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Design for Flexibility in Low Carbon Offices

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Abstract: Ambitious targets have been set to reduce energy consumption in non-domestic buildings to a theoretical point of carbon neutrality in the coming decade. The Green Building Council's recent report, *Building Zero Carbon – the case for action*, targets zero-carbon in regulated consumption by 2019. This is defined as a reduction in Building Regulations Part L standards by 30-40%, with the remaining contribution derived from 'allowable solutions' (e.g. sequestration and carbon offsetting). 'Zero-carbon' in regulated and unregulated terms is targeted by 2022.

However, while predictions for regulated energy consumption in new buildings continue to fall, the consensus is that there is little correlation between predicted and actual energy use. The 'Performance Gap' has highlighted that modelling of behavioural impacts on energy use remains rudimentary at best. Recently CIBSE TM54, *Evaluating Operational Energy Performance of Buildings at the Design Stage*, has proposed a methodology that 'closes the gap'. One aim is to accurately assess the impact of occupancy and management profiles on final energy consumption.

Decisions about occupancy and management are often taken by architects at the beginning of the design process, and can impact on the flexibility of different spaces, structural elements and servicing systems, as well as the life expectancy of different building components. What is more, occupancy and management patterns can change over time.

This paper will begin by documenting the current state of play regarding energy prediction and the performance gap, before considering a case study of a large non-domestic office building in Edinburgh in order to raise important questions about decisions made at the design stages that impact on energy performance over a building's lifespan.

Key words: prediction, flexibility, energy performance

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1 Introduction

The Performance Gap

Ambitious targets have been set to reduce energy consumption in non-domestic buildings to a theoretical point of carbon neutrality in the coming decade. The Green Building Council's recent report, *Building Zero Carbon – the case for action*, targets zero-carbon in regulated consumption by 2019. This is defined as a reduction in Building Regulations Part L standards by 30-40%, with the remaining contribution derived from 'allowable solutions' (e.g. sequestration and carbon offsetting). 'Zero-carbon' in regulated and unregulated terms is targeted by 2022.[i]

It is frequently assumed that improved regulation together with political pressure and public awareness are all contributing to an improvement in the operational energy performance of the non-domestic building stock of the UK, which currently accounts for approximately 18% of all carbon emissions.[ii]

However, while predictions of regulated operational energy consumption in new buildings continue to fall, approaches for estimating unregulated operational energy consumption are often systematically flawed, failing to account for increased energy consumption by building occupants. According to the Carbon Trust, energy consumption in non-domestic buildings can be up to five times higher than initially predicted.[iii] This discrepancy – the 'performance gap' between predicted and actual operational energy consumption – has received much attention recently as post-occupancy evaluation of newly completed buildings has become more routine, and as data on actual energy consumption has entered the public domain (e.g. Display Energy Certificates).

Studies such as the Technology Strategy Board's ongoing Building Performance Evaluation Programme have identified problems during construction as a significant cause of missed energy targets, including poor strategic decision-making, last-minute alterations to the design on-site and poor commissioning processes. This programme investigated 15 office buildings as part of a wider dataset including 366 domestic dwellings and 25 educational buildings.[iv]

Other research has demonstrated, however, that the adaptability of different spaces and their potential to perform in terms of occupant satisfaction, comfort, as well as energy efficiency, very often rely on the under-studied processes of architectural decision-making at the beginning of the design process.

While much research has sought to quantify and explain the 'performance gap', the consensus is that there is little correlation between predicted and actual energy use.[v] There are related reasons for this: prediction models systematically underestimate energy consumption of buildings in use (often they are based on models required for compliance that do not measure total energy consumption); and energy consumption can vary widely between physically similar buildings (partly because there is little understanding or modelling of behavioural impacts on energy use).[vi]

This paper aims to help address the performance gap by increasing knowledge and understanding about the issues surrounding flexibility in the design of non-domestic buildings. If design teams can better predict the likelihood of future uses of buildings in the medium and long term as well as immediately following construction, it may be possible to ensure that environmental strategies are robust enough to resist unknown pressures that can increase the performance gap in the years following completion.

