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Predicted vs. Actual Energy Performance of Non-Domestic Buildings

Anna Carolina MENEZES^[1,2], **Andrew CRIPPS**^[1], **Dino BOUCHLAGHEM**^[2],
Richard BUSWELL^[1]

[1] AECOM, Building Engineering

[2] Loughborough University, Centre for Innovative and Collaborative Construction Engineering, Loughborough, Leicestershire, LE11 3TU, United Kingdom

Abstract

With the increasing demand for more energy efficient buildings, the construction industry is faced with the challenge to ensure that the energy efficiency predicted during the design is realised once a building is in use. There is, however, significant evidence to suggest that buildings are not performing as well as expected and initiatives such as PROBE and CarbonBuzz aim to illustrate the extent of this so called 'Performance Gap'. This paper discusses the underlying causes of discrepancies between detailed energy modelling predictions and in-use performance of occupied buildings (after the twelve month liability period). Many of the causal factors relate to the use of unrealistic input parameters regarding occupancy behaviour and facilities management in building energy models. In turn, this is associated with the lack of feedback to designers once a building has been constructed and occupied.

This paper aims to demonstrate how knowledge acquired from Post-Occupancy Evaluation (POE) can be used to produce more accurate energy performance models. A case study focused specifically on lighting, small power and catering equipment in a high density office building is presented. Results show that by combining monitored data with predictive energy modelling, it was possible to increase the accuracy of the model to within 3% of actual electricity consumption values. Future work will seek to use detailed POE data to develop a set of evidence based benchmarks for energy consumption in office buildings. It is envisioned that these benchmarks will inform designers on the impact of occupancy and management on the actual energy consumption of buildings. Moreover, it should enable the use of more realistic input parameters in energy models, bringing the predicted figures closer to reality.

Keywords

Building energy modelling, building performance, building simulation, energy benchmarks, energy performance, performance gap, post-occupancy evaluation

Introduction

There is extensive evidence to suggest that buildings designed for energy efficiency are not performing as well as predicted [1, 2, 3]. This is often attributed to the lack of feedback given to designers after handover. The practice of Post Occupancy Evaluation (POE) aims to address this issue by evaluating the performance of a building after it has been built and occupied to provide designers with valuable feedback on its actual performance in-use. This paper aims to demonstrate how knowledge acquired from POE can be used to produce more accurate energy performance models.

In recent years, UK Building Regulations have become increasingly stringent, demanding higher standards of energy performance. This can be linked to the implementation of the European Energy Performance of Buildings Directive (EPBD) as well as the Government's legally binding commitment to reduce UK carbon dioxide emissions by 80% by 2050 in relation to the 1990 baseline [4]. As a result, all new buildings must achieve a Building Energy Rating (BER) lower than the prescribed Target Energy Rating (TER) for the specific building type, calculated using a Simplified Building Energy Model (SBEM). However, this methodology does not aim to predict the actual energy consumption of a building, as its purpose is solely to ensure compliance with Building Regulations. Instead, detailed Dynamic Simulation Models (DSMs) can be used to obtain predictions of in-use energy performance. DSMs are more suited to the functional and volumetric complexities of non-domestic buildings as they allow for more detailed input options whilst also containing extensive databases for materials and systems [5]. Despite these and many other added capabilities, there is still a significant gap between predicted and actual energy consumption in non-domestic buildings [2]. This discrepancy is commonly referred to as the 'Performance Gap'.

The Performance Gap

The PROBE studies (Post-occupancy Review of Buildings and their Engineering) investigated the performance of 23 buildings previously featured as 'exemplar designs' in the Building Services Journal (BSJ) [3]. The research project ran from 1995 to 2002, highlighting the lack in feedback regarding the actual performance of buildings. It also brought to light the so called 'performance gap', suggesting that actual energy consumption in buildings will usually be twice as much as predicted [3]. More recently, initiatives such as the Low Carbon Buildings Accelerator and the Low Carbon Buildings Programme, have aimed to provide feedback regarding the performance of buildings in-use [6].

In 2008, the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE) launched CarbonBuzz, a free online platform allowing practices to share and publish building energy consumption data anonymously [7]. It enables designers to compare predicted and actual energy use for their projects, whilst also allowing for comparison against benchmarks and data supplied by other participating practices. Figure 1 illustrates the predicted and actual CO₂ emissions associated with the energy consumption in three building sectors: education, offices and retail. The graph depicts the median predicted and median actual emissions for the buildings within the database, which are assumed to be broadly representative of each sector. As shown, the actual CO₂ emissions are approximately 70% higher than predicted in both the retail and offices sector, and over 250% higher than predicted in the education sector.

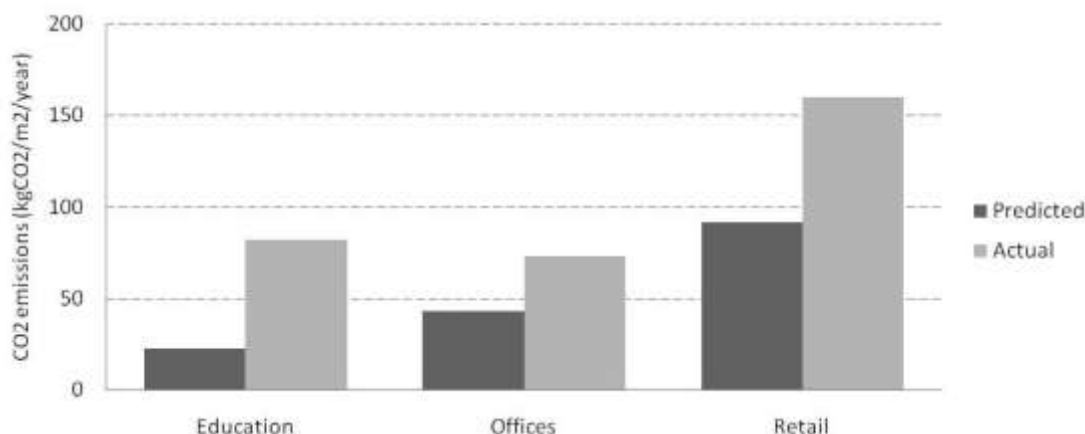


Figure 1: CarbonBuzz median CO₂ emissions per sector - predicted vs. actual [7]

Sources of Discrepancy

Results from the PROBE studies suggest that such discrepancies transcend the expected shortcomings of current modelling programs; being a result of poor assumptions, as well as a lack of monitoring following construction [3]. Table 1 summarises the main causes of discrepancies between predicted and actual energy performance in buildings.

