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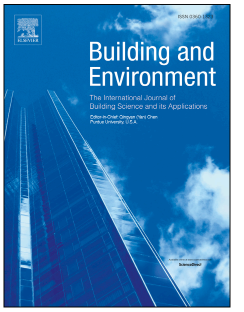

Post occupancy evaluation and internal environmental monitoring of the new BREEAM "Excellent" Land Rover/Ben Ainslie Racing team headquarters offices

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Post Occupancy Evaluation and Internal Environmental Monitoring of the New BREEAM "Excellent" Land Rover/Ben Ainslie Racing Team Headquarters Offices.

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Keywords Post Occupancy Evaluation (POE), perceptions of comfort, BREEAM, building management systems, thermal mass.

Abstract

This paper describes a study carried out on the office floor of the Land Rover/Ben Ainslie Racing (LR/BAR) Team headquarters building in Portsmouth, UK. The building was recently constructed and has a Building Research Establishment Environmental Assessment Method (BREEAM) "Excellent" award/certification. The study examines the physically monitored thermal environment within the office floor of the building, and compares these measurements with both the occupant's perception of comfort regarding the same parameters, and the building management system's (BMS) input and output. The occupants perceptions are quantified by a post occupancy evaluation (POE) carried out by survey/questionnaire. Existing research suggests there is often a "performance gap" between parametric, objectively designed standards for comfort and subjective, user/occupants', experiences of comfort levels. This research suggests that early commitment to sustainable design, coupled with occupants that are knowledgeable of (and engaged in) this ethos, can produce good user experience and comfort levels. However, this appears to be contingent on the building being of low thermal mass, such that, the BMS is responding to something very close to the operative temperatures within the building. In addition to thermal comfort, occupants were questioned on other aspects of their perception of comfort e.g. light quality, air quality etc. The results also demonstrate the importance of seemingly small details to the level of comfort experienced by occupants.

1. Introduction

It is known that there is a performance gap in the architecture, engineering and construction (AEC) industry [1]. Few designer's go on to monitor their buildings once completed [2]. This creates a gap in the feedback loop. Often buildings have been constructed with the design intention of having a low energy, low carbon environmental impact. In addition to these energy efficiency objectives, buildings are generally (or should be) designed to provide occupancy comfort. The building should be appropriate for its intended use. Current industry guidance recommends formal agreement above and beyond construction and occupation to achieve this soft landing [3, 4]. Occupancy comfort can be designed-in by aiming to provide objective parametric values, for example, "the internal air temperature will be held between 20°C and 24°C". However, occupants' subsequent perceptions of comfort (in reality) and the expected perception of (designed) comfort have often been shown to differ [5]. Human perceptions of (thermal) comfort are influenced by many variables (such as age, gender, clothing, air velocity etc.). There can be, therefore, a performance gap between what was intended to provide occupancy comfort and the actual subjective experience of the occupants. Simply providing a space with good parametric design parameters does not necessarily provide subjective user comfort, and reduced user perception of comfort decreases productivity [6, 7]. This is one reason why it is important to carry out post-occupancy evaluations. Both to record the actual performance with regard to closing the feedback loop and also to inform (when it may be necessary) any follow-on measures to increase occupancy satisfaction (and hence productivity) within the building being investigated [8]. Being able to understand an occupant's sensation of comfort can potentially improve both the management of facilities and occupant performance. One current method of assessing post occupancy sensation of comfort is through the Post Occupancy Evaluation (POE) survey. By asking occupants to directly assess their own feelings regarding various aspects of their experience of working within a building it is possible to increase building performance and improve facilities management [9]. Some POE studies have tended to report performance findings based on relatively short time periods [10]. This study had access to the BAR building and its occupants for a full year. Furthermore, as the database from long term POE studies increases it should be possible to feedback and inform future building design and operation and so to minimise the performance gap [11-13].

This research aims to determine how well the BAR Team HQ building office floor complies in providing a thermally comfortable environment for the occupants. In order to do this, data were gathered covering the internal thermal environment over the course of the study. Over the same period external weather conditions were monitored and a POE survey was carried out. The data gathered were also compared to the data collected from the Building Management System (BMS) which had been used to monitor and control the internal environment.

2. Background to the BAR Building, Design and History

The America's Cup is an international yacht sailing competition involving match races that has been held since 1851. The renowned and highly successful competitive sailor Sir Ben Ainsley was aiming to win the 2017 competition (the 35th America's Cup) with a British challenger team.

In 2015 Ben Ainslie Racing (now Land Rover/BAR) had a new purpose built team headquarters facility built in Portsmouth, Hampshire, UK. It is a mixed use building comprising the racing yacht assembly areas, gymnasium for the competing sailors and office space for administration and design work. Alongside its functional use, the building was designed to be exemplary in terms of sustainability in construction and usage. However, the building was designed and built over a very short timescale, with occupation even beginning before completion [14].

The final decision to build the new BAR team headquarters on the Portsmouth site was made in early February 2014 and construction started a mere 5 months later on 4 July 2014. Occupation started 22 June 2015 even though construction was not completed until November 2015. The design of the building was made very quickly and many factors were not decided upon until it was absolutely necessary. During the last few months of construction the BAR Chief Operating and Chief Finance Officer (Andy Hindley) was resident on the site and making day-to-day decisions to complete the build while occupancy was already increasing [14]. To quote Mr Hindley "We went from having no staff to 70 in nine months, that's not normal" [15].

Shortly after the decision to build was made, 11th Hour Racing (www.team11thhourracing.com) offered a sponsorship deal. This was with the condition that sustainability would be championed by the team. The team made the commitment to be the most sustainable sports team in the UK. This lead to the decision to apply for Building Research Establishment Environmental Assessment Method (BREEAM) accreditation. The elements that determine the performance of a new building project assessed using BREEAM include the BREEAM rating level benchmarks, minimum BREEAM standards, environmental section weightings and BREEAM assessment issues and credits. The building was awarded the BREEAM "Excellent" standard on 3 May 2016. This means that the building is considered to broadly represent performance equivalent to the top 10% of UK new non-domestic buildings. To attain this rating, sustainability measures such as 97% demolition materials recycled, BIM 3D modelling to reduce costs, more than 40 energy usage meters, more than 400 PV panels covering nearly 100% of the roof space, advanced natural ventilation and daylighting were utilised (along with many others).

One of the challenges involved in designing a building such as the BAR Team HQ is one of satisfying the diverse groups of occupants that work in different environments and in different ways within the building's structure. The building was required to house administration offices, design offices, a manufacturing and boat assembly area, catering facilities, VIP entertainment areas, a high technology gym, a mission control technical suite and an educational area. The difficulty of providing a comfortable and therefore productive indoor environment across all these different groups and areas is further increased by the fact that human sensation of comfort is known to be subjective to a certain extent [16]. Satisfying human comfort requirements is not necessarily the result of complying with building standards, codes and regulations [17]. Consequently, simply complying with design standards does not necessarily guarantee that occupants will find a given indoor environment either comfortable or productive.

3. Description of the Building

The final building is just under 7000 square meters and is a 6 storey (including 2 mezzanine floors) steel framed structure. The lowest three levels (including the 2 mezzanines are a large hangar area where the yachts are fabricated and assembled. The yachts are taken out of the building via three large hangar doors, put together on the quayside and craned into the sea which is a few meters away. Above this area is the office floor where all administration and most design work occurs. The office floor is home to about 30-40 personnel. Above this are the educational facilities, staff canteen/kitchens and then the VIP entertainment area [18].

The building has been shrouded in a fabric wrap that has been designed to provide a heat saving air cushion of approximately 4-5°C. It is also designed to control the amount of sunlight that enters the building thus reducing the energy required for cooling and hence reducing the carbon footprint [18]. The shroud also performs the role of mitigating the occasional, direct flow, of high speed westerly winds into the openings of the natural ventilation system (thus reducing the possibility of drafts and noise).

The building relies on natural ventilation and 64 fan coil units (FCU). The FCU are controlled via an extensive building management system (BMS) and occupants are not able to adjust heating themselves [18]. The FCU sample the air temperature, via their on-board sensors, relay this information to the central BMS which then adjusts the output of the FCU according to the environmental regime desired/organised by the operator/client, see figure 1. The BMS receives information regarding air temperature from the FCU on-board air intake temperature sensor and responds (if necessary) by adjusting the fan and heating/cooling coils while receiving feedback from the FCU on-board air output temperature sensor. The responses depend on pre-programmed criteria which can be “manually” overridden by the BMS operator.

Figure 1. Typical Fan Coil Unit (FCU) as fitted at BAR Building and diagrammatic representation of FCU function and relationship to BMS

The building was initially planned to house 80-90 occupants but it has housed approximately 120 personnel depending on what phase of yacht construction/design/activity is occurring. In addition, the building is occasionally occupied by groups of visiting personnel from sponsoring organisations, school and university guests on inspection visits for educational reasons and VIPs who can view the yacht sailing on the Solent from the top floor VIP area [14].

