Jarman Building - School of Arts

This document contains a Building Performance Evaluation report from the £8 million Building Performance Evaluation research programme funded by the Department of Business Innovation and Skills between 2010 and 2015. The report was originally published by InnovateUK and made available for public use via the building data exchange website hosted by InnovateUK until 2019. This website is now hosting the BPE reports as a research archive. As such, no support or further information on the reports are available from the host. However, further information may be available from the original project evaluator using the link below.

Innovate UK project number	450059
Project lead and author	Kent School of Architecture
Report date	2014
InnovateUK Evaluator	Roderic Bunn (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Higher education	Canterbury	N/A	2010
Floor area	**Storeys**	**EPC / DEC (2014)**	**BREEAM rating**
2492 m^2 (NIA)*	3	A (49) /D (84)*	N/A

*Disparity in reported usable floor area of 2492 m^2 in TM22 and other analyses, and 2683 m^2 in the 2014 DEC. Researchers should check whether the rateable floor area was used for DEC calculation rather than the actual usable floor area.

Purpose of evaluation

The study investigated comfort conditions in different spaces, differentiating from offices to circulation zones and their occupant satisfaction, the effectiveness of the ventilation strategy, particularly the use of passive stack ventilation systems, and control strategies (particularly interaction of the BMS with the various systems). The study also covered aspects of the building's operation and maintenance that needed to be improved to reduce energy consumption without jeopardising occupant satisfaction. User-specified benchmarks were also developed for the complex and multi-functional use of the building.

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

Measured operational electrical energy consumption reported as 101.2 kWh/m² per annum, with thermal energy (gas) at 102.4 kWh/m² per annum. Electricity sub-meters were installed in January 2013 to enable end-use assessment. The composite benchmark was based on the respective percentage of floor area for zones with specific end uses that were not strictly academic in nature (eg: the recording studios). Composite values were derived from CIBSE *TM46* typical (median) benchmarks, CIBSE *Guide F* (2004), HEEPI, and *ECON 19*. The final report makes the arguments and allocations explicit. High electricity consumption attributed to internal lighting running 24/7, partly owing to use of the building outside normal occupancy hours.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	28	56%

The summary 12 variables showed that the building generally scored acceptably against scale midpoint and benchmark references. Scores for noise overall were typical against the benchmarks but below the scale midpoint, as were some other noise variables due to reverberation from exposed thermal mass. The occupants perceived temperature and air quality in summer to be typical, but thermal comfort in winter was scored below BUS scale midpoint, as were scores for winter air conditions. Note that the sample size was small statistically, although the response rate was acceptable.

Innovate UK is the new name for the Technology Strategy Board - the UK's innovation agency. Its role is to fund, support and connect innovative British businesses through a unique mix of people and programmes to accelerate sustainable economic growth.

For more information visit www.innovateuk.gov.uk

About this document:

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

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

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

The Technology Strategy Board is an executive non- departmental public body sponsored by the Department for Business, Innovation and Skills, and is incorporated by Royal Charter in England and Wales with company number RC000818. Registered office: North Star House, North Star Avenue, Swindon SN2 1UE.

Contents

1 Introduction and overview

This report investigates the BPE of the Jarman Building School of Arts at the University of Kent. It is a multi-use space with a variety of activities. The study investigated the following:

- the comfort conditions in different spaces, differentiating from offices to circulation zones and their occupant satisfaction;
- the effectiveness of the ventilation strategy, particularly the use of passive stack ventilation system (Passivent);
- the control strategies; particularly interaction of the BMS with the various systems;
- the energy performance of the building and the reasons for potential differences in the performance between the as designed and as operated scheme;
- the aspects of the building operation and maintenance that need to be improved to reduce energy consumption without jeopardising occupant satisfaction.

User-specified benchmarks were also developed for the complex and multi-functional use of the building.

The BUS survey highlighted that overall, the building is very well received by its occupants, despite areas of dissatisfaction with noise transmission in the open plan areas, and consistently poor thermal conditions in some of the spaces.

However, the energy consumption of the building was continuously increasing for the first three years since its occupation in 2010, with the highest increase found in 2012. The EPC had a B rating, while the latest DEC had a D rating. The breakdown between electricity and gas use showed that this was predominantly due to gas. Detailed analysis enabled savings to be made and such consumption to be reduced in 2013.

Significant heat losses have been attributed to the independence of the underfloor heating control from the passive stack ventilation control and the BMS's wider influence, most notably the possibility of providing and discarding heat simultaneously. Additional energy losses from the heating are attributed to the poor balance of the LTHW heating circuits during commissioning, which led to portable electric heaters being employed to compensate for the system's inefficient operation.

Electricity use has a very high base load, indicating that some end uses are constantly left on. The TM22 analysis highlighted the very high consumption by lighting, where the extensive use of internal lighting accounts for 37% of the total electricity consuming 36.6 kWh/m^2/year. The existence of a single centralised password-protected lighting control for all the main circulation spaces in the building leads to huge energy waste with the lights left on throughout the day.

Due to the complex nature of the Jarman building, in terms of activities and uses, published benchmarks for educational buildings were not appropriate, therefore composite benchmarks were developed, resulting in 43.7 kWh/m^2 for electricity and 124.6 kWh/m^2 for fossil fuel.

The new benchmarks for electricity confirmed the very high electrical energy use, indicating the large amount of electricity used, while for thermal energy, the composite benchmark is very close to the gas consumption in 2013 (102.4 kWh/m^2) and the 4-year average consumption (102.2 kWh/m^2).

The review of the procurement process highlighted the importance of integration between standalone controllers and the BMS, to avoid the limitations of standalone self-acting controls.

A key message, which the owner followed up in subsequent buildings, was the importance of retaining the authors of the environmental performance specifications or appointing an independent commissioning engineer to oversee the commissioning process, to check against design specifications and integration of individuals systems. This is particularly critical for ensuring the success of complex buildings.

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

2.1 Design intent

The Jarman Building-School of Arts is a 2,500m^2 floor area, three-storey building (Fig. 1), conceived as a flexible area for the varied uses in the School; the Departments of Drama, Films and Visual Arts.

Fig. 1: The Jarman Building, School of Arts

The accommodation comprises rehearsal studios drama and film studios, computing and editing suites, a large art gallery, teaching rooms, academic and administrative offices. These are based around a series of internal volumes, which create distinct environments appropriate to their function (see Appendix for floor plans and images of the internal circulation spaces). The spaces in-between encourage interaction between the students and staff of the different departments through the use of wide staircases and top lit spaces. The top floor provides office accommodation for staff with a roof terrace and voids allowing light into the lower levels.

The zinc-clad building is constructed with blockwork cavity walls, a heavyweight steel structure and exposed pre-cast concrete soffits internally providing thermal mass, allowing natural ventilation and passive cooling.

The aim was to maximise use of passive means of design. The ventilation strategy has a particularly important influence on energy use; challenging given the external noise intrusion and noise break-out in the School. Except for certain internal rooms, natural ventilation is used in all teaching, office, circulation and social spaces, as well as the dance, drama and arts studios, where high internal heat loads and deep plan spaces normally prohibit its use. This was made possible through the use of low-level acoustic openings, combined with chimneys that harness the stack effect and prevailing winds to drive the airflow. Shading these spaces from direct sunlight and making use of exposed thermal mass, it has been possible to control heat gains passively, without the need for mechanical cooling.

Solar gains have been controlled, and daylight levels maximised, using a combination of north facing rooflights, an enclosed courtyard garden at second floor level, and high performance glazing that makes use of an expanded zinc mesh mounted between the glazing panes to provide daylight whilst also controlling shading and glare.

The building is a gateway, having transformed the point of arrival on campus with the creation of two new squares. Aligned with the University's carbon management plan, the building can be reached by public transport, with dedicated bus-routes and provides extensive cycling storage facilities.

The School moved into the completed building in January 2010. The building won a RIBA-2010 award[1].

The Jarman Building-School of Arts is owned by the University of Kent (Freehold) and it is managed by the University of Kent's Estates Department.

2.2 Design team and contractors

The Architect, Hawkins Brown, was appointed following a fee bid competition. The Architect in turn appointed Arup as M&E Engineers. The design was developed to Stage E+ (Stage E plus additional detailed information). The intention was to protect the design intent whilst still allowing the Main Contractor, when appointed, scope to develop the design and deliver best value for money.

Briefing sessions took place that followed a very traditional process to develop a set of Employer's Requirements. This document included architectural specifications and drawings, engineering specifications and drawings together with operating parameters and information comprising the performance description. Tenders received for construction of the building were based on the requirements of this document. The Employer's Requirements for the Jarman Building was a useful starting point in comparing the University's expectations with the building delivered by the Main Contractor.

Morgan Sindall was appointed as Main Contractor on a Design & Construct basis. The Architect and Engineer were not novated to the Main Contractor. The Main Contractor employed their architect, RHP Partnership, to take over design development. The Employer's Requirements were considered to be sufficiently detailed.

For the Commissioning of Services, there was a structured commissioning programme and commissioning certificates were issued with the O&M manuals. The University chose not to reappoint Arup to assist in any way during the commissioning process. The Main Contractor had their own M&E Engineer throughout who was responsible for snagging the M&E works and overseeing all M&E subcontractors.

There was no independent commissioning engineer to compare the performance of the final product with the original design intent, the implications of which are discussed in Section 5.3.

2.3 Conclusions and key findings for this section

The original design intent was maintained and overall the building has been a big success with staff and students. As the RIBA Awards Jury highlighted, it "…reinforce a sense of community in teachers and students, who benefit from well-delivered studios for drama, film and visual arts. This building demonstrates how good design can improve learning and is an exemplar for future campus architecture".

Although, architecturally, the building can be regarded as successful, there have been a number of issues that have arisen in the building performance evaluation, which jeopardise the passive means of design and overall successful integration of building services. These have had a significant impact on thermal comfort and energy consumption as discussed later in the report.

[1] These awards from RIBA set the standard for good architecture.

3 Review of building services and energy systems

3.1 Introduction

The building uses a condensing modular gas boilers for heating, with a mixture of underfloor heating on the dance studios, gallery and ground floor areas, and radiators for the various offices on the upper floors.

The principal ventilation strategy is Natural Ventilation: via opening windows and Passivent chimneys, vents and low level louvres.

Where mechanical systems were necessary in seminar rooms which have no direct access to outside air, IT hardware-intensive spaces, as well as in recording studios, where the acoustic requirements and high heat loads prohibited the use of natural ventilation, cooling is provided by fan-coil units and VRV system.

The available sub-meters included separate circuits for the plantroom, VRV air-conditioning and the ground floor.

The electrical energy is provided direct from the University's High Voltage Main.

3.2 Ventilation strategy

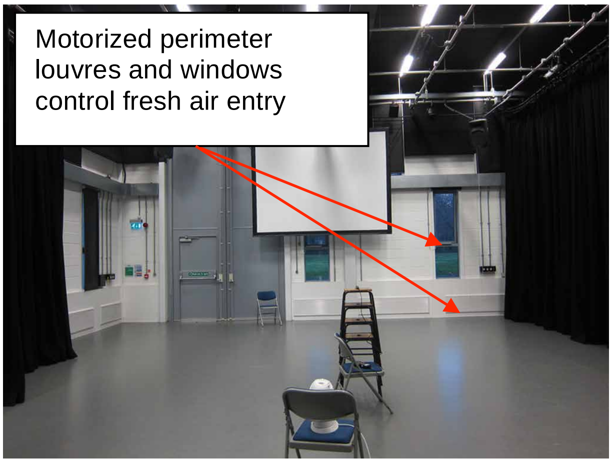
The building is designed for the majority of the spaces to be naturally ventilated. Nine ventilation stacks enhance the ventilation, with one each serving the three double height spaces (two dance studios and gallery), and six serving the two central circulation spaces or atria. This passive stack ventilation system is the main provider of ventilation to the building.

Fresh air enters the circulation atrium at ground floor level through the main entrance doors and through motorized openable windows on the front façade and at either end of a corridor. Air is extracted through high level stacks that start at the ceiling of the second floor and extend through the roof to stack terminals, which have motorized louvres to control the flow.

The dance studios and gallery have perimeter ventilation openings, controlled by motorized louvres, together with windows (both motorized and manually openable). Each of the double height spaces has a single stack (approx 2.5 x 1.5m cross-section) taking air from the ceiling level up through the second floor and up to a discharge terminal above the roof. The flow of air through these stacks is controlled by motorized louvres at the top of the stack, together with the control of the fresh air supply at ground level.

The fresh air intake and extract is controlled according to the air temperature and the carbon dioxide concentration, with separate set-points for summer and winter operation. Automatic night-time ventilation can also be enabled for warm summer conditions to reduce cooling requirements the next day.

Individual offices on the perimeter of the building have single-sided ventilation through manually openable windows as do the second floor corridors on the north side around the atrium. In extremis this can enable cross-ventilation of the offices when the doors are left ajar.



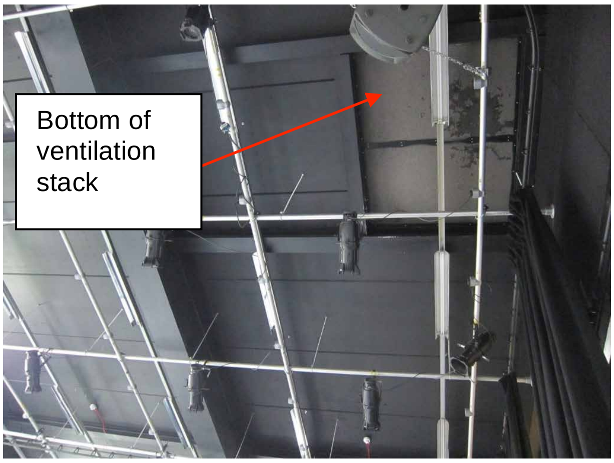


Figure 2: The main Drama Studio, showing fresh air entry and exit points

Figure 3: The top of the ventilation stack of the main Drama Studio, showing the louvres controlling air flow out, measurement of the air speed and the external terminal

3.3 Control strategies

The underfloor heating's own control system controls the flow of water to individual zones according to the set-points on its dedicated air temperature sensors. These are independent of the air temperature and carbon dioxide sensors used to control the passive stack ventilation. The underfloor heating system may operate to warm spaces, simultaneously with the passive stack ventilation operating to vent excess heat[2].

Seminar rooms and IT intensive areas have occupancy sensors to control the air conditioning which provides balanced supply and extract to each space. Heat generated by the computers may accumulate when they are left active but the space is unoccupied.

[2] As a result of the BPE findings, new controls are going to be installed in the BMS, controlling rather than simply enabling communication between the different systems.

Lighting in the reception and foyer area are controlled from the reception desk, though a password-protected controller[3]. There are no daylight or movement sensors in the circulation areas. Movement sensors exist only in the offices.

3.4 Conclusions and key findings for this section

A major aspect of the building's design is the use of passive stack ventilation to provide the bulk of the fresh air supply and removal of vitiated air. The flow of air is controlled according to dedicated temperature and carbon dioxide sensors. As the underfloor heating system is controlled through separate air temperature sensors it is possible for heat in a zone to be provided and vented at the same time.

The Main Contractor tendered packages of work in the traditional manner, and as a result a lack of integration between the various systems installed has been observed.

[3] Training was carried out at the initial stage to inform the Estates of the control's use, with a poor turnout. Subsequent attempts to invite the company back for additional training have been unsuccessful, while charging high fees for follow-up visits and canceling appointments at the last minute. This control is now going to be removed completely.

4 Key findings from occupant survey

4.1 Introduction

Different types of occupant surveys were carried out along with the walkthrough surveys. These included the BUS and thermal comfort surveys with concurrent monitoring of the internal thermal environment to evaluate the seasonal performance of the building.

4.2 BUS survey

The Building Use Study was carried out in June 2012. The date was selected along with the Head of School to ensure maximum participation. An email was sent out to all staff in advance, with a second reminder of the forthcoming survey the day before. All survey results were delivered on one day. There was approximately a 60% response rate with 28 questionnaires returned. The BUS summary results are shown below, whereas the various grouped categories are discussed analytically.

