Energy efficiency interventions in office buildings: refurbishment, interactive technologies

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ABSTRACT

Improving the energy performance of non-domestic buildings can play an important role in meeting UK energy targets. Halcrow aim to investigate whether/how innovative interventions can be employed to save energy without compromising occupants’ satisfaction, well-being and productivity. Halcrow’s recently refurbished HQ, known as Elms House (EH), has been taken as a case study for this research. Employees were moved to EH from two other London offices, one of them being the old HQ, Vineyard House (VH), adjacent to EH.

This research looks at two different interventions: the first (and main) intervention was to provide a newly refurbished work environment, while the second is to introduce interactive posters to the building which will encourage employees to save energy at their workplace. An employee benchmark survey and two post-occupancy surveys were conducted to indicate to what extent the first intervention has improved employees’ level of satisfaction with their environment. Also, a full year’s energy data were collected in order to assess whether the new building is likely to be more sustainable than VH.

The results showed that, in terms of energy consumption per m², the first intervention was a success. However, in terms of performance gap, CO₂ emission at EH in 2011 was 3 times higher than what anticipated. The new environment has increased the level of satisfaction of employees, but not significantly so. It was also noticed that spaces are not efficiently in use in the new building.

Keywords:
Energy saving, Non-domestic buildings, Occupants’ behaviour, Refurbishment and Post-Occupancy Evaluation

1. INTRODUCTION

The UK government has set a target to reduce CO₂ emissions to 80% of the 1990 level by 2050. To achieve such saving will require effective leadership and management of change in all UK industry sectors. Non-domestic buildings in the UK are responsible for 18% (Carbon Trust, 2008). According to IEA (2010), total energy demand in the building sector will increase by about 60%, from 2,759 Mtoe in 2007 to 4,407 Mtoe in 2050; non-domestic
buildings account for 41% of this projected growth. Therefore, the building sector is potentially a key contributor to meeting this ambitious target of total UK emissions.

In the UK, although significant work is being undertaken on new low energy buildings, it is the existing building stock that dominates energy use in buildings, due to the vast number of older buildings and the slow rate of replacement.

Halcrow wishes to investigate how innovative interventions can be applied to non-domestic buildings in order to save energy and improve employees’ satisfaction. The company is part of CH2M Hill Company, an international consultancy specialising in planning, design and management services for infrastructure development worldwide.

This research looks at technology, information systems and building occupants at the three areas to address in order to save energy in non-domestic buildings.

2. ENERGY TECHNOLOGIES

There are broadly two kinds of technical solution for energy reduction in commercial buildings: supply side and demand side. Supply opportunities, also called ‘alternative measures’ by MacKenzie et al. (2010), include renewable energy technologies such as wind turbines, solar panels and biomass fired combined heat and power. The UK has signed up to the EU Renewable Energy Directive, which sets the UK a target of 15% of its energy to be generated by renewable sources by 2020 (DECC, 2009). Renewable energy technologies have the advantage of having lower fuel and operating costs compared with conventional energy sources. However, the higher initial capital cost required for renewables can make them unattractive to companies and landlords, depending on the companies’ financial circumstances.

Demand side solutions, on the other hand, include equipment measures, building services and fabric measures such as better lighting, energy efficient boilers and better insulation (MacKenzie et al., 2010). There are already a number of government policies in place to encourage energy efficiency within the non-domestic building sector. For example, ‘Green Deal’, which is set to be available in autumn 2012, will enable companies to employ energy efficiency measures with no upfront cost. Companies will repay the cost via their future energy bills.

3. BUILDING INFORMATION SYSTEMS

Building information systems involve using devices such as Smart meters, sub-meters and Building Management Systems (BMS) to collect both energy and employees’ satisfaction data. In new and refurbished buildings, gathering energy data and occupants’ satisfaction data will help companies to carry out post-occupancy evaluation (POE) which, in turn, will help them to manage and control the workplace more effectively in terms of energy consumption.

3.1 Post-Occupancy Evaluation

Presiser et al. (1988) define POE as “a process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time”. POE is achieved by gathering data and collecting occupants’ feedback about their work environment via questionnaire, interview or workshop. Occupants’ satisfaction surveys can gather detailed
information about features of the building, which can help designers in their future projects. POE should provide feedback on a building’s performance compared with that of benchmark buildings/design targets, and lessons learned may be highlighted.

