Cranfield UNIVERSITY

Carbon brainprint case study

Intelligent buildings

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Carbon Brainprint Case Study

Intelligent buildings

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Summary

It is estimated that non-domestic buildings were responsible for 18% of UK total greenhouse gas emissions (582 Mt CO_2e/year) in 2010. Of non-domestic building emissions, 34% (36 Mt CO_2e/year) was due to lighting, office equipment and catering and 46% (49 Mt CO_2e/year) was due to heating.

A team consisting of researchers at the University of Reading, the University's Facilities Management Directorate and Newera Controls Ltd. conducted two separate investigations to measure and demonstrate the potential for two important and complementary approaches in achieving energy efficiency and greenhouse gas emission reductions in buildings. The first focused on influencing user behaviour, in an office building on the main campus. The second considered an interventionist approach in an accommodation block at the Henley Business School using intelligent monitoring and control systems.

To date, the first investigation has demonstrated a 20% saving in lighting, office equipment and catering energy use, largely through user awareness and behaviour change.

The second has indicated that savings in heating energy of the order of 24% can be achieved by enhancement of legacy Building Management Systems (BMS) using a Building Energy Management System (BEMS). There is also scope for further savings if the BEMS system is extended to other services such as lighting.

General description

Over the past 20 years many different buildings have been labelled as "intelligent" (Clements-Croome, 2004). Industry has many established intelligent building solutions but finds it difficult to demonstrate and prove their benefits. Intelligent sustainable buildings improve business value because they take into account environmental and social needs, and occupant wellbeing, which leads to improvement in work productivity. The ideal system links the building, systems within it and the occupants so they have some degree of personal control. Intelligent controls help to match demand patterns (Qiao *et al.*, 2006; Noy *et al.*, 2007). It has been demonstrated that effective action on greenhouse gas emissions requires building users to be involved in both the process and the operation, so that they feel part of carbon management plans(Elmualim *et al.*, 2010).

An integrated building management system (BMS) allows separate systems to work together, in this case for effective building control. Often, a BMS cannot meet the user expectations due to a number of challenging factors:

- The systems may be wrongly specified because of multiple stakeholders with conflicting requirements.
- The systems have not considered usability.
- It is difficult to reach a consensus on the criteria for optimum performance of the BMS to match the building's behaviour.
- The lack of compatibility and inter-operability between different systems.
- Confounding factors arising from socio-economic and organisational issues can complicate the operation of the BMS.

A team from the University of Reading School of Construction Management and Engineering, University of Reading Facilities Management Department and Newera Controls Ltd. conducted two separate investigations to provide examples of reducing emissions through both technical solutions and novel ways of encouraging behavioural change.

The first investigation considered reducing energy use in the Carrington Building at the University of Reading, by influencing the behaviour of building users. It is part of a wider energy reduction project involving a number of buildings on the Reading Campus.

The Carrington Building is a modern, three storey office block, completed in September 2007, housing the university's Student Services. The building is occupied by office-based university staff, students visit the building with queries (e.g. housing, finance etc), and several meeting rooms are available for use by other university staff. The building has several environmental design features, including a ground source heat pump, and was designed to be energy efficient. However, it became apparent that, in practice, the building was not performing as efficiently as anticipated.

Therefore, during the first academic term of 2009/10, the university's Facilities Management Directorate (FMD) energy team and Carnego Systems set up a project to investigate the poor energy performance of the building and to determine whether energy savings could be made by influencing user behaviour in the building. The key feature of the project was the attempt to complete a feedback cycle that is often missing in the relationship between the building and the users.

The second investigation took place in the in the Windrush Building on the Geenlands Campus of University of Reading's Henley Business School (HBS). The building provides a high standard of accommodation for visitors, conference attendees and students of the school. It is used by high-fee paying guests, and the HBS is committed to providing a high standard of accommodation, conforming to the guests' requirements and perceptions of comfort. The building consists of two blocks, so comparisons could be made by introducing changes to the management of one block.

The project was funded by Newera to evaluate the performance of their software suite for the monitoring, diagnosis and control of energy demand and to provide the HBS with indicators of best practice for the reduction of energy use and hence carbon footprint in their estate. In this case, the software was used as an enhancement of an existing legacy BMS, for the monitoring, diagnosis and control of energy demand and hence supply.

