Building 'in' tenant energy performance:

A new method of benchmarking variations in patterns of use by building tenure

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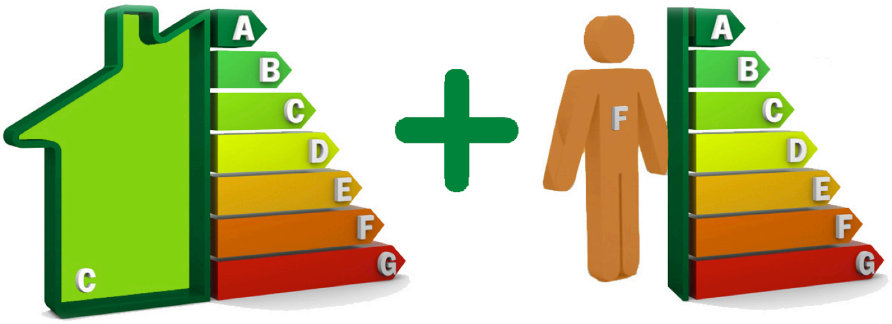
A thesis submitted by Emma Morton to the Energy Systems Research Unit, Department of Mechanical and Aerospace Engineering, University of Strathclyde, submitted for the degree of Doctor of Philosophy.



I, Emma Morton, hereby state that this report is my own work and that all sources are made explicit in the text.

March 2017

This thesis is the result of the author's original research. It has been composed by the author and contains material that has been previously submitted for examination leading to the award of an MSc degree in Environmental Studies at University of Strathclyde in 2009.

‘We shape our buildings, then they shape us’
Winston Churchill

‘Don’t judge each day by the harvest you reap, but by the seeds that you plant’
Robert Louis Stevenson

‘Become the change that you want to see in the world’
Mohandas Karamchand Gandhi

Abstract

To deliver the overarching EU Energy Performance of Building Directive energy reduction targets and deliver efficient building energy performance in practice, improved methods of communicating building performance evaluation, at design and operational stage, are necessary to review (i) the impact of variation in patterns of use and its effect on overall building performance and (ii) whether the building or the occupants patterns of use are operating effectively. The thesis aims to make contributions in these areas. The approach taken was to make the hypothesis that a new method could be developed, to ensure a fairer and more informed demonstration of a tenant's patterns of use on energy performance, which could be integrated into the existing design and evaluation process.

The new method is developed through (i) consideration of the building energy performance evaluation field and reference to current regulatory processes and guidance (ii) tested in application through evaluating the impact of variations in patterns of use on energy performance between building tenures, sharing the same building (ii) furthermore by simulating and calculating potential impacts of extreme usage patterns by demonstrating how the building would perform under minimum and maximum scenarios and (iv) critically evaluating integration into the existing energy performance evaluation process.

The new method is defined from adjustments to the articulation of occupancy capacity present in regulatory and compliance calculations, which are offered and critically reviewed. The adjustments are (i) to assess tenure energy performance scenarios with new minimum and maximum tenure occupancy load factor benchmarks (ii) measure aggregated energy use of a full-time employee defined by tenure occupancy load factors and (iii) determine occupant and building ineffective practices. The new method of evaluating a building's energy performance range takes into account variations in patterns of use, which exist between building tenant groups to identify where the tenant group sits in relation to a set of

predefined benchmarks to evaluate if the building is performing badly or if in fact, it's the practices of the building users, which are inefficient.

The research demonstrates that variations in patterns of use can account for a 44% increase in energy use per m^2 and 112% increase per person in commercial offices. This illustrates that the current method of predicting energy consumption patterns based on fixed occupancy and set hours of operation for a sole tenant is misleading and allows for a large margin of uncertainty unless the exact patterns of use can be established at the design stage.

The outcome of the new method is intended to contribute energy efficient building design and operation to improve energy resource efficiency in practice. This results in a new method, integrated throughout the lifecycle of the building, to support green tenancy agreements, such as the Tenant Energy Efficiency Regulations 2018 and other energy performance contracts.

The integration of the proposed new method into the existing regulatory and guidance methodologies is proposed and demonstrated. The development of the method is focused on a specific building purpose group; yet, the method could be reviewed and applied to other building groups with appropriate methods and metrics. The thesis provides foundation and motivation for further research in this area.

Acknowledgements

I would like to thank my Supervisors Stephen Garvin, John Counsell and Paul Tuohy for their guidance, support, and faith. I would also like to thank Joe Clarke and my colleagues at ESRU for their assistance.

Thank you to my family, Steven and Eva for giving me the time to carry out this work graciously and patiently. It’s not been without irrevocable sacrifice to you both and I am eternally grateful. As such I hope this research finds its purpose and I dedicate the work to us, it’s our achievement.

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Introduction to the Energy Performance Gap, Regulatory Framework, and Building Performance Evaluation Case Studies

1.0 Chapter Introduction

This chapter gives a summary of the energy performance gap, regulatory framework, and definition of building performance evaluation by defining the context, the problem statement, structure of the thesis, outline of research carried out and states the key contributions.