As shown, the causal factors relate to both predictive and in-use performance, implying that current predictions tend to be unrealistically low whilst actual energy performance is usually unnecessarily high. However, the overall problem could be interpreted as an inability of current modelling techniques to represent realistic use and operation of buildings. This in turn can be associated with the lack of feedback regarding actual use and operation of buildings as well as the resulting energy consumption. Currently, there is a significant lack of information concerning the actual energy performance of our existing building stock [8]. A continued absence of such data is likely to lead to a progressive widening of the gap between theory and practice and a failure to achieve strategic goals [9].

Recent developments in the field of thermal modelling have resulted in increasingly complex simulation software based on calculations of dynamic heat transfer. In addition, stringent procedures are being implemented to ensure the validity of a range of modelling programs [10]. As a result, the impact of modelling tools on the overall discrepancy between predicted and actual performance is consistently being diminished. Meanwhile, some issues with built quality are slowly being tackled by the construction industry, encouraging more airtight buildings and better construction techniques. Extensive research on the actual performance of built elements is also being conducted, whilst most modelling software now allow for assumptions regarding the built quality of specific building elements.

Despite these improvements, current simulation tools do not accurately model the impact of occupants and management on the energy performance of buildings. This is usually attributed to the use of inadequate assumptions at design stage, more so than an inability of the modelling tools themselves. As such, there is scope for further investigation into the actual use of buildings, focusing on occupancy and management behaviour, as well as their impact on unregulated energy consumption. This can be achieved through the practice of Post Occupancy Evaluation (POE).

Table 1: Causes of discrepancies between predicted and actual energy performance

	Causal factors
Predicted Performance	<p>Design Assumptions</p> <p>The input of data into a building energy model relies significantly on assumptions, which often go unchallenged. These are usually made at design stage when many aspects of the building's function and use are unknown or uncertain. This can result in oversimplified and/or unrealistic inputs regarding the built quality and fabric performance, occupancy patterns and behaviour as well as the management and control of the building and its services [10].</p>
	<p>Modelling Tools</p> <p>Building energy modelling software can contain fundamental errors embedded in the equations used by the program, leading to inaccuracies in the predictions. This should be avoided by choosing modelling tools that have been appropriately validated according to the procedures defined by CIBSE TM33 [11]. The choice of software should also consider the specific type of building being modelled and should allow for adequate representation of the building itself as well as its use and operation. Restrictive or oversimplified tools can result in models that are unrepresentative of reality [10].</p>
Actual Performance	<p>Management and Controls</p> <p>Facilities managers (FM) have control over central plant equipment, accounting for a great portion of the energy consumption in a building (especially in highly automated buildings). Good management and controls can result in an efficient operation of the building services whilst inappropriate strategies can result in unnecessary waste of energy [3]. Frequent energy audits as well as re-commissioning exercises can help maximise the efficiency of building services, avoiding unnecessary energy waste [12].</p>
	<p>Occupancy Behaviour</p> <p>Building occupants do not always have direct control over building services such as heating and cooling, yet even in highly automated buildings, occupants can affect their energy consumption by influencing the internal conditions (e.g. opening windows, blocking air inlets/outlets, etc) [1]. Moreover, occupants have control over various energy consuming equipment and appliances, commonly referred to as 'unregulated loads' (i.e. not controlled by Building Regulations).</p>
	<p>Built Quality</p> <p>The in-use energy performance of a building is affected by the quality of its construction. Issues such as gaps in the insulation and thermal bridging are common, but are rarely considered in the predictions of energy consumption. Moreover, changing requests from clients and/or value engineering exercises can result in significant deviations from what was originally specified [2]. Yet these alterations are rarely fed back into the energy model.</p>

Post Occupancy Evaluation

Post Occupancy Evaluation (POE) is a structured process of evaluating the performance of a building after it has been built and occupied. This is achieved through systematic data collection, analysis and comparison with explicitly stated performance criteria, providing designers with valuable information regarding the in-use performance of their designs [13].

The scope of POE can be divided into three strands [14]:

- Feedback: a management aid mechanism aimed at measuring building performance mostly as an indicator of business productivity and organisational efficiency.
- Feed-forward: aims at improving building procurement through the use of acquired data as feedback to the design team and future briefings.
- Benchmarking: aims at measuring progress striving towards increasingly sustainable construction and stricter targets of energy consumption.

POE can take several approaches, varying from highly technological methodologies involving hard data, to socio-psychological interests where more subjective parameters are used to evaluate the performance of a building. Hence, the method to be undertaken in a POE is usually defined by the objectives being pursued and the areas of interest to the stakeholder. Seeing as POE concerns the analysis of individual buildings, methods vary in scale, type, level of interactivity and suitability for specific projects [15]. As a consequence, a vast number of POE methods and techniques are available worldwide, allowing for an array of different evaluations to be performed in numerous types of buildings.

One of the most widely recognised tools for evaluating the energy performance of buildings in the UK is the Energy Assessment and Reporting Methodology (EARM). Originally developed for the PROBE studies, it was later published by CIBSE as a technical memorandum (CIBSE TM22). The document describes a method for assessing the energy performance of an occupied building based on metered energy use, and includes a software implementation of the method. It can be used to identify poorly performing buildings and systems, indicating the causes of poor performance and benchmarking procedures [16]. Figure 2 illustrates the underlying structure of the TM22 methodology, depicting the breakdown of energy consumption by end-uses (such as lighting and ventilation) whilst highlighting the impact of low-level factors such as hours of use and equipment efficiency.