Installation of the software, together with the required sensors and actuators, was completed by Newera at the beginning of November 2009. An initial two week trial was conducted up until the end of November, when a major refurbishment of the accommodation was started. On completion of the refurbishment work, the study resumed at the beginning of October 2010 and is still continuing.

System boundaries

In the case of the Carrington Building, the reductions achieved were due to behavioural changes, the improved use of existing timer systems and the removal of unnecessary electrical items such as vending machines. Therefore, embodied greenhouse gas emissions for the building and the monitoring equipment could be omitted.

The work at the Henley Business School included the installation of monitoring and control equipment. Therefore it was prudent to confirm that the expected emissions from the manufacture of the monitoring system fell below the cut-off limit of 1% by environmental relevance recommended in the carbon brainprint guidance (Parsons & Chatterton, 2011a). The LCA database EcoInvent suggests a value in the region of 10 kg CO_2e for an electronic control unit weighing approximately 1 kg (EcoInvent Centre, 2011), so, even allowing for additional sensors, emissions for the monitoring unit could be omitted.

Data

Monitoring equipment was installed in the Carrington Building during October 2009 to collect detailed energy data. Monitoring was limited to combined measurement of lighting and small power. Due to the electrical layout on the main floors, it would have been prohibitively costly to separate the two items. Data were collected at one minute or five minute intervals and transmitted back to Carnego's central database and application suite, using a GPRS (mobile phone) connection. The data were available for viewing via a secure online application and for download in csv format for use in other programs. This frequent collection of data gave a very detailed picture of energy use within the building, allowing precise reduction targeting (Figure 1).

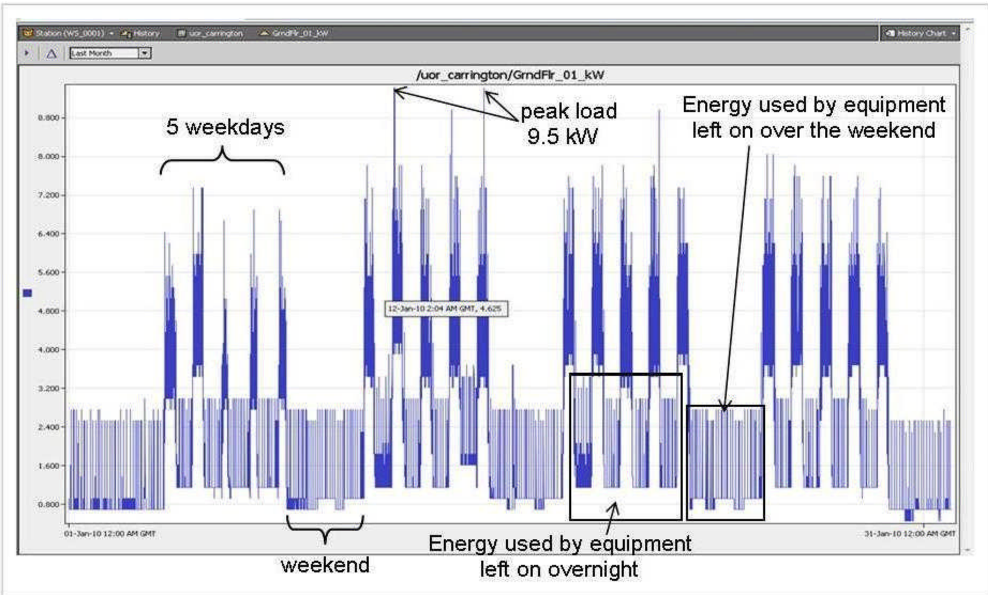

Figure 1. Screenshot of detailed energy trace data

User behaviour was initially observed during a number of walk-around visits to the building between July 2009 and January 2010. Various observations were made including lighting levels and usage, and user behaviour with respect to office equipment. In January 2010, the project team began engaging with the building users. Initially the main focus was with the Building Manager (BM) and the Deputy Building Manager (DBM). The initial conversations concentrated on demonstrating the level of monitoring being carried out and how a detailed energy trace could be used to determine many things about the energy use in the building.

It appeared from the baseline data that there was considerable scope for energy savings out-of-hours, at night and over the weekends, and this was the area the project team focused on to achieve the first phase ‘easy win’ reductions.

The monitoring data also identified a number of other simple interventions, including the removal of vending machines, the use of timer switches for water heaters and coolers, and encouraging behavioural change with respect to building lighting. A new energy efficient upgrade to the lighting system was completed in July 2010, designed to provide further energy savings.