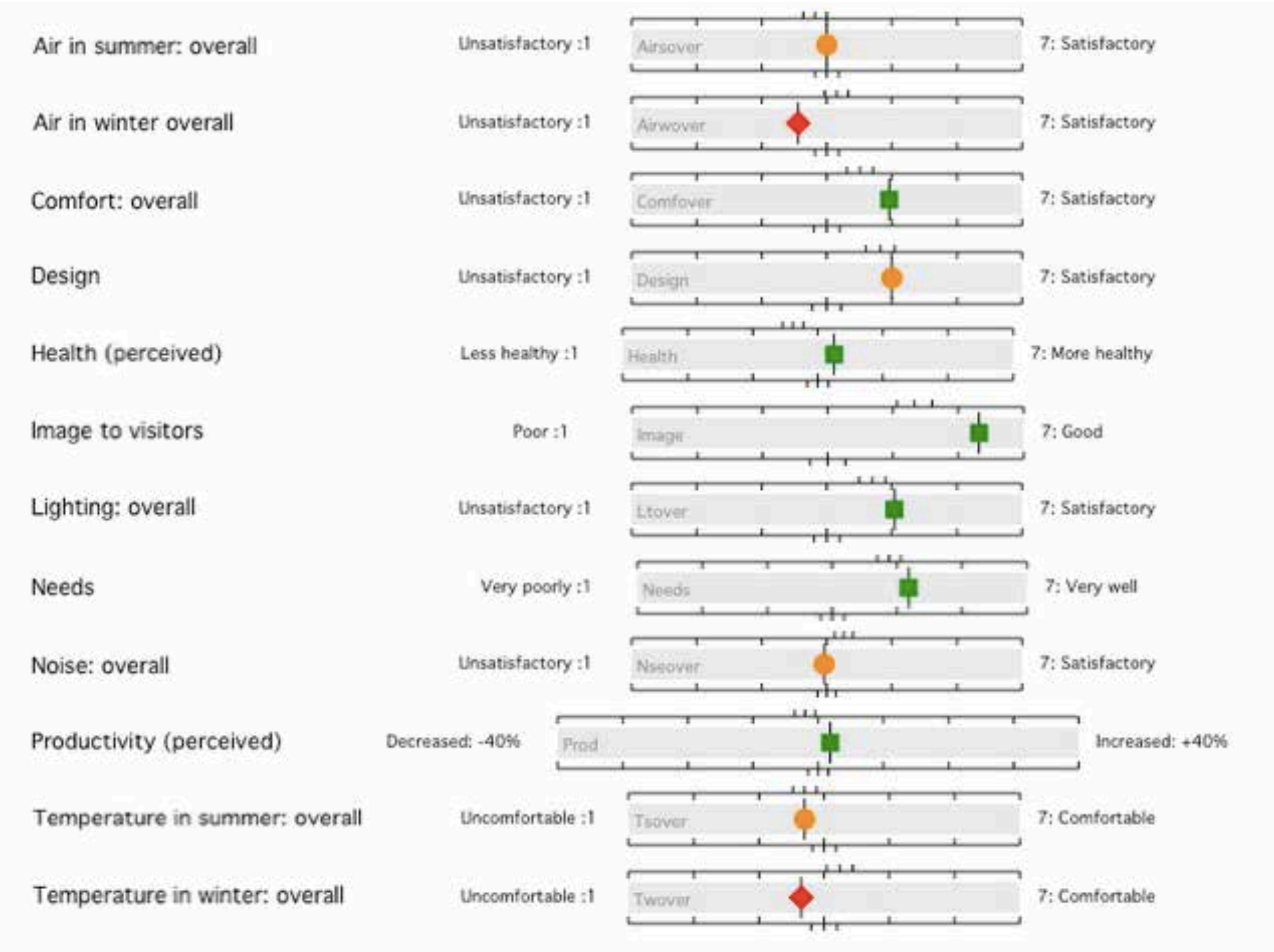


Figure 4: The summary of the BUS survey results for all the variables

To ensure understanding of the BUS graphic system, the explanation of the 'slider' graphic tools is also shown (Fig. 5). Effectively the results for each variable are shown for the building under consideration and benchmarked with other buildings in the database.

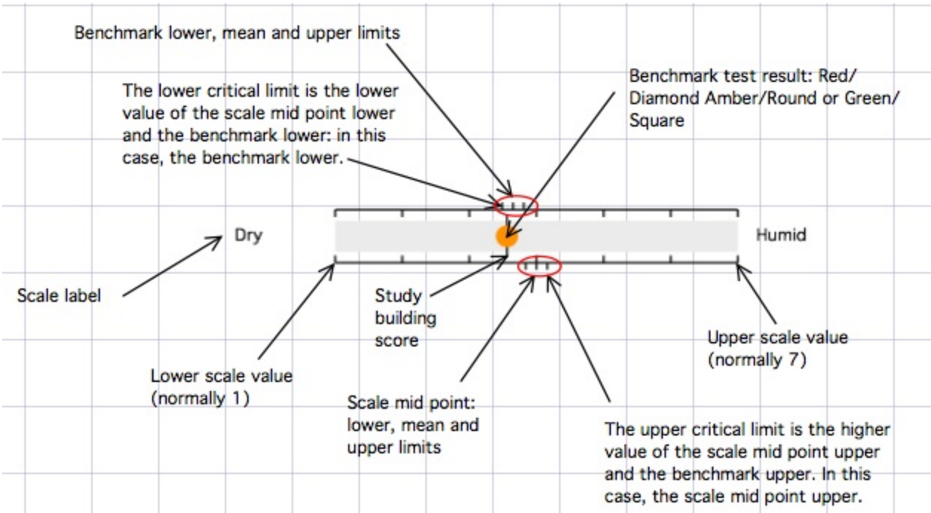
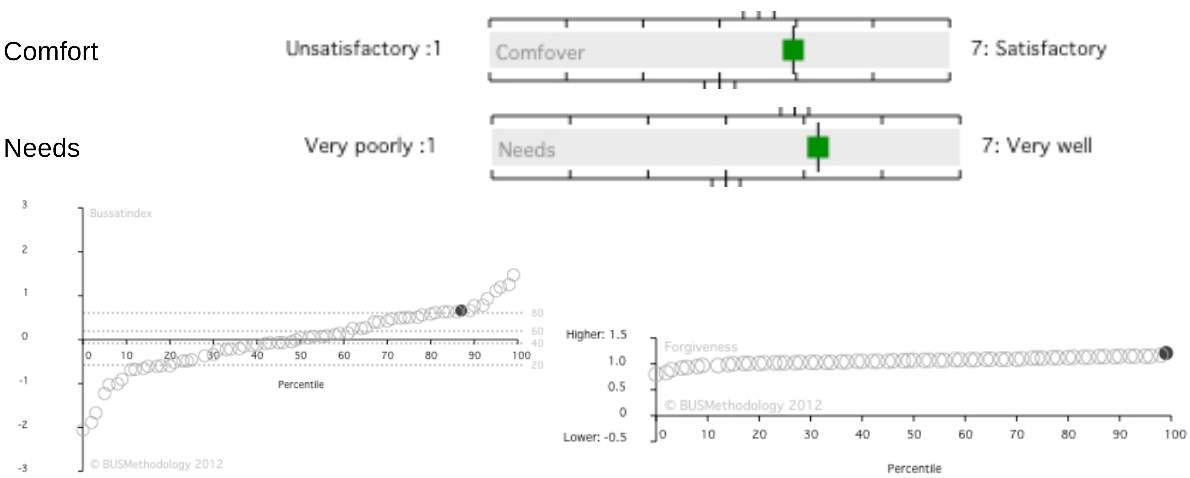


Figure 5: The BUS 'slider' graphic details

Overall, the occupants are satisfied with the building, as it is covering their needs well (Fig. 6), giving a satisfaction index of 0.69 (in a +-3 range), which is very high when compared to other buildings in the dataset. This along with the fact that 93% of the participants mentioned they have a window seat, which enables them a higher degree of control and pleasant views, provide a very high Forgiveness index[4] (1.24, in a range from -0.5 to 1.5), which can be viewed as a measure of tolerance with the building. More specifically, the building has the highest Forgiveness index from the dataset (Fig. 6)



Satisfaction index Forgiveness index

Figure 6: BUS survey results for overall comfort, needs, with a high satisfaction and forgiveness index when compared with the benchmark

[4] Forgiveness index is the degree to which occupants are said to more tolerant or 'forgiving' of the conditions they encounter in buildings. Statistically, the forgiveness variable is derived from dividing individual building mean scores for the variable comfort overall by the average of scores for the variables temperature in summer overall, temperature in winter overall, ventilation/air in summer overall, ventilation/air in winter overall, lighting overall, and noise overall. A higher value thus obtained implies that occupants are more forgiving of the conditions they experience (Building Use Studies).

These help to explain the high satisfaction with the building, as when different environmental parameters are examined independently, various issues arise.

4.2.1 Acoustic environment

Noise is the most common complaint (Fig. 7). The sources for these are the following.

- The open plan nature of the building with the many informal meeting spaces at ground-floor and first floor level cause problems with noise transmission, which is exacerbated by the hard surfaces and the exposed thermal mass of the building (Fig. 8).
- The poor acoustic insulation between offices, leading to conversations being overheard.
- Noise from the air-conditioning. This was mentioned in relation to the seminar rooms and the recording studios. Potentially, it is more problematic for the latter, when high quality recording is taking place.

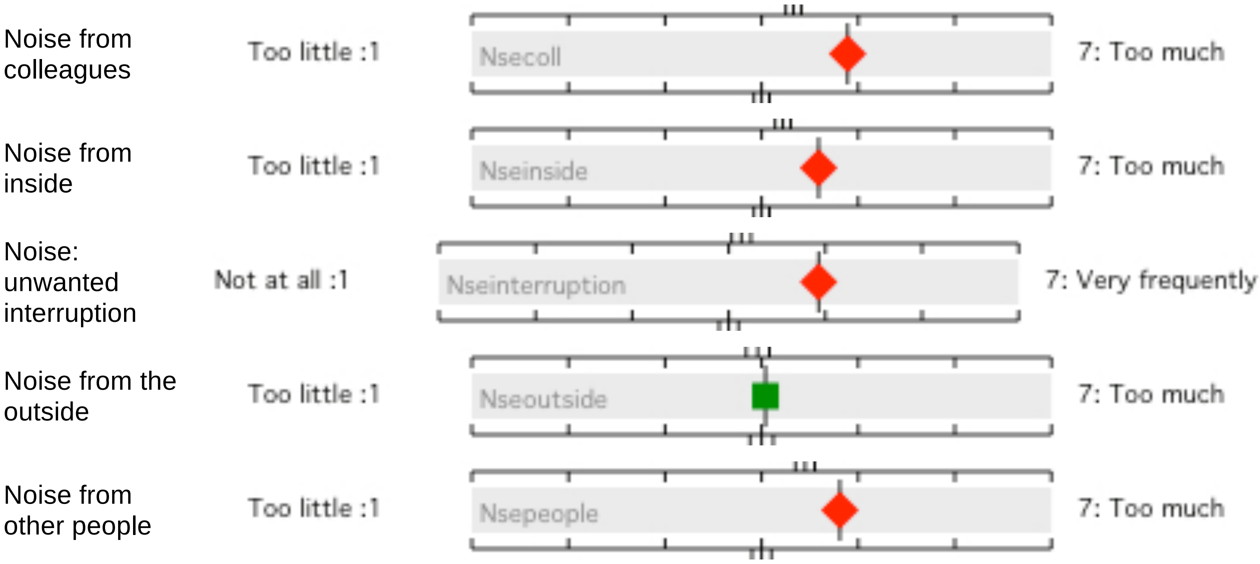


Figure 7: BUS survey results for noise

Fig. 8: Hard surfaces and exposed thermal mass in the open plan area, causing problems with reverberation.

4.2.1 Thermal environment

There were significant issues regarding the thermal environment, particularly in winter (Fig. 9). Although overall the building was regarded as comfortable (with similar mean values for the two seasons), people felt the temperature in winter was too cold (mean 5.37).

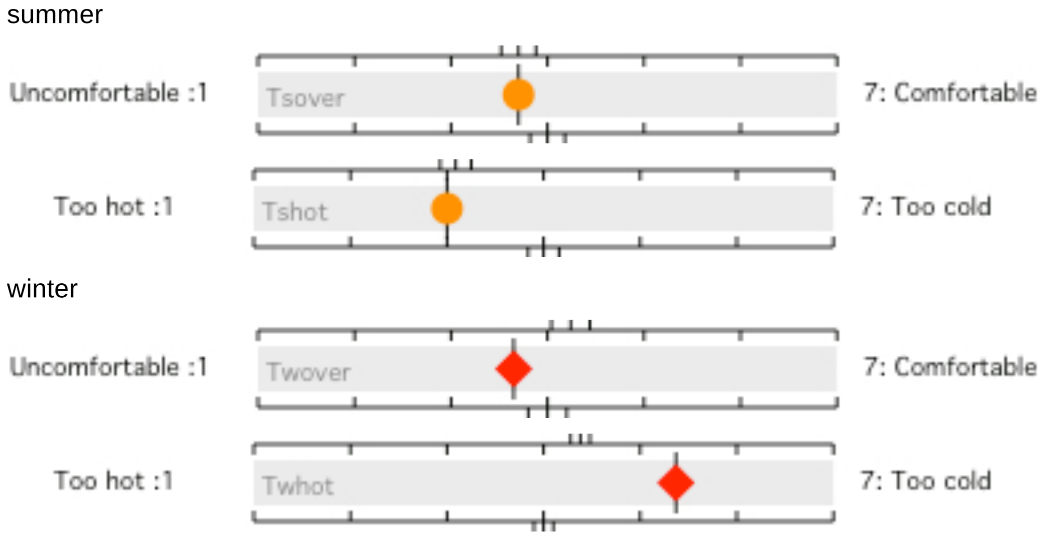


Figure 9: BUS survey results for thermal comfort in summer and winter.

The most frequent complaint to the Estates' team was the control of the heating system in the offices and the studios. Focusing on the responses from the offices, although most reported to have satisfactory thermal environment, a few suffered from the cold. Interestingly, there is also a small number of offices, where it gets so hot that the occupants have asked for the heating to be turned off completely in their room at wintertime. This clearly demonstrates that there are issues of control throughout the building, as complaints of ineffective heating are not limited to the offices but are also prominent in the studios on the ground-floor.

4.3 Comfort surveys

To identify the sources of discomfort seasonal comfort surveys were carried out along with temperature measurements in a selection of offices. The selection of spaces was based on the BUS findings. Offices where occupants were found to be dissatisfied, cold and/or uncomfortable with the indoor thermal environment, were selected for monitoring. The orientation of spaces introduced an additional criterion (hence offices were monitored on each orientation). Particularities of some offices led to the selection of additional spaces. More specifically:

- Some occupants often make use of personal heaters. This could result in misleading results, therefore nearby offices that were on the same piping network were also chosen.
- The heating pipework is split at the points of offices 2.14 (West) and 2.33 (East) (Fig. 10), and the ends of these systems are at the offices 2.23/2.24 and 2.42/2.43 on the north and south side of the building respectively. Office 2.23 has repeatedly complained about the cold conditions in the room (eventually using a portable heater).
- The reception was also selected for monitoring due to the frequent complaints of discomfort.

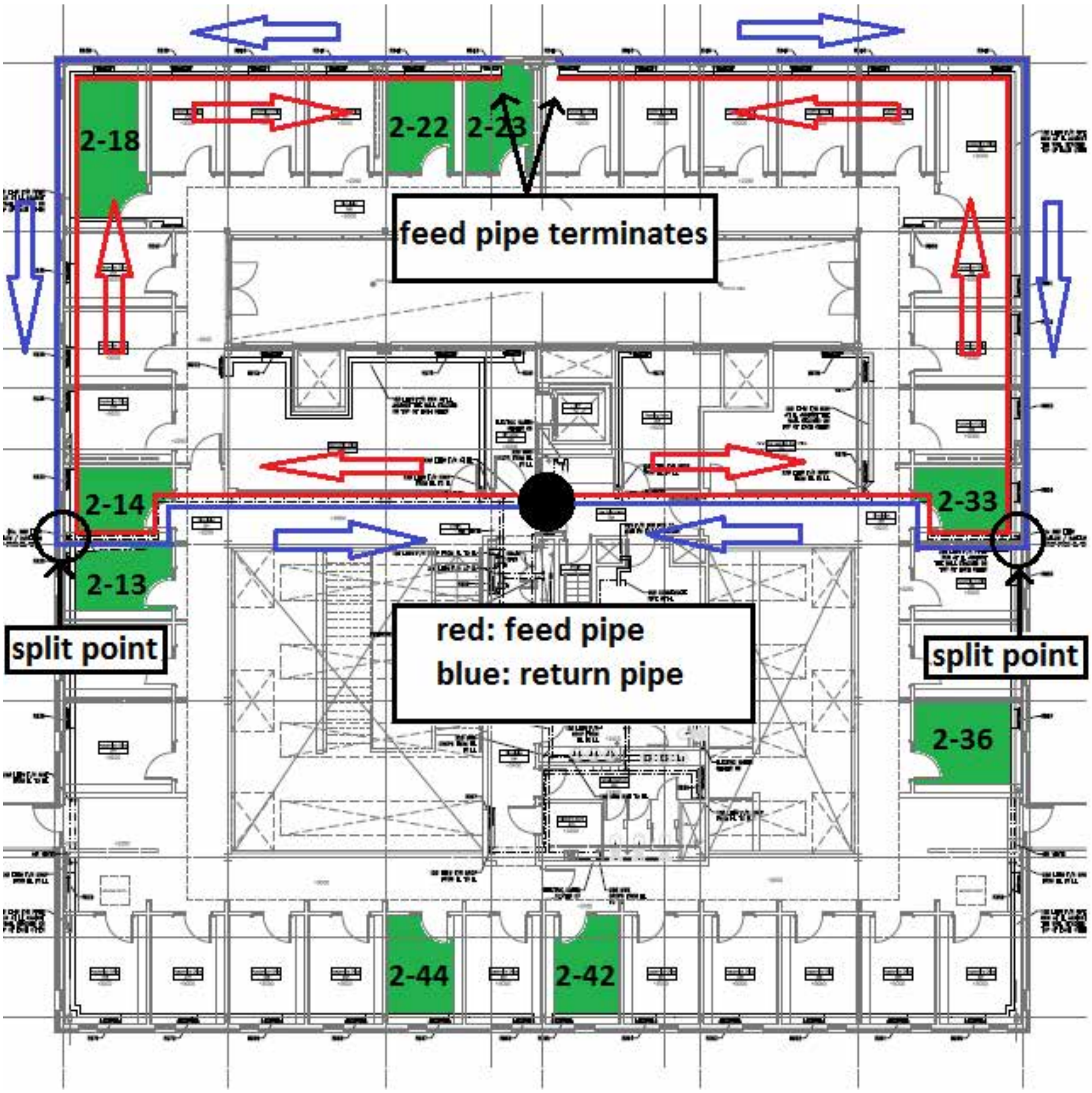


Fig. 10: Monitored offices (shown in green) on the 2nd floor and the schematic diagram for the LTHW system on the northern side of the building

The surveys took place in the period 17-25 January 2013. The occupants of the monitored spaces were asked to rank their thermal sensation on a 7-point scale (from very hot to very cold) and thermal preference on a 5-point scale (for ease of completion varying from cooler to warmer) twice a day (mid-morning and mid-afternoon).