Design for Flexibility

Flexibility in the design of sustainable non-domestic buildings is often considered desirable because it provides for adaptability in future use, potentially extending the lifespan of new developments, and reducing carbon emissions through embodied energy due to refurbishment or replacement. However increased flexibility can also include a hidden operational cost, usually either in terms of increased complexity (impacting on financial and carbon cost), or in decreased efficiency in use, or a combination of both. Decisions about the extent of flexibility that should be incorporated into a design are usually taken on a case-by-case basis and are often the result of existing beliefs held by the client or design team as to what is appropriate in particular circumstances.

Recent work undertaken by the EU FP7 CILECCTA Project (Construction Industry Life Cycle Cost and Analysis) has sought to define more evidence-based methods to support design decision-making regarding spatial flexibility, in particular the study of lifecycle cost assessment (derived from pricing financial options)[vii], and a major EPSRC research project led by Dr Ruchi Choudhary at the University of Cambridge is exploring the application of uncertainty theory to modelling approaches that reveal risk to future energy performance in the built environment.[viii] The real-world information that can be gathered from case studies may offer useful validation of the findings of more theoretical research that can be fed back into the body of knowledge available to built environment practitioners at the design stage.

This paper seeks to further extend the study of flexibility in non-domestic buildings by investigating the relationship with decisions regarding environmental design strategies (e.g. servicing), and consequently emissions due to operational energy consumption.

William Fawcett has demonstrated through employing a Gibbsian approach to spatial flexibility (systematically analysing all possible answers to a limited set of choices) that provision for the maximum number of physical configurations does not necessarily equate to accommodating the most likely activities as efficiently as possible.[ix] Similarly, we should not assume that an environmental design strategy that can accommodate the most diverse set of possible functions would equate to one that is efficient for the most likely future operational circumstances.

2 Case Study: Potterrow Informatics Forum

Post Occupancy Evaluation

Completed in 2008, Phase 1 of the Potterrow development for the University of Edinburgh (the Informatics Forum building) was widely recognised as an exemplar in sustainable design and won a number of awards including the RIAS Andy Doolan Prize in 2008. The building was designed with future flexibility as a stated aim of the brief, with moveable partitions providing cellular accommodation with rooms and breakout spaces at a range of scales to meet evolving departmental requirements. Partly for this reason the development won the British Council for Offices' National Corporate Workplace Award in 2009.

Fig.1 The Informatics Forum building, Potterrow

An occupant satisfaction survey conducted by William Bordass Associates in 2010 returned results for overall comfort that put the building in the top 15% of buildings surveyed using the Building User Survey (BUS) methodology[x], whilst the detailed results and individual comments highlighted specific areas where improvements could be made. Analysis of energy consumption also identified several performance issues, including:

1 Higher than predicted energy consumption generally. This appears to be due to unrealistic expectations of performance based on compliance model predictions of occupancy and management patterns.
2 Overheating in offices surrounding the atrium. This was the result of limited ventilation of the atrium, air leakage in the underfloor plenums reducing the supply of cool air, and internal gains from IT exceeding design predictions.
3 High energy consumption due to lighting. Internal lighting levels were specified at 350-400 lux, but have been installed up to 600-700 lux. The building was installed with programmable lighting that can be adjusted to suit occupancy patterns, but this was not fully utilised.

Fig.2 The atrium of the Informatics Forum building

Energy Performance

The Informatics Forum building used 209kWh/m2 of electricity in 2010-2011, and 180kWh/m2 in 2012, compared with a design estimate of 80kWh/m2. Gas usage for heating was close to the design estimate, at 61.9kWh/m2. Regulated electricity use accounted for some 71.4kWh/m2 of total consumption, with unregulated electricity use accounting for 108.9kWh/m2.