Figure 2 shows several views of the new building, both externally and internally. All photographs courtesy of HarryKH/LandRoverBAR.

Figure 2a. External view of the new Land Rover Bar Team HQ building from the west. Showing yacht being craned out to the sea. The sea is on the immediate left of the photograph

Figure 2b. View from the office floor into the central atrium and boat assembly area below

Figure 2c. One of the self-contained office spaces on the south face of the office floor

Figure 2d. View of the office floor taken from the south east corner

4. Methodology

The main aim of this research was to determine if the new BAR building (which was built within a very short time span) provides a thermally comfortable working space for its office employees or not. Depending on the results found, the further aim was to understand why this was or was not the case.

In order to determine this, the following questions needed to be answered:

Want are the temperature conditions in the offices at BAR?

Does the existing FCU/BMS system measure and react to the "correct" conditions within the office space?

Do the occupants of the office space feel comfortable in their working environment?

To do this, the methodology comprised two main data gathering operations (quantitative and qualitative). That is, a programme of physical environmental monitoring and a post occupancy evaluation survey to be distributed among the building occupants. The methodology adopted was to:

Monitor the office spaces with an independent set of temperature sensors over the course of a year.

Gather temperature data from the BMS over the same monitoring period.

Gather external environmental data from the BAR weather station over the same monitoring period (to isolate key periods of time when the building would have been under the most external thermal stresses).

Carry out a POE survey of the employees who work in the offices (to determine their subjective evaluation of the working conditions in the offices).

Analyse the physical data and compare with the POE responses.

Although in the UK there is guidance concerning the provision of thermal comfort to employees (recommended maximum and minimum working temperature) these temperatures are not absolute legal requirements [19]. However, it is the legal duty of the employer to determine what "reasonable" comfort will be (in the employees' particular circumstances). A POE survey goes someway to providing proof of occupancy thermal comfort levels.

4.1 Physical Monitoring

4.1.1 Preparation Prior to Main Data Recording Period

Prior to the year-long period in which internal air temperature data was recorded, there was an initial period in which the significance of any mean radiant temperature effects was determined. In a series of two-week sessions, a black bub sensor and air temperature sensor were located near to each other in different areas of the office floor. They were co-located for two weeks in the north side of the building then, the south, the east and the west. The results of this pre-experimental period demonstrate that the effects of radiant heat were not significant in this building. The office floor has a low thermal mass (in all directions). The difference between the black bulb temperature and the air temperature was never found to be more than +/- 0.75°C.

Air velocities were also measured at several locations around the office floor on many different occasions (using a testo 405i thermal anemometer smart probe) and were always found to be low.

Given:

the accuracy of the air temperature sensors of +/-0.4°C,

the maximum difference between the black bulb temperatures and the air temperatures of +/- 0.8°C (i.e. low thermal mass), and,

the air velocity being less than 1m/s,

it was possible to dispense with the black bulb during the main data recording period and utilise an error (or accuracy) band for the calculations of operative temperature (i.e. maximum possible, minimum possible and mean likely operative temperature).

4.1.2 Main Monitoring Period

The office floor was monitored continuously over the course of a year with temperature and relative humidity data loggers. A total of11 sensors were deployed. The majority were Tinytag TR-3500-A sensors working together as a wireless sensor network, with the remainder being Tinytag TGP-4500 standalone sensors. These sensors are manufactured by Gemini Data Loggers UK and have a resolution of 0.01°C and an accuracy of 0.4°C (in the range 20°C to 30°C). Each sensor would record a temperature and relative humidity measurement every 15 minutes and the sensors were located throughout the office space. This meant that sensors were located in the north, west, south and east of the building to detect if any location factors would have an effect. The monitoring commenced in May 2016 and finished in May 2017. This gave an objective measure of the air temperatures over the course of the year. In addition, a black bulb temperature sensor (globe diameter 150mm with a Tinytag temperature sensor at its centre) was deployed in different parts of the office space to ascertain the degree to which radiant heat might be affecting the building's occupants. Figure 3 shows the (internal) office floor plan with the locations of the 29 FCU controlled by the BMS, and the 11 sensors installed by the authors, supplied by the University of Portsmouth, School of Civil Engineering and Surveying (UoP). The office floor occupants are able to choose where they wish to sit and are not allocated to any particular desk. In general, the UoP sensors where placed near to fan coil units in order to validate the data that the BMS was using to respond to office space environmental data.

Figure 3. Simplified Office Floor Plan Showing Location Plan of BMS Controlled FCU and UoP Installed Temperature and Relative Humidity Sensors

With a combination of:

the air temperatures,

the black bulb temperatures,

an estimate of the range of possible air velocities in the office floor and

a knowledge of the limits of accuracy of the sensors,

it was possible to calculate the operative temperatures experienced in the various parts of the office floor by the occupants. The operative temperature is important to calculate as it is a measure of the human perception of thermal comfort. Human perception of thermal comfort is not as simple as knowing what the air temperature is. The perception of comfort depends on various other factors such as relative humidity, air velocity, personal metabolic heat, health and the uniformity (or otherwise) of any of these conditions/factors [16].

As part of the team's preparation for the America's Cup race a private weather station was located on the top of the building. It was installed to enable the sailing operations, training and testing (not as part of the building monitoring system). As part of the race competition regulations, this information was available to anyone who wanted to view it. The rationale being that no racing team could gain an advantage by having access to some extra specialised form of weather prediction not available to their competitors. The data available included wind speed, maximum gust speed, wind direction, atmospheric pressure, precipitation rates, UV levels, solar power (W/m2) and more. Again, the weather data were collected continuously at 15-minute intervals (24 hours a day, 365 days a year). Much of the data was not required in this research, however, the data that was used (temperature, humidity and solar power), being recorded every 15 minutes for a full year still produced an abundance of data to be analysed. By observing the weather data as an indicator of “extreme” external conditions it was possible to narrow the analysis of the internal data down to specific finite number of periods. The internal sensor data that was recorded during the hottest and brightest and coldest and dullest days was analysed in detail.

The building incorporates a BMS that controls 64 FCU (29 of which are on the office floor). Each FCU has a space temperature sensor. This temperature is recorded at the input side of the FCU and is used by the BMS to then adjust the FCU and controls the output temperature of each unit. From the BMS it was possible to download the space temperature sensor measurements of these FCU (again at 15 minute intervals) over the course of the same year. This was done in order to validate the BMS data and to ensure that what it was believed was being measured, actually was being measured.

4.2 POE Survey

The POE survey was written after consulting various industry “standard” POE surveys, with additions and amendments to reflect the special nature of the BAR Team HQ. It was very broadly based on the Building Use Studies (BUS) survey [20].

Ideally, several POE surveys spread over the course of the year would have been better but this was not possible due to staff rotations and working practices etc. Although this was a single POE survey (conducted at the end of the monitored year), the respondents were explicitly asked to consider their general, overall impressions of their working environment over the course of the year (or for whatever period they had been employed). The POE survey was responded to by 29 individuals who considered the office floor to be their main working area. It is impossible to say what percentage that is of the total number of personnel employed mainly on the office floor. This is due to the shifting patterns of employment over the course of the teams preparations for the racing events. However, by simply counting the number of people on the office floor during each visit to download data (approximately every 3 weeks), it is estimated that this is a high percentage (approaching 100%) and therefore a large sample. The demographic profile of the respondents are shown in Table 1. The survey was distributed online via Google Forms. Note that nearly 80% of respondents grew up in the UK or a region with a similar temperate climate.

Table 1. Demographic profile of survey respondents

As per industry guidance [21-23], most questions on the survey asked for participants to respond on a 7-point Likert scale, from very uncomfortable to very comfortable (or strongly agree to strongly disagree). Other questions focused on how distracting any perceived discomfort was for the individual and what actions they would take under those circumstances. The participants were also asked to locate themselves within a floor plan of the office space. This was intended to highlight if there were location specific comfort perception problems associated with the office floor.

5. Results

5.1 Results from Environmental Monitoring

As described earlier, measurements of temperature at 15-minute intervals were recorded over the course of a year. Data from 11 sensors, 29 FCU (via the BMS) and temperature data from the team's weather station were collected. This produced a very large amount of data. In order to manage these data and analyse the internal temperature environment experienced by the occupants it was necessary to focus on specific critical periods of time. These critical periods of time were chosen with reference to the external conditions (the weather station data). A series of individual weeks were selected that corresponded to the warmest, coolest, brightest and dullest weeks of the year.

