a careful analysis of the existing building and its use by its occupants. After this primary consideration the approach was orientated around the opportunities and limitations of the WHISCERS™ system. There was very limited flexibility from the WHISCERS™ installer to modify or develop the system for the specific needs of the project.

Any future approach to a similar project would place greater emphasis on integrating the project team and supply chain with better lines of communication from design team to subcontractors carrying out the works. The primary difficulties in this project came about from this factor rather than a problem with the innovative technologies.

6.2 Stakeholders

In general the partnerships between members of the project team worked effectively. Bicester Town Council was kept informed at all stages of the process and there was an integrated design team. Ridge and Kingerlee are experienced in working together while Oxford Brookes University and Bioregional have significant experience working on innovative low carbon projects. Time and care was also given to understanding the needs of the occupants. As documented in this report the WHISCERS™ contractor, as a key stakeholder, was not successfully integrated into the aims and process of the project. Greater success could have been achieved had the relationship with the patent holder and the WHISCERS™ contractor been more collaborative.

6.3 Development of the project plan

The project plan was kept to closely with the build phase completed on time. However an extension of time was requested and accepted to allow for a full year of monitoring data.

6.4 Critique of Methodology

Notwithstanding the limited integration of the WHISCERS™ installer, the project was successful. The individual elements of the design were integrated to improved the entire thermal envelope of the building. The improved airtightness along with improved air quality enhances the internal comfort levels beyond purely insulating the external walls.

A detailed electrical survey of the building prior to insulation works resolved rewiring issues as enabling works. This was important as all electrical sockets were extended through the internal insulation and prevented any re-commissioning issues.

Some typical site management issues occurred by having two principal contractors (e.g. no clear line of contractual responsibility). As documented there were issues with on-site supervision and subcontractors competencies during the WHISCERS™ installation. This methodology was necessitated by the WHISCERS™ contractor insisting on not being a subcontractor to the principal contractor. For future projects the license or patent holder should avoid this approach to mitigate the project management issues that occurred in this study.

6.5 Future developments and market penetration

Market penetration is deemed fully possible with the following developments:

- Greater training and supervision for WHISCERS™ installers
- The development of partnerships to create turn-key solutions which integrate all of the retrofit elements with WHISCERS™ system
- Development of an affordable advanced survey with issues of design liability resolved
- Integration of other building surveys for existing services that may be concealed or reused
- The use of collaborative contracts and delivery mechanisms
- Use of a larger CNC machine to increase minimum insulation board dimensions
- Use of a local or on-site CNC machine to reduce transportation issues
- Allow full size uncut board to be installed to reduce number of joints and fixings
- Investigation of a variety of insulation types including natural and breathable insulation boards
- The decision of the patent holder to further develop WHISCERS™ in a non-domestic and heritage context

Experience from this project suggests that multi-skilled workers are unlikely to be economically viable solution. This is due to the high and uncompetitive cost of a multi-skilled worker in comparison to a multi-skilled team.

The integration of the insulation / secondary glazing and use of ventilation strategies are concepts that could be reviewed for appropriateness in any other building.

The aerogel insulation was successful and provided an effective solution for ground floor insulation with minimal loss of ceiling height and effect on historical features. Although existing flooring was concealed, this was not considered of significant historical value.

MVHR. The use of small section 75mm flexible ducting for the MVHR was easier to install in comparison to standard rigid ductwork. The design development from individual through wall MVHR units resulted in a reduced heritage impact.

6.6 Feed back to project participants

A series of public dissemination events were held; including talks, national conferences and press articles. A public facing report is also being produced for a non-technical audience.

The occupants of the building were often consulted from Building User Surveys, a building user manual, inclusion in the design process and building occupant training.

This report and other information have been shared with the then WHISCERS™ license holder and a copy of the final report will be given to the patent holder.

7 Extending this solution to other buildings

7.1 Application to future project and suitability of UK buildings for the system

WHISCERS™ could applicable to any building under the right management conditions. Assessing the suitability of WHISCERS™ would be similar to assessing the appropriateness of internal insulation generally. The existing construction should be assessed with consideration given to:

- existing wall construction;
- existing thermal performance;
- space available for internal insulation including around door opening;
- insulation type suitable;
- continuity of insulation;
- condensation risk;
- how to deal with windows – especially if single glazed;
- level of airtightness required;
- summer overheating;
- existing services on walls;
- existing internal feature – assess their significance;
- consideration of heritage impact

WHISCERS™ laser survey could be most efficiently used in complex spaces or those that are difficult to read using conventional surveying techniques. Laser surveys generally are becoming more common in general building surveying. Therefore do make sense to translate this type of survey to a cutting schedule.

The new policy *Private Rented Sector Energy Efficiency Regulations* will oblige all landlords to bring their properties to a EPC (energy performance certificate) rating of at least E before being permitted to make or renew any leases. This project demonstrates that the WHISCERS™ can with some changes to project management be very suited to these properties.

7.2 Limitations

This demonstrator project did not explore the market potential for buildings with statutory heritage protection. This demonstrator project used phenolic insulation boards which are not breathable. In order to achieve *listed building consent* breathable insulation materials are often required. A project in Austria using the WHISCERS™ system used a breathable wood fibre system that would be appropriate.

There are significant concerns in the industry regarding moisture build up in poorly executed internal insulation projects. This project has the advantage of extensive monitoring inclusive of moisture sensors on the battens. The results were positive showing non-detrimental levels of moisture build up in the cavity between the existing wall and the insulation board. Nevertheless a greater number of demonstrator buildings may be deemed necessary before universal and unmonitored application.

The most significant limitation is the lack of policy drivers and economic incentives to support carbon reduction in the built environment.