A simplified version of the 17 step CIBSE TM54 methodology was used to retrospectively analyse the predicted energy consumption of the Informatics Forum. TM54 offers guidance to address the operational energy consumption of buildings ‘more fully, and accurately’, using a 17 step process.[xi] TM54 recommends the testing of high and low-end scenarios (altering ‘the variables that are considered to be least certain’[xii]) combined with sensitivity analysis to identify assumptions that have the potential to impact most significantly on energy use. Importantly this recognises the uncertainty in estimating the operation of a new building at the point of occupancy, but it does not differentiate between this uncertainty and deliberate actions that may affect performance due to changes in occupancy, management or function in the future. It was hoped that analysis using TM54 may help differentiate between design predictions of specific energy uses which proved too low due to inherent flaws in the modelling methodology, and those which were not fully explained by the application of more realistic occupancy and management profiles.

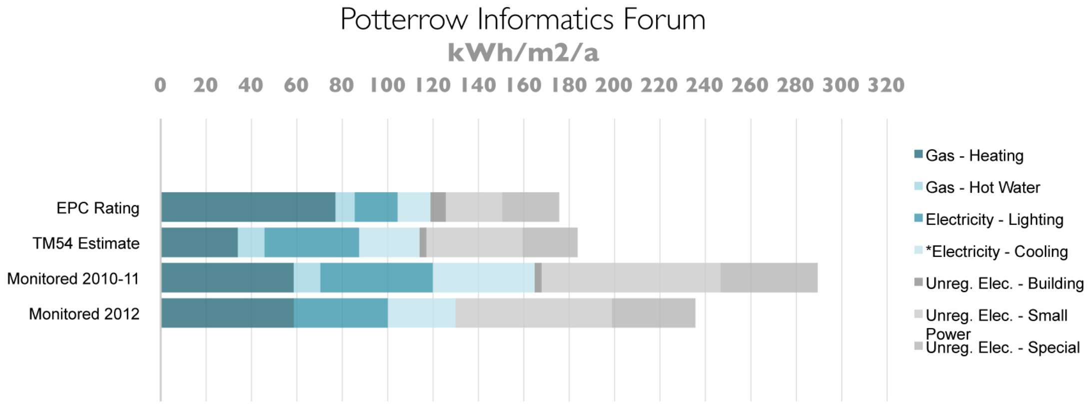

Fig.3 Predicted and monitored energy consumption

Of the regulated electricity supply, 41.5kWh/m2 was accounted for by lighting (compared with an EPC estimate of 18.9kWh/m2 and a TM54 estimate of 41.6kWh/m2), and 29.9kWh/m2 was accounted for in cooling, fans and pumps (compared with an EPC estimate of 14.5kWh/m2 and a TM54 estimate of 25.4kWh/m2). Compared with the building as monitored, the EPC data underestimated regulated electricity consumption by 38kWh/m2, while the TM54 estimate underestimated regulated electricity consumption by only 3.1kWh/m2. This difference can be attributed to cooling, fans and pumps rather than lighting.

Ventilation and Cooling Problems

In order to investigate the efficacy of the environmental strategy of the building, in 2012 David Sterratt (School of Informatics Energy Coordinator) conducted a survey of comfort in the building, employing a methodology similar to that suggested by Fergus Nicol, which rather than measuring perceived thermal sensation, measures thermal preference by asking whether the interviewee feels “about right”, “too” cold or hot, or “much too” cold or hot, on a scale from -2 to +2.

The sample size was 107, with the following scores:
Winter: -0.18
Spring: +0.16
Summer: +0.61
Autumn: +0.14

Generally interviewees seem to feel “about right” for most of the year, except in summer, when there was a tendency to feel “too hot”.[xiii] However, when the data from the report was extrapolated into internal and external rooms, more details emerged about which spaces in the building were perceived to be more or less comfortable, as well as the range of environmental conditions in different spaces. The internal rooms surrounding the atrium (and entirely dependent on mechanical ventilation) were perceived as significantly warmer than the external rooms (with opening windows), and on average were never perceived to be cooler than neutral, even during the coldest months.