The results from POE can also be used to measure a project’s success, set benchmarks and contribute to the change management and communication process (BCO, 2007).

3.2 POE barriers: the credibility gap

The results from the PROBE (Post Occupancy Review of Buildings and their Engineering) studies, which reviewed post occupancy of 23 buildings, showed that actual energy consumption in buildings is usually twice as much as expected (Menezes, 2012). This is due to the fact that several sources of energy usage are not considered in the calculations of design targets. These sources are known as unregulated loads and include IT equipment, server rooms, external lighting and lifts. Unregulated loads accounted for more than 30% of the total energy consumption in an office building (Menezes, 2012).

It is not very clear who should pay for POE and who should conduct it. So, not many building designers monitor the performance of their project after completion (Bordass et al., 2004). Therefore, building designers cannot gauge the accuracy of their assumptions made at the design stage. There is significant evidence that actual energy consumption in buildings continues to fail to meet the anticipated targets/intended benchmarks. Bordass et al. (2004) refer to this issue as the “credibility gap”. The credibility gap occurs due to over simplified or wrong assumptions about built quality, occupants’ behaviour and management and control of the building and its services (De Wit, 1995) and it recurs due to the lack of feedback after occupancy.

As discussed earlier, actual energy consumption in buildings is usually twice as much as anticipated. However, according to studies by Carbon Trust, in-use energy consumption in buildings can even be up to 5 times higher than predicted (Menezes, 2012). This is because, in addition to unregulated loads, there are various factors which affect the accuracy of predictions. Occupants’ behaviour, itself often unpredictable is one of these, so designers have to make assumptions about it (De Wit, 1995). Occupants’ behaviour will be discussed further later in this paper.

3.3 Space Utilisation

Although space is companies’ second largest administrative expense after personnel, in most organisations utilisation is well below 100%, and is typically between 50% to 60% (BCO, 2009). This when the average service charge for air-conditioned offices, for example, is about £69.39 per m$^2$, 19% (£13.18 per m$^2$) of which is the cost of energy (RICS, 2008). Gathering the right data can help the facilities managers within an organisation to manage the space more effectively. The efficiency of an office space can be measured in m$^2$ per person by calculating the office occupancy density. Good UK practice is between 12m$^2$ and 17m$^2$ per person of net internal area (BCO, 2009).

4. BUILDINGS’ OCCUPANTS

From the literature, it is evident that the physical environment of a building affects the occupants’ comfort, satisfaction and productivity, and those occupants who have some degree
of control over their environment are more satisfied (Leaman and Bordass, 2006). However, energy performance of buildings where occupants have control over their environment is highly dependent on the occupants’ behaviour. The knowledge gap is whether/how innovative interventions can be used in existing non-domestic buildings to change occupants’ attitudes and behaviours towards saving energy.

4.1 Attitude and behaviour change theories

Most people have a positive attitude towards aimed at saving energy. However, this does not mean that the behaviour will actually be performed (Olander and Thogersen, 1995). There are a number of reviews of literature about behaviour and behaviour change in social psychology. Some of the theoretical models that are relevant to this study are outlined in this section.

4.1.1 The theories of reasoned action and planned behaviour

In 1975 and 1980, Fishbein and Ajzen created a major model of the relationship between attitude and behaviour, the theory of reasoned action (TRA) (Ajzen, 1991). According to the TRA, the immediate determination of behaviour is one’s intention to perform that behaviour.

The theory of planned behaviour (TPB) is an extension of the TRA developed by Ajzen(1991). According to TPB, behavioural intention is formed by three factors: attitude, subjective norm and perception of control over performance of the behaviour. Levels of perception of control influence one’s motivation to perform the behaviour (Furnham, 2006).

4.1.2 Motivation-opportunity-ability (MOA) and its relationship to Fogg’s behaviour model

Olander and Thogersen (1995) developed the motivation-opportunity-ability (MOA) model of consumer behaviour. According to this model, motivation, opportunity and ability are the three factors that can influence behaviour. Motivation is determined by the desirability of the outcomes of a behaviour. One’s ability to perform the behaviour depends on his/her knowledge about how to perform the behaviour as well by habit. Opportunities are external factors that make performance of behaviour easier or can trigger certain behaviour.

A model that is closely related to the MOA model is Fogg’s behaviour model (Fogg, 2003). This model proposes that the higher motivation and ability are, the more likely it is that a person will perform the target behaviour; “triggers” can be used to stimulate the tendency to perform the behaviour.