Additional interaction with users took the form of regularly circulated ‘green’ emails from BMs/Project team members to the building users in order to foster a continuing interest in environmental and energy issues, such as use of double-sided photocopying, recycling, the University of Reading ‘Green Impact Award Scheme’, appointment of ‘Environmental Champions’ for each floor, announcement of ‘Green and Clean’ areas and Green Week. A complete schedule of actions, interventions and interactions throughout the period of the study is provided in the Technical Annex (*An indicative approach to sustainable intelligent buildings using university of reading case studies*).

At the Henley Business School, the monitoring software, sensors and actuators were installed by Newera Controls. Water temperature and flow data from both blocks, together with room temperature and occupancy data from each room in the Main Block, were captured at one minute intervals by the Newera software, which then adjusted the radiator actuator valves in each room to maintain the required room temperature. The initial temperature control regime was a set-point range of 12–14°C in unoccupied rooms and 18–22°C in occupied rooms. Set-points were controlled by facilities management staff via remote software access, but occupants were able to fine tune within the set-point range using the room thermostats.

The software enabled room temperature control graphs to be produced showing occupancy, set-points, actuator opening and room temperature, which could be used for monitoring and diagnostics. Information on energy used and CO_2e emissions were calculated from the data.

Data from an initial trial was analysed and two significant changes were made to the heating system in the test block with the aim of maximising CO_2 emission reductions, minimising cost and still maintaining a perceived high level of guest "comfort":

- The Main Block temperature set-point range was raised from 12–14°C to 14–16°C when unoccupied and from 18–22°C to 18–24°C when occupied.
- Two "boosting" periods were introduced in the Main Block heating. One for use in the early morning and one for the late afternoon, to allow rooms be "pre-warmed" prior to guests getting up or returning to the room after work.

The monitoring resumed in October 2010 and is continuing at the time of this report.

Brainprint

Carrington Building

Greenhouse gas emissions resulting from electricity use were calculated from the conversion factor for grid electricity given in the Defra/DECC Guidelines (DECC, 2010). The most up to date value of 0.61707 kg CO_2e/kWh (2008) was used, including both direct and indirect emissions.

The results from the monitoring equipment were divided into 'occupied' and 'unoccupied' categories and averaged to give daily consumption values for each month (Table 1, from Table 2.1 in the annex). 'Occupied' is defined here as a twenty four hour normal working day, including out of working hours periods at the start and end of the day. 'Unoccupied' is defined as a twenty four hour weekend day or public / university holiday.

Table 1 Carrington building initial electricity consumption results

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Occupied							
Mean consumption 2009–10, kWh/d	395	394	363	365	399	343	304
Mean consumption 2010–11, kWh/d	302	312	298	298	308	287	233
Mean reduction , kWh/d	93	82	65	67	91	56	71
Mean reduction , %	24%	21%	18%	18%	23%	16%	23%
Mean reduction in GHG emissions, kg CO_2e/d	57	51	40	41	56	35	44
Unoccupied							
Mean consumption 2009–10, kWh/d	163	158	139	145	144	129	107
Mean consumption 2010–11, kWh/d	116	121	101	115	120	114	116
Mean reduction , kWh/d	47	37	38	30	24	15	-9
Mean reduction , %	29%	23%	27%	21%	17%	12%	-8%
Mean reduction in GHG emissions, kg CO_2e/d	29	23	23	19	15	9	-6

The retrospective brainprint could be calculated in several ways. To minimise uncertainty, a year-on-year improvement for the 7 months with measurement data was calculated. Because the pattern of use varied between the two years, standardised months of 20.5 occupied days and 9.9 unoccupied days were used. The estimated total emissions reductions were 6,640 kg CO_2e for occupied days and 1,110 kg CO_2e for unoccupied days, giving a total brainprint of 7.8 t CO_2e over the 7 month period. The total emissions for October 2009 to April 2010 using the same standardised months were 38.4 t CO_2e, so the reduction was approximately 20%.

Table 2. Estimated emissions reductions from Carrington building for 7 standardised months

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Mean reduction, occupied , kg CO_2e/d	57	51	40	41	56	35	44	
Mean reduction, unoccupied, kg CO_2e/d	29	23	23	19	15	9	-6	
Total reduction, occupied , kg CO_2e	1,169	1,046	820	841	1,148	718	902	6,644
Total reduction, unoccupied, kg CO_2e	287	228	228	188	149	89	- 59	1,110
Total reduction, kg CO_2e	1,456	1,274	1048	1029	1,297	807	843	7,754

The total consumption for May–September 2010 was 32.8 MWh using the mean recorded daily occupied and unoccupied consumption for these months (from Table 2.1 in the annex) with the same standardised months as above. Assuming the 20% reduction could be maintained throughout the year, the emissions for these five months would be 4 t CO_2e giving a total reduction for 2010–11 of 11.8 t CO_2e.