The highest level of discomfort was found in the reception (mean value of 6 in the morning and 5 in the afternoon) and room 2.42 (mean value of 5 in the morning and 6 in the afternoon), closely followed by room 2.23 (mean value of 5). The reasons for this discomfort become apparent when focusing on the temperatures recorded[5] in these spaces (Fig. 11). Given the recommended CIBSE temperature range for offices during winter (21-23 °C) and the Estates aiming to provide temperatures that are not below 20 °C, there are a number of problems.

[5] Temperatures were monitored using HOBO dataloggers (accuracy ±0.21°C from 0° to 50°C), which were calibrated prior to the surveys.

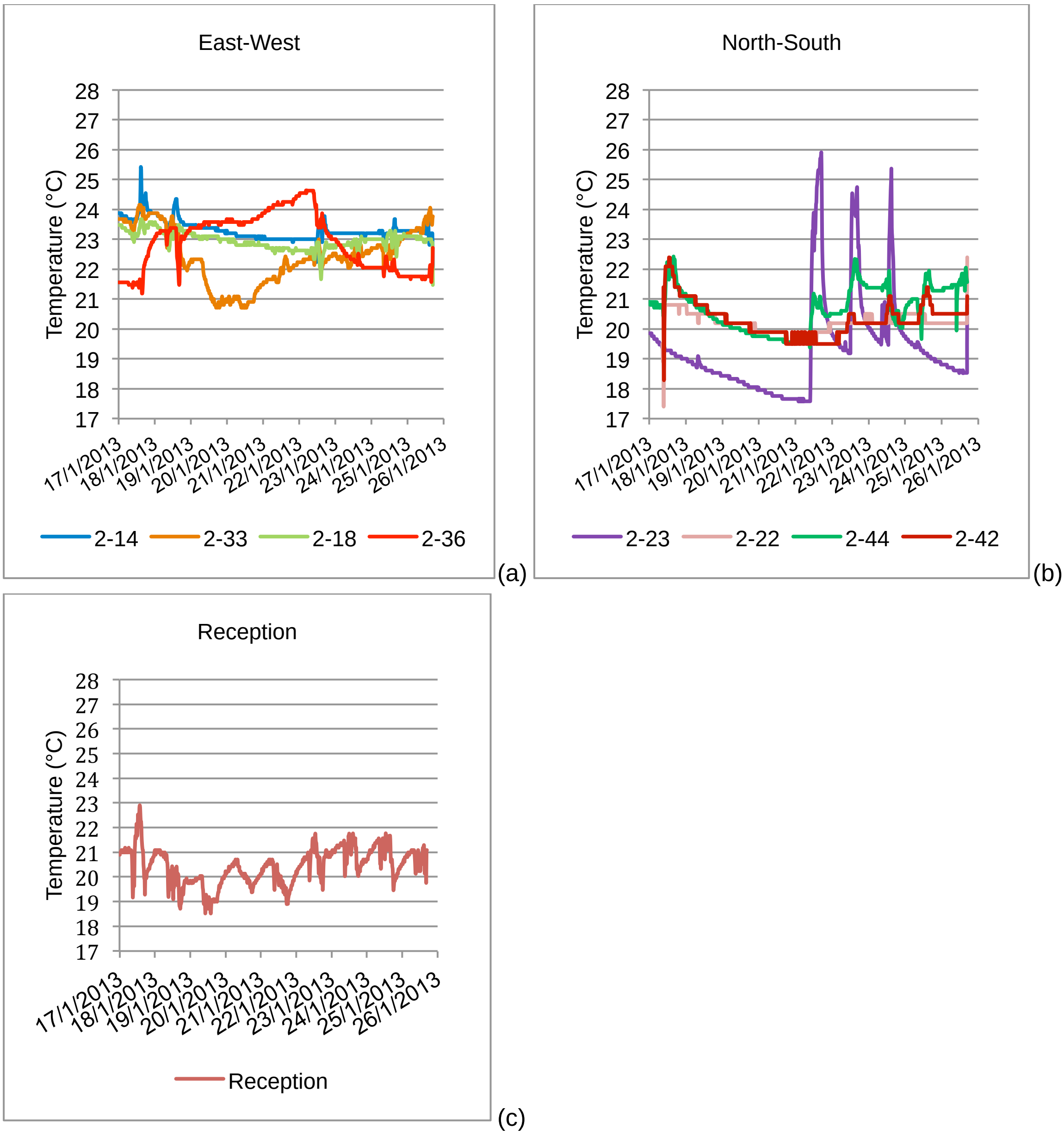


Figure 11: Air temperature profile in the different rooms monitored in winter (see Fig.10 for the location of the rooms on 2nd floor)

Rooms on the north and south have the lowest temperatures (Fig. 11(b)) when compared to the eastern and western orientation (Fig. 11(a)), with the rooms on the N/S being regularly below the recommended comfort conditions. Room 2.23 (Fig. 10) has the lowest temperature, dropping to below 18 °C (Fig. 11(b)). The sudden rise in temperature is due to the use of a portable heater. In fact, it is only with the use of the heater that temperature reaches acceptable levels. Room 2.22 also has low temperatures, at around or just under 20°C (Fig. 11(b)).

Examining the schematic diagram for the LTHW system (Fig. 10) it is noticeable that the warmer rooms (E/W) are at the beginning of the network with the rooms on the N/W, which are towards the end of the network, being consistently lower. The coldest room 2.23 is at the end of the network. This suggests that there is insufficient pressure in the main system to provide adequate heating for the rooms at the end of the network.

On the other hand the rooms where the pipework splits (2.14 and 2.33) air temperature is higher (23-24 °C) (Fig.11(a)), frequently causing problems with overheating throughout the year. This higher mean temperature and a more constant temperature profile is noticeable even during the weekend (19-20 Jan).

At the reception on the ground–floor temperatures often drop below 20°C (Fig. 11(c)). During the day, it manages to reach the comfort zone, but only with the use of portable heaters. As shown in Fig. 10, the reception area is only partly included in the under-floor heating zone. More importantly, one side is open to the foyer area (Fig. 12), which experiences frequent draughts from the nearby sliding doors.

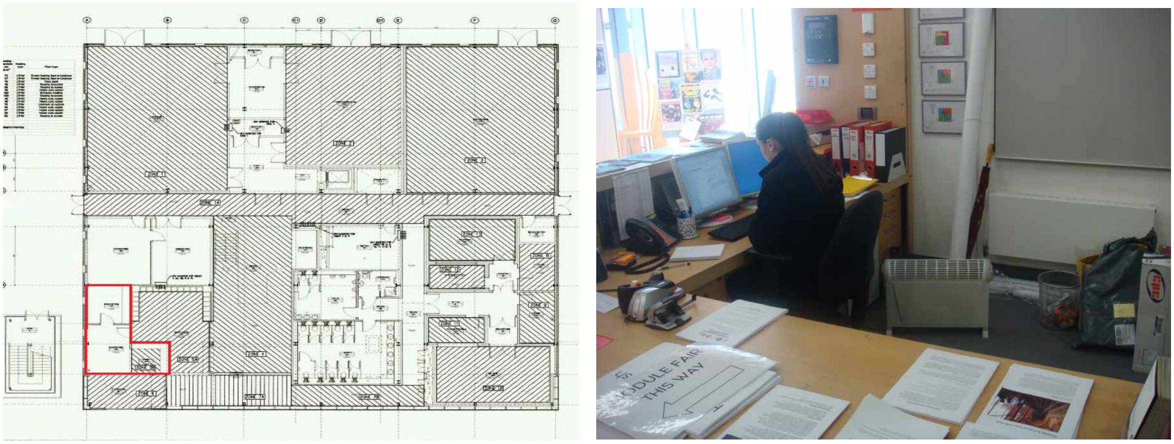


Figure 12: Reception desk open to the foyer next to main entrance (drawn in red on the plan); Area is partly served by the underfloor heating (hatched areas are included in the underfloor heating zone)

4.3.1 Summer surveys

The same offices were also monitored during the summer, in the period 14-28 June 2013. In most offices, occupants voted on the comfortable side of the scale. The rooms with the highest comfort levels (2.18, 2.33 and 2.44) are the ones whose occupants' mean thermal sensation does not vary between morning and afternoon. On the other hand, the lowest mean comfort scores were received from staff in the reception, where the mean thermal sensation differs by one unit between mid-morning and mid-afternoon, varying from the cool (4.6) to the warm side (3.6). To reduce discomfort the reception staff employ different adaptive actions daily; closing/opening of the door and windows, as well as making use of personal heaters, especially in the mornings.

Figure 13 presents the temperature profile for the monitored spaces. In most offices the temperature lies within CIBSE's recommended comfort range for offices in summer (22-24°C) (Fig. 13(a), 13(b)). This range refers to air-conditioned offices, and as the Jarman is predominantly naturally ventilated, higher temperatures are regarded as acceptable. This is the case in 2.33, where the temperature often exceeds 24°C (Fig. 13(b)) and its occupant calls for "no change" (vote "3" in thermal preference).

The rooms where the occupants are frequently absent have a fairly uniform thermal environment, unlike the daily occupied rooms; e.g., 2.33 (Fig. 13(b)) and reception (Fig. 13(c)). The reception is the most exposed space to the outdoor conditions, as already discussed, due to the frequent opening of the sliding doors. As a result, its temperature is outside the narrow 22-24°C range for most of the time, experiencing wide fluctuations of 5°C (Fig. 13(c)).

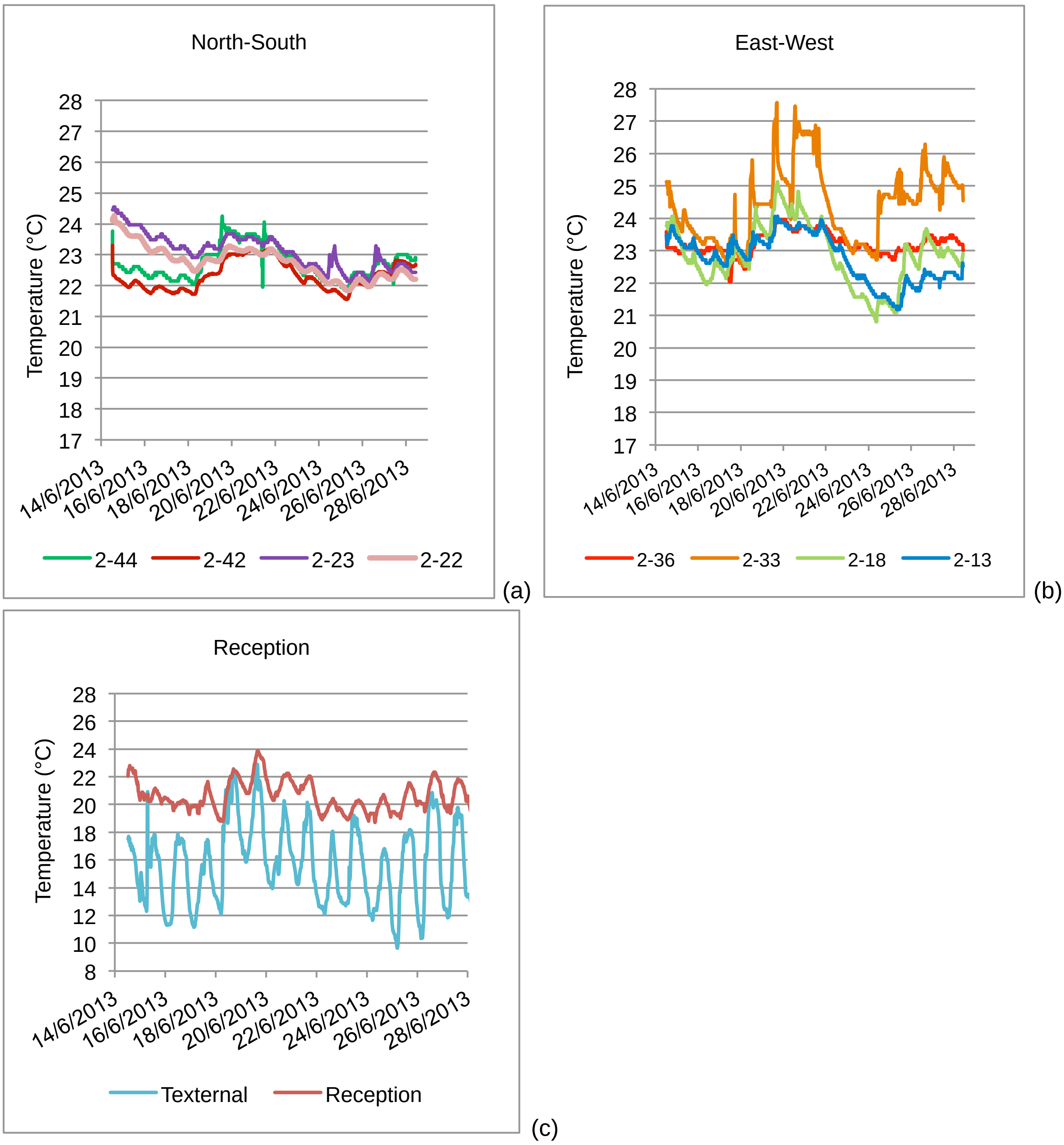


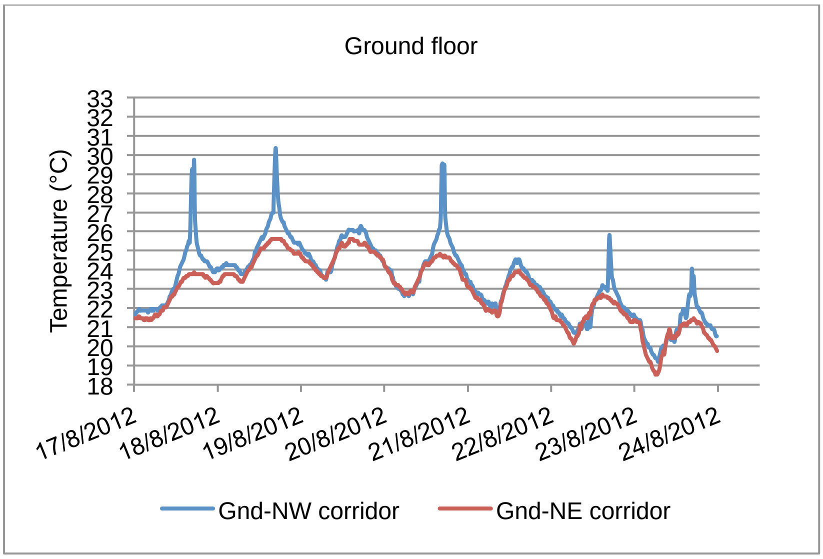
Figure 13: Air temperature profile in the different rooms monitored in summer

Figure 14: Temperatures sensors on (from left to right): NE main corridor (ground-floor), parapet (1st floor) and under east middle Passivent (2nd floor).

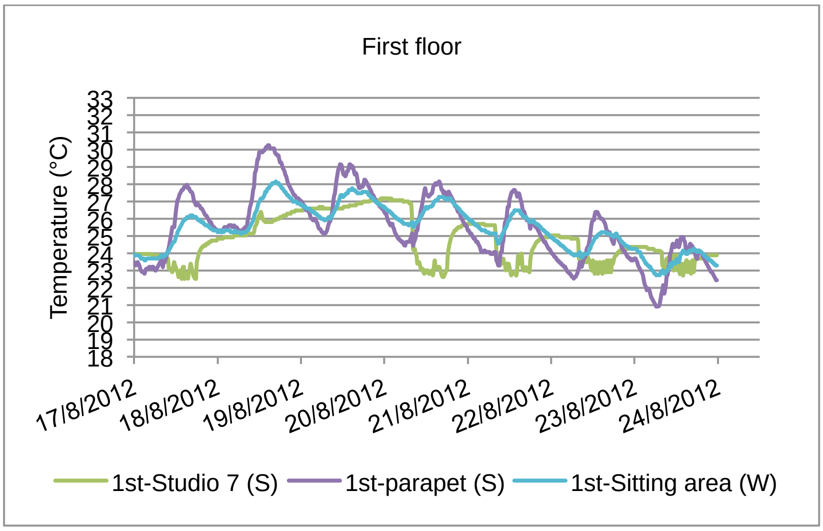
To evaluate comfort conditions in the circulation spaces and potential overheating, these were monitored separately in August 2012 (Fig. 14).

Stratification is noticeable in the building, with a temperature difference, which can reach up to 8K between the ground and the second floor (Fig. 15(a)-15(c)), with an average of 4K. The ground-floor has noticeably cooler temperatures (Fig. 15(a)), with the exception of the NW corridor at the time that sunlight is entering through the window in the evening. The areas around the atrium reach higher temperature of up to 30°C. The highest temperature is consistently on the second floor north corridor outside the offices, where the mean air temperature exceeded 28°C with the mean maximum varying from 27.5°C to 31.8°C (Fig. 15(c)), reaching what would be regarded as discomfort zone.