5. CASE STUDY BACKGROUND

In September 2010, Halcrow employees from two buildings, the previous HQ, Vineyard House (VH), and Shortlands (Sh), moved to the newly refurbished global headquarters (HQ), Elms House (EH). Halcrow’s aspiration was to provide a sustainable HQ building which could also increase collaboration, knowledge sharing and creativity. However, due to the owner-tenant split and also a tight budget, Halcrow decided to focus on improving the energy efficiency and changing occupants’ behaviour rather than applying renewables. EH is adjacent to VH and is structurally similar to it, particularly in terms of general office layout. The key features of these three buildings are described below.
VH
VH was a 5-storey office building built in 1962, with 5,202.6m$^2$ floor area. It was mainly open-plan with few cellular offices and a number of formal meeting rooms with video conferencing facilities. There was a high level of lighting available at VH from both daylight and artificial (mainly fluorescent tube) sources. Although mechanical ventilation was available, due to the poor performance of the system, the building was mainly naturally ventilated. VH was heated by gas fired boilers via radiators throughout the building. These were complemented by portable heaters supplied to individual members of staff. A small canteen was located on the ground floor. About 479 and 505 employees were working at VH in 2009 and 2010 respectively.

Sh
Halcrow’s Sh office, with 1,526m$^2$ floor area, was located on the 5th floor of the 10-storey building in Hammersmith which was built in 1970s. The office was predominantly open plan with a few cellular offices and a few meeting rooms. The office benefited from high levels of lighting from both daylight and artificial (mainly recessed modular) lighting. Sh was mechanically conditioned using both variable air volume (VAV) and fan-coil systems. The office was heated using gas and perimeter convection heaters. In 2010, 100 employees were working at EH.

EH
EH is a 5-storey office building which was built in 1930s with a floor area of 11,725m$^2$. EH was completely stripped out and refurbished in 2010 and achieved a BREEAM rating of “Very Good”. The office is completely open plan with a number of small and large meeting rooms equipped with teleconferencing and video conferencing facilities. There are a number of designated areas for socialising and informal meetings as well as areas for concentration and contemplation phone booths are available on each floor. A 60-seat restaurant is located on the ground floor as well as kitchens on each floor. Facilities for cyclists are good, and include 6 showers. The office is mechanically air conditioned by use of fan-coils. A high level of lighting, from both daylight and artificial sources is available. The lighting system incorporates both daylight and PIR sensors. Services at EH are mainly centrally controlled by a BMS system and the employees do not have control over their immediate environment. In 2011, 596 employees were working at EH.

6. BENCHMARKS

Benchmarks are set as guidance as to how the building should perform depending on the intended level of performance to be achieved - which is usually “typical” or “best practice”. There are different benchmarking tools available in the UK, such as CIBSE Guide F, ECON19 and CIBSE TM22. In this paper, CIBSE TM22 was used as a standard benchmark. For air-conditioned, prestige offices, the benchmarks are:

- **Good practice:**
  - fossil fuels: 91kWh/m$^2$
  - electricity: 118kWh/m$^2$
  - CO$_2$ emissions: 79kg CO$_2$/m$^2$
- **Typical:**
  - fossil fuels: 171kWh/m$^2$
  - electricity: 208kWh/m$^2$
CO₂ emissions: 140kg CO₂/m²

In this study, the refurbishment’s design target is also considered to measure the performance gap, if any. The design target for CO₂ emission was 37 kg CO₂/m². This figure does not include unregulated loads (i.e. IT equipments, lifts, security, external lighting and catering).

7. METHODOLOGY

For this study, a combined approach using action research and case studies is taken as methodology. This research looks at two different interventions. The first (and main) intervention was to provide a newly refurbished work environment, while the second one will be interventions designed to change occupants’ behaviour.

In July 2010, a pre-occupancy online survey was carried out at VH and Sh, to investigate employees’ levels of satisfaction with their current work environment. A full year’s (2009) electricity and gas consumption data were also collected at VH. This data and the results from the survey were used as a benchmark to evaluate EH’s performance.

In February 2011, a post-occupancy survey was conducted at EH to measure the change in employees’ level of satisfaction with their work environment 6 months after the move. At the same time, observations were also carried out by the research engineer to assess two areas: 1- space usage and 2- occupants’ behaviour towards energy saving.

