A post occupancy evaluation of a BREEAM ‘excellent’ rated office building in the UK

S.J. Birchall
University of Leeds, Leeds, England

J.A. Tinker
University of Leeds, Leeds, England

ABSTRACT: Designing a ‘green’ building by incorporating sustainable, low-energy technologies is one of the ways in which their energy demand and related CO_2 emissions can be reduced. In reality however, it doesn’t necessarily follow that a ‘green concept building’ will perform as such during post occupancy.
At present, the performance rating of many buildings relies on values obtained during design stage and it does not necessarily follow that a building will perform as it was designed during post-occupancy.
Using a BREEAM ‘Excellent’ rated office building as a case study, this paper presents the in-use performance of some of its installed technologies. The building incorporates numerous green technologies and many of these are being monitored during post-occupancy. In addition to this, an occupant satisfaction survey has been carried out.
This paper presents the actual performance of a selection of the installed technologies and compares them with their design performance. The paper also presents the results of the occupant satisfaction survey.

1 INTRODUCTION

It is has been reported on many occasions that buildings are responsible for just under half of the energy use and CO_2 emissions in the UK (Turrent 2007). For this reason, sustainability and energy efficiency are major drivers in the design of all new buildings. In the UK, new government legislation has recently set targets to reduce 80% of carbon emissions from buildings by 2050, when compared with 1990s levels. Meeting these ambitious new targets and stricter building regulations will be challenging and will encourage designers to incorporate more ‘green’ technologies in future projects. However, designing a ‘green’ building is only one aspect needing consideration. They must also perform ‘green’ once occupied and in-use as the measured performance of a building can often be different from that predicted during design stage (Piette, Kinney et al. 2001). In the UK, probably the best know post-occupancy monitoring projects were those in the PROBE (Post-occupancy Review of Buildings and their Engineering) series (Cohen, Standeven et al. 2001). The results of these studies reported that the actual energy used in a building was often different to that predicted and that the best performing buildings were not always those expected to do so (Bordass, Leaman et al. 2001).

BREEAM (BRE 2009) is an environmental assessment method originating in the UK which rates a building’s performance on information obtained during the design stage. A recent study reported that a BREEAM ‘Excellent’ rated building does not necessarily mean that it will deliver an excellent energy performance once in use (Sawyer, Wilde et al. 2008). A different study carried out in the USA, showed that green buildings can perform well when compared to their conventional counterparts (Newsham, Mancini et al. 2009). The few studies that have been reported show there is a general lack of post-occupancy evaluation and performance monitoring of buildings being undertaken (Way & Bordass 2005) (Palmer 2008) and on the few occasions when this has been carried out, the results are rarely published (Newsham, Mancini et al. 2009). Carrying out such routine monitoring of a building's performance should be the norm so that it can provide valuable feedback to the design team (Andreu & Oreszczyn 2004). Additionally, by routine monitoring and evaluation, the actual energy performance of a building can be assessed and optimised to deliver improved energy efficiency.

This paper investigates the in-use performance of a 'green' office building located in the UK that was awarded a BREEAM 'Excellent' rating of 87.55%. It reports on some of the installed technologies that have worked well and on those which have not worked as well as expected. The paper also evaluates the level of occupant satisfaction provided by the building.

2 BUILDING DESCRIPTION

The building monitored for post-occupancy performance was a 4350 m^2 office building located in the North-East of England, UK. The design, with its 'green' credentials was expected to produce an energy efficient office building having low carbon emissions when in-use. The construction phase of the project was carried out in a sustainable manner by using offsite prefabrication techniques for many of the building elements, segregation of construction waste on site together with energy and water management. The building materials used were, where possible, sourced locally and incorporated recycled materials including PFA, Lytag aggregate and recycled steel as reinforcement.