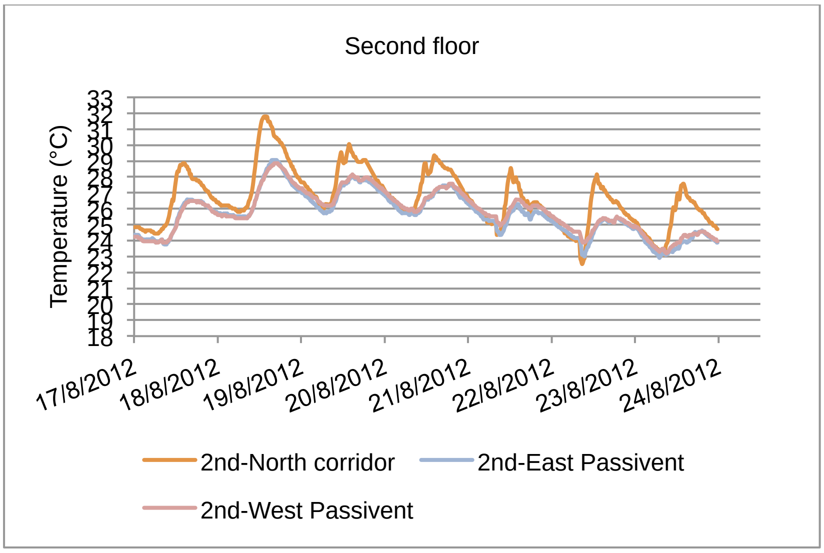
As these are predominantly circulation spaces, it is not a cause for concern, although it would be recommended to open the windows on the corridors outside the offices (Fig. 15(d)) to ensure ventilation and remove some of the excess heat gains. These windows are manually operated and would require the occupants to take action. However, this is frequently the problem with corridors or other circulation areas, which may be regarded as un-owned spaces, and people do not take ownership and control.



(a)



(b)



(c)


(d)

Figure 15: Mean indoor air temperature in all monitored circulation spaces per floor (a-c); (d) corridor on the second floor, where temperature was consistently higher than the rest of the spaces.

4.4 Conclusions and key findings for this section

Overall, the building is very well received by its occupants.

The most common issues arise from dissatisfaction with the acoustics in the building, predominantly from the open plan nature with noise transmission, augmented by the hard surfaces and the poor acoustic insulation between offices.

Regarding the thermal conditions, overheating in the summer does not cause any problems and the adaptive measures available (opening windows, shading blinds) support thermal comfort conditions for the users. The overheating observed in the circulation spaces of the top floor does not cause any problems either, as these are transition spaces and the users do not spend long periods of time there. The noticeable stratification also enables the stack effect ventilation to enhance natural ventilation through the Passivent stacks with fresh air entering the building at ground-floor level.

Comfort conditions are more problematic in winter, where some offices experience overheating, while others complain of cold conditions. The offices located where the heating pipework separates experience overheating with high air temperature even during the weekend. On the other hand, the offices located where the pipework ends complain of colder conditions, with some of the offices on the northern facade experiencing very low temperatures of 17-18 °C. Orientation also seems to be important, as offices on the northern side have lower temperatures than on the south.

Despite the low scores with the results on some of the BUS variables, the building has a very high Forgiveness index (the highest Forgiveness index in the BPE dataset), which along with the high individual control offered to its users mask some issues of thermal and acoustic discomfort discussed earlier.

5 Details of aftercare, operation, maintenance & management

5.1 Sub-metering strategy

Additional electricity sub-meters were installed in the building in January 2013, to enable assessment of the different loads. However, in the wiring of the distribution boards many different loads have been included in one meter, which does not allow refinement of the loads for the assessment of separate end uses.

A more considered approach to metering is necessary to improve building management. That might lead to more meters, so that small power, lighting and plant are separately sub-metered, or depending on the building and the building managers' capacity to operate and act upon, to fewer meters, better located. The strategy to segregate end uses should take place before installation and the respective drawings should demonstrate this.

5.2 Lessons learned from the operation of the building management system

Challenges and lessons learned in relation to the BMS and interlock of different systems are for: (i) the underfloor heating, (ii) the Passivent natural ventilation system, (iii) cooling.

5.2.1 Underfloor heating

The underfloor heating specification is of a conventional system. The 'Engineering Performance Specification' Document specifies operation of the boilers by the BMS, but it does not specify in clear terms that the zone valves and the manifolds are to be controlled by the BMS. This has been a constant difficulty in the control of the system, as effectively the BMS only enables or disables the underfloor heating by making hot water available, acting as an independent system (see Section 7.1 for a more extended discussion).

For future projects of a similar nature, consideration should be given to linking systems together to avoid the limitations of standalone self-acting controls and this was taken forward with the new Library building on campus.

5.2.2 Passivent

The 'Engineering Performance Specification' Document specifies that the position of vents and chimneys will be controlled by the BMS. There were a range of issues with the Passivent system.

The controller originally installed by the sub-contractor was incompatible with the University's main BMS. The problem identified in the project led to the recent replacement of this controller with a compatible unit.

However, despite the compatibility of the unit, it remained unclear to what extent Passivent was operating under autonomous control, with the BMS enabling it and monitoring its operation but not controlling it.

Another important issue was the fact that the operation of the Passivent was not linked with the underfloor heating resulting in simultaneous heating and cooling through increased ventilation.

The Design Specifications explicitly state that to ensure system performance the perimeter blackout curtains must not block the air vents, as the system relies on there being a free air path between the external vents and the chimney (see Section 7.1 for a more extended discussion).

5.2.3 Cooling

For most rooms where cooling is required, there is no interlock between the VRV and underfloor heating; in effect the two systems can be working against each other at the same time. Even in the two rooms where such control is available, this is only active in Boost mode, when the local setpoint is lowered by 5 °C with the underfloor heating disabled. This arrangement can lead to significant energy waste both for heat and electricity.

Although in the initial specification it was clear that VRV and UF heating should not work together, the problem surfaced installing individual controls for the different systems in the same room which are not centrally controlled.

Future projects must achieve a higher level of integration between standalone controllers and the Honeywell BMS if energy reduction targets are to be met.

5.3 Commissioning of Services and handover

Given the advanced specifications at the design stage (Stage E+), the University chose not to reappoint the authors of the environmental performance specifications to assist in any way during the commissioning process. The Main Contractor had their own M&E Engineer throughout who was responsible for snagging the M&E works and overseeing all M&E subcontractors.

There was no independent commissioning engineer either to compare the performance of the final product with the original design intent. The Main Contractor tendered packages of work in the traditional manner resulting in a lack of integration between the various systems installed.

For future projects consideration should be given to retaining the M&E Engineer to oversee the commissioning process or an independent commissioning engineer be appointed, to check against design specifications and integration of individuals systems, which is critical in complex buildings. This was taken forward with the new Library building on campus.

5.4 Conclusions and key findings for this section

A review of the procurement process revealed a number of issues, which will benefit future projects with a high level of complexity and systems involved. The main points include:

- Careful integration will need to be secured between standalone controllers and the BMS if energy reduction targets are to be met. Manufacturers' specifications of standalone controllers and central systems are not always clear, hence at the commissioning stage such potential shortcomings need to be critically evaluated to ensure actual control of a system rather than simply visibility.
- Linking systems together to avoid the limitations of standalone self-acting controls (e.g. control of underfloor heating system and Passivent via the BSM). Appropriate integration will also avoid

controls working against each other. The commissioning stage will be critical to identify potential shortcomings.

- Retaining the authors of the environmental performance specifications or appoint independent commissioning engineer to oversee the commissioning process, to check against design specifications and integration of individuals systems.

Regarding sub-metering, the strategy to segregate end uses should take place before installation and the respective drawings should demonstrate this. Sub-metering should be at a level that is commensurate not only with the engineering systems but also within the capacity of the building managers to operate and act upon.

6 Energy use by source

6.1 Energy consumption as monitored

The building's energy consumption was continuously increasing for the first three years since its occupation in 2010. The EPC had a B rating, while the latest DEC had a D rating. The highest increase was in 2012 when the annual consumption rose by 23% compared with 2011 (Fig. 16). The breakdown between electricity and gas use shows that this is predominantly due to gas. As a result of frequent complaints of cold discomfort in winter the heating has increased. In 2013 the gas consumption decreased, mainly as a result of the revised shorter time schedule for heating (the gas boiler was reset from 24/7 to 8am-6pm daily operation in February 2013). The lack of integrating of the different controls by the BMS meant that the continuous operation was discovered in the maintenance process.

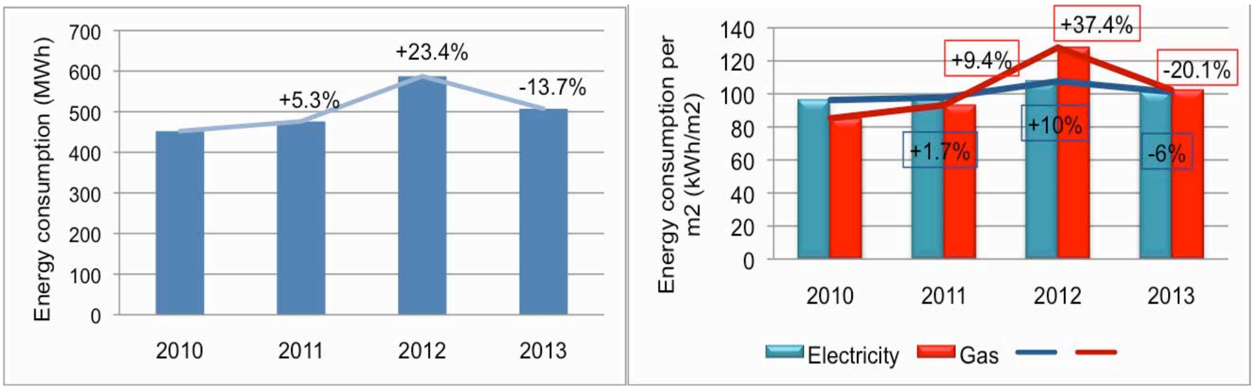


Figure 16: Annual energy consumption for the Jarman building since its occupation, (left) overall and (right) for gas and electricity per m^2

Aiming to evaluate the differences in the gas use further, degree-day data from Manston (13 miles away) was used to investigate its relationship with the outdoor weather conditions, for the standard base temperature of 15.5°C. The plot between the daily gas consumption and the degree days/day for the period 2010-2013 shows that gas consumption varied highly under similar weather conditions and therefore was not well controlled at all times (Fig. 17). Looking at the same data over time (Fig. 17), there appears to be poor correspondence of gas consumption with weather severity during the winter months of each year and particularly for 2011 and 2012.

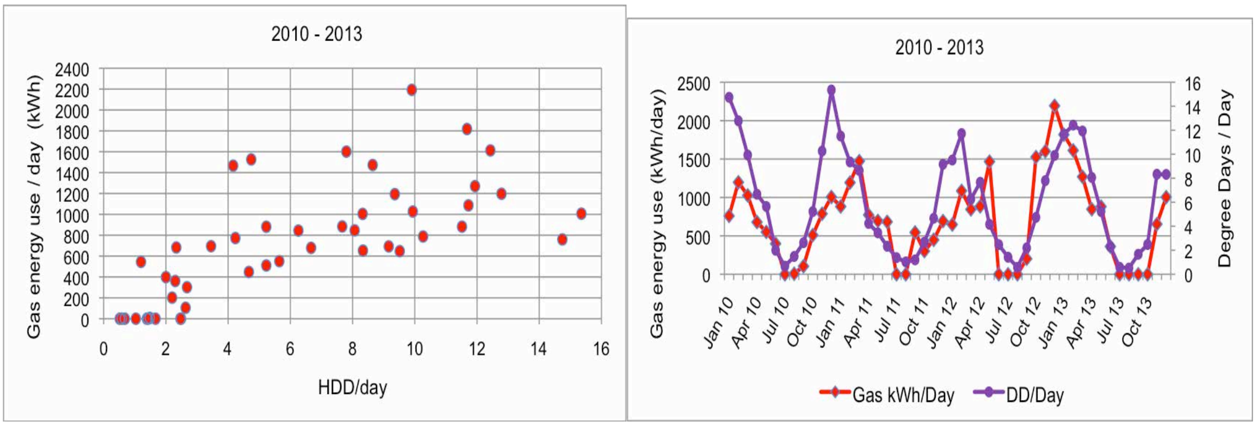


Figure 17: Degree-day analysis: (left) Daily gas consumption plotted against the degree days/day; (right) Gas and degree days/day data plotted against time.

Indeed, the relationship between gas consumption and degree days/day, examined separately for each year (Fig. 18), is very strong for 2010 and 2013 when 78% and 89% of the gas use variance respectively was associated with the DD variation. This is significantly weaker for 2011 and 2012 (54% and 43% respectively) indicating poor control of gas use.

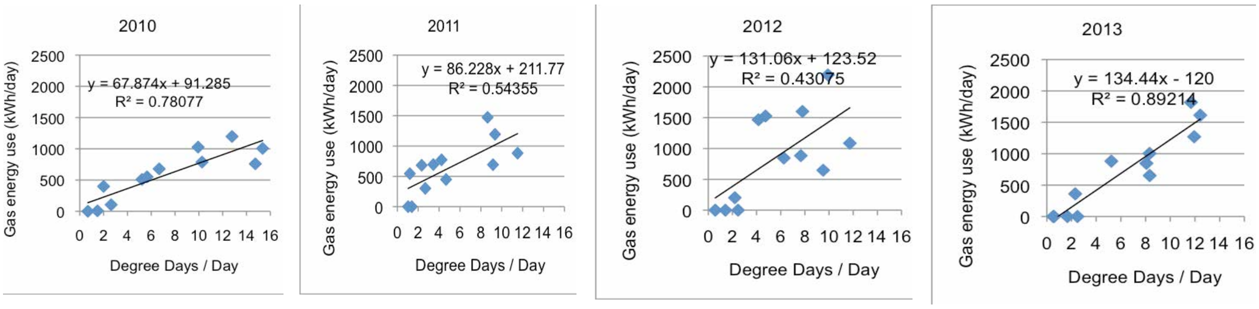


Figure 18: Daily gas consumption against degree days/day separately for each calendar year.

Seasonal analysis of energy consumption shows variation in electricity is considerably smaller than gas (Fig. 19). However, there appears to be high consumption during the summer, considering that the majority of students leave in June and staff have annual leave in this period.

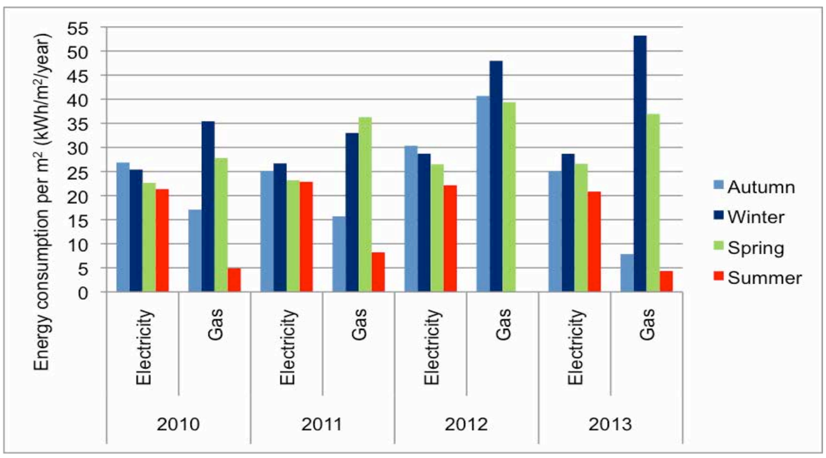


Figure 19: Seasonal electrical and gas energy consumption

To understand the profile of electricity use further electricity consumption was manually recorded on a daily basis over a period of four weeks in autumn 2012 (Fig. 20). The analysis demonstrates a very high base load over the week-end, when there are hardly any people in the building. This indicates that some end uses are constantly left on. The TM22 analysis enabled investigation of the various uses.

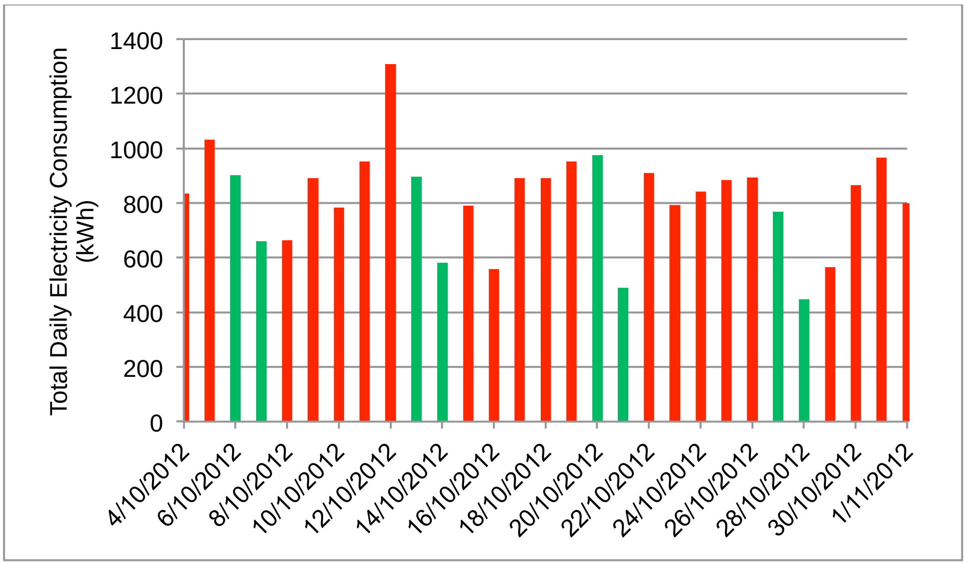


Figure 20: Total daily electricity consumption in weekdays (red) and weekends (green)

6.2 TM22 assessment

Due to the unusual nature of the building, the description of use is grouped according to activites and speciallist equipment into five areas (Fig. 21). For benchmarking puposes (the development of the user defined benchmarks is described in Section 6.2.1 below) the following have been assumed:

- Area 1: Offices representing 21% of the total GIA.
- Area 2: Specialist rooms mainly due to the equipment used; sound and film studios, control rooms and edit-suites, corresponding to 8% of the GIA.
- Area 3: Three large studios (one art gallery and two performance studios) accounting for 15% of the GIA, where the main energy consumption is from professional lighting.
- Area 4: Teaching spaces; a digital studio, a board-room and two seminar rooms accountings for 5% of the GIA.
- Area 5: unusually large circulation spaces on the ground and first floor and along with supporting services accounting for 51% of the GIA.