For each of these week-long periods the operative temperature was calculated for the north, south, east and west sides of the office floor. This was possible by combining the sensor temperature data with the black bulb data (measuring radiant heat), the air velocity and a knowledge of the limits of accuracy of the sensors. From the black bulb data, it was seen that the building does not have a high thermal mass and radiant heat is quite low. Minimal thermal mass effects were recorded. This is in-line with expectations, given the nature of the construction (mainly steel-framed and glass-clad). The operative temperatures were calculated according to ISO 7726:1998 and ANSI/ASHRAE Standard 55-2010. The calculated operative temperatures were compared to the FCU (space) temperature data. Because the sensors were located throughout the building, it was possible to analyse the data from all faces of the building. Similarly, occupants were seated in all areas of the office floor and their working location was recorded in their POE responses so that their location could be compared with the relevant sensor data.

Using the external environmental conditions (determined using the BAR weather station data) as indicators of which weeks to particularly concentrate analysis on, four "extreme" days were identified (see table 2).

Table 2. Four “extreme” days during year-long monitoring period

These four days were used to identify the following four working weeks for more detailed analysis:

Monday 08 Aug 2016 to Friday 12 Aug 2016 (hottest week),

Monday 06 Feb 2017 to Friday 10 Feb 2017 (coolest week),

Monday 04 Jul 2016 to Friday 08 Jul 2016 (brightest week),

Monday 19 Dec 2016 to Friday 23 Dec 2016 (dullest week).

For each of these week-long periods the data from FCU air temperature sensors were compared with the operative temperatures calculated using the UoP installed temperature sensors

Figure 4 shows a graph of the first of these four weeks identified in table 2. For simplicity, only one FCU (and the operative temperature calculated from the installed UoP sensor located near to that FCU are shown). This analysis was done with all FCU and UoP data (so included data from the east, south, west and north faces of the building). Figure 4 demonstrates the general trend found.

Fig 4. One typical set of FCU and operative temperatures in the office floor for the period 08 Aug – 12 Aug 2016

In order to understand the correlation between FCU and UoP sensor temperature data, a series of linear regression analyses were carried out. The FCU and UoP data were compared directly and then in a series of 15 minute UoP lags i.e. at UoP + 15 minutes, UoP + 30 minutes and so on. Figure 5 and table 3 show the results of this analysis.

Table 3. R-values for linear regression analysis of FCU v UoP data at a sequential series of 15-minute (UoP) lags (all P-values < 0.001) for the period 08 Aug – 12 Aug 2016

Fig 5. Graphs of regression analyses of FCU and UoP data (UoP data lagged sequentially every 15 minutes) for the period 08 Aug – 12 Aug 2016

From table 3 and figure 5, it can be seen that the optimally correlated lag between FCU and UoP data occurs at UoP + 45 minutes. The regression equation for FCU v UoP+45 was found to be:

$$FCU = 4.887 + 0.772*UOP45$$

A two-sample t-test (assuming unequal variances) carried out on the original FCU v UoP data gave the following results:

Estimate for difference: 0.1064
95% CI for difference: (0.0623, 0.1504)
T-Test of difference = 0 (vs ≠): T-Value = 4.74
P-Value = 0.000 DF = 943

This appears to show that the two data sets come from different populations (P=0.0). However the same test carried out on the FCU v UoP+45minutes data gave these results:

Estimate for difference: -0.0013
95% CI for difference: (-0.0426, 0.0400)
T-Test of difference = 0 (vs ≠): T-Value = -0.06
P-Value = 0.951

The data have a highly significant correlation. This means that the BMS is indeed responding to an accurate proxy of the occupants working environment or operative temperature (even if the response is somewhat behind the instantaneous conditions).

Over the course of all the critical weeks that were analysed (and in all the locations of the office floor that were being monitored) it was seen that there was never a case of overheating as defined by CIBSE Guide A (5.10.1). i.e. "the internal operative temperature should not exceed 25 °C for more than 5% of occupied hours and 28 °C for more than 1% of occupied hours."

As for low temperatures, according to the UK Health and Safety Executive (HSE) Approved Code of Practice [20], office work place temperatures should never fall below 16°C (although this is not an absolute legal requirement). Again, in all locations and over the entire period of monitoring the internal temperatures were never found to be below this HSE recommended value (in fact they were never found to be below 18°C).

5.2 Results from POE Survey

Figure 6 shows the results of the survey regarding the 3 questions concerning perceptions of thermal comfort. For simplification the original 7-point Likert scale was converted into a 3-point scale, as per common industry practice [24, 25]. This was accomplished by combining the first 2 points on the scale into the "uncomfortable" category and the last 2 points into the "comfortable" category. The 3 middle points of the scale were combined to form the "at least moderately comfortable" category. The questions asked were:

How would you describe the temperature in your work area?

1*Fig. 6. Distribution (%) of respondents' answers regarding sensations of thermal comfort*

Survey participants were also asked if discomfort due to temperature had an effect on their work performance. If they responded yes to this question (as 9 people, or 31%, did) they were asked to quantify how significant this effect was on their work. The results, from "very significant" to "not at all significant" are shown in Figure 7.

Fig. 7. Significance (%) of effect for those participants who felt there was any effect at all on their work performance due to temperature discomfort

6. POE. Occupant's Views of Their Thermal Comfort Levels

From Figure 6 it can be seen that 90% of respondents feel comfortable and 10% uncomfortable. No respondents felt hot but 10% did feel cold and 86% felt that the temperature did not vary overly during the working day.

To put Figure 7 into context, from the total number of participants in the survey, the number who felt that discomfort (due to temperature) had a significant effect on their work performance was one individual (or 3%).

It can be concluded that the occupants of the new BAR Team HQ are comfortable (in terms of perceptions of temperature) in their working environment.

No statistical difference was found in response between the genders, age groups, cultural background or location within the office floor.

7. POE. Occupant's Views of Other Measures of Comfort

7.1 Air

Occupants were surveyed on their perceptions of comfort with regard to air quality. On three of the parameters (freshness/staleness, dryness/humidity and odourless/smelly) the occupants expressed no sense of discomfort. On one scale (perception of air movement) two occupants expressed a sense of discomfort due to draft. Cross-referencing these two participants revealed that they were located very close together and in close proximity to one of the natural ventilation access points in the extreme south west corner of the building. The prevailing wind direction in this part of the country is from the south west. Looking at the responses these participants described when faced with this discomfort their answers were to block the ventilation channels with coats of other obstructions.

7.2 Noise

Occupant's perceptions of noise comfort were not so favourable. 35% of participants indicated that they were distracted by noise in their working environment to such an extent that it had some effect on their performance. Of those occupants who felt that noise distraction did have an effect on their performance, 36% felt that the effect on their performance was significant or very significant. Again, cross referencing these respondents with their location in the office half were located very close to the eastern side of the central atrium and the other half were located very close to the office entrance way and western ventilation points. Figure 8 shows the two locations where noise was felt to be a problem for some of the respondents. It may be of interest to note that the locations to the west of the building where noise was felt to be a problem are not shielded by the environmental shroud that covers the majority of the building. It is possible that the speed of the air coming in through the two ventilation points in that location is too fast and hence noisy.

At all times when the authors were monitoring the air velocities in this area they were found to be low. However, the monitoring of air velocity was not continuous. It only occurred on those occasions when the authors were present with the thermal anemometer.

Fig. 8. The two locations (marked in red) where noise was considered, by a significant proportion of occupants, to be distracting

The main sources of noise distraction according to the POE were noises from within the building e.g. colleagues, other people or machinery. 23% of occupants cited these internal noises as the source of distraction compared to only 3% complaining that external noise, such as traffic, caused discomfort.

One of the guiding rationales or architectural philosophies guiding the design of the building was the existence of the (almost full building height) glass-walled, central atrium. Partially this was put in place to allow more natural light down into the boat assembly area. The other reason was that the owners and designers wanted the building to be a constant reminder to the occupants that they are all part of a team with a unified mission (to win the America Cup). The central atrium enables, from almost anywhere on the office floor, the activities going on in the ground floor assembly area to be visible to the workers in the office space. A constant reminder of the team's purpose. However, thanks to the POE, it can be seen that this seems to have caused a significant degree of noise distraction for those who work very close to the north-eastern area of the atrium glass.

7.3 Light

Occupants were questioned about their perceptions of comfort with regard to the light quality where they worked. 23% of respondents indicated that they felt distracted by light quality issues and of these 29% felt it to be a significant distraction.

The light quality questions referred to amount of natural light compared to artificial light and if glare from the sun/sky or artificial lighting was a cause of concern. The amount of natural light and artificial light provided in the building did not seem to cause any discomfort but the amount of glare did. Those participants that stated that glare from the exterior (sun/sky) was a significant distraction amounted to 16%. Several comments referred to the meeting rooms on the office floor.

These are discrete offices all located on the south most periphery of the floor. The southern façade of the office floor is entirely glazed and is not covered by the fabric shroud described in earlier.

8. Overall Level of Comfort in your Working Environment

Finally, the occupants were asked to rate their overall experience of comfort in their working space. 61% felt that their level of overall comfort was very positive and 39% felt that their overall level of comfort was at least adequate. No respondents felt that their comfort was very negative.