The building comprises of two 54m x 13m wings (a two storey east wing and a three storey west wing) separated by a central glazed atrium. The building was designed to provide flexible office space to be used as either open plan or as cellular offices. The building incorporates a number of green technologies which include an exposed thermal mass internally, a good level of air tightness, a low-volume vacuum drainage system using low-flush WC's which utilise rainwater harvested from the roof of the west wing, a 'green' sedum roof on the east wing, CHP with matching absorption chillers for tri-generation, a low energy lighting installation incorporating an atrium design and a low energy heating, cooling and ventilating 'Termodeck' system. The building is controlled by a Building Management System (BMS) with specifically designed control strategies to optimise the operation of the building so as to provide a comfortable and energy efficient work space. High levels of insulation were used in the external fabric to minimise heat loss from the building and typical U-values are shown in Table 1.

Table 1. Typical U-values.

Building component	Specified U-value (W/m^2K)
Floor	0.15
Walls	0.15
Windows	1.50
Roof glazing	1.76
Roof	0.15

The building was completed and opened in February 2007 and since then occupancy uptake has been slow. Now, after almost three years of operation, the occupancy is still only around 50%.

3 POST OCCUPANCY MONITORING AND EVALUATION OF THE GREEN TECHNOLOGIES

Throughout the period of occupancy to date, the in-use performances of the ‘green’ installed technologies have been monitored and evaluated and a selection of these are presented in the paper.

3.1 Total water use in the building – a comparison between the predicted and actual performance.

The typical water consumption for an office building, with no canteen, is quoted as 25.0 litres/full time employee/day (Envirowise 2009). In close agreement with this value, another source (WATER UK 2008) estimates the average water consumption in an office building to be 24.5 litres/full time employee/day (based on 253 working days in a year).

In an attempt to minimize water use in the building a vacuum drainage system for the WCs, waterless urinals and the low volume fittings in the hand wash basins were all installed. The low volume WCs used rain water harvested from the west wing roof and used only 1.2 litres per flush compared with around 6 to 9 litres per flush in a conventional system. The harvested rain water is stored in an underground tank and treated prior to use.

In the building being monitored, the water consumption was predicted to be around 1.27m^3/person/year, representing a water usage of 5.0 litres/full time employee/day. It was also predicted that the use of mains water for flushing would be virtually eliminated (King 2007).

Over the monitoring period, the average occupancy in the building was around 100 people. Based on current occupancy, Figure 1 shows the predicted, typical and actual water usage from May 2008 to May 2009. In February 2009, a fault occurred in the harvested rainwater tank and this caused an increase in mains water use over a short period of time. Due to the fault, the mains water data from February 2009 onwards has been extrapolated based on previous usage (see vertical dashed line at 01/02/09 on Figure 1).