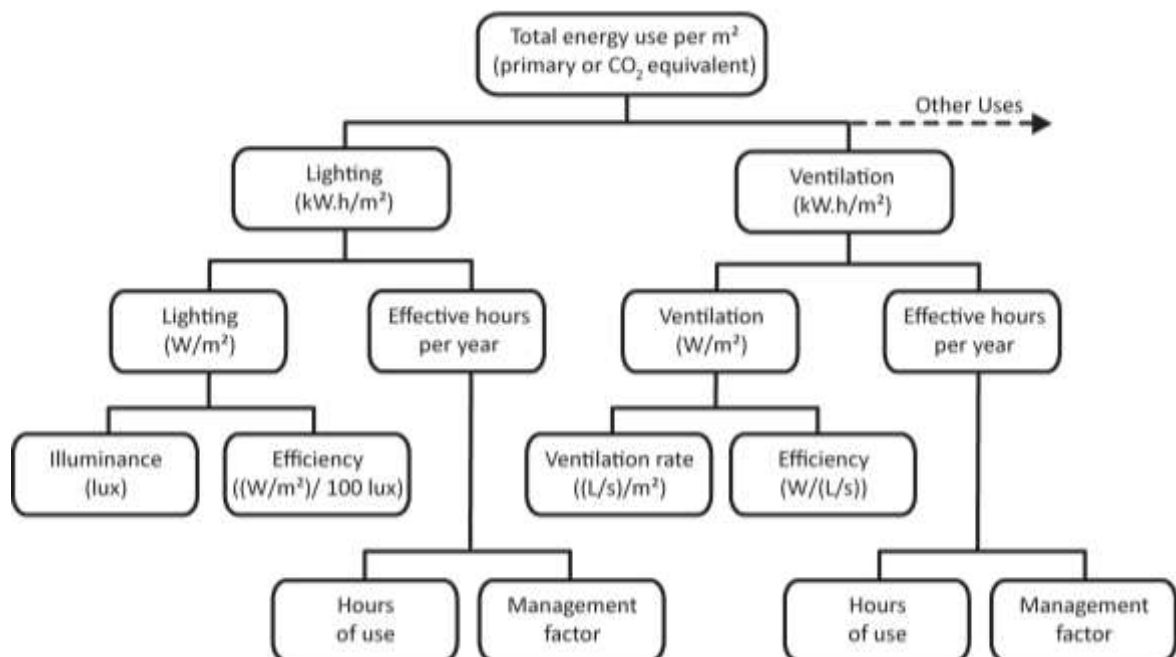


Figure 2: TM22 ‘Energy Tree Diagram’ illustrating the breakdown of energy use [16]

The first edition of TM22, published in 1999, consisted of 3 stages:

- Stage 1: a quick assessment of the energy consumption, breaking it down into use per unit floor area and can be carried out by in-house resources. Information required includes description of the building, floor area and annual energy consumption records.
- Stage 2: a more detailed assessment of the energy consumption including special energy uses or occupancy and can usually be carried out in-house. Information required includes details of building occupancy and usage as well as any special or unusual uses.
- Stage 3: a full understanding of the performance of the building and its systems, and will usually require a specialist to carry out the assessment. Required information includes building operation and maintenance manuals as well as details of building occupancy, use and cleaning, plant operation procedures and schedules.

In 2006, a second edition of the TM22 was published, updating the previous edition by describing procedures for compliance with emerging energy performance legislation [17]. It also included treatment of on-site energy generation and renewable energy sources. Overall, it provided a simpler and more effective method for energy assessment and reporting, whilst keeping up to date with current developments in the construction industry. An updated version of TM22 is currently being developed and will be published by CIBSE in early 2011. It will be used as a guidance framework for the Technology Strategy Board's Building Performance Evaluation call [18]. This government-funded project is anticipated to be the largest POE study since PROBE.

Methodology

Taking a case study approach, this paper focuses on the energy performance of an office building in central London. The assessment was guided by the TM22 methodology, followed by in-depth monitoring of electricity consumption due to lighting, small power equipment and catering equipment. Monitoring of occupancy patterns were also conducted via half-hourly walkthrough inspections. Results from the monitoring exercise were then fed into energy models, aiming to produce more accurate predictions of energy consumption.

Building Description

The selected building accommodates the offices of four different companies throughout its six floors and basement. It includes an atrium that reaches all floors (except the basement). Each floor comprises mainly of open-plan office spaces with a treated floor area of approximately 2,000m². The ground floor houses a large reception and the basement houses meeting rooms and cellular offices. The building is fully air-conditioned, three rooftop air-handling units (AHUs) provide heating/cooling as well as fresh air to all floors and atrium. A separate system provides heating for the basement, whilst fan coil units (FCUs) provide cooling to the meeting rooms and small individual offices. Two gas-fired boilers provide hot water to all toilets and kitchens throughout the building.

A building management system (BMS) monitors and controls the performance of each AHU as well as other building services equipment based on normal occupancy patterns. The BMS uses real-time temperature data (intake and off-air temperatures as well as supply and return temperatures) to adjust the percentage of re-circulated air necessary. This ensures that the temperature and humidity throughout the building is maintained within pre-defined levels, whilst minimising the intake of outside air.

Figure 3 illustrates the metering strategy for the supply of electricity and gas to the building. As shown, the landlord is responsible for the electricity consumed by all air conditioning equipment including the AHUs, FCUs, chillers, pumps and fans as well as the BMS and other control equipments. The lighting throughout the common areas of the building as well as the toilets is also supplied and maintained by the landlord. As such, the energy supplied for the landlord services is metered together, with no sub-metering for individual end-uses. Meanwhile, the electricity supplied to the tenants for lighting, small power equipment and catering in each of the floors is metered separately. A total of 24 sub-meters provide a further breakdown for each of the 4 zones in each floor: North-East (NE), Northwest (NW), Southeast (SE) and Southwest (SW).