9. Discussion

Overall, the new BAR building provides good occupancy satisfaction levels. There are some individual elements (such as certain aspects of noise and light distraction) where there are slightly lower levels of satisfaction. Can any useful lessons be learned from this building?

One of the most important aspects of sustainable "green" buildings is the early commitment of the project to these aims [26]. In the case of this building, one of the major sponsors were dedicated and committed to sustainability and, as a requirement for their sponsorship, this became a major aim of the project. The need for early involvement (and involvement in every stage of the project) is described in industry guidance [27]. It is not insignificant that the most numerous tasks listed in the RIBA green overlay are those in the conceptual design stage [28]. In the case of the BAR building it was designed and constructed in a very short time but it had the input of environmental consultants from the very beginning. Although industry guidance now recommends a formal soft landings agreement to cover every phase from pre-construction right through to occupation (with a soft landing's champion), that was not implemented in this project. However, the client (in the form of the CFO/COO) was on-site and in direct contact with the environmental consultants and contractors and was making daily construction decisions for a period starting nine months before occupation began.

However, in addition to the early involvement and commitment to good design practice, this particular building had another important aspect that made for good occupancy satisfaction. Of major importance is the correct and efficient functioning of the BMS. The building has a low thermal mass. This means that the difference between air temperature and operative temperature is reduced (due to minimal radiant temperature effects). The BMS is sensing the air temperatures, via the sensors on each FCU, and responding to that temperature. If the building had a high thermal mass the operative temperature would not be as close to the air temperature. Consequently, the BMS would not be responding to pertinent information (as far as the building's occupants are concerned).

Previous literature has suggested that the use of thermal mass can be a solution to low energy buildings (passive design principles) [29, 30]. This can only be an effective solution if that mass is correctly placed and is available (e.g. not inadvertently obstructed by occupants' behaviour) and corresponds to the occupancy profile of the building (which can change). Perhaps, what is more important for commercial, centrally controlled buildings is that, if the BMS is measuring air temperature and the building has a high thermal mass it is not likely that the BMS will be responding to the operative temperature (perceived by the occupants).

In addition, the BMS is monitored and checked regularly not only by a dedicated member of staff at BAR but also by a contracting BMS controls company. A mal-functioning BMS, even within a building designed to a high environmental standard, such as a LEED Silver building, can have a very large effect on users' perceptions of comfort [31]. Many problems during the occupation phase of a project can be linked to an inefficiently set-up BMS or an incomplete understanding of the way to use it [32]. In addition, the 29 FCU (and associated sensors) that monitor and service the office floor are dispersed evenly throughout the floor. This means that occupants are never far from an FCU and they are receiving the "correct" temperatures for where they are and at that time. There are no time-lag effects introduced by having remote FCU responding to conditions away from the occupants.

Buildings which respond to the occupants' requirements through a combination of efficient systems and systems management are generally perceived as more comfortable by occupants [33]. Thanks to the efficient and well-operated BMS, the new BAR building maybe considered to be such a case.

There is some evidence that users who are aware of the green credentials of their building maybe more tolerant with regard to their perceptions of comfort [34, 35]. This may have had some effect in this case. The ethos and message of environmental responsibility is an ever-present aspect of working within the BAR building and, aside from the attempt to win the America's Cup, it is, thanks to a major sponsoring organisation, one of its *raison d'etre*. It is thought that if an occupant believes the building is "worthy" it gives a slight boost to their subjective judgement of the building's comfort [35]. Although the notion that an occupant's ability to control their own environmental conditions is regarded as an important feature of occupancy satisfaction [36], in this case the respondents seemed to be satisfied with what small measures were available to them (put on/take off clothing, open/close a door, drink a cold/hot drink).

Previous research has highlighted the importance of seemingly minor details when it comes to occupants' perception of comfort [31]. One of the few aspects that did cause some level of distraction for the new building's users was the noise factor. As pointed out above, this only affected two distinct areas of the office space and there seems to be a reason behind both areas. As far as the noise levels in the far south west of the floor are concerned it seems that personnel are choosing to seat themselves there due to the very pleasant view across the harbour that can be enjoyed from those seats. The reason there is this view is because the environmental shroud does not obscure it from these few seats. Although the shroud is not opaque it is similar to looking through a fog or mist. When it rains, it does almost become opaque. However, because the shroud is not present in this location, whenever a directly west flowing strong wind blows, the air is able to come through the ventilation points unrestricted. This can cause both noise and draft. The occupants counter these occasions by blocking the ventilation ports at this location (with clothing, books or boxes). This was determined by allowing comments from occupants within the POE survey questionnaire. The other area where noise was a distraction was near the north east extremity of the glass atrium. Here, there are excellent views of any work activity being carried out in the boat assembly area on the ground floor. People are choosing to sit here in order to see these views and seem to be willing to accept the noise distraction. Within certain limits the personnel at BAR are able to choose where they locate themselves and although the environment could be fine-tuned (increase the length of the shroud, move the desks away from the atrium) it is assumed that the occupants choosing to locate themselves in these areas feel the pain/gain balance to be acceptable.

The only areas where light quality appeared to be a problem were the self-contained meeting rooms which run along the south facing glass wall of the office floor (see figure 2c). Several comments were made indicating that when the sun was bright the level of glare became obtrusive and the ability to see the audio-visual presentation screens (all facing the glass wall and hence the sun) severely diminished. This could be easily solved by the fitting of blinds.

It is believed the use of physical environmental monitoring in combination with a program of POE can give a competitive advantage in comparison with those buildings where this is not the case. [31, 37]. This advantage will probably decline as the use of POE becomes more widespread [31].

10. Conclusions

Early commitment to sustainable design is critical. Having dedicated team members involved from the very beginning of the project is a key aspect of producing sustainable, environmentally friendly buildings. According to RIBA, this involvement and commitment should extend from the conceptual design phase right the way through to construction and post occupation [27]. Similarly, it has been stressed that formal agreement above and beyond construction and occupation is necessary to ensure a delivered building is appropriate [3, 4]. In this case there was not a formal soft landings agreement. However, despite potential for problems that may have arisen due to the very quick construction time-frame, the occupants’ perception of comfort of this building’s office space was generally favourable.

A BMS that is responding to the relevant parameters, regarding occupancy perception of comfort, is critical. If a BMS is responding to air temperatures, then it is important (regarding occupancy comfort) that the building has a low thermal mass. This means the air temperatures are approximately equal to the operative temperatures. That is the situation in the case of the BAR office floor. If the office floor were not of a low thermal mass, it is quite possible that the occupancy satisfaction would not have been so high.

In the case of a "green" building it is important that occupants have knowledge and understanding of, the sustainable development aspect of their building's purpose [35]. Similarly it is true that occupants tend to value different environmental parameters differently when judging their overall level of comfort [39]. Thermal comfort is consistently rated as the most important parameter to influence occupancy comfort levels [40, 41]. Even if one of the other parameters is less than satisfactory, the "forgiveness factor" phenomena has been described if other parameters are satisfactory [36]. In the BAR case, whatever lower levels of comfort that some occupants felt, they seemed to be satisfied overall, perhaps because of their understanding of their building's environmental credentials, perhaps because of the generally high level of thermal comfort experienced.

An energy efficient building does not necessarily lead to good occupancy satisfaction as many other factors contribute [38]. In addition to the main conclusions above, it is also true that small details do matter [31]. This is shown by the reasons for the slightly lower satisfaction levels regarding light and noise in very specific areas of the building, with highly localised phenomena, due to seemingly trivial specifics of layout etc.

Despite the lack of a formal soft landings approach, this building has been completed in a very short time (to budget and on-time), has achieved a BREEAM excellent certification and has now been shown to provide office space occupancy satisfaction. This is a very good result for the construction team and the client.

11. References

[1] A. Menezes, A. Cripps, D. Bouchlaghem, R. Ruswell. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. Applied Energy 97 (2012) 355-364.

[2] B. Bordass, A. Leaman. Making feedback and post-occupancy evaluation routine 3: case studies of the use of techniques in the feedback portfolio. Build Research & Information (2005) 33(4):361e75.

[3] Building Services Information and Research Information Association (BSRIA) guide to Soft Landings: http://www.bsria.co.uk/news/soft-landings-framework

[4] Government Soft Landings, Cabinet Office, Government Construction Strategy of May 2011 http://www.cabinetoffice.gov. uk/resource-library/government-construction-strategy

[5] M. Agha-Hossein, S. El-Jouzi, A. Elmualim, J. Ellis, M. Williams. Post-occupancy studies of an office environment: Energy performance and occupants' satisfaction. Building and Environment 69 (2013) 121e130.

[7] D.P. Wyon. Thermal effects on performance. In: J. Spengler, J. M. Samet and J. F. McCarthy, eds. IAQ Handbook, chapter 16, New York, 2001. McGrawHill.