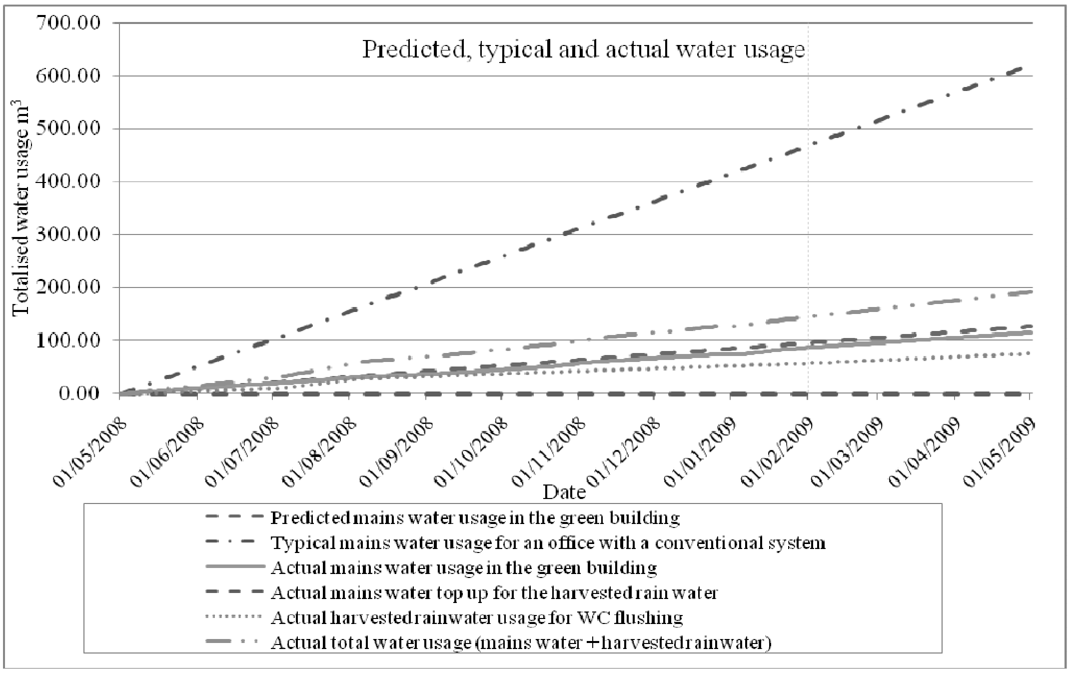

Figure 1. Annual predicted, typical and actual water usage in the building.

The results indicate that the annual amount of mains water used in the building was only 20% of the mains water used in an office with a conventional flushing system and was around 10% less than the predicted value. No mains water was required to supplement the harvested rain water, therefore the use of mains water for flushing the WCs was eliminated. The total annual water usage, for both mains water consumption and the harvested rain water, was 30% of the total water used in an office with a conventional flushing system. This reflects the effectiveness the low volume system and fittings. In summary, the water usage met the design expectations.

3.2 Air tightness – comparison between the specified and actual achieved.

One of the most effective ways to reduce the energy losses from a building is to minimize air infiltration by ensuring a well sealed building envelope. An air tightness test is a compulsory requirement on all new building constructed in the UK under Part L of its Building Regulations and the maximum allowable air permeability index must be less than, or equal to 10.0$m^3/h/m^2$. During the commissioning stage of the building an air tightness test was carried out according to CIBSE TM23:2000 and BS EN 13829:2001 when the air permeability index was measured to be 3.3 $m^3/h/m^2$ at 50Pa. The air permeability of the building was only 33% of its permitted maximum value and compared well against its predicted air permeability index of 5.0 $m^3/h/m^2$.

3.3 The low energy lighting system – a comparison between the predicted and actual energy performance.

The orientation of the building and the use of a central atrium allowed the building to take full advantage of any available natural daylight. A low energy lighting system using T5 luminaries is controlled by light sensitive photoelectric cells which dim down their output in response to any natural daylight. The artificial lights are also controlled by presence motion sensors.

In a normal air-conditioned office building, the artificial lighting typically accounts for 24% of the total amount of electrical consumption within a building (Action Energy 2003). During the design stage of the building being monitored and based on full occupancy, the total electrical demand for all the artificial lighting was predicted to be 75,266 kWh per annum (including office, corridor, atrium, toilet and ancillary fittings). The building was only partially occupied and in the occupied zones, the annual electrical consumption was predicted to be 29,670 kWh. Table 2 compares the predicted and actual annual amount of electrical consumption of the artificial lighting system in the various occupied office zones. The predicted amounts were obtained from documentation supplied by the design team and the actual electrical consumption was obtained from energy data measured by the BMS system over a 12 period.

It was found that the electricity consumed by the artificial lighting in the occupied zones accounted for only 14% of the total electricity consumed in the building. However, as previously noted the building was only partially occupied.

Table 2. Predicted and actual annual lighting electrical consumption.

Zones	Treated area* (m^2)	Predicted annual lighting electrical consumption (kWh)	Actual annual lighting electrical consumption (kWh)	% increase in actual electrical consumption
East wing ground floor	625.50	7045	11664	66
East wing 1st floor	687.36	5369	544	Unoccupied zone
West wing ground floor	506.10	6991	13563	94
West wing 1st floor	609.36	5622	27300	386
West wing 2nd floor	609.36	4644	894	Unoccupied zone
TOTAL	3037.68	29670	53965	82

Note: * areas were calculated from architects drawings supplied

From Table 2 it is clear that the occupied zones, which included the east wing ground floor, west wing ground floor and 1st floor; all consumed far more electricity than was predicted. In these zones, the percentage increase in the actual electrical consumption when compared to the predicted was 66%, 94% and 386% respectively, with an overall average increase of 82%. The electrical consumption within the unoccupied office zones was due to the artificial lights being on during cleaning periods and occasional use of the space.