1.1 Context

Humankind has cultivated the earth's fossil fuel energy resources to meet our demands with undue regard for their finite nature or impact on the natural environment. To sustain ourselves we need to evaluate and measure how we allocate and conserve natural resources to serve future generations with minimal environmental impact. The United Nations Educational, Scientific and Cultural Organisation [UNESCO] intimate's trends in world population show a predicted increase of 80 million people per year between now and 2050. As a result, as shown in Figure 1.1, in 35 years globally we will need 70% more energy and 100% more electricity than we have today.[1], UNESCO. [2]

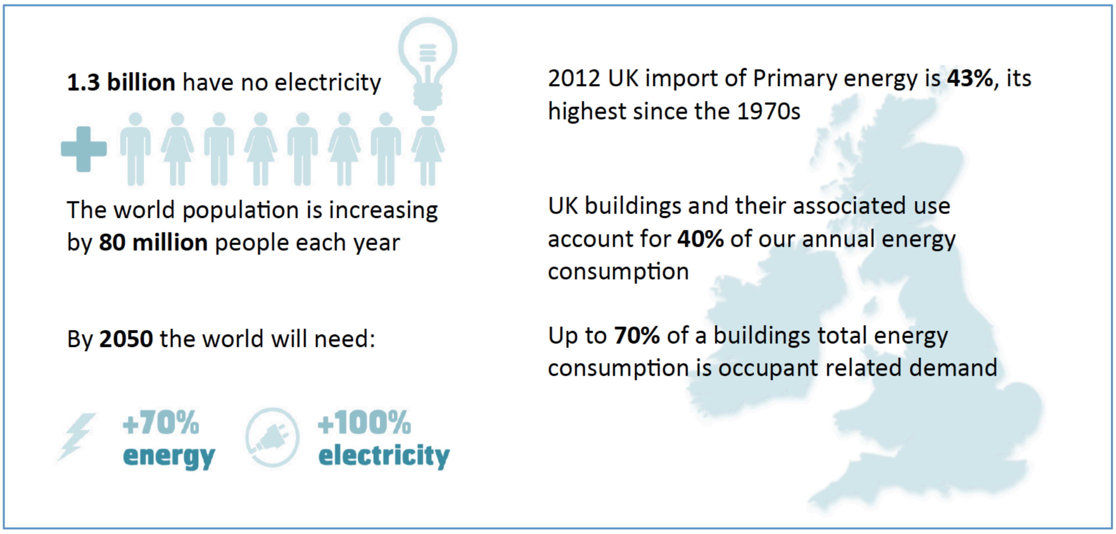

Figure 1.1 Global and UK Energy Demands[a]

[a] Figure Source: UNESCO Water and Energy. Accessible at: <http://visual.ly/water-and-energy-sustainable-future>

In 2012, The Department of Energy and Climate Change [DECC] published the current net United Kingdom [UK] import of primary energy at 43%, its highest since the 1970s.[3] Accordingly, the UK needs to become very good at producing and conserving energy in a sustainable manner. Optimising energy efficiency and reducing energy demand is a UK government led initiative under the European Energy Performance of Buildings Directive. UK buildings and their associated use account for 40%[4] of our annual energy consumption and are the focus of our mitigation strategy. Office buildings are the highest use of UK non-residential floor area [Figure 1.2] and hence an important UK energy reduction target. To conserve office building energy we first need to know specifics regarding how much we use; however, current calculations are generic and not accurate.

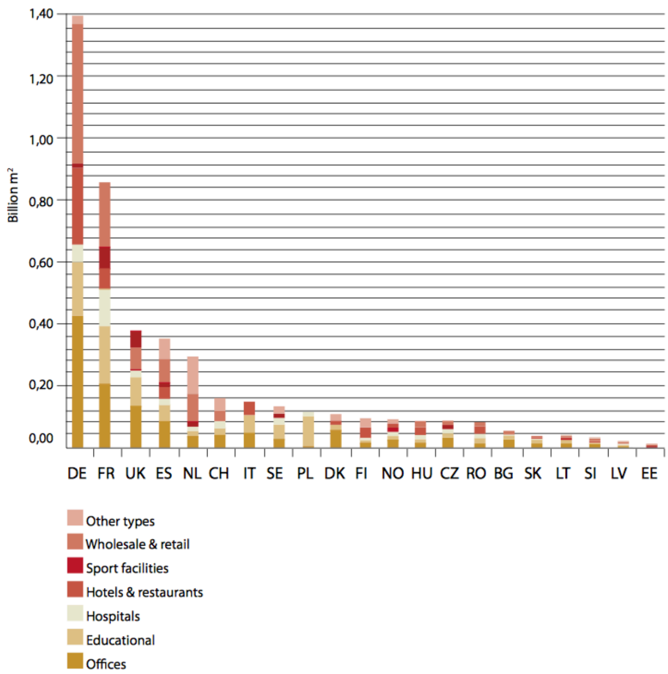

Figure 1.2 Europe's buildings under a microscope: A country-by-country review of the energy performance of our buildings 2011. Illustration showing the breakdown of non-residential floor space in selected countries.[b]

[b] Figure Source: BPIE Survey. Accessible at: <http://www.europeanclimate.org/documents/ LR_%20CbC_study.pdf>

Therefore, it is difficult to see how office-building tenants can actively reduce energy consumption if the correct methods are not available to measure their impact.[c]

Inconsistency has arisen between predicted office building performance [at design stage] and actual energy performance [at operational stage]. The gap is well documented and referred to as the energy performance gap.[5-12] The energy performance gap has arisen, as mandatory compliance calculations currently measure how much energy buildings consume, not people and secondly do not recognise variations in 'Patterns of Use' that occur between tenants. This is misguided as occupant related energy accounts for up to 70% of a building's total energy consumption.[13] As such, building regulation has to evolve between now and 2030 to establish new techniques to improve energy efficiency in the non-residential sector. Accounting for occupant related energy performance is a significant contribution to achieving this goal.

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[c] *"If you cannot measure it, you cannot improve it" is a well known and often quoted dictum attributed to* Sir William Thomson [Lord Kelvin]. The original reference is documented in a lecture on "Electrical Units of Measurement" (3 May 1883), published in *Popular Lectures* Vol. I, p. 73, as quoted