[8] R. Lawrence, C. Keime. Bridging the gap between energy and comfort: Post-occupancy evaluation of two higher-education buildings in Sheffield. Energy and Buildings 130 (2016) 651–666.

[9] M. Riley, N. Kokkarinen. M. Pitt, Assessing post occupancy evaluation in higher education facilities, Journal of Facilities Management, (2010) 8 (3): 202-213.

[10] Y. Hua, A. Oswald, X. Yang. Effectiveness of daylighting design and occupant visual satisfaction in a LEED Gold laboratory building. Building and Environment, (2011) 46: 54-45.

[11] Designing Buildings. Performance Gap Between Building Design and Operation. https://www.designingbuildings.co.uk/wiki/Performance_gap_between_building_design_and_operation (2016).

[12] S. Imam, D.A. Coley, I. Walker. The Building Performance Gap: Are Modellers Literate? Building Services Research and Technology (2017) vol. 38(3) 351-375.

[13] A. Menezez. The Performance Gap. Carbon Bites from the Chartered Institute of Building Services Engineers Energy Performance Group. https://www.cibse.org/getmedia/55cf31bd-d9eb-4ffa-b2e2-e567327ee45f/cb11.pdf.aspx (2012).

[14] A. Hindley. Interview between author and Andy Hindley, Chief Operating and Finance Officer, Land Rover BAR (23 February 2016).

[15] J. Doward. In Ainslie's hi-tech HQ, experts perfect a craft fit to bring America's Cup home. https://www.theguardian.com/sport/2015/jul/25/in-ainslies-hi-tech-hq-experts-perfect-a-craft-fit-to-bring-americas-cup-home.

[16] ASHRAE, 2010. ANSI/ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air Conditioning Engineers.

[17] F. Nicol, M. Humphreys. Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251. Building and Environment, (2010) 45(1): 11-17.

[18] S. Thomson. Interview between author and Susie Thomson, Sustainability Director, PCSG Group, on secondment as Sustainability Manager, Land Rover BAR (02 February 2016).

[19] HSE (2013) L24 Workplace (Health, Safety and Welfare) Regulations 1992. Approved Code of Practice and Guidance (London: HSE). See http://www.hse.gov.uk/pubns/priced/l24.pdf

[20] Usable Buildings Trust. https://www.busmethodology.org.uk/

[21] F. Nicol, M. Humphreys, S. Roaf. Adaptive thermal comfort: principles and practice. Routledge (2012).

[22] M. Agha-Hossein, S. Birchall, S. Vatal. Building Performance Evaluation in Non-Domestic Buildings: A BSRIA Guide (2015).

[23] D. Teli, M.F. Jentsch, P.A. James. Naturally ventilated classrooms: An assessment of existing comfort models for predicting the thermal sensation and preference of primary school children. Energy and Buildings, (2012) 53, 166-182.

[24] M. Hussin, M.R. Ismail, M.S. Ahmad. Subjective Perception of Thermal Comfort Study in Air-Conditioned University Laboratories. Procedia – Social and Behavioral Sciences, (2013) Vol. 91 192-200.

[25] S. Sameni, M. Gaterell, A. Montazami, A. Ahmed. Overheating investigation in social housing flats built to the Passivhaus standard. Building and Environment, (2105) vol 92, pp. 222-235.

[26] L. Bragança, S.M. Vieira, J.B. Andrade. Early Stage Design Decisions: The Way to Achieve Sustainable Buildings at Lower Costs. The Scientific World Journal, 2014, Article ID 365364.

[27] RIBA. Green overlay to the RIBA outline plan of work. Royal Institution of British Architects. November 2011.

[28] H. Hartman, Green Overlay: RIBA Sustainable Design Guidance. The Architect's Journal 24 November 2011.

[29] E. Shaviv, A. Isaac, G. Capeluto. Thermal mass and night ventilation as passive cooling design strategy. Renewable Energy (November 2001) vol. 24, issues 3–4, 445-452.

[30] B. Givoni. Comfort, climate analysis and building design guidelines. Energy and Buildings. Volume 18, Issue 1, 1992, Pages 11-23.

[31] P. Fairley. Feedback Loop With A Frequent Gap Between Predicted And Actual Performance, Post-Occupancy Evaluations Begin To Catch On. Architectural record. (2015) 203(8):114-124.

[32] M. Way, B. Bordass. Making feedback and post-occupancy evaluation routine 2: Soft landings – involving design and building teams in improving performance. Building Research & Information, (2005) 33:4, 353-360.

[33] B. Bordass, A. Leeman, P. Ruyssevelt. Assessing building performance in use 5: conclusions and implications. Building Research & Information (2001) 29(2), 144–157.

[34] A. Leeman, B. Bordass. Are users More Tolerant of Green Buildings? Building Research & Information (2007) 35(6), 662–673.

[35] Z. Brown, R.J. Cole. Influence of Occupants' Knowledge on Comfort Expectations and Behaviour. Building Research & Information (2009) 37(3), 227–245.

[36] A. Leeman, B. Bordass. Productivity in Buildings: The "Killer" Variables. Building Research & Information (1999) 27(1), 4–19.

[37] K. Fowler, E. Rauch, J. Henderson, A. Kora. Re-Assessing Green Building Performance: A post occupancy evaluation of 22 GSA Buildings. U.S. Dept. of Energy Technical Report PNNL-19369 (Sept. 2011).

[38] A.L. Hauge, J. Thomsen, T. Berker. User evaluations of energy efficient buildings: Literature review and further research. Advances in Building Energy Research (2011) vol.5 109-127.

[39] M. Fronjtczak, P. Wargocki. Literature Survey on How Different Factors Influence Human Comfort in Indoor Environments. Building and Environment, (2011) 46(4), 922-937.

[40] J.H. Choi, V. Loftness, A. Aziz. Post-Occupancy Evaluation of 20 Office Buildings as Basis for Future IEQ Standards and Guidelines. Energy and Buildings, (2012) 46, 167-175.

[41] G.J. Levermore. Occupants' Assessments of Indoor Environments: Questionnaire and Rating Score Method. Building Services Engineering Research and Technology, (2016) 15(20, 113-118.

Table 1. Demographic profile of survey respondents

Age Distribution	Male	Female	Total
20-25	3	1	4(14%)
25-30	2	2	4(14%)
30-35	8	3	11(38%)
Over 35	8	2	10(34%)
Raised in climate:	Male	Female	Total
UK or similar	16	6	22(79%)
Warmer than UK	4	1	5(18%)
Cooler than UK	0	1	1(4%)
Unidentified	1	0	-
Total	21(72%)	8(28%)	29

Table 2. Four "extreme" days during year-long monitoring period

Date	**Max. Air Temp.**	**Min. Air Temp.**	**Max Solar Power**	**Min. Solar Power**
10/08/2016	**33.9^{o}C**	**18.9^{o}C**	-	-
11/02/2017	**2.2^{o}C**	**1.7^{o}C**	-	-
05/07/2016	-	-	**1223 W/m^2**	**0 W/m^2**
24/12/2016	-	-	**156 W/m^2**	**0 W/m^2**

Table 3. R-values for linear regression analysis of FCU v UoP data at a sequential series of 15-minute (UoP) lags (all P-values < 0.001) for the period 08 Aug – 12 Aug 2016

	UOP	UOP+15	UoP+30	**UoP+45**	UoP+60	UoP+75	UoP+90	UoP+105	UoP+120
FCU	0.448	0.482	0.504	**0.773**	0.677	0.583	0.493	0.406	0.325