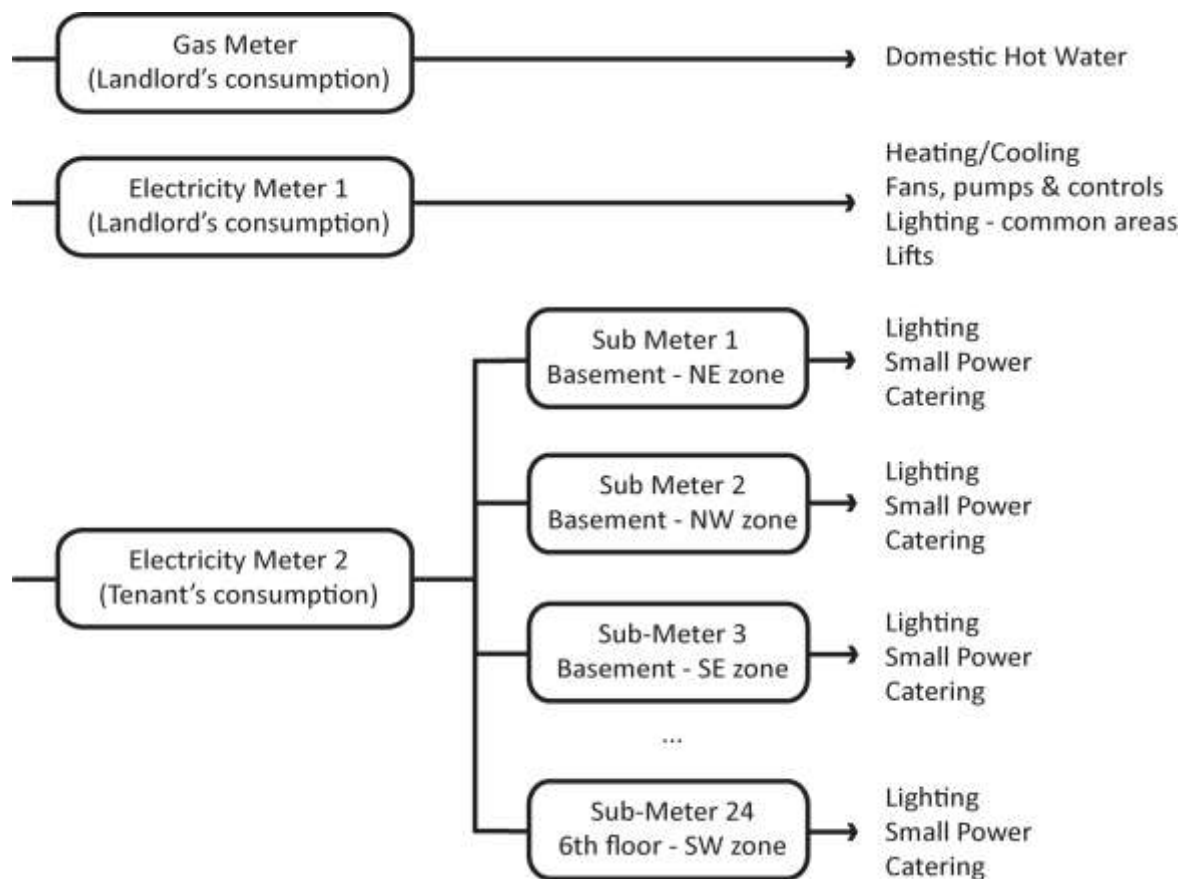


Figure 3: Metering strategy for the supply of gas and electricity to the building

Monitoring Process

Monthly meter readings were taken and recorded over a one-year period for each electricity meter and sub-meters, as well as the gas meter. In addition, half hourly data was acquired from the utility provider for both electricity meters for the same one-year period. Portable 3-phase data loggers were connected to individual equipment such as fans, chillers, lifts, AHUs and pumps to monitor their impact on the overall energy performance of the building in line with the TM22 methodology. Each piece of equipment was monitored for at least two months and assumptions were made for variations in thermal loads for the chillers and AHUs. The 3-phase portable data loggers were also used to monitor half hourly consumption in specific tenant zones (covering lighting, small power and catering loads).

Following a full TM22 assessment of the building, a further analysis of the tenants' consumption was undertaken through an in-depth study of the electricity consumption for lighting, small power and catering within each of the tenant zones. The results shown in the next section focus on this further study rather than the initial TM22 assessment. This relied on the use of combined plug monitor / loggers connected to individual small power office equipment such as laptops, computer screens and docking stations. These were also used to monitor the electricity consumption of catering equipment such as fridges, microwave ovens and coffee machines. Occupancy patterns were also monitored by manually recording the number of occupants within the office in half-hour intervals.

Monitoring Results

Figure 4 illustrates the annual tenant electricity consumption per floor (normalised by m^2). This includes lighting, small power and catering equipment loads. It is worth noting that the lighting specification and controls are consistent throughout the entire building and the catering facilities in each floor are of a similar size and nature (consisting mainly of an instant hot water heater, a microwave, a dishwasher and a full size fridge). Some floors have additional coffee machines and/or vending machines, and the tenants on the ground floor have a large bar with multiple fridges. In regards to small power, a fairly consistent volume of office equipment is present throughout the building. Despite their different nature of work, all 4 tenant companies have similar occupation densities and office equipment specifications. Most workstations consist of a computer screen, laptop and docking station as well as phone. Some workstations have individual desk lamps, personal fans and/or desktop printers. In addition, all floors have large printer/copiers (typically 6-8 per floor) as well as projectors and/or flat screen displays in meeting rooms.