Area 1	Area 2	Area 3	Area 4	Area 5
Academic, Admin&Tech. Offices	Specialist: digital studio, control rooms, sound & film studios, edit suites	Studios 1,2 & 3	Teaching Spaces	ation, WCs, kitchen, services
General Office	Workshop	Cultural activities	University campus	University campus
Offices - cellular, naturally ventilated	Recording studios	Art Gallery	Classroom	University
Gross Internal Area (m2)	Gross Internal Area (m2)	Gross Internal Area (m2)	Gross Internal Area (m2)	Gross Internal Area (m2)
519.62	192.04	366.3	131.55	1282.81

Figure 21: General description of use and building specific type for the five areas in the Jarman building.

6.2.1 Composite benchmarks

The multi-use nature of the Jarman building does not allow for a comparison with existing benchmarks derived from single-use buildings. The calculation of composite benchmarks is based on the relative percentage of total floor area allocated to each distinct 'area' of the building. Table 1 summarises the existing benchmarks which describe better the use of the spaces in each 'area' of the building. Values from TM46 refer to typical benchmarks, while values from CIBSE F (2004), HEEPI and ECON 19 correspond to good practice benchmarks. The selection of the benchmarks considered to be the closest match for the building is discussed in the following paragraphs. This is based on a subjective assessment of each benchmark and how applicable it is for each 'area' (a scale from 1 to 5 is used, where 5 suggests 'very applicable') shown in Table 3.

Table 1: Existing benchmarks for each of the five areas in the Jarman building.

	Area 1		**Area 2**		**Area 3**		**Area 4**		**Area 5**	
Floor area GIA (m^2)	519.62		192.04		366.3		131.55		1282.81	
% of total GIA	21%		8%		15%		5%		51%	
Benchmark source	ECON 19	HEEPI 2004	CIBSE F 2004	TM46	CIBSE F 2004	TM46	HEEPI 2004	CIBSE F 2004	CIBSE F 2004	TM46
Refers to	TFA	n/a	TFA	GIA	GIA	GIA	n/a	GIA	NLA	GIA
Electricity (kWh/m^2/p.a.)	33	**46**	29	**35**	**57**	70	41	**67**	**29**	80
Fossil fuel (kWh/m^2/p.a.)	79	**107**	75	**180**	**96**	200	88	**100**	**103**	240
Applicability score	4/5	4/5	2/5	2/5	4/5	3/5	4/5	5/5	3/5	3/5

Area 1: Both ECON 19 and HEEPI can be used for the calculation of the composite benchmarks. ECON 19 is the most widely used for offices. The office 'type 1' option describes accurately the offices in Jarman (cellular-naturally ventilated). However, benchmarks from HEEPI are more recent (2004) and, despite the small sample size they come from (22 offices), they are very representative of the sector having originated specifically from Colleges and University buildings. For that, HEEPI is considered more suitable.

Area 2: None of the existing benchmark categories describe accurately the use of these spaces. The closest matches are found to be the TM46 'workshop' and the 'workshop' from CIBSE F (refers to Ministry of Defence buildings). The benchmarks in CIBSE F date from the 1990s and provided the base for the development of TM46. Between the two, TM46 is selected as more recent.

Area 3: The use of studios 1, 2 and 3 can be matched to either CIBSE F 'Museums and art galleries' or to TM46 'Cultural activities-art gallery'. However, the benchmark value from TM46 for fossil fuel (200 kWh/m^2/year) is twice the actual gas consumption in the Jarman building (102.4 kWh/m^2/year). Therefore, CIBSE F is selected for this area.

Area 4: Benchmarks from HEEPI come from 36 "teaching" spaces in Universities and Colleges. CIBSE F benchmarks refer specifically to "education-lecture room, arts" which accurately describe the use of the spaces in "Area 4" and thus it is selected as more suitable.

Area 5 represents 51% of the total GIA and thus the selected benchmark values have a great effect on the overall composite benchmarks. The two closest options are TM46 and CIBSE F referring to 'University campus' and 'University-non-residential' buildings respectively. The specific data in CIBSE F come from a small sample size (39 buildings) in Northern Ireland. However, the fossil fuel benchmark from CIBSE F is more applicable than TM46 as it excludes the residential facilities, which often require higher thermal energy. The TM46 database contains all types of buildings in University campuses with the generous 240 kWh/m^2. For these reasons CIBSE F data are preferred in this case over TM46. On the other hand it should be noted that the CIBSE F benchmark for electricity (29 kWh/m^2) is too low for the extensive use of electricity in the Jarman building.

In the calculations below the appropriate area conversion factors have been used as per table B4 in ECON 19 (1.3 for the conversion of NLA to GIA). In HEEPI 2004 the type of floor area is not specified, thus it is assumed that the benchmark values refer to GIA.

Electricity	Gas
Area 1: 46 x 0.21 = **9.7** kWh/m^2	107 x 0.21 = **22.5** kWh/m^2
Area 2: 35 x 0.08 = **2.8** kWh/m^2	180 x 0.08 = **14.4** kWh/m^2
Area 3: 57 x 0.15 = **8.6** kWh/m^2	96 x 0.15 = **14.4** kWh/m^2
Area 4: 67 x 0.05 = **3.4** kWh/m^2	100 x 0.05 = **5.0** kWh/m^2
Area 5: 29 x 0.51 x 1.3 = **19.2** kWh/m^2	103 x 0.51 x 1.3 = **68.3** kWh/m^2

This results are **43.7 kWh/m^2** for electricity and **124.6 kWh/m^2** for fossil fuel.

The composite benchmark for electricity is about 50% lower that the DEC (80 kWh/m^2) and Raw TM46 (89.9 kWh/m^2) and nearly 60% less than the electrical energy consumed in 2013 (101.2 kWh/m^2). The reason for this is the very small electricity benchmark from CIBSE Guide F (29 kWh/m^2) used in the calculations above for the building's 'Area 5'. If the benchmark from TM46 (80 kWh/m^2) was used instead the composite benchmark for electricity would be 65.3 kWh/m^2, closer to actual consumption but still significantly lower. Despite the selection of the most appropriate building categories for the five different areas in the Jarman building, it was not possible to develop an accurate benchmark for the electrical energy use. This indicates the large amount of electricity used in the building, mainly from internal lighting kept on 24/7.

As far as the thermal energy is concerned, the corresponding composite benchmark is very close to the gas consumption in 2013 (102.4 kWh/m^2) and to the 4-year average consumption (102.2 kWh/m^2). Contrarily, benchmarks from BRUKL, DEC and Raw TM46 are higher than the heating energy use in 2013 by 174%, 162% and 131% respectively (Fig. 22).

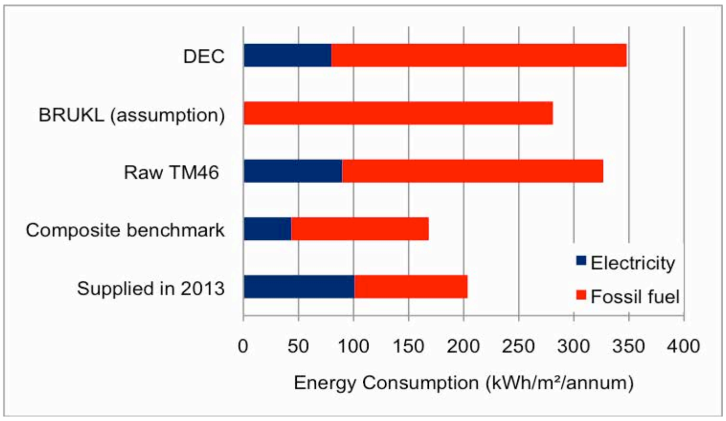


Figure 22: Composite electricity and fossil fuel benchmark compared to energy supplied and benchmarks from DEC, BRUKL and Raw TM46.

Note on the estimated BRUKL benchmark: In the BRUKL, the Jarman is categorised as 'Further education universities'. In the 'As built' section the heating consumption for the actual building is 31.2 kWh/m^2. Assuming that this refers to monthly consumption and taking into account that heating is off during summer (in 2010 & 2011 it was off in July and August, in 2012 & 2013 off since June), the benchmark value is 31.2 kWh/m^2 x 9 months = 280.8 ≈ 281 kWh/m^2/year. Regarding the electrical energy use no information is provided in the BRUKL report, either including or excluding small power.

6.2.2 Simple assessment of the annual energy use

As already mentioned all end-use categories are electric with the exception of heating, which is provided by two modular condensing gas boilers with a combination of underfloor heating and radiators.

Figure 23 compares the delivered energy to the DEC and User Specified Benchmarks. The latter is a result of the calculated composite benchmark values discussed in Section 6.3. Since there is an official DEC, benchmarks from Raw TM46 have been excluded.

The energy supply for heating is 102.4 kWh/m^2 GIA resulting in 19.9 kgCO_2/m^2. This is well below (62% less than) the benchmark from DEC and 18% less than User Specified benchmark. On the other hand, the electrical energy (101.2 kWh/m^2) is 27% higher than the DEC benchmark and significantly higher than the User Specified benchmark (43.7 kWh/m^2). The reason for this is discussed in Section 6.3. The carbon dioxide emissions attributed to the electrical energy use are 55.6 kgCO_2/m^2 GIA.

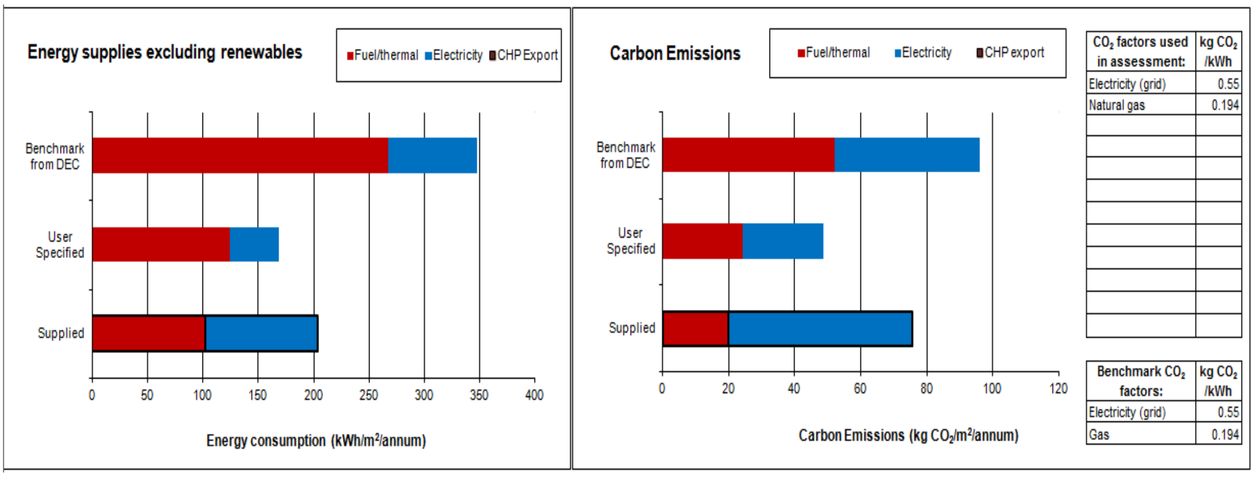


Figure 23: Electricity and fossil fuel consumption and resultant carbon dioxide emissions for the Jarman Building for the 12 months in 2013, plotted against DEC and User Specified (composite) benchmarks.

6.2.3 Detailed assessment of energy use

Lighting is by far the highest electrical end use in the building representing 46.4% of the total in-use electricity (Fig. 24). The extensive use of internal lighting (left on 24/7) accounts for 37% of the total electricity consuming 36.6 kWh/m^2/year. External lighting represents 9.4% of the total electricity. However, this figure is not representative of the actual electricity for external lighting, as it includes the campus street lighting metered in the Jarman building. Subtracting the energy consumption associated with street lighting (18,527 kWh/year) from the total electricity, the actual electricity consumption for external lighting is only 1.9 kWh/m^2/year, representing 2.1% of the total.

Catering (distributed), refrigeration and ICT equipment are the next highest end uses accounting for a similar percentage of the total electricity. Energy consumption from catering is atttributed to the vending machines and the kitchen appliances, equating to 11.1% of the total electrical energy use.

Refrigeration is responsible for 10.1 kWh/m^2/year representing 10.2% of the building's total in-use electrical consumption. This includes the cooling from a single AC unit for what was designed to be the server room. However, the server room was installed elsewhere, so the AC unit effectively was cooling a store-room. This was in operation until 22nd April 2013. Subtracting the associated 5,728 kWh consumed in 2013 from the total metered electricity, the actual cooling energy in the specialist rooms of Jarman building is 7.8 kWh/m^2/year, representing 8% of the total electricity.

Energy consumption from the ICT equipment is 8.9 kWh/m^2/year, equating to 9% of the total.

Other end uses accounting for a smaller fraction of the total electrical energy consumed include the hot water provided by seven electric water heaters working on demand (4.9 kWh/m^2/year and 5% of total), small power (4.4 kWh/m^2/year, 4.5% of total), and the entertainment equipment and lighting used in specialist rooms (5.5% of the total electricity).

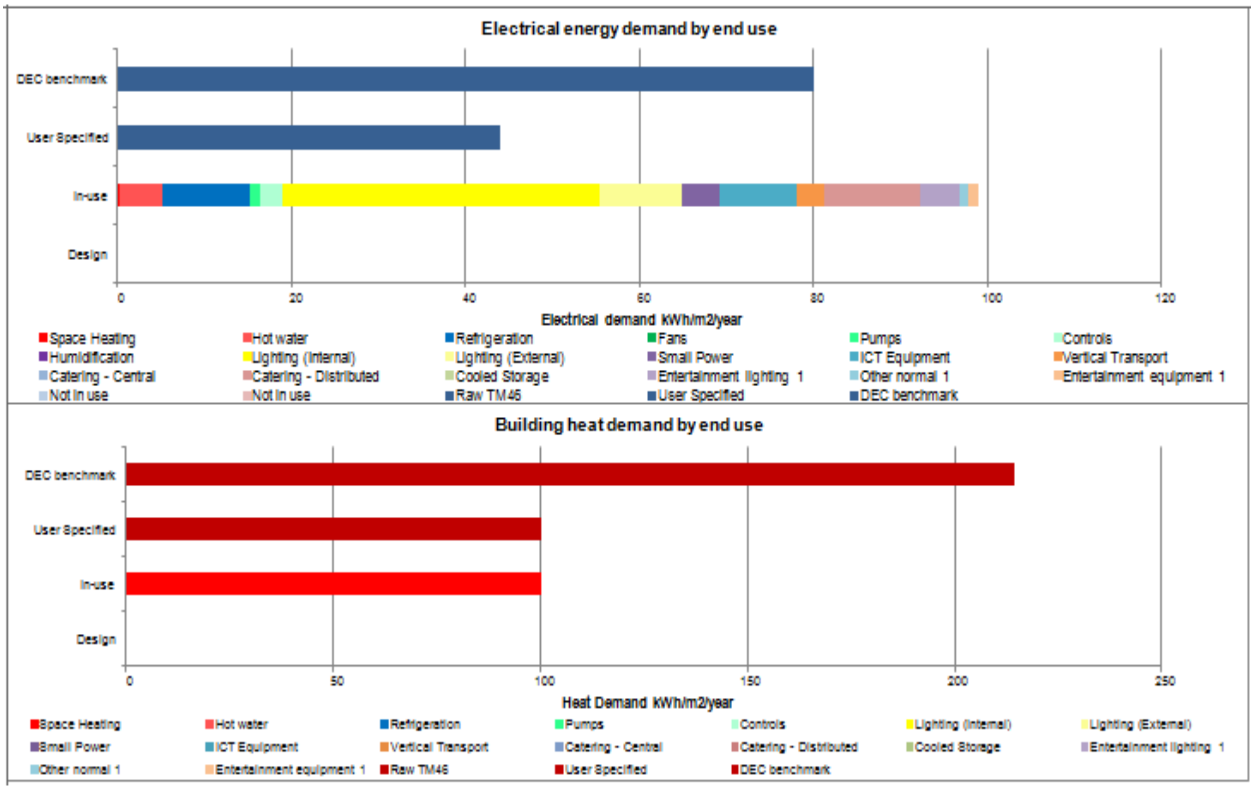


Figure 24: Detailed assessment for electrical and thermal energy demand.

With regard to the annual carbon dioxide emissions (Fig. 25), the thermal energy is associated to 19.9 kgCO_2/m^2/year. Electricity is responsible for 54.4 kgCO_2/m^2/year, of which 25.2 kgCO_2 is attributed to lighting.