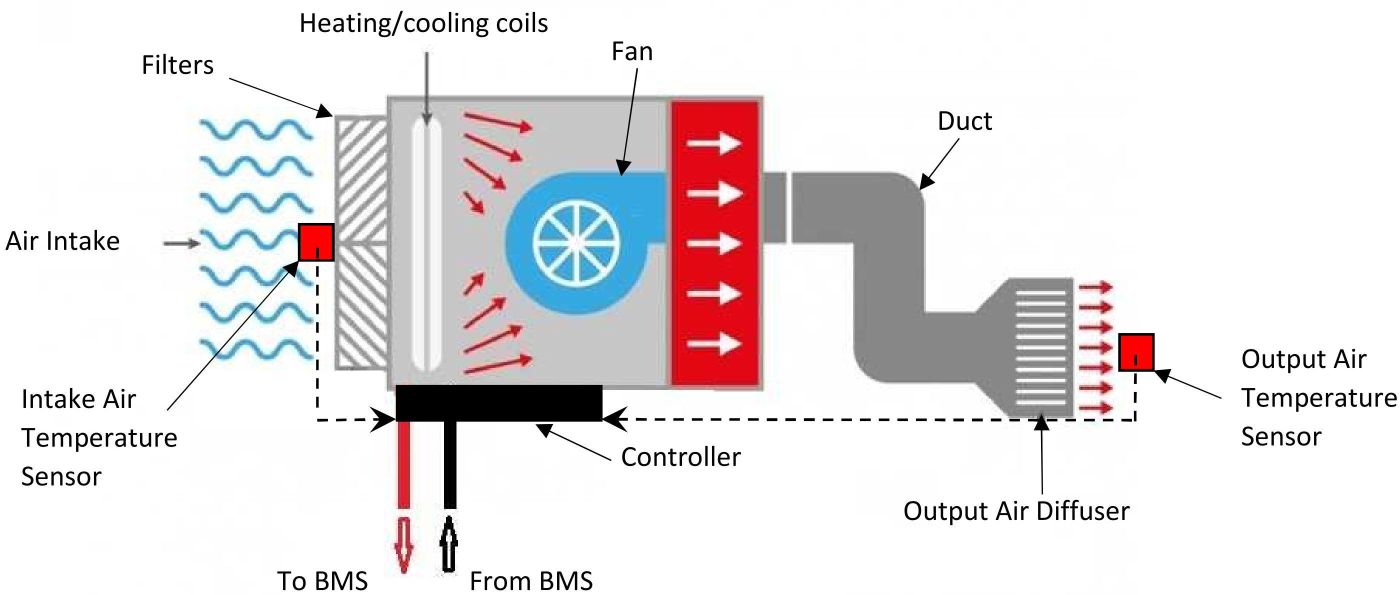

Figure 1. Typical Fan Coil Unit (FCU) as fitted at BAR Building and diagrammatic representation of FCU function and relationship to BMS

Figure 2a. External view of the new Land Rover Bar Team HQ building from the west. Showing yacht being craned out to the sea. The sea is on the immediate left of the photograph

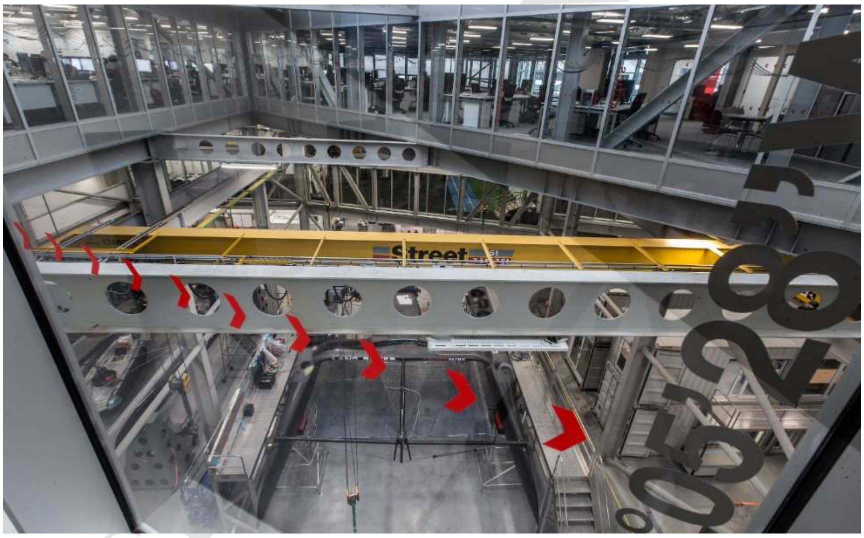

Figure 2b. View from the office floor into the central atrium and boat assembly area below

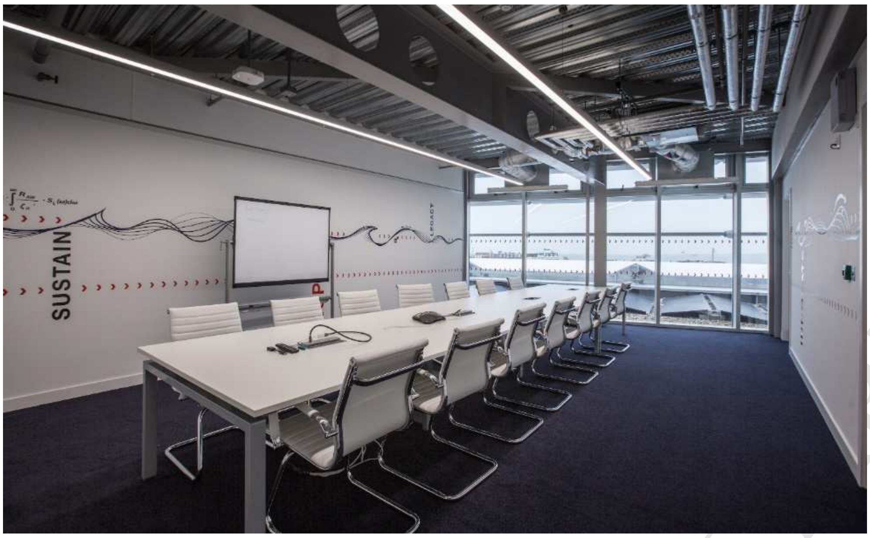

Figure 2c. One of the self-contained office spaces on the south face of the office floor.