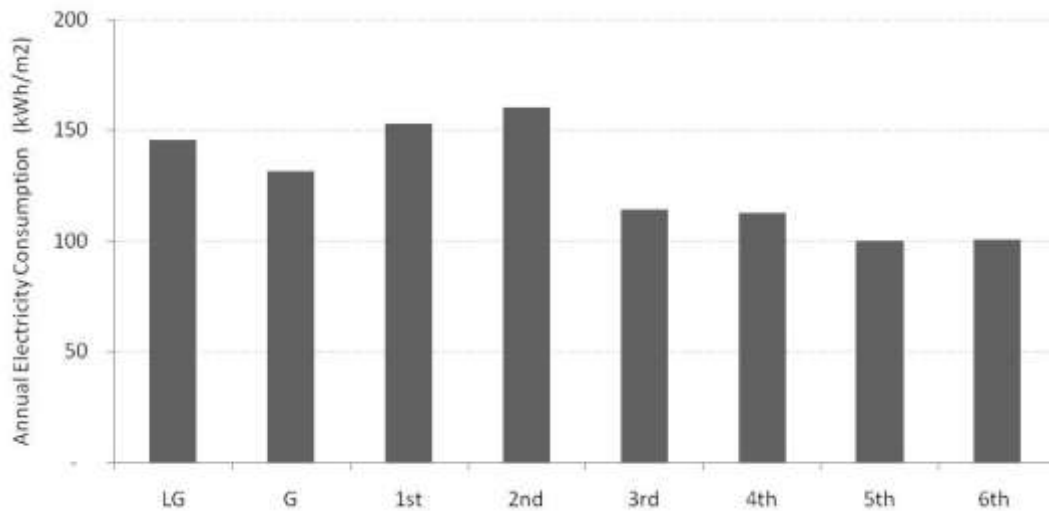


Figure 4: Annual tenant electricity consumption per floor area

As seen, the 2nd floor consumes approximately 60% more electricity per m^2 than the lowest consumer (5th floor). This is quite a significant variation considering the consistency in lighting specification and controls as well as the similarities in installed equipment and occupation density. However, when relating the electricity consumption to the tenants occupying each of the floors, a clearer pattern can be observed. Figure 5 illustrates how the different tenant companies are located throughout the building. As shown, the lowest consuming floors (5th and 6th) are wholly occupied by Tenant C. Similarly, the 3rd and 4th floors are mainly occupied by Tenant B, presenting similar annual consumption values.

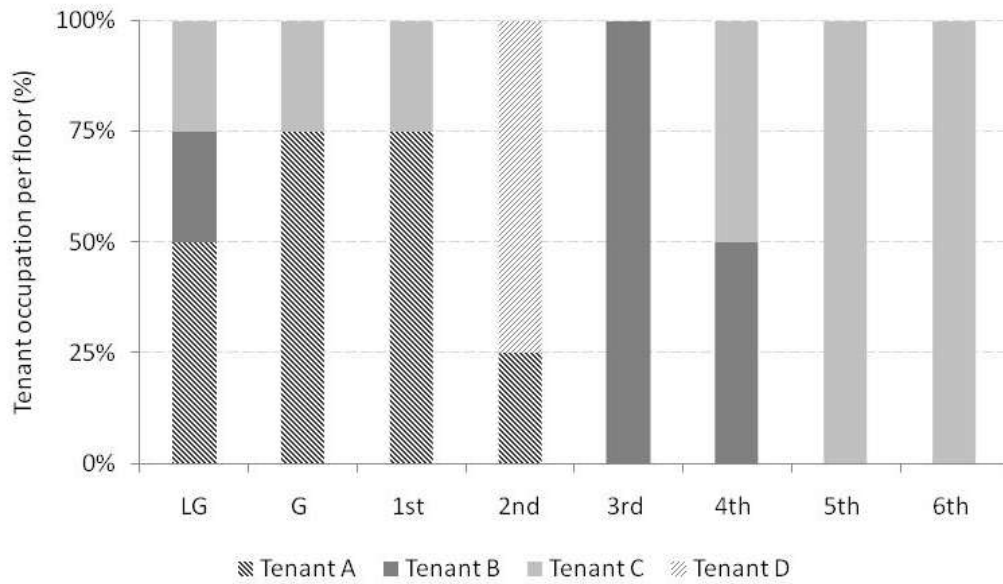


Figure 5: Location of tenant companies throughout the building

Figure 6 illustrates the annual electricity consumption of each tenant per m^2 of office space they occupy. Not surprisingly, Tenant C has the lowest electricity consumption at $90\text{kWh}/\text{m}^2$. Tenant A has the highest annual consumption at $155\text{ kWh}/\text{m}^2$, followed closely by Tenant D at $139\text{ kWh}/\text{m}^2$. This would explain why the 2nd floor has the highest consumption seeing as it is occupied by both Tenants A and D.

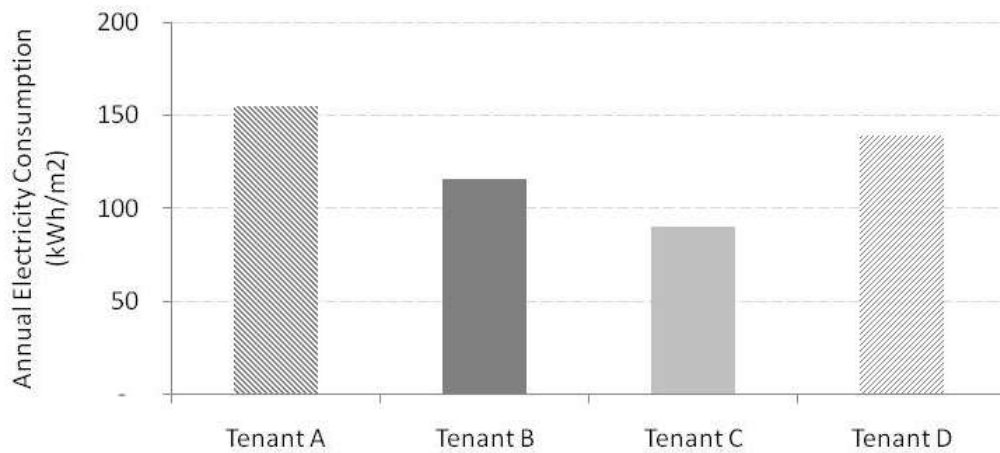


Figure 6: Annual electricity consumption per tenant (normalised by floor area)