Uncertainties

To estimate the uncertainty in the 7 month and projected 12 month emissions reductions, a Monte Carlo simulation was run using @Risk software (Palisade Corporation, 2007) with Microsoft Excel, assigning normal distributions to the main variables as follows.

In the absence of other data, the carbon brainprint guidance (Parsons & Chatterton, 2011a) was followed, so a normal distribution with coefficient of variation (CoV) of 1% was applied for energy meter readings. Similarly, a normal distribution with a CoV of 5% was used for combustion emissions per unit energy from mains electricity.

In the case of the 12 month projection it was assumed that 20% savings per day for both occupied and unoccupied days were achievable. This estimate was assigned a normal distribution with a CoV of 15%, based on values suggested for expert judgement in Parsons & Chatterton (2011a).

The reduction in emissions for the 7 month period for which two years of data were available had lower uncertainty, with mean 7.75 t CO_2e and 95% confidence interval 6.94–8.58 t CO_2e. For the 12 month projected brainprint, the mean was 11.8 t CO_2e, with 95% confidence interval 10.1–13.6 t CO_2e.

Henley Business School

Greenhouse gas emissions from heat energy input were calculated from the conversion factor for 'kerosene used as a heating oil' (DECC, 2011). A value of 0.30786 kg CO_2e/kWh was used, based on the net calorific value of kerosene, including both direct and indirect emissions.

The results for the Henley Business School were highly variable, in part due to the constantly changing room occupancy. An initial trial showed a mean daily heat input for the Auxiliary and Main Blocks of 37kWh and 26kWh respectively, equivalent to approximately 11.4 and 8.1 kg CO_2e/day respectively.

Following the initial trial, two system parameter changes were introduced to the Main Block management regime and results observed over the following months. Results from this were highly variable and raised further alternatives for the BEMS that will be trialled later. A more marked reduction in energy use was achieved when buildings were unused, and the team suggest that it is therefore not unreasonable to expect a BEMS to deliver overall annual savings in the order of 24%, given appropriate management and user participation.

Prospective brainprint

The retrospective brainprint demonstrates that greenhouse gas reductions can be achieved in small scale implementations. No attempt has been made to quantify a prospective brainprint from the this work due to the number of variables that can impact upon this calculation. These include:

- The nature and use of the buildings in which the reduction is to be attempted.
- The wide variety of technological solutions (cost, efficacy) available for the management of energy use and greenhouse emissions.
- The focus and imperatives of the management charged with project delivery and their competence in that delivery.

References

Clements-Croome, D. J. (2004). Intelligent Buildings: Design, Management & Operation. Thomas Telford, London, 424 pp.

DECC (2010). Guidlines to Defra/DECC's GHG Conversion Factors for Company Reporting. Department of Energy and Climate Change, London

DECC (2011). UK Emissions Statistics. Department of Energy and Climate Change, London

EcoInvent Centre (2011). EcoInvent database (accessed 08/04/2011). http://www.ecoinvent.ch/

Elmualim, A.; Shockley, D.; Valle, R.; Ludlow, G.; Shah, S. (2010). Barriers and commitment of facilities management profession to the sustainability agenda. Building and Environment , 45(1), 58-64.

Noy, P.; Liu, K.; Clements-Croome, D. J.; Qiao, B. (2007). Design Issues in Personalising Intelligent Buildings. In Proceedings of 2nd International Conference on Intelligent Environments, Athens, 5-6 July 2007, Institute of Engineering and Technology, 143-149

Palisade Corporation (2007). @RISK 5.0 risk analysis software. http://www.palisade.com/risk/

Parsons, D. J.; Chatterton, J. (2011a). Guidance for the calculation of carbon brainprints of higher education institution activities. Cranfield University, Report for HEFCE project LDSHE43

Qiao, B.; Liu, K.; Guy, C. (2006). A Multi-Agent System for Building Control. In Proceedings of IEEE/WIC/ACM International Conference on IAT, 18-22 December 2006, IEEE Computer Society Washington, DC, 653-659