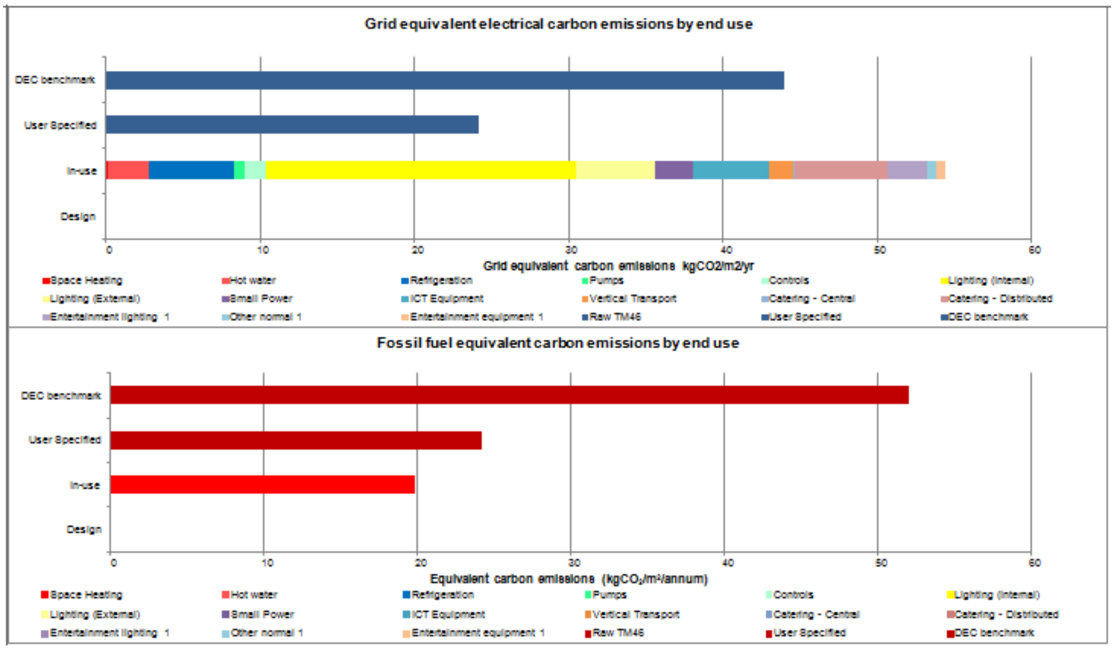


Figure 25: Fossil fuel and electrical carbon emissions by end use.

6.3 CarbonBuzz

The TM22 figures have been exported in CarbonBuzz and presented in Figure 26. Figure 27 benchmarks the annual energy use and carbon dioxide emissions with other buildings in the educational sector.

However, it should be noted that some of the CarbonBuzz features and respective filters are not in operation; hence the figures presented are for buildings with a floor area between 2000 m^2 and 3000 m^2 with a comparison range of ±500m^2. Out of the 33 buildings shown, 24 are single use and 9 are mixed use buildings.

Another limitation is that the dataset contains various versions of the Jarman, which cannot be deleted. During the development stage various unpublished iterations had been imported with the understanding that they could subsequently be deleted. However, due to bugs in the systems and breakdown in communications with the software developers, the database currently contains at least five different versions of the building, which is skewing potential comparisons. As a result most of the mixed-use buildings in the database (between 2000 m^2 and 3000 m^2 floor area ±500m^2) correspond to the Jarman.

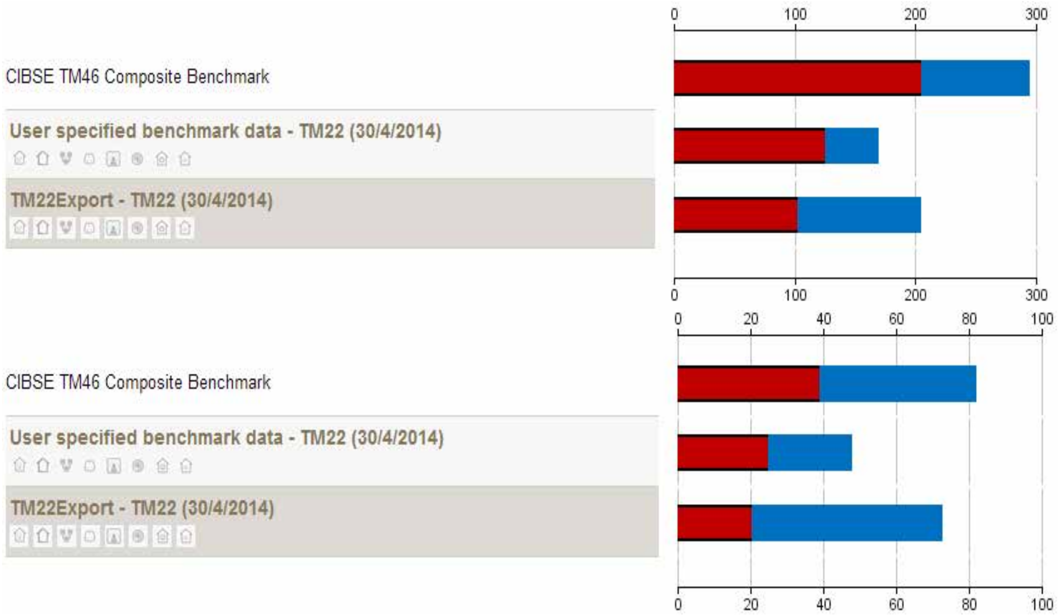


Figure 26: Annual energy consumption (top) and carbon dioxide emissions (bottom) per m^2 for the 12 months in 2013, plotted against CIBSE TM46 and the User specified composite benchmark.

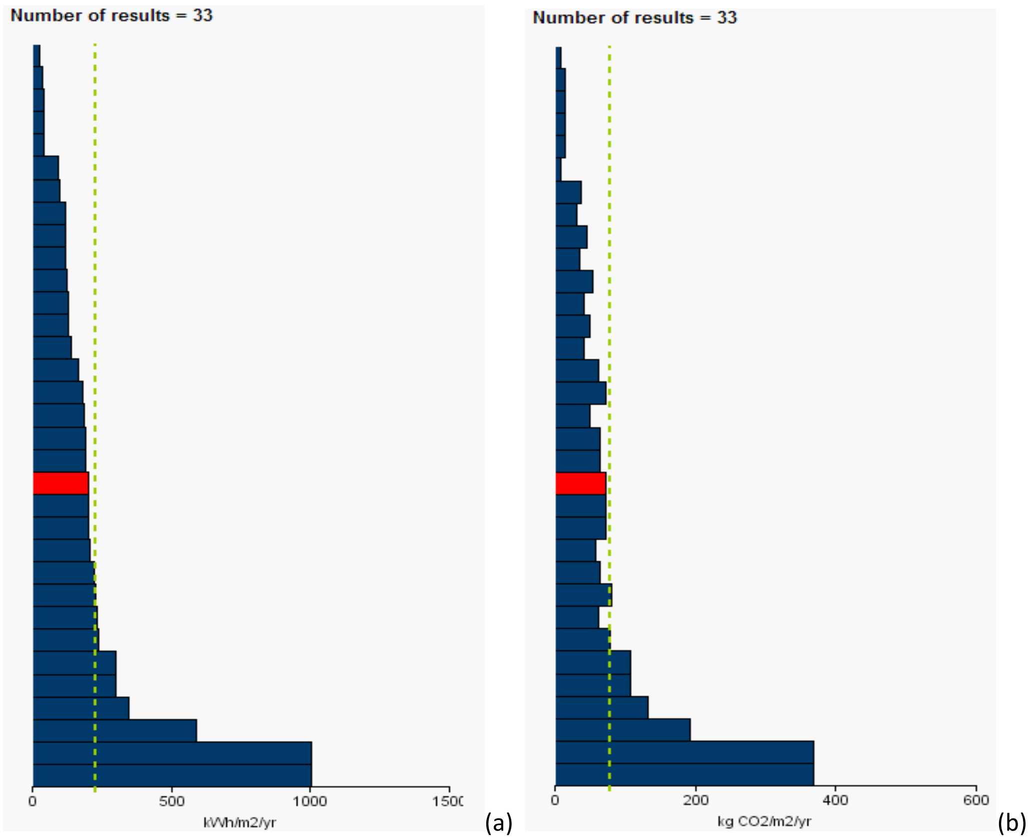


Figure 27: Benchmarking (a) energy use (kWh/m^2/yr) and (b) carbon dioxide emissions (kgCO2/m^2/yr) with other educational buildings including single and mixed use.

6.4 Conclusions and key findings for this section

The energy consumption of the building was continuously increasing for the first three years since its occupation in 2010, with the highest increase found in 2012. The EPC had a B rating, while the latest DEC had a D rating. The breakdown between electricity and gas use showed that this was predominantly due to gas, which led to increased use of heating as a result of frequent complaints of cold discomfort in winter. Further analysis demonstrated poor correspondence of gas consumption with weather severity during the winter months of each year and particularly for 2011 and 2012. Revision of the heating schedules led to a decrease in gas consumption in 2013.

The case above highlights the dangers of not fully integrating the control of heating, ventilation and mechanical cooling systems, which, acting independently, can fight each other and get into a vicious dependency circle of energy wastage. Poor manufacturers' specifications and inadequate commissioning processes can exacerbate such problems. As a result of this work, the Estates' procurement practices have changed, regarding commissioning.

Electricity use was also high, demonstrating a particularly high base load over the week-end, when there are hardly any people in the building. This indicates that some end uses are constantly left on. The TM22 analysis enabled investigation of the various uses and highlighted the very high consumption by lighting, where the extensive use of internal lighting accounts for 37% of the total electricity.

Poor control of the artificial lighting, in a building that was designed to be predominantly daylit, is a major shortcoming and leads to high energy wastage. Complicated and inflexible password protected controls that none of the users of the building can access should be avoided. Another interesting issue is the unexpectedly high electricity use of catering, predominantly vending machines. Their extended use, which becomes increasingly popular in mixed-use buildings, should be revisited, as they can account for nearly up to 10% of the electricity consumption.

Benchmarking, whether typical or best practice, should be used with caution, particularly for mixed-used and/or complex, as over-simplistic benchmarking can have little resemblance to reality. Due to the complex nature of the Jarman building, in terms of activities and uses, composite benchmarks were developed, resulting in 43.7 kWh/m^2 for electricity and 124.6 kWh/m^2 for fossil fuel.

The new benchmarks for electricity confirmed the very high electrical energy use, indicating the great amount of electricity used, mainly from internal lighting kept on 24/7. Appropriate controls for lighting supplemented by daylight and movement sensors, particularly for the atrium and decorative lighting outside the offices, would enable significant reductions in electricity. Reducing by half the operational hours of the internal lighting, it would be possible to reduce electricity by at least 18 kWh/m^2. Further savings could be expected by removing vending machines (at 11 kWh/m^2). Overall savings would reduce the energy consumption by 30%, further closing the gap between the electricity consumed and the composite benchmark.

Regarding the thermal energy, the composite benchmark is close to the gas consumption in 2013 (102.4 kWh/m^2) and to the 4-year average consumption (102.2 kWh/m^2).

7 Technical Issues

7.1 Ventilation and Underfloor heating

It is a significant challenge for the heating system's heat output to be controlled in an efficient manner, as likewise it is for the air flow of the passive stack ventilation system. The reason for this is that neither the passive stack ventilation control system nor the underfloor heating control system knows of the existence of the other.

The building's BMS only partly controls the underfloor heating, in so far as it enables it or disables it, by making hot water available for the occupied hours of the day, and then switching this off at night. The actual use made of the hot water availability during the occupied hours is outside the BMS's control and is determined independently by the underfloor heating system's dedicated air temperature sensors. Neither the value of these temperatures nor the degree of heating provided is available to the BMS.

This independence in both sensors and control systems can lead to the underfloor heating system continuing to provide heat while the passive stack ventilation is venting it away. The use of independent temperature sensors alone means that the control system is vulnerable and sensitive to the sensor's accuracy, and actual thermostat setting in relation to the ventilation controller's space temperature setting.

The motorized windows that are adjusted by the passive stack ventilation system's controller are not as quiet in operation as some users would like. This is not an issue in the foyer or corridors, but in the drama studios when the creaking and whirring noise can be distracting during a performance. There have also been cases where windows appear to hunt for the right position, leading to excessive noise from the actuators.

Another issue for the ventilation in the drama studios (Fig. 28) is the provision of fresh air through perimeter louvres without any conditioning of the incoming air. If there is a call for fresh air, and this is not satisfied by the openable windows, the low level perimeter louvres will open. This can lead to an inrush of cold air across the floor. Given the relatively light attire of those using the drama spaces, this could lead to discomfort. However, there is a curtain track, offset 300mm from the perimeter and at 3m height, from which black-out curtains are hung down to the floor (Fig. 29). This is usually in place in the drama studios and extends completely round the studio forming an annulus with the perimeter wall. In practice fresh air enters first this annulus space and is warmed by the underfloor heating system as it builds up behind the curtain and diffuses through its gaps into the body of the studio space. It is this continuous fabric curtain that avoids the potential discomfort of cold air entering the space unconditioned. However, it was not part of the original design intention to have this curtain in place all the time.

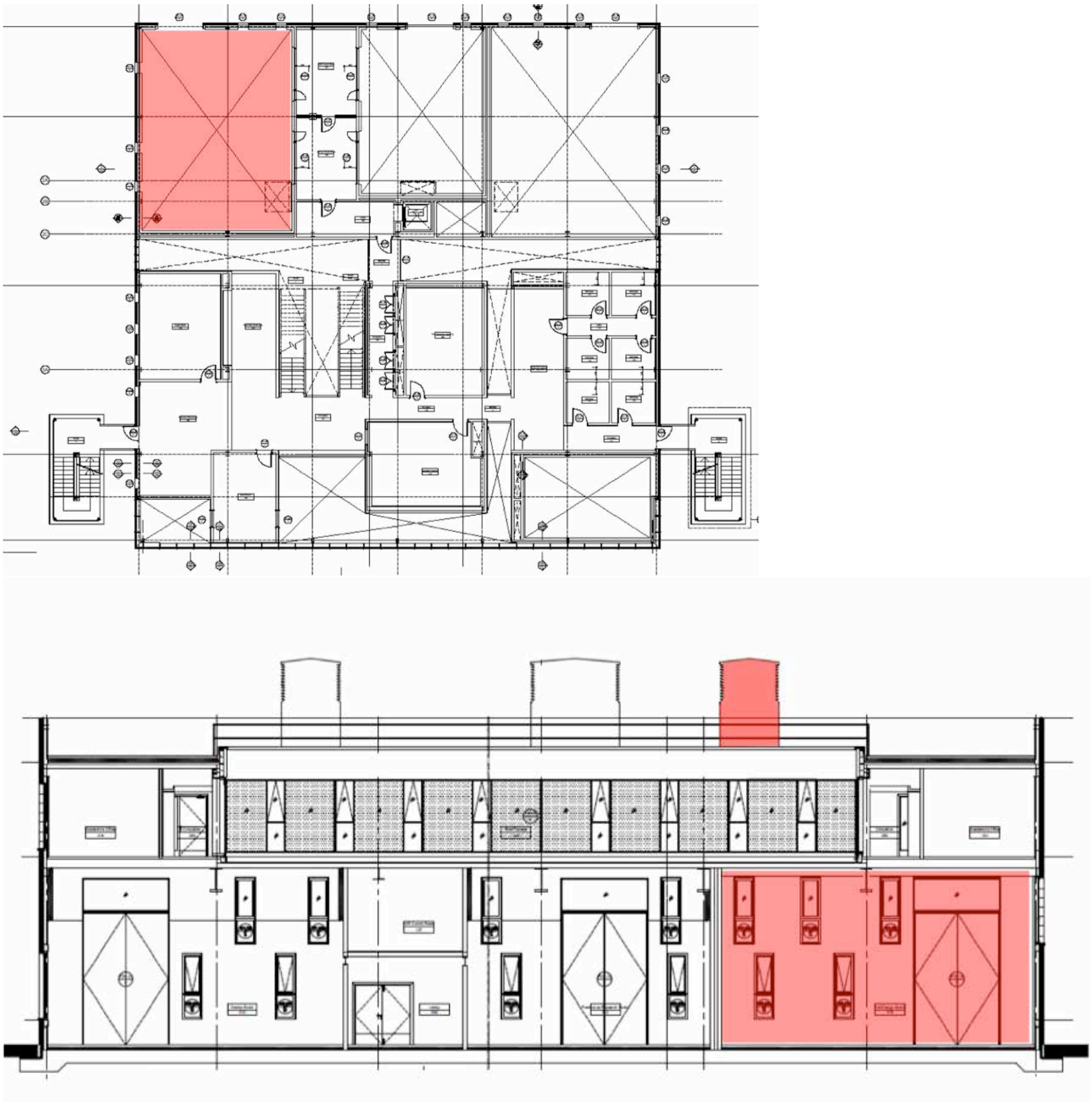


Figure 28: Floor plan (top) and section (bottom) of the drama studio showing the stack at roof level

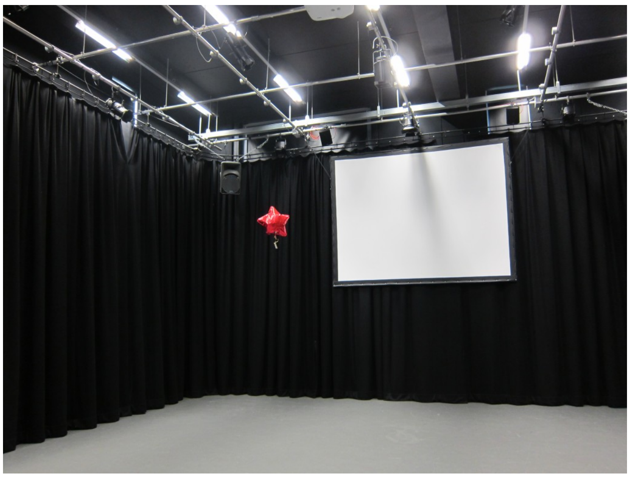
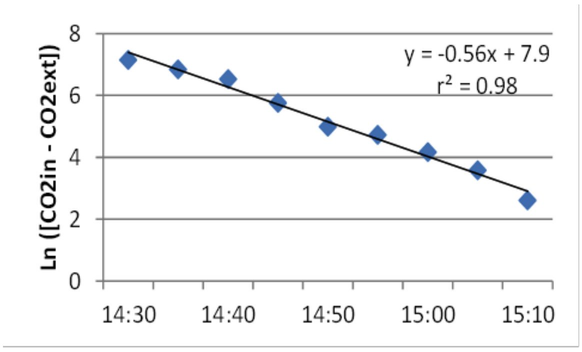
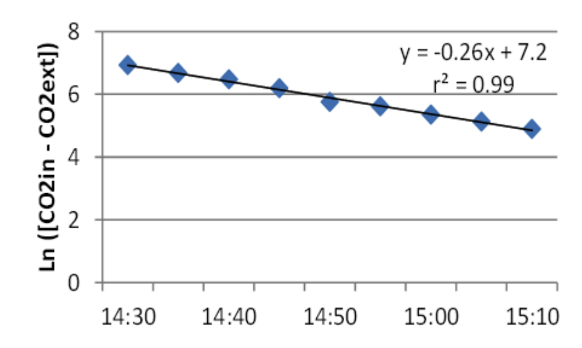


Figure 29: Blackout curtains hung down to the floor obstruct cold air from entering the space unconditioned.