Further investigation into the causes of such variations uncovered that the employees of Tenant A are instructed to leave their computers on overnight for IT upgrades. As such, a large quantity of electricity is used outside the normal operating hours of the building, accounting for a significant portion of their overall consumption. Similarly, employees of Tenant D often leave their computers on at the end of the day so that time-consuming tasks, such as high quality rendering, can be performed overnight. On the other hand, employees of Tenants B and C are heavily encouraged to save energy by turning off their computers and screens at the end of the day. Tenant B has also trained their facilities co-ordinators to switch off printer/copiers and non-essential catering equipment such as coffee machines at the end of each day.

Detailed Analysis of Electricity Demand

Following the analysis of annual electricity consumption data, an in-depth study was undertaken to examine the variation in electricity demand throughout a typical week. Figure 7 illustrates the half hourly electricity consumption for a single zone in the 4th floor of the building (occupied by tenant B).

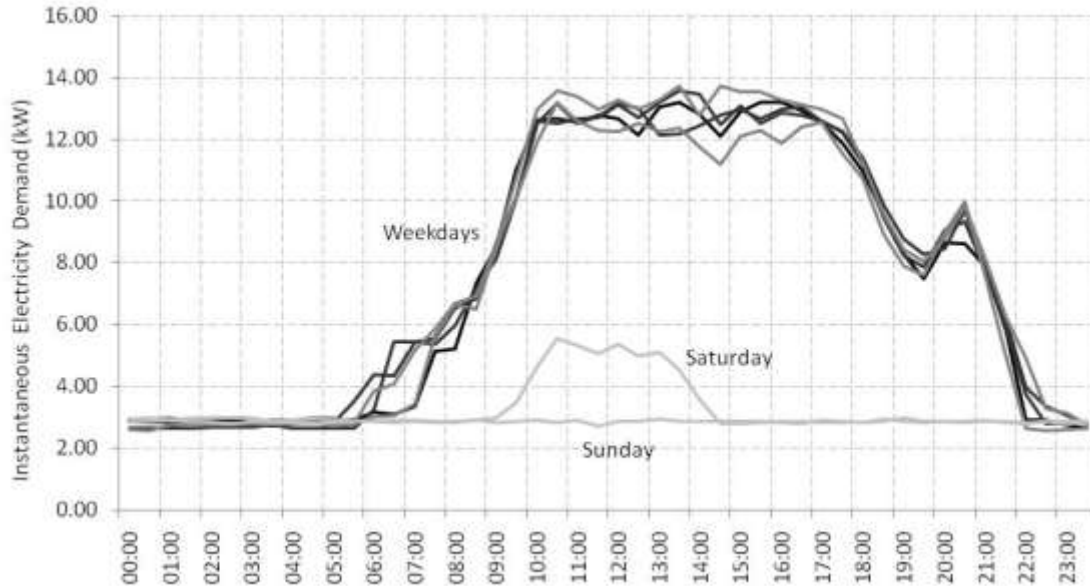


Figure 7: Monitored electricity consumption for 4th floor – Northeast zone

As shown, the base load is approximately 3kWh/m² outside working hours. The electricity demand starts to escalate around 06:00 peaking at approximately 13kWh/m² by 10:00. This can be associated with the arrival of employees who trigger the motion sensors, turning on the lights. This will usually be followed by office/catering equipment being turned on. From 10:00 to 17:00 the demand remains fairly high, varying between 11-14kWh/m², eventually decreasing to approximately 8kWh/m² by 19:30. This can be associated with equipment being turned off as employees leave the office. A steep rise in the demand is then observed at approximately 20:30, followed by a fairly quick decrease, bringing the demand down to the base load at around 22:00. This late peak can be associated with the cleaning schedule of the building. It is assumed that the rise in demand is due to the use of vacuum cleaners as well as the dishwasher being turned on. The electricity demand during the weekend is fairly constant at a similar base load to the evenings. The only deviation occurs on Saturday between 9:00 and 15:00 when the electricity demand rises to approximately 5kWh/m². This can be associated to individual employees going into the office to work extra hours.

The analysis of half hourly electricity consumption has suggested a high correlation between occupancy hours and electricity consumption. In order to determine the extent of this correlation, real occupancy levels were monitored and plotted against the half hourly electricity consumption. Figure 8 illustrates the results of this monitoring. As shown, the electricity demand follows the monitored occupancy profile quite closely. The initial peak in demand is observed around 08:00 when occupancy numbers start to increase rapidly. Similarly, a steep decrease in electricity demand is observed after 17:30 when occupancy starts to decrease. However during lunchtime, the quick decrease in occupancy is not reflected in the electricity demand. This is because most computers are kept on and lighting levels remain constant. As previously mentioned, the sharp peak around 20:00 is associated with the cleaning.