The zone of most concern was the west wing 1st floor as this had the highest electrical consumption, and was only partially occupied. Analysis of electrical consumption data revealed that in all the occupied zones, except the west wing 1st floor, the office lighting appeared to be activated only during occupied periods. In the west wing 1st floor, the electrical consumption was much higher than expected and after analysis of the systems use it became apparent that the motion sensors in this area were not working as expected and on many occasions the artificial lighting would remained on overnight. Additionally, the occupant satisfaction survey and further discussions revealed that some of the occupants had been given hand held remote controls with which to over-ride the automated lighting controls.

The excessive electrical consumption in the two ground floor wings was partly due to the office occupants lowering their louvered window blinds to get privacy from people in the adjacent atrium space. This effectively reduced most of the natural daylight entering the office space from the atrium and necessitated the permanent use of artificial lighting.

4 OCCUPANT SATISFACTION SURVEY

4.1 The survey and methodology

A successful low energy building minimizes its environmental impact without compromising occupant comfort. A key element therefore, when evaluating the overall performance of any building is occupant feedback. Initially it was intended to develop new questionnaire however to allow comparisons to be made with other buildings and existing benchmarks, a well established occupant survey was selected (Building Use Studies (BUS) survey) with additional questions being added to suit the building being monitored.

The BUS survey was completed by the building occupants in June 2009 and included questions related to temperature, comfort levels, noise and lighting satisfaction levels, along with questions on health, productivity and travel to work. Most questions required a response on a 7 point scale with ‘1’ being unsatisfactory and ‘7’ being satisfactory, with ‘4’ being neutral.

4.2 Results from survey

There were 85 occupants in the building on the day of the survey and 67% responded. 52% were male and 48% were female. 23% were under 30 years of age and 58% had worked in the building for one year or more. The results of the survey are shown in Figure 2.

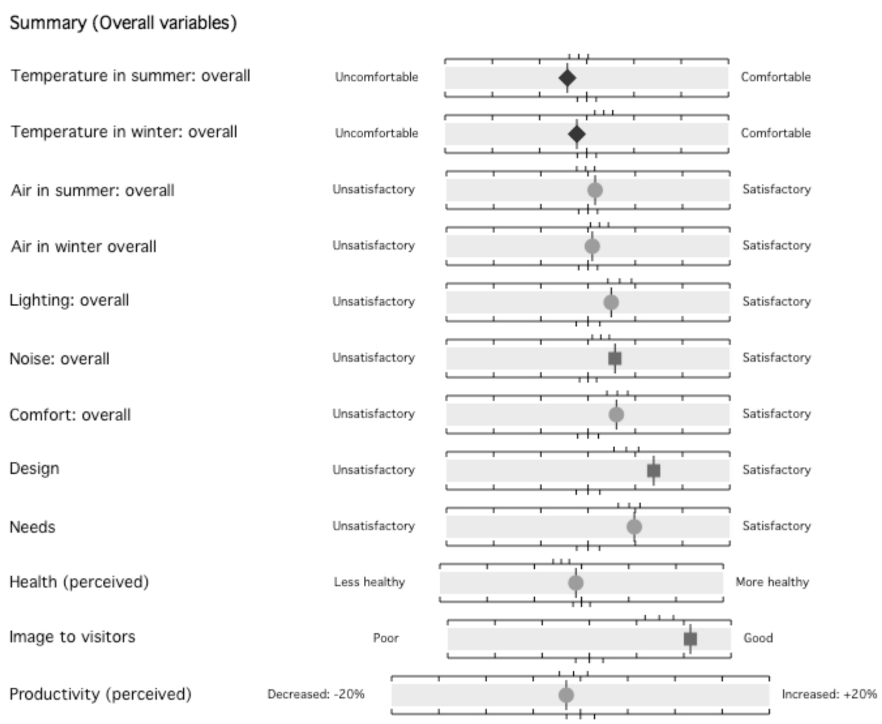

Figure 2: BUS survey results, overall variables (Building Use Studies (BUS) 2009)

The results of the survey are shown on the 7 point scale either by a diamond shape (indicating a design feature which failed to achieve a critical acceptance level of performance), a circle (indicating a design feature which achieved a critical acceptance level of performance) or a square (indicating a result which exceeded a critical acceptance level of performance).