Testing of the air flow in one of the main drama studios showed that even when the louvres are fully closed at the top of the stack, the air flow rate up the stack is still significant. The flow rate when the stack's louvres were completely closed remained at about 0.33 m^3/s up the stack, equivalent to 1.5 air changes and hour, or potentially sufficient fresh air for over thirty people. Given that the underfloor heating schedule is continuous (24 hours a day, seven days a week), this represents a significant waste of heating energy, at a rate of about 9 kW at 0°C outside.



Decay of CO_2 in stack – Curtains CLOSED



Decay of CO_2 in studio – Curtains CLOSED

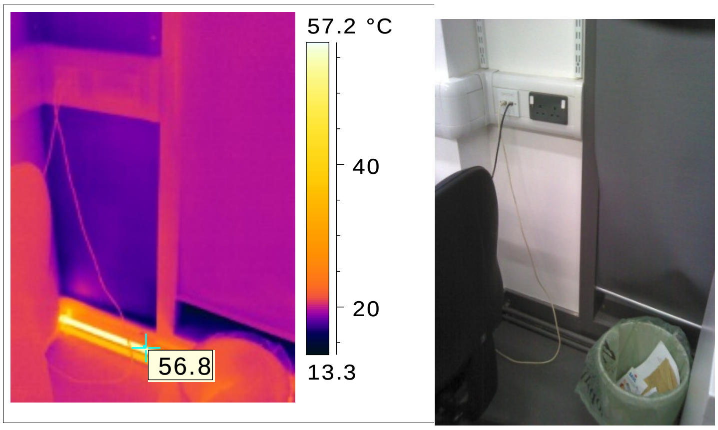
Figure 30: Ventilation tests showed that the use of the curtains led to much of the fresh air supply bypassing the centre of the studio. This is shown as a reduced decay rate.

7.2 LTHW heating system

Problems with hot and cold discomfort in winter highlighted some shortcomings of the LTHW system serving the offices on the top floor.

The rooms situated at the start of the LTHW pipe system are warmer than those offices at the end with a 6°C difference between cooler and warmer areas. These problems indicate that the LTHW heating circuits have not been balanced properly during commissioning. The situation is further exacerbated by the lack of insulation of the LTHW heating pipework to the radiators resulting in uncontrolled heat gains (Fig. 31). Thermal insulation of the building envelope is good, and the radiators relatively small, so these uncontrolled heat gains are significant. Additionally, supplementary electric heaters being used by the occupants of the cooler offices result in increased electricity consumption.

(a)



(b)

Fig. 31: Absence of insulation for the horizontal pipes for the LTHW system in the offices on the top floor (a); thermographic images showing the heat losses for these pipes (b).

7.3 Lighting controls

Lights in the reception and foyer area are controlled by a centralised control at the reception desk (Fig. 32(c)). The lighting controller requires a password to access and change control settings. The lighting controls have been found to be too inflexible and complicated and as a result all the circulations lights in the main foyer are left on 24/7 (Fig. 32(a)), even on very bright days with the sunlight entering the building (Fig. 32(b)).

Internal lighting is responsible for over a third of the building's energy consumption (37%), which is significant for a building, which has been designed to be predominantly daylit. Appropriate controls would enable great savings.

Figure 32: Extended artificial lighting left on throughout the day (a), even on bright days (b); centralised lighting control (c)

7.4 Conclusions and key findings for this section

The independence of the underfloor heating control from the passive stack ventilation control and the wider BMS's influence leads to a system vulnerable to inefficient operation, most notably the possibility of providing and discarding heat simultaneously. This issue of careful integration of independent systems and appropriate control through the BMS is a recurrent theme and has to be addressed with appropriate professional oversight at the commissioning stage. This will avoid energy waste and improve thermal comfort for the occupants.

Natural ventilation through stack effect needs to be carefully considered and evaluated both at the design and commissioning stage. The blackout curtains, which have been used partly to improve thermal comfort in the large studio by obstructing cold air from entering the space unconditioned were not part of the initial design. They represent a barrier to the fresh air entering the main space and cause the incoming air to migrate upwards towards the stack exit, effectively bypassing the central part of the studio. However, without these in place cold air entering from the windows and low-level louvers is a source of thermal discomfort.

Furthermore, the apparent leakiness of the stack terminal in the main drama studio, with louvres in the closed position, leads to significant heat loss and should be avoided. It highlights the importance of provision of well-sealed air dampers and the importance of designing a fresh air supply that matches the way a space is used.

Additional heat losses are noticed in relation to the LTHW heating system, where the heating circuits appear to have not been balanced properly during commissioning. The problem is further exacerbated by the lack of insulation of the LTHW heating pipework to the radiators resulting in uncontrolled heat gains. Such issues become significant in the context of a well-insulated building, where the radiators are small and should be carefully evaluated at the design stage.

Poor centralised lighting control leads to energy waste. Centrally controlled lighting systems should be avoided in future with the emphasis placed on local control, appropriate zoning, supplemented by daylight and movement sensors.

8 Key messages for the client, owner and occupier

The successful development of low energy buildings requires careful consideration of the building envelope, building services and occupants' interaction with the building. In the case of the Jarman, the main issues are identified below.

8.1 Control of building services

The nature of the contractual arrangements encouraged a sub-contractor to install an underfloor heating system that would operate independently – even to using independent internal air temperature sensors. Whilst this was contractually perfectly acceptable, it undermined the controllability and interoperability of the heating, cooling and ventilation systems. It was not the design intention, elucidated in the Environmental Performance Specification. However, the authors of this specification were not retained to oversee compliance with it.

It must be fundamental that a design, or implementation of it, should avoid allowing the simultaneous heating and cooling/venting of a space in a building in order to maintain comfort. Such an approach is necessarily going to be energy profligate. Additionally, it is important to achieve high level of integration between standalone controllers and the BMS if energy reduction targets are to be met, avoiding standalone self-acting controls. For that, professional oversight is critical, through either the involvement of the authors of the environmental performance specifications or an independent commissioning engineer to oversee the commissioning process and successful integration of individuals systems.

Simplicity of controls is also a critical parameter, if the aim is for users of the building to control some of the systems. The password-protected control for the lights in the central circulation areas was too inflexible and demonstrated a complete failure in controlling the lights (that was the case for all users, whether student, staff working in the building, or security staff locking up the building at the end of the day).

The most environmentally sound building design can be undermined by the simplest deficiency in control strategies.

8.2 Design of passive systems and occupants' satisfaction

For the design of low energy buildings, thermal mass to enable passive cooling, openings for lighting and ventilation are very important. Often, however, these systems can have unintended consequences impacting on occupants satisfaction; e.g. extensive hard surfaces to provide thermal mass for passive cooling increase reverberation time and impact negatively on acoustic comfort. It is important to manage occupants' expectations and ensure there is adequate understanding of such interactions.

Similarly ownership and environmental control of the conditions in circulation spaces, such as corridors and foyer, should be discussed with the occupants to provide optimum conditions in the building and avoid energy waste.

Provision of individual controls through openable windows, shading devices, etc., can improve satisfaction with the building, with the occupants being more forgiving of potential shortcomings at different times of the year. This aspect of perceived control has been proven to be very important in the day-to-day running of the building, particularly in the summer, when occupants find comfort at a wider range of temperatures than prescribed by the traditional comfort standards.

8.3 Natural ventilation of complex spaces

Natural ventilation of large spaces with intense activities is challenging. Beyond the sheer size, anticipated use is important to design a fresh air supply and extract that matches the way a space is to be used. For that detailed discussions with the client are critical, along with understanding of conflicting needs, e.g. fresh air supply and thermal comfort. The blackout curtains used in the drama studios obstructed cold air from entering the space, but led to the incoming air rising upwards and exiting through the stacks effectively bypassing the central part of the studio.

Furthermore, the provision of air dampers that are well sealed when in closed position is very important both to maintain thermal comfort and avoid energy waste.

9 Wider lessons

The Jarman is a complex building comprising a range of activities; rehearsal studios drama and film studios, computing and editing suites, a large art gallery, teaching rooms, academic and administrative offices.

Architecturally, the building can be regarded as successful (the building won a RIBA-2010 award) maximising the use of passive means of design for daylighting, natural ventilation and cooling. However, a number of issues have jeopardised the passive means of design and successful integration of building services, impacting on thermal comfort and energy consumption.

The overall **users' satisfaction** is high, which is partly due to the fact that the vast majority of its permanent occupants have a window seat, enabling them a higher degree of control and pleasant views. This along with the high individual control offered to its users lead to a very high 'Forgiveness index'. In fact in the BUS survey the building achieved the highest 'Forgiveness index' in the database, which can be viewed as a measure of tolerance with the building's shortcomings in terms of thermal and acoustic comfort.

Areas of **dissatisfaction** refer to noise transmission, which is always a challenge in large open plan areas with hard surfaces to maximise thermal mass and poor thermal conditions in some of the spaces. In similar contexts managing occupants' expectations, informing them of the trade-offs between thermal and acoustic comfort would be advisable.

Overheating in the summer does not cause any problems in the circulation areas where raised temperatures are noticed as a result of stratification. **Comfort** conditions are more problematic in **winter**, where some offices consistently experience overheating, while others complain of cold conditions. The offices located where the heating pipework splits experience overheating with high air temperatures, while those at end of the pipework network experience the coldest conditions. The problem is further exacerbated by the lack of insulation of the heating pipework to the radiators resulting in uncontrolled heat gains/losses. Similar issues have to be carefully considered, particularly in the context of well-insulated buildings, where such uncontrolled heat gains/losses are proportionately significant. Orientation is also important, as offices on the north side have lower temperatures than on the south.

The building's **energy consumption** was continuously increasing for the first three years since its occupation in 2010, with the highest increase found in 2012. The EPC had a B rating, while the latest DEC had a D rating. The breakdown between electricity and gas use showed that this was predominantly due to increased gas consumption. Detailed analysis enabled savings to be made and such use to be reduced in 2013.

Significant **heat losses** have been attributed to the independence of the underfloor heating control from the passive stack ventilation control and the wider BMS's influence, most notably the possibility of providing and discarding heat simultaneously. Additional heat losses are attributed to the poor balance of the LTHW heating circuits during commissioning, which is also responsible for the thermal discomfort in the offices.

Natural ventilation of large spaces has to be carefully considered and balanced against comfort conditions, as the provision of fresh air through perimeter louvres without any conditioning of the incoming air can lead to an inrush of cold air across the floor, which could lead to discomfort. Further shortcomings regard ineffective ventilation of the space, with the incoming air rising upwards and exiting through the stacks effectively bypassing the central part of the studio.

Electricity use demonstrated a very high base load, indicating that some end uses are constantly left on. The TM22 analysis highlighted the very high consumption by lighting, where the extensive use of internal lighting accounts for 37% of the total electricity. The existence of a single centralised password-protected lighting control for all the main circulation spaces in the building is too inflexible and complicated and leads to huge energy waste with the lights left on throughout the day. Appropriate local controls supplemented by daylight and movement sensors would enable great savings.

Analysis also highlighted the high energy consumed by vending machines for confectionery and soft drinks, which along with the small kitchen appliances account for 11% of the total electricity.

Benchmarks should be treated with caution, particularly for complex buildings incorporating a variety of uses. As none of the available benchmarks were appropriate for the Jarman, user defined composite benchmarks were developed. Despite the selection of the most appropriate building categories for the different areas in the building, it did not succeed to develop a good benchmark for the electrical energy use. This indicates the large amount of electricity used in the building, mainly from internal lighting kept on 24/7. Appropriate controls for lighting along with reduction of unnecessary loads such as vending machines, could reduce the energy consumption by 30%, closing the gap between the electricity consumed and the composite benchmark.

As far as the thermal energy is concerned, the corresponding composite benchmark is close to the building's gas consumption. Contrarily, benchmarks from BRUKL, DEC and Raw TM46 are significantly higher than the heating energy use.

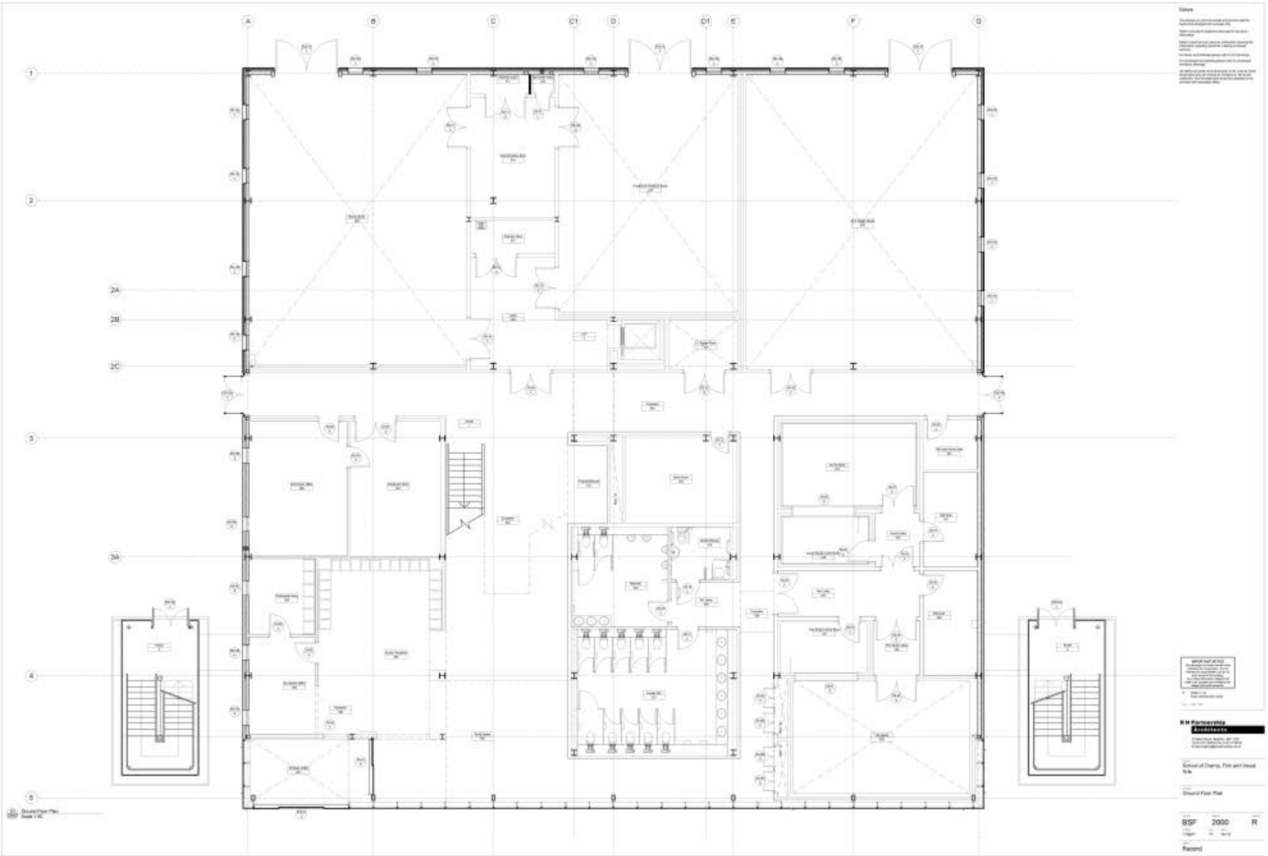
Regarding **sub-metering**, the strategy to segregate end uses should take place before installation and the respective drawings should demonstrate this. Sub-metering should be at a level that is commensurate not only with the engineering systems but also within the capacity of the building managers to operate and act upon.

The review of the **procurement** process highlighted the importance of full integration between standalone controllers and the BMS, to avoid the limitations of standalone self-acting controls.