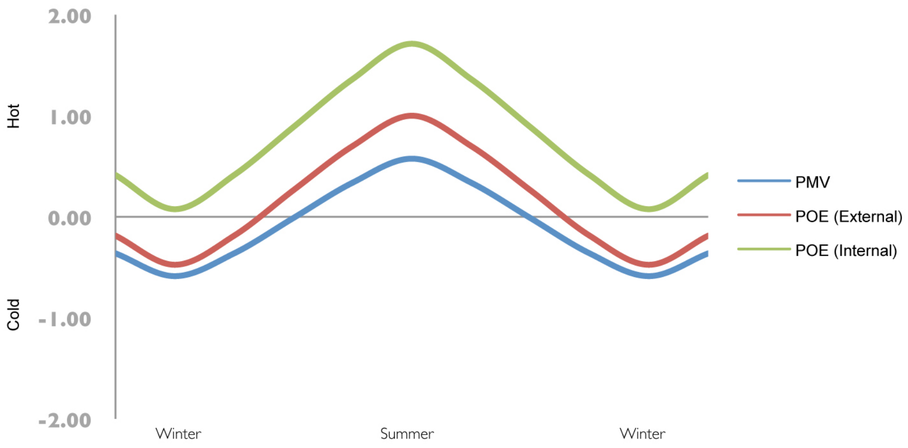

Fig.4 Comfort scores in internal and external rooms

This finding served to highlight the significance of the role of the underfloor ventilating plenums fed by the main cooling ducts. The air pressure in the floor voids was found to be unusually low due to leaks, and rooms further from the main duct outlets were reported to be stuffy. As a result, the power rating for the fans in the main Air Handling Units was doubled soon after handover.

The higher than expected cooling load may also be explained by solar gains through the atrium roof, which may not have been adequately ventilated, and internal gains that were not fully mitigated due to the air leakage in the plenums.

Improvements Achieved

Of the 39kWh/m2 saving in electricity consumption achieved from 2010-11 to 2012 (equivalent to approximately 15% of the total), 15kWh/m2 was attributable to reductions in energy use by the fans. This was probably related to the alterations made to the louvres at the top of the atrium, which were retrofitted to purge hot air as directed by the Building Management System without requiring manual operation. The programming of the extract fans was also altered so that they did not operate when the louvres were open.

Further savings of approximately 10kWh/m2 were achieved by reducing energy consumption due to unregulated small power. This was probably attributable to improved occupant ‘behaviour’ (e.g. turning off IT equipment at night). The computer ‘sleep’ policy has been improved by Informatics’ computing department and encouraged by the energy coordinator.

A further saving was attributable to the reduction in cooling load required by bypassing the heat exchanger when the atrium louvres were open. In David Sterratt’s Progress Report of 25th September 2012, Dougie Williams (Controls Systems Manager, University Estates Operations) reports that: ‘Holding off the extract fans helps to keep any heat transfer down between the extract and supply ducts through the cross flow heat exchanger – which shouldn’t occur due to the ‘face/bypass’ damper arrangement, but it does! Consequently, the roof vents are open for a large proportion of the night and day – dependent on external temperatures.

3 Discussion

Current research efforts to quantify the performance gap focus on seeking to identify its root causes and propose methodological solutions, so that predictions of energy consumption are more reliable. The energy analysis of Potterrow has demonstrated that CIBSE TM54 can be an effective tool for modelling occupancy patterns in a more realistic way than can be achieved by simply relying on design assumptions alone. However, while CIBSE TM54 provides a more accurate methodology for calculating the energy performance of buildings immediately post-construction, it cannot accurately predict performance in the medium and long-term, as the occupancy patterns, small power demand and management factors are all time-limited variables. While the methodology recommends that performance be quoted within a range that recognises the relative uncertainties in these variables, it does not account for long-term changes that may have more drastic effects such as major changes in occupancy behaviour or programme.