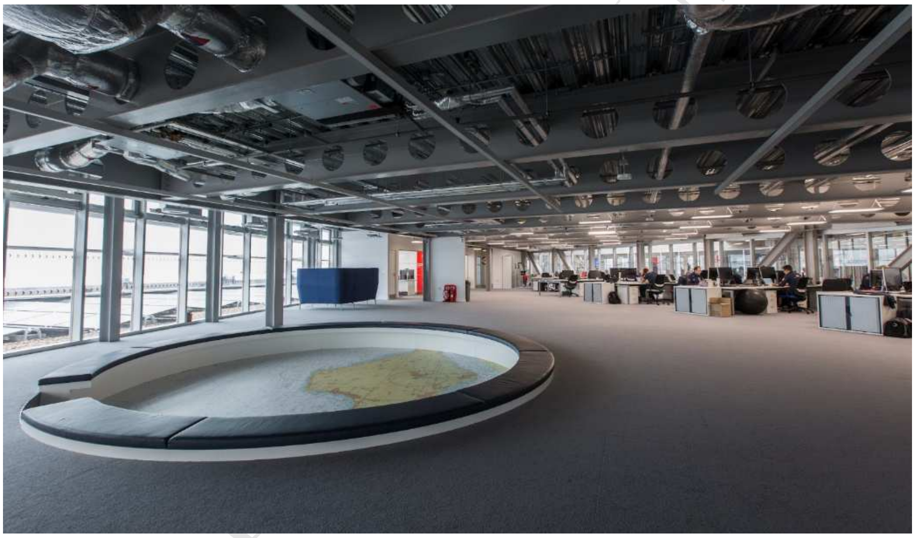

Figure 2d. View of the office floor taken from the south east corner

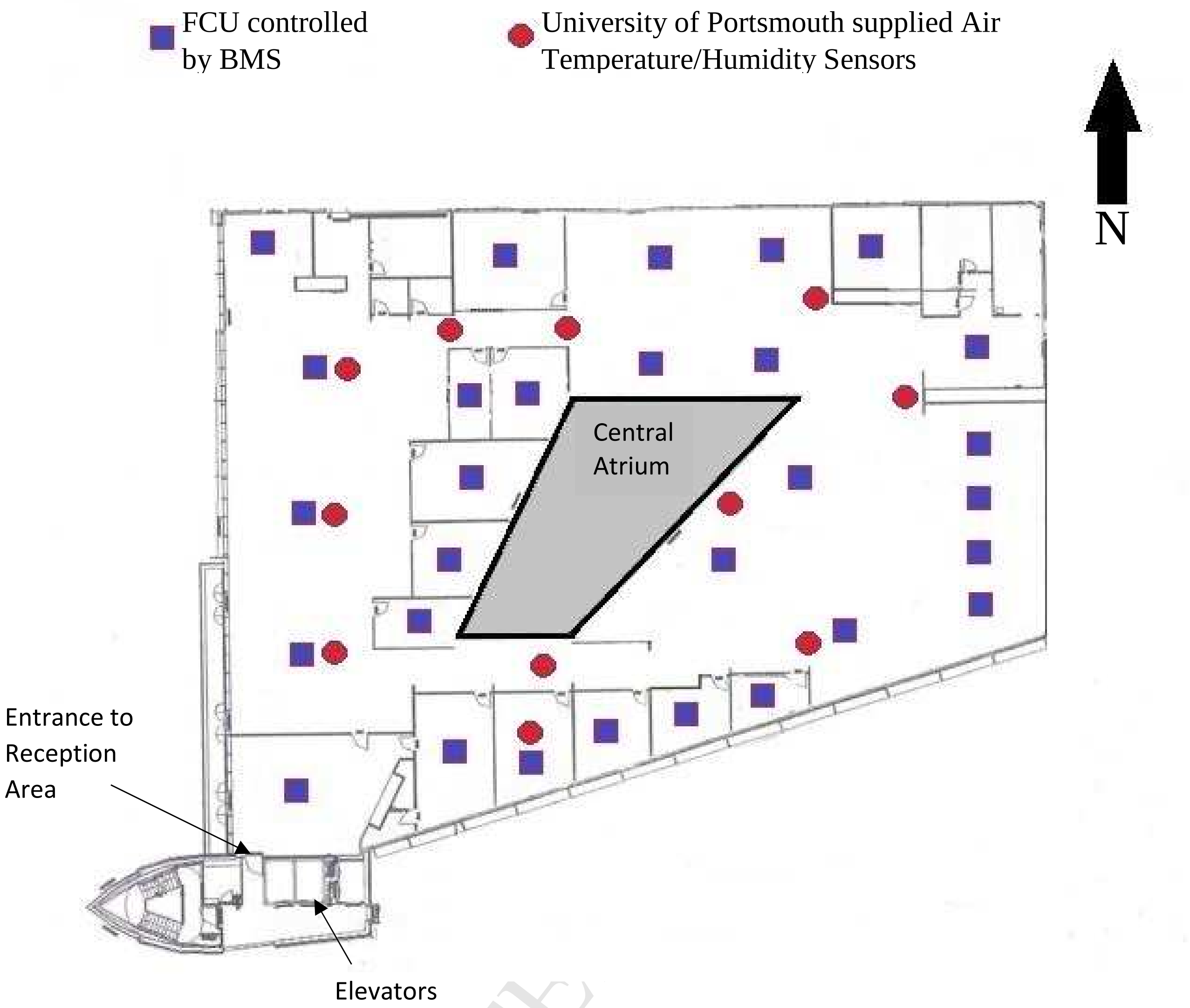

Figure 3. Simplified Office Floor Plan Showing Location Plan of BMS Controlled FCU and UoP Installed Temperature and Relative Humidity Sensors

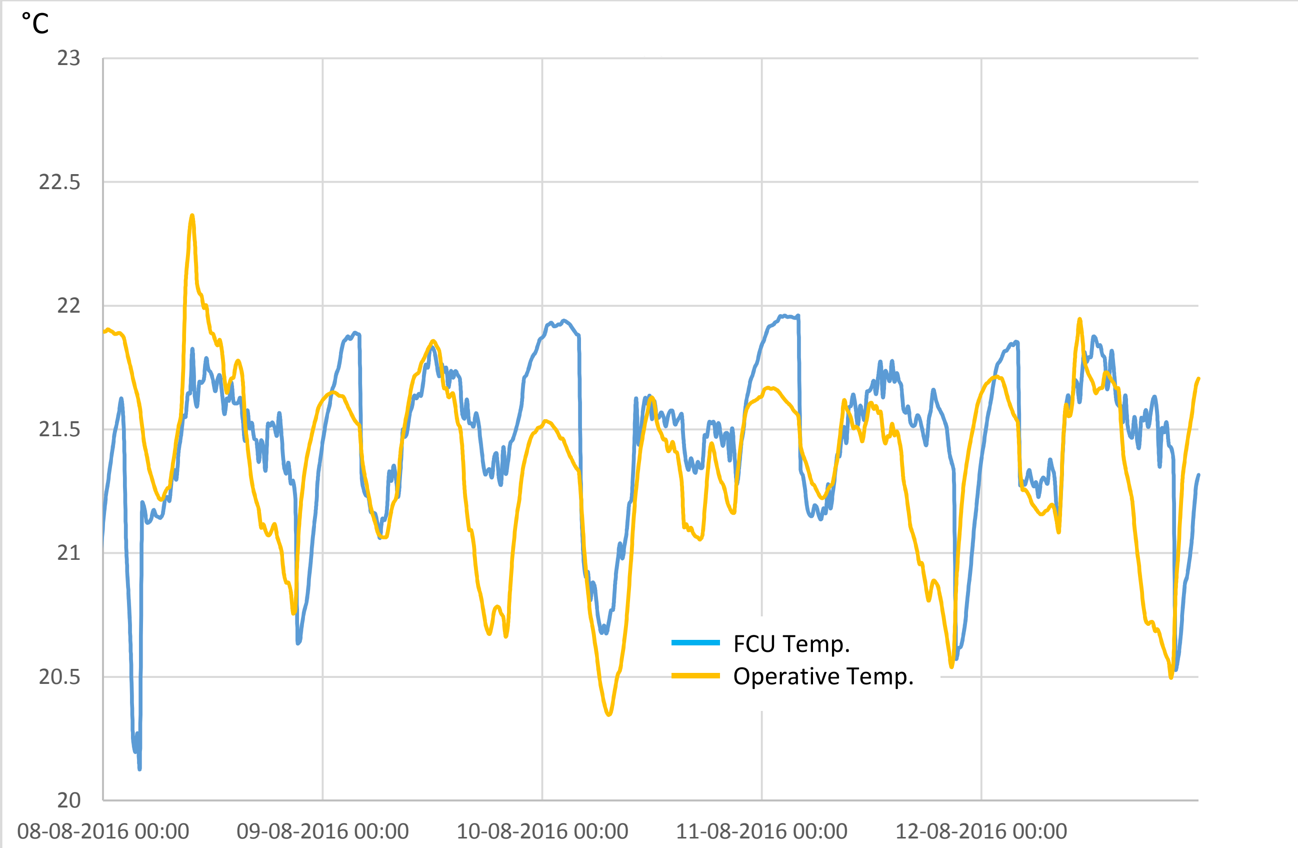

Fig 4. One typical set of FCU and operative temperatures in the office floor for the period 08 Aug – 12 Aug 2016

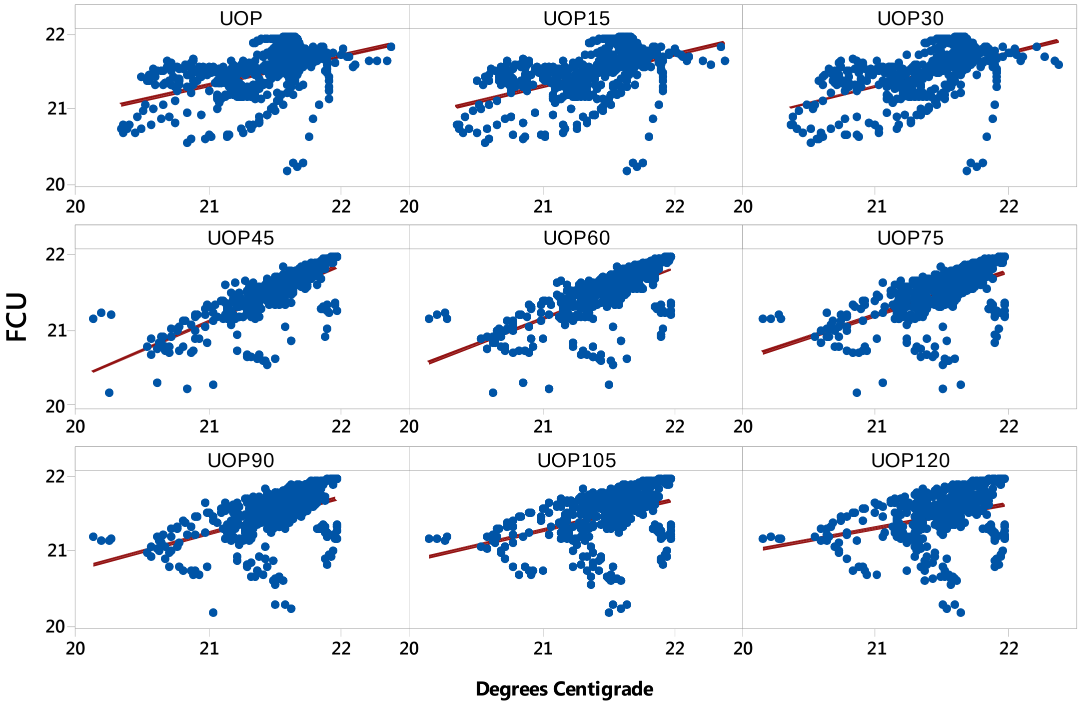

Fig 5. Graphs of regression analyses of FCU and UoP data (UoP data lagged sequentially every 15 minutes) for the period 08 Aug – 12 Aug 2016