A full year’s (2011) energy data were collected at EH to evaluate the energy consumption of EH in comparison with that of VH. The basis for the design of both pre- and post-occupancy surveys was the Building Use Studies (BUS) methodology. Taking account of the behaviour change theories mentioned above, interactive posters are being designed, to be installed in the building to encourage employees to save energy, e.g. by taking the stairs rather than the lifts.

8. RESULTS

This section illustrates the results of the two surveys, collected energy data and observations.

8.1 Pre- and Post-Occupancy Surveys

Having excluded data from ineligible participants, the final sample consisted of 189, 162 from VH and 27 from Sh. The response rate for the pre-occupancy survey at VH was 32%, while for Sh, was 27%. The response rate for the post-occupancy survey was 30%. For the post-occupancy survey, having excluded data from ineligible participants, the final sample consisted of 183, generating a response rate of 31%.

Each survey was divided into two parts. The first part of the questionnaire included items concerning demographic factors such as age, sex and employment status. Also, in this part, employees were asked to specify their modes of travel to work and their willingness to work at home. In the second part, employees were asked to indicate their levels of satisfaction with their workplace physical environment, use of interior space, indoor facilities and current policies. For these questions, 5-point response scales were used, where: 2= Strongly Agree, 1= Agree, 0= neither Neither Agree nor Disagree, 1=Disagree and -2 = Strongly Disagree. In the latter part, employees were asked to state whether they were aware of Halcrow’s sustainability targets and whether they felt personally responsible for contributing to Halcrow’s sustainability objectives.
8.1.1 Demographic and Travel questions

The sample of respondents was broadly representative of the employees at VH, Sh and EH, as indicated by responses to the demographic questions and the question regarding office set-up.

A good number of the respondents in both surveys, over 40%, worked occasionally from home, while 39% indicated that they could work from home if the opportunity were available. About 13% of the respondents in both surveys indicated that they used a car to come to work, while 30% of these could work from home if the opportunity were available. In VH just above 50% (81) of the respondents indicated that they did not use the canteen, while in EH only 15% did not use the restaurant. The majority of the respondents in the both surveys, 80% (129) in VH and 87% (155) in EH, indicated that they never used the shower facilities in their building.

8.1.2 Work Environment Satisfaction and Sustainability awareness questions

On average, respondents in VH were slightly dissatisfied (-0.29) with their workplace environment, whilst respondents in Sh were just satisfied (0.06). As shown in Table 8-1, respondents in VH were slightly dissatisfied with all aspects of their work environment. Respondents in EH, on average, were slightly satisfied (0.38) with their work environment.

<table>
<thead>
<tr>
<th>Satisfactory mean score</th>
<th>Physical Environment</th>
<th>Interior Use of Space</th>
<th>Indoor Facilities</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>-0.42</td>
<td>-0.17</td>
<td>-0.24</td>
<td>-0.29</td>
</tr>
<tr>
<td>Sh</td>
<td>0.33</td>
<td>0.18</td>
<td>-0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>EH</td>
<td>0.11</td>
<td>0.51</td>
<td>0.52</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Table 8-1: Employees' level of satisfaction with their work environment

The results from both surveys showed that the respondents who used to work in Sh had a statistically significant lower level of satisfaction at EH than those who had moved from VH.

As shown in Table 8-2, the respondents, on average, in VH indicated that their workplace environment did not have a positive effect (-0.10) on their productivity, well-being and enjoyment at work. However, the respondents in Sh and EH, indicated that their workplace had a slightly positive effect (0.27 and 0.29 respectively) on their productivity, well-being and enjoyment at work.

<table>
<thead>
<tr>
<th>Mean values</th>
<th>Productivity</th>
<th>Well-being</th>
<th>Enjoyment at work</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>-0.02</td>
<td>-0.20</td>
<td>-0.10</td>
<td>-0.10</td>
</tr>
<tr>
<td>Sh</td>
<td>0.24</td>
<td>0.20</td>
<td>0.36</td>
<td>0.27</td>
</tr>
<tr>
<td>EH</td>
<td>0.29</td>
<td>0.24</td>
<td>0.36</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Table 8-2: Respondents’ perceptions of the effects of their current work environment on their productivity, well-being and enjoyment at work

In both pre- and post-occupancy surveys, the majority of the respondents, 58.7% and 71% respectively, indicated that they did not know about their company’s environmental sustainability targets. About 51% of the respondents in the pre-occupancy survey, and 46% in the post-occupancy survey indicated that they felt personally responsible for contributing to Halcrow’s environmental sustainability targets, but that they were not sure how they could
contribute. In the pre-occupancy survey, 11% of the respondents said they did not feel responsible at all and in the post-occupancy this figure had increased to 14%.