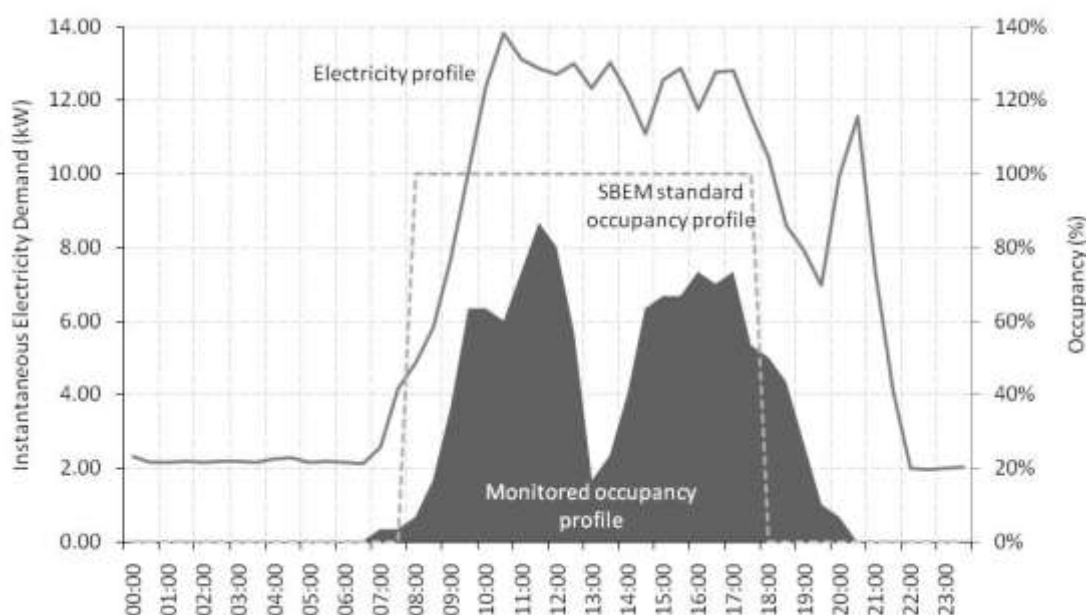


Figure 8: Relationship between monitored electricity consumption and occupancy profiles

Figure 8 also illustrates the standard occupancy profile for offices used by SBEM for compliance predications. Despite its simplistic nature, standard profiles such as this are normally used in DSMs. As shown, there is little correlation between the SBEM profile and the monitored electricity consumption. The impact of using a standard occupancy profile in predictive models is discussed in further detail below.

Predictive models

Following the detailed analysis of electricity consumption in the 4th floor NE zone, the acquired data was used to produce 5 predictive models of electricity consumption. These predictions refer to the annual electricity consumption for lighting, small power and catering for the same zone (occupied by tenant B). An increasing level of detail was used in each subsequent model, replacing typical assumptions with monitored data. The parameters used for each of the electricity demands are detailed in Table 2. It is worth mentioning that due to increasing complexities in the input parameters of small power and catering equipment, a spreadsheet approach was taken to predict annual electricity consumption. Although most DSMs will allow such detailed parameters to be used, the process of doing so can be quite onerous. In addition, most DSMs rely on a ‘black box’ approach, meaning that the user has no control over how the calculations are carried out [19], making it difficult to visualise the impact of such detailed inputs in the overall electricity consumption of the building. As such, a bottom-up approach to CIBSE TM22 was used to produce the predictive models. This methodology (illustrated in Figure 2) has previously been used to predict electricity consumption [2, 20], allowing for detailed parameters such as load and usage factors to be used. This approach was used in predictive models 1 and 2. Alternatively, metered data can be used to replace assumptions, increasing the accuracy of the model. This approach was used in models 3, 4 and 5.

It is worth mentioning that the actual electricity consumption value displayed in Figure 2 was unknown at time these predictive models were developed. The author was aware of the average consumption per m² for Tenant B but did not have access to the actual consumption figure for the specific zone being modelled.

Table 2: Input parameters used in each predictive model

	Brief description	Lighting	Small Power	Catering
1	Typical compliance model using lighting specification from the design brief, using SBEM standard occupancy hours and overlooking small power and catering equipment.	11W/m ² 2600 hrs/year	Not considered.	Not considered.
2	'Enhanced' compliance model using industry rules of thumb to account for small power loads [21], but overlooking catering equipment.	11W/m ² 2600 hrs/year	15W/m ² 2080 hrs/year (due to 80% usage factor)	Not considered.
3	Initial bespoke model using monitored data regarding the installed lighting load as well as measured electricity demand for basic small power and catering equipment. SBEM standard occupancy hours were used accounting for an 80% usage factor of small power equipment.	13 W/m ² 2600 hrs/year	170 laptops, 170 screens, 5 printers = 11W/m ² 2080 hrs/year	1 water heater 1 fridge = 0.3 W/m ² 2600 hrs/year
4	Intermediate bespoke model using monitored data for lighting as well as measured electricity demand for all small power and catering equipment installed. SBEM standard occupancy hours were used once again with allowances for usage factor of small power equipment.	13 W/m ² 2600 hrs/year	170 laptops, 170 screens, 5 printers 8 desk lamps 6 desk fans = 11.5W/m ² 2080 hrs/year	1 water heater 1 fridge 1 microwave 1 dishwasher 2 coffee machines = 1 W/m ² 2600 hrs/year
5	Advanced bespoke model using monitored data for lighting as well as measured electricity demand for all small power and catering equipment installed. Monitored hours of use were used for all lighting, small power and catering equipment.	13 W/m ² 3640 hrs/year	170 laptops, 170 screens, 5 printers 8 desk lamps 6 desk fans = 11.5W/m ² [monitored hours of use per individual equipment]	1 water heater 1 fridge 1 microwave 1 dishwasher 2 coffee machines = 1 W/m ² [monitored hours of use per individual equipment]

Results from the predictive models are illustrated in Figure 9. The predictions are labelled 1-5 accordingly and reflect the inputs specified in Table 2. As seen, the predictions are compared against the actual electricity consumption, which is not subdivided into the specific end-uses due to the limitations of the sub-metering strategy of the building. Two benchmark values are also illustrated in the graph for further comparison. These were acquired from ECON 19 [22] and illustrate industry benchmarks for Typical (TYP) and Best Practice (BP) energy consumption for lighting, small power and catering in office buildings of a similar specifications (i.e. Type 3).