The building is automatically controlled by the BMS and the occupants have little control over the internal environment apart from being able to open windows and control the window blinds within their office space.

The overall dissatisfaction with the general lack of control over the indoor temperature during both the summer and winter was evident and the occupant's response fell below the critical range. The occupants were not only dissatisfied with the overall temperature control in both the winter and summer periods, but also with the variations and stability of these temperatures which caused severe discomfort issues with the occupants.

Most other parameters including the air quality, lighting, comfort and health etc all fell within the critical design range. The artificial lighting in particular appeared to be not well received by the occupants. The more positive findings included the design and aesthetics within the building, the image the building conveys to visitors and the low noise intrusion from outside. The occupants were however unhappy about internal noise transfer and particularly the poor noise control through the office partitions.

By adding additional questions to the survey it was possible for the respondents to record additional comments. These revealed positive support for the amount of natural daylight admitted into some of the office spaces and into the atrium. The more negative comments were about poor temperature control in the building, smells from the vacuum flush WC's, annoyances associated with the artificial lights switching off after a period without movement, artificial lighting levels being too low and poor control of their automatic 'dimming down'. The kitchen areas were also criticised for being too small.

The BUS summary index calculates a result for the building's overall performance and this is displayed on one common, normalized scale in Figure 3. The overall result for the building is represented by the shaded circle, and the diamond, triangle and square superimposed on the figure represent results from other surveys done on UK 'green' office buildings. Within the existing benchmark data set it can be seen that the result for the building is in the 57th percentile and the occupant satisfaction result for the building was average overall. When compared to the other 'green' office buildings surveyed the building was the worst performing.

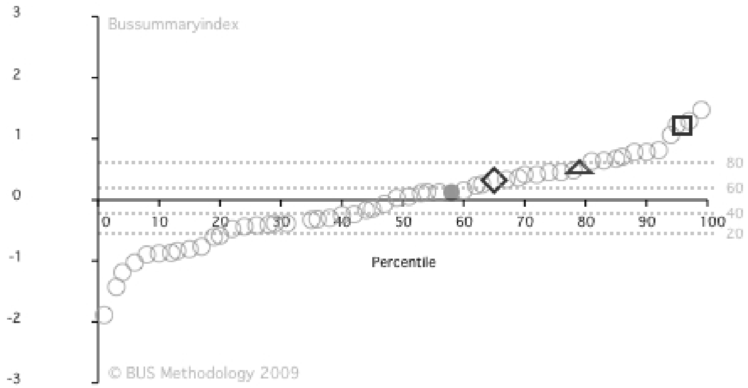

Figure 3. BUS summary index.

5 CONCLUSIONS

This paper has presented the in-use performance of a selection of the 'green' technologies installed in a BREEAM 'Excellent' rated office building in the UK.

Some aspects the building performed well such as the amount of mains water used in the building and its actual performance met design expectations. The air permeability index of 3.3 $m^3/h/m^2$ exceeded the design specification of 5.0 $m^3/h/m^2$ and was well within the required UK Building Regulation value of 10.0 $m^3/h/m^2$.

Some aspects of the building did not perform as well as expected and the results were disappointing . In the occupied zones, the energy consumed by the artificial lighting was far more than predicted and from the occupant satisfaction survey it was apparent that the control of lighting levels was often unsatisfactory. The major finding from the occupant satisfaction survey was that the heating and cooling control in the building was failing to provide comfortable conditions.

When compared to other buildings within the BUS dataset, the overall performance of the building was average and this was a further disappointment considering that the building was a green building with an Excellent BREEAM rating. Additionally, when the performance of the building was compared with three other 'green' office buildings in the UK, its performance was the worst.

The findings in this work supported the finding reported by others in that a BREEAM 'Excellent' rated building doesn't necessarily mean a green building in use.

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