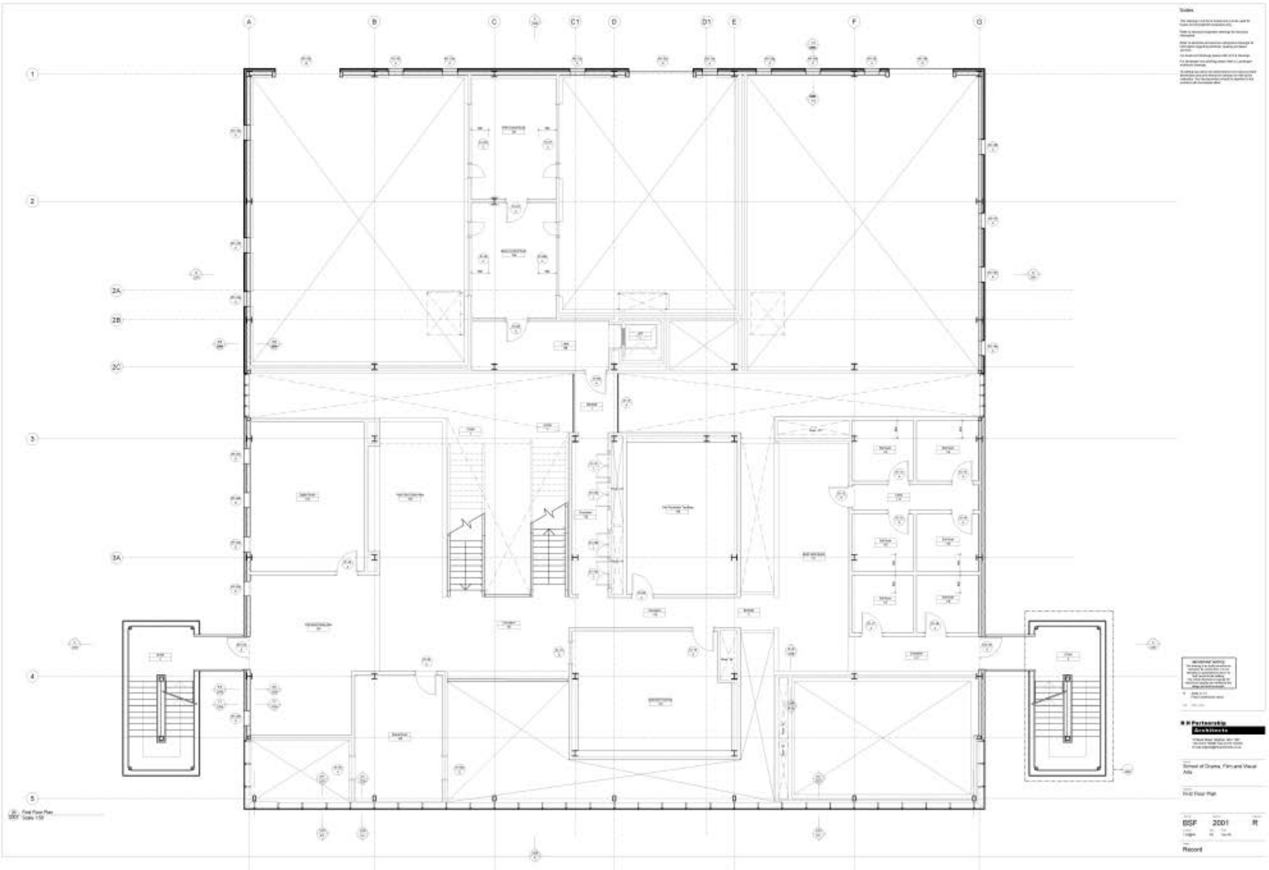
Finally, it is important to retain the authors of the environmental performance specifications or appointing independent commissioning engineer to oversee the commissioning process, to check against design specifications and integration of individual systems. This is particularly critical for ensuring the success of complex buildings.

10 Appendices

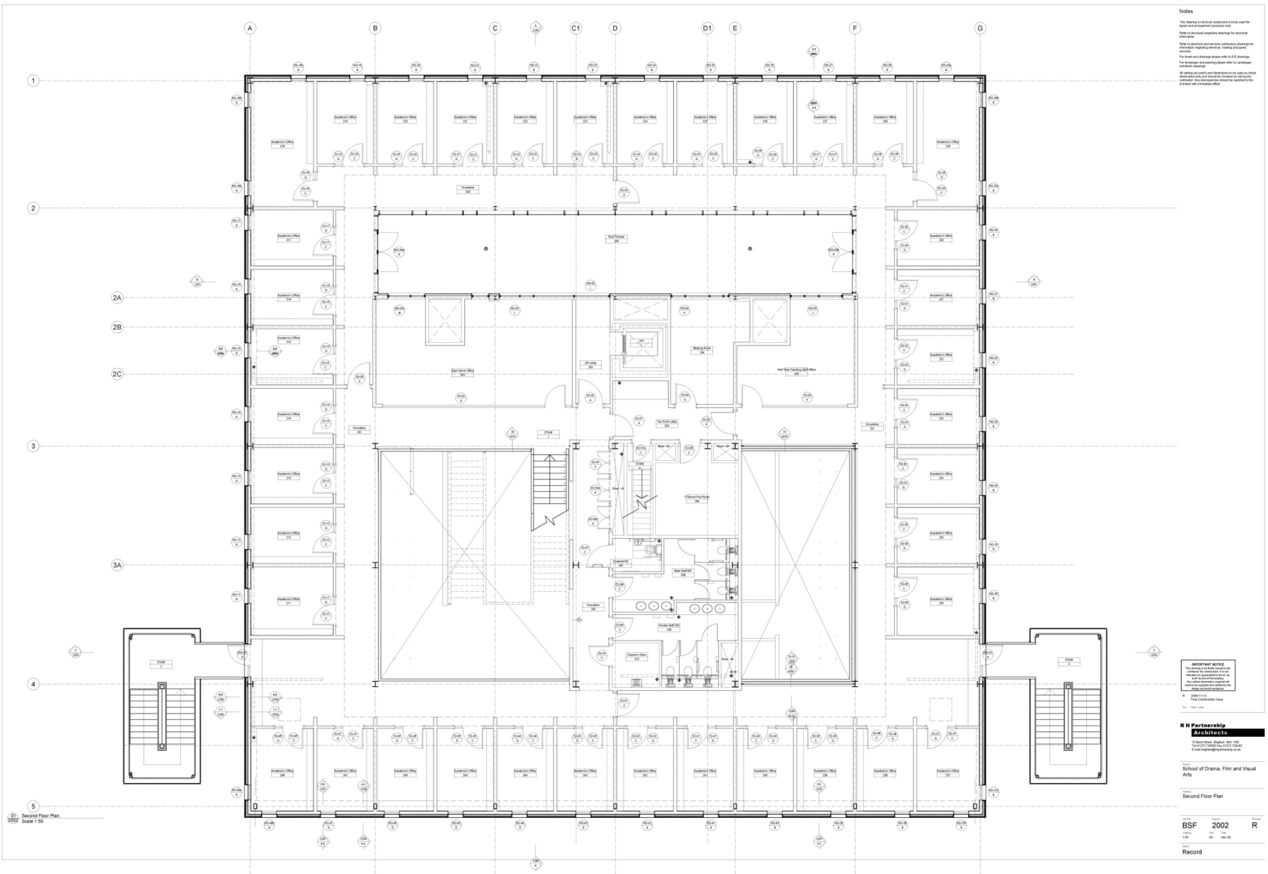
10.1 Floor plans (as built)



Ground-floor

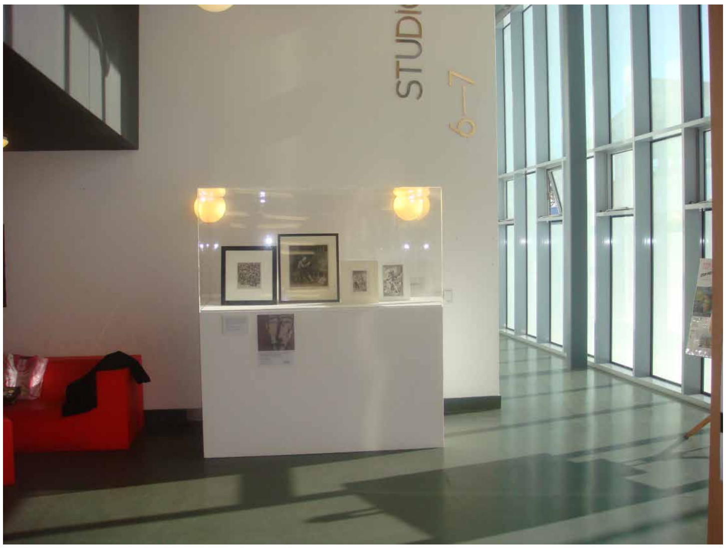


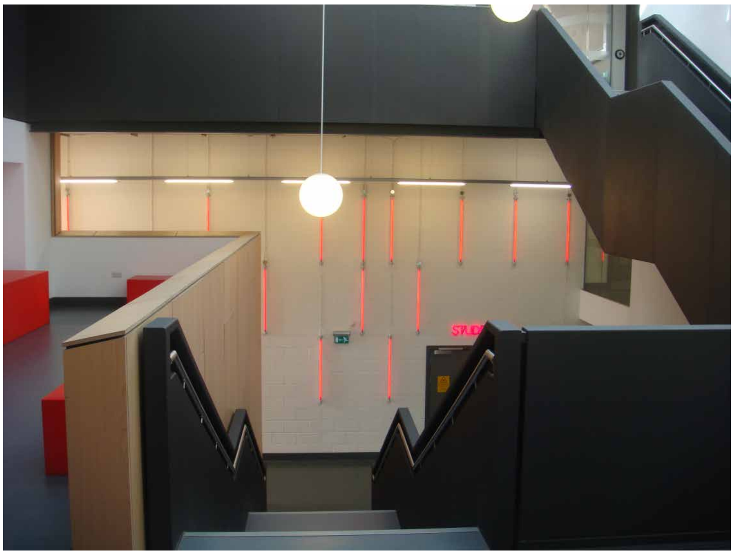
First floor

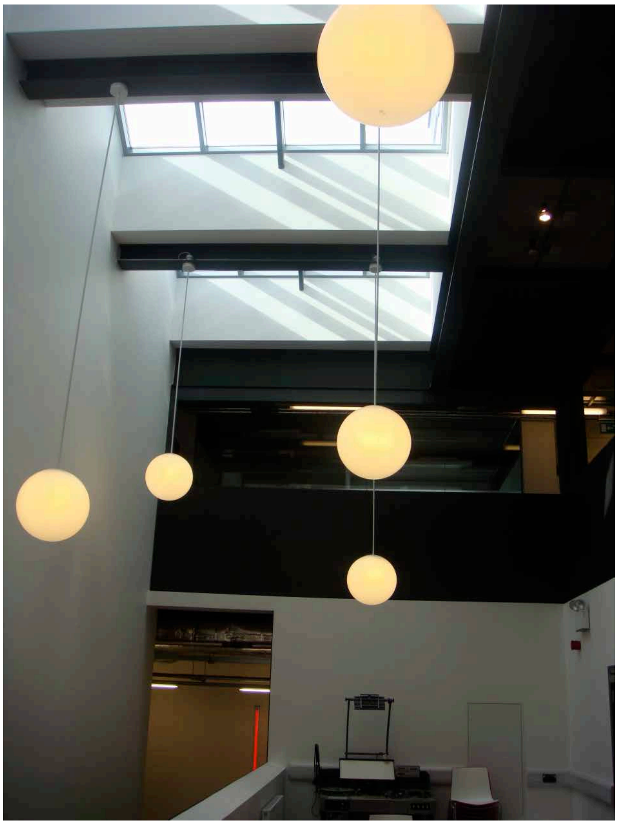


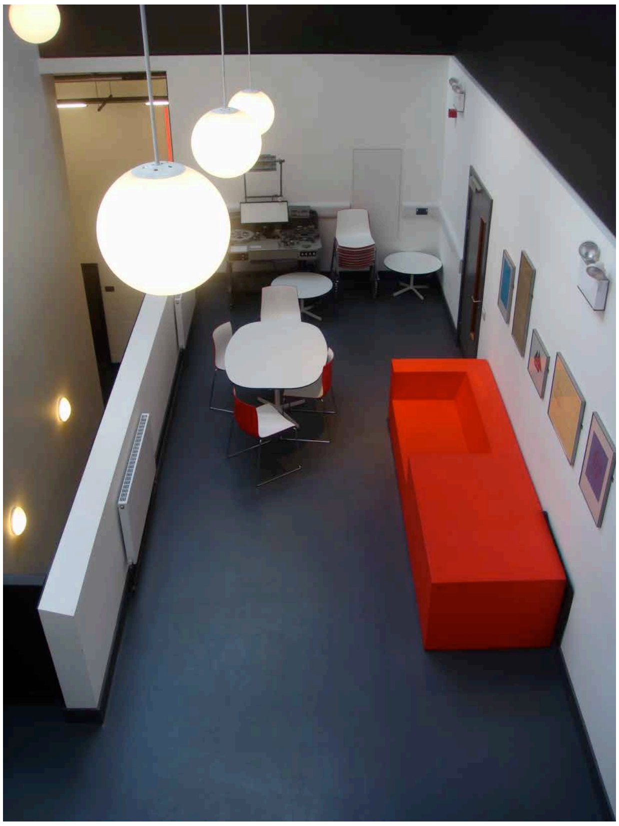
Second floor

10.2 Photos of internal circulation spaces

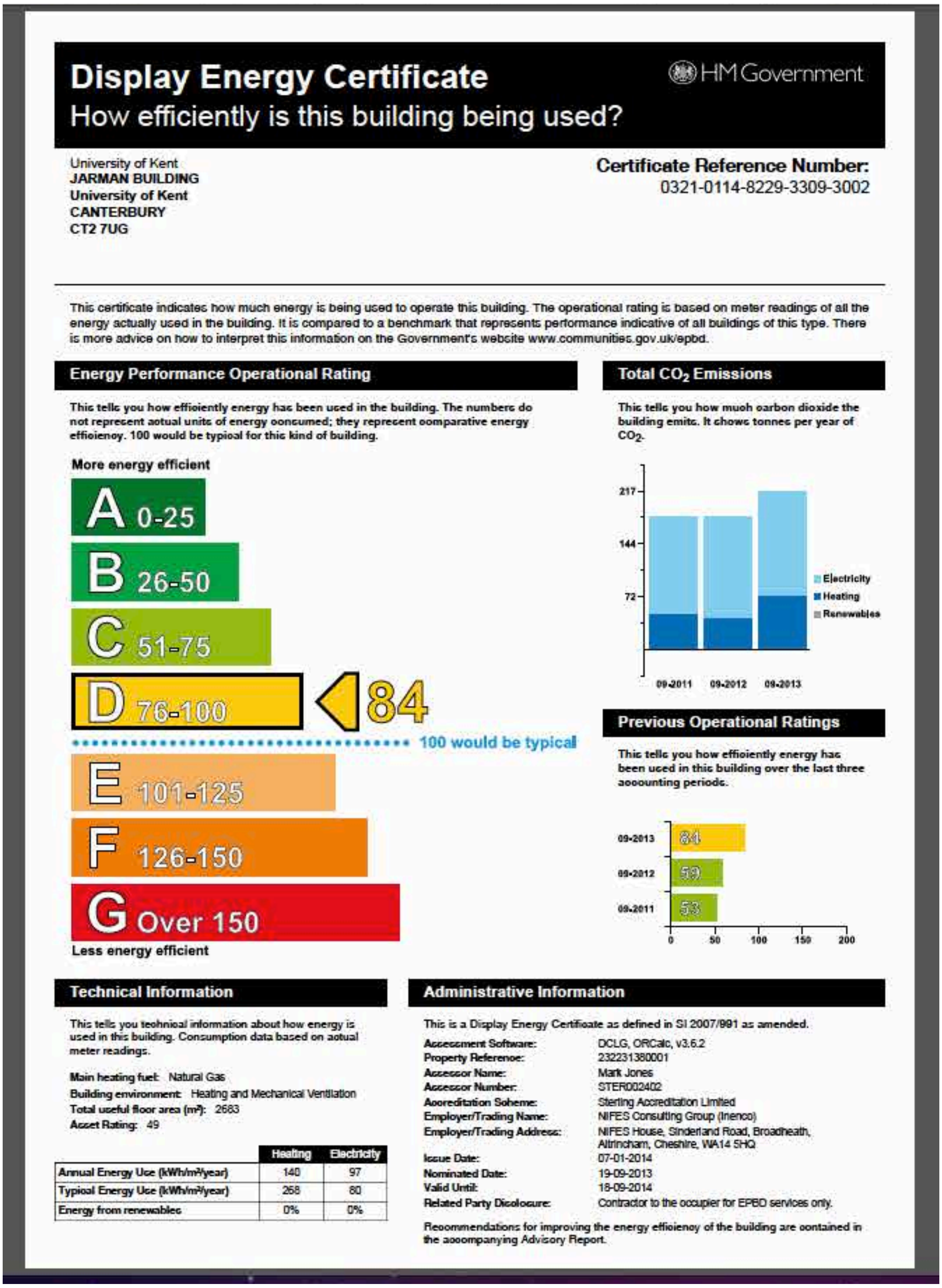








10.3 DEC



Display Energy Certificate

How efficiently is this building being used?

HM Government

University of Kent
JARMAN BUILDING
University of Kent
CANTERBURY
CT2 7UG

Certificate Reference Number:
0321-0114-8229-3309-3002

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

Energy Performance Operational Rating

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

Total CO_2 Emissions

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

Previous Operational Ratings

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

Technical Information

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

Main heating fuel: Natural Gas
Building environment: Heating and Mechanical Ventilation
Total useful floor area (m^2): 2683
Asset Rating: 49

	Heating	Electricity
Annual Energy Use (kWh/m²/year)	140	97
Typical Energy Use (kWh/m²/year)	268	80
Energy from renewables	0%	0%

Administrative Information

This is a Display Energy Certificate as defined in SI 2007/991 as amended.

Assessment Software: DCLG, ORCalc, v3.6.2
Property Reference: 232231380001
Assessor Name: Mark Jones
Assessor Number: STER002402
Accreditation Scheme: Sterling Accreditation Limited
Employer/Trading Name: NIFES Consulting Group (Inenco)
Employer/Trading Address: NIFES House, Sinderland Road, Broadheath, Altrincham, Cheshire, WA14 5HQ
Issue Date: 07-01-2014
Nominated Date: 19-09-2013
Valid Until: 18-09-2014
Related Party Disclosure: Contractor to the occupier for EPBD services only.

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