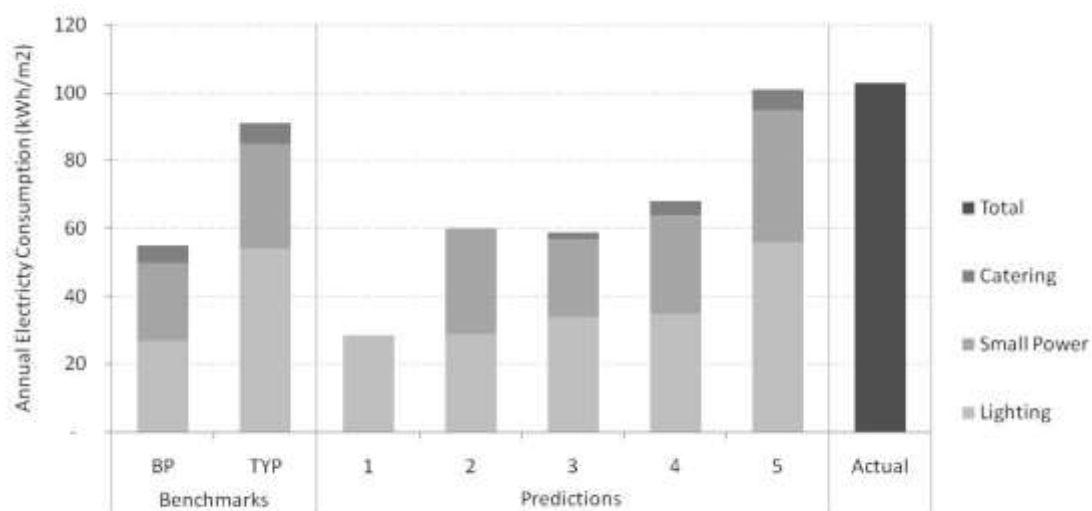


Figure 9: Comparison of benchmarks, predicted and actual electricity consumption

As shown, the increased detail in the input parameters of models 1-5 have resulted in incremental increases of the predicted annual electricity consumption. By using a typical compliance model in prediction 1, the calculated electricity consumption was shown to be less than 1/3 of the actual in-use consumption. The predicted value was then increased significantly in prediction 2, when rules of thumb for small power consumption were used to account for the electricity demand office equipment. It is worth mentioning such rules of thumb are commonly used in DSMs when trying to predict energy consumption of buildings in-use [23]. In the 3rd prediction model, design specifications and rules of thumb were replaced by monitoring data of installed lighting and equipment. At this point however, only basic equipment were considered and SBEM standard occupancy hours were assumed. This resulted in a similar total prediction of electricity consumption, yet this total consisted of higher lighting loads and lower small power loads. This demonstrates that actual installed lighting loads were higher than specified at design stage. Meanwhile the small power prediction seems to have been fairly conservative by having considered only basic office and catering equipment. In prediction model 4, all installed equipment were included, resulting in an increase of approximately 15% in the total electricity consumption. Finally, in prediction 5, the SBEM standard occupancy hours were replaced by monitored occupancy hours. By doing so, the predicted electricity consumption came within 3% of the actual consumption of the building in-use.

When comparing the results from the predictive modelling against the ECON 19 benchmarks, it is possible to conclude that the final prediction is only slightly higher than the typical benchmark for a Type 3 office building. However, when considering that Tenant B had the second lowest consumption per m² in the building, one would expect it to be lower than the typical benchmark and perhaps closer to best practice. Considering that the ECON 19 benchmarks were compiled over 10 years ago, they might not be representative of current office buildings. With the fast advancements in the design of low energy IT equipment, energy consumption due to small power would be expected to have decreased in the last decade. However, current offices are now run for longer hours and tend to contain more items of small power equipment. The same would be expected for lighting and catering, resulting in similar proportions of electricity being consumed by each end use. The lack of more up-to-date benchmarks makes it hard for further conclusions to be drawn.

Conclusion

This paper has discussed the existence of a gap between predicted and actual energy consumption in non-domestic buildings. It has highlighted the main causes of such discrepancies and indentifying POE as a key tool to understanding this issue further. It also indentified the potential for using POE results to inform predictions, enabling better assumptions to be used in detailed energy modelling. A case study revealed that by conducting basic monitoring exercises it is possible to feed results into energy models and gain a more accurate prediction of a building's actual performance (within 3% of actual consumption for this specific study). Despite the limited applicability of this methodology to non-speculative buildings, the results are encouraging and demonstrate that reliable predictions can be obtained by using realistic assumption in the modelling process.

Key findings from this study highlight the need for better understanding of occupancy patterns and behaviour in office buildings. Variations in the electricity consumption of different tenants occupying the same building have demonstrated that modelling software should account for different occupancy patterns and behaviours if realistic predictions are to be achieved. In addition, a clear correlation was observed between monitored occupancy profiles and tenant electricity consumption. It should be noted however, that energy demand can vary largely with tenant behaviour throughout the day (not only when they arrive or leave). The impact of management was not analysed in this study due to its focus on tenant consumption. It is important to highlight, however, that management decisions, such as the running of IT updates outside of occupancy hours, were observed to have a significant impact on the tenant consumption.

If the UK is to experience real reductions in its CO₂ emissions, it is imperative that we start achieving energy efficiency in practice. With Building Regulations relying heavily on predictive indicators of performance, it is vital that we understand the limitations of the current compliance modelling and aim to predict realistic energy consumption levels by using detailed DSMs that account for realistic occupancy and management behaviours. The widespread practice of POE can help us understand how occupants and FMs interact with the built environment. It can also provide valuable information regarding the performance of the current building stock.

Future work

Future work will seek to use detailed POE data to develop a set of evidence based benchmarks for energy consumption in office buildings. It is envisioned that these benchmarks will inform designers regarding the impact of occupancy and management on the actual energy consumption of offices. Moreover, it should enable the use of more realistic input parameters in energy models, bringing the predicted figures closer to reality.

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