The robustness of the methodology as a design tool relies on the broad profile established at the beginning of the design process remaining relatively unchanged for the building's lifespan. Similarly, as the occupancy profile is often established based upon work patterns in an existing building (which may present a very different context), the implication is that architectural design decisions will have no impact on the occupancy patterns or behaviour of occupants once they move to an entirely new building.

However the design problems and solutions encountered at Potterrow highlight the importance of design decisions regarding flexibility and energy efficiency made on a case-by-case basis.

While the Informatics building was designed primarily as a flexible office environment, this has led to choices (notably a HVAC strategy that accommodates for a changing internal spatial arrangement) that have negatively impacted on energy performance in the short term. This flexibility is only worth the energy 'investment' if future changes in internal space arrangement are likely to occur.

Similarly, overly optimistic design modelling that underestimates internal heat gains combined with changes in building practices that have sought to tackle heat loss in winter may cause significant problems in future with rising global temperatures. It is arguably still unclear how resilient MVHR systems are to the 'urban heat island' effect. But if conservative assumptions about occupancy and management are made, environmental systems can be designed with a greater tolerance for future change.

Another source of uncertainty is the role played by individuals in sharing technical knowledge in order to achieve energy efficiency savings through improved occupant behaviour. Bill Bordass has characterised office buildings as dividing into three subsets: those with complicated servicing strategies requiring significant management resources (which can be expensive to run and fail easily), those which are less complicated and more robust (ideal especially for the public sector), and those that deploy significant innovation and are managed by specialist professionals (which are not often easily replicable).[xiv] Arguably the Informatics building at Potterrow is an example of a building with a complex servicing strategy supported by enthusiastic individuals acting as specialist professionals – this has had significant positive short-term effect on energy consumption, but the status quo cannot be guaranteed over the longer term.

4 Conclusion

The recent focus on the performance gap has highlighted how little designers know about occupant behaviour in buildings. The Soft Landings Framework represents one attempt to rectify this situation, but critically this only addresses performance issues in the short term. Soft Landings may even have a detrimental effect as complacency sets in about improved performance due to technical knowledge that may be lost as occupancy changes over time. As well as trying to improve occupant behaviour, it is therefore critical that we also educate designers about the impact of building design on energy performance in the medium and long term. Complex systems that are overly customised to a narrow set of operating conditions that are not easily adjustable, and strategies that do not conform to intuitive expectations of use, pose the biggest risks to future performance. While it is difficult to predict future events accurately, a range of possibilities may be estimated that design decisions can be tested against. Performance over a wide range of outcomes would demonstrate a more flexible design approach than a solution that is optimised for a particular set of events, which may or may not prove to be accurate.

The various technical problems with the complex HVAC system at Potterrow (optimised based on compliance modelling) may have persisted were it not for the continued interest of both the designers and client in the building's energy performance. Similarly, the programmable lighting (installed to improve flexibility) proved to be too complicated for day-to-day adjustment. Time will tell whether energy savings due to the various alterations that have been made will continue in the long-term, but one conclusion that might be drawn is that a less technologically optimised environmental strategy can prove more robust over a building's lifespan, even if initial predictions suggest otherwise.

Ever since RIBA President Alexander Gordon first stated that architects should design 'long life, loose fit, low energy' buildings, the doctrine has been widely accepted as a sound basis for defining sustainability in the built environment.[xv] The perceived requirement that high standards of performance (whether defined in terms of energy, maintenance costs, or functional efficiency) should be maintained across an extended building lifespan emphasises the importance of understanding the likelihood and impact of changing occupancy and management scenarios.

Only analysis of specific case studies can provide the robust evidence required to address these kinds of conundrums. Once future scenarios are quantified they can be subjected to rational analysis during the design process so that the risks and benefits of decisions made at concept stage (e.g. regarding flexibility of servicing strategy, or assumptions made about occupant behaviour) can be clearly communicated to the client.

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