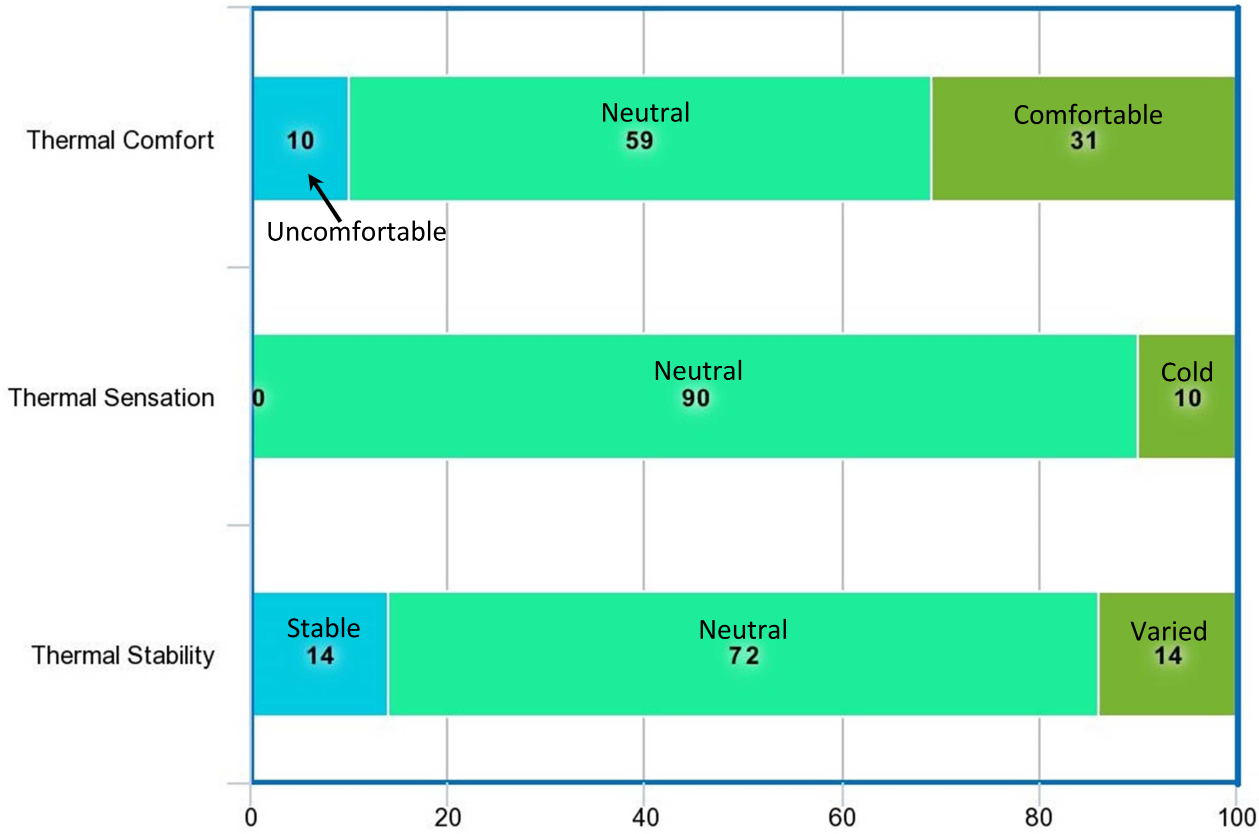

Fig. 6. Distribution (%) of respondents' answers regarding sensations of thermal comfort

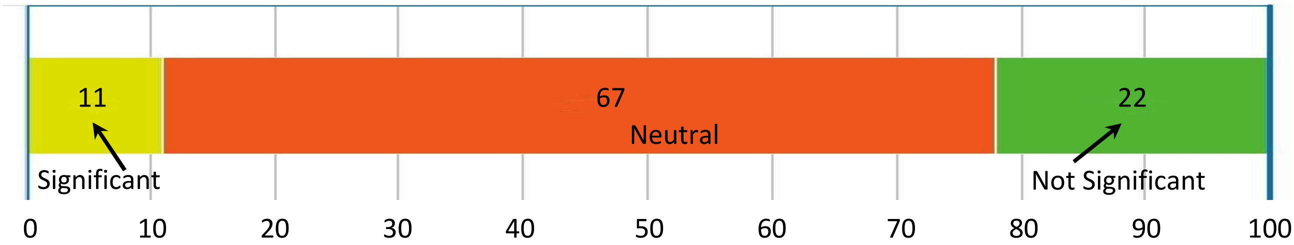

Fig. 7. Significance (%) of effect for those participants who felt there was any effect at all on their work performance due to temperature discomfort

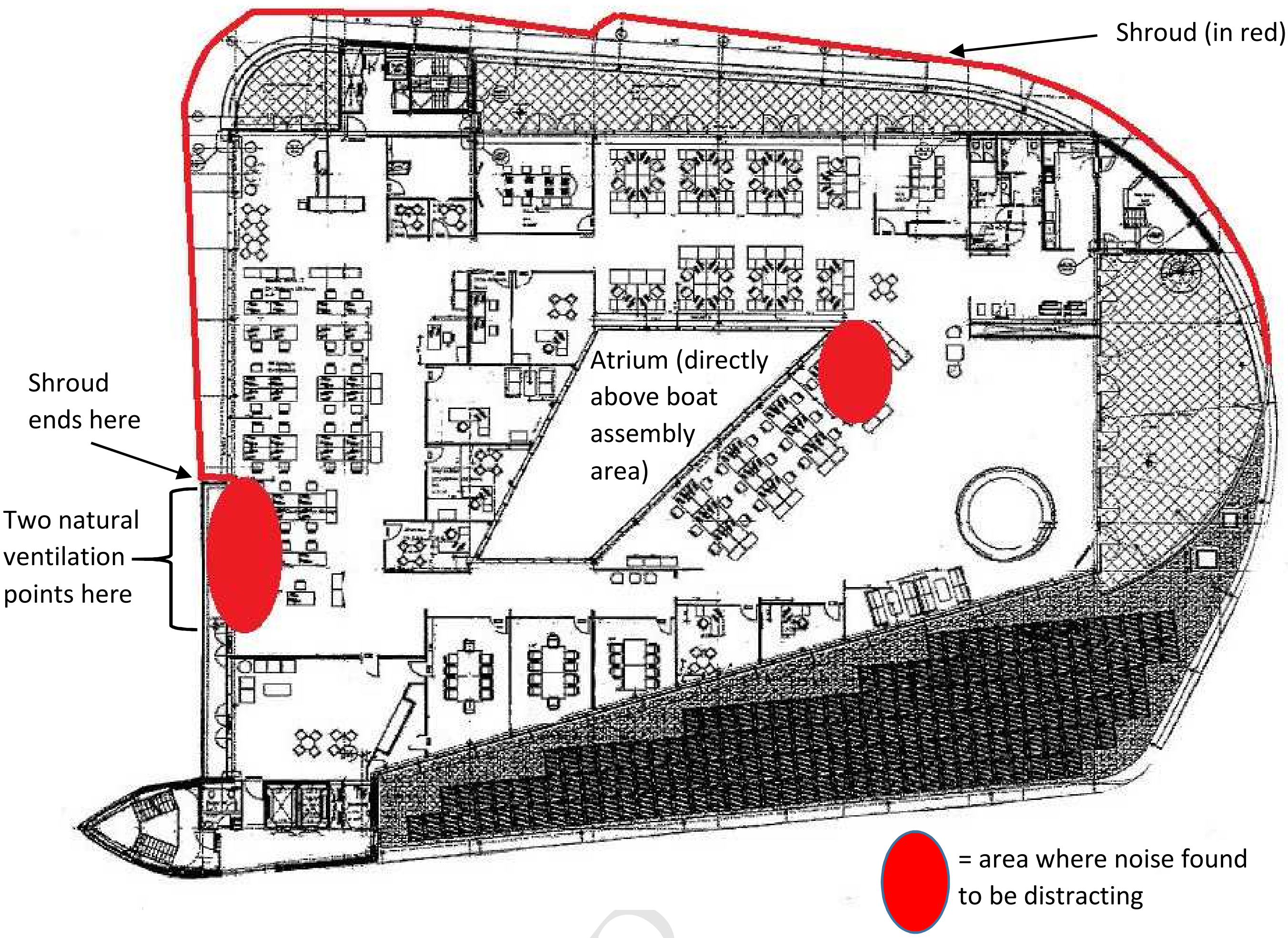

Fig. 8. The two locations (marked in red) where noise was considered, by a significant proportion of occupants, to be distracting

Post Occupancy Evaluation and Internal Environmental Monitoring of the New BREEAM "Excellent" Land Rover/Ben Ainslie Racing Team Headquarters Building.

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Highlights.

This paper describes a study carried out on the office floor of the Land Rover/Ben Ainslie Racing (LR/BAR) Team headquarters building in Portsmouth, UK. The building was recently constructed and has a Building Research Establishment Environmental Assessment Method (BREEAM) "Excellent" award/certification. The study examines the physically monitored environment within the building, in terms of temperature, acoustics and lighting and compares these measurements with both the occupant's perception of comfort regarding the same parameters, and the building management system's (BMS) input and output. The occupants perceptions are quantified by a post occupancy evaluation (POE) carried out by survey/questionnaire. Existing research suggests a "performance gap" between design intentions and users' (occupants') satisfaction levels. This research suggests that early commitment to sustainable design, coupled with occupants that are knowledgeable of and engaged in this ethos, can produce good user experience and comfort levels. However this appears to be contingent on the building being of low thermal mass, such that, the BMS is responding to something very close to the operative temperatures within the building. The results also demonstrates the importance of seemingly small details to the level of comfort experienced by occupants.