It was found from both the surveys that when the level of satisfaction increased the level of perceived positive effect increased as well.

8.2 Energy consumption

The annual electricity consumption at EH was measured to be 144kWh/m$^2$ which was 42% less than the total electricity consumption at VH in 2009 (205kWh/m$^2$). Gas consumption at EH in 2011 was found to be 98.4kWh/m$^2$, about 62% less than 158.79kWh/m$^2$ gas consumption at VH in 2009. Figure 8-1, overleaf, shows these results in more detail.

The average electricity base-load (from 9pm to 7am) at EH was about 256,320kWh (21.9kWh/m$^2$) which accounted for 15% of the total electricity consumption. This figure, per m$^2$, was 188% less than the average base-load at VH which was measured to be 328,580kWh (63.16kWh/m$^2$), accounting for 31% of the total consumption.

Figure 8-1: Electricity and gas consumption at VH in 2009 and at EH in 2011

Figure 8-2, overleaf, shows the CO$_2$ emissions from electricity and gas consumption in VH (2009) and EH (2011). The total CO$_2$ emission at EH in 2011 was 93.6kWh/m$^2$ which was 68% less than that measured at VH in 2009 (136.8kWh/m$^2$).

EH consumed 2831.11kWh/person electricity in 2011 which was 27% higher than that which was measured at VH in 2009 (2,229.59kWh/person). EH also consumed 12.3% more gas in 2011 compared with VH in 2009 (1936.51kWh/person at EH vs. 1724.68kWh/person at VH).
8.3 Observations

Observations showed that, at the time of the post-occupancy survey, on average, only 39% (263) of the workstations were usually in use. Observations also confirmed that, on the ground floor, contemplation and socialising areas (excluding the restaurant) were not effectively in use. It was also observed by the researcher that more than half of the employees do not usually switch their monitors off and about 10% leave their computers on when they leave their office.

9. DISCUSSIONS AND CONCLUSION

As mentioned earlier, moving into a newly refurbished building was used as an intervention to increase employees’ level of satisfaction with their work environment, and consequently to improve their productivity, and also to the reduce energy consumption and CO₂ emission of Halcrow’s HQ.

9.1.1 Benefits to the Occupants

The results showed that, after the move, the overall VH employees’ level of satisfaction with the work environment (physical conditions, interior use of space and indoor facilities) increased by 18.6%. Employees’ responses indicated that their satisfaction with the physical conditions of their workplace had increased by 15.4%. The results showed an 11.64% increase in the level of perceived positive effect (productivity, well-being and enjoyment at work) of the workplace on the employees. The employees who had moved from VH felt their productivity had increased by an average of 9.6% because of the environmental conditions of the building. Considering that employees at VH had had a sense of control over their work environment (but were not, in fact, able to achieve much improvement!), and also taking into account that the building was naturally ventilated, these results do not completely support arguments in the prevailing literature.
For those who had moved from Sh, the survey revealed that the overall level of satisfaction with physical conditions, interior use of space and indoor facilities had increased by only 1.3%. Employees stated that their satisfaction with the physical conditions in their workplace had decreased by 14.5%. Also, it was found that the level of perceived positive effects (productivity, well-being and enjoyment at work) of the workplace on the employees had declined by 7.8%. These employees felt their productivity had reduced by an average of 8.8% because of the environmental conditions in the building. These results were expected as Sh employees had had a more satisfactory office environment than VH employees, and, therefore, they may have had higher expectations of EH.

In general, the new work environment improved employees’ satisfaction and productivity, but not significantly so.

9.1.2 Energy Performance

EH showed better performance, in terms of electricity and gas consumptions and CO₂ emission per m², than VH. The electricity base-load at EH was 50% less than VH. So, the intervention was a success in terms of energy saving. However, in this case study the CO₂ emissions were more than 3 times higher than anticipated. Occupants’ behaviour, facilities management and space utilisation should be reviewed to detect whether there are any opportunities for more improvement.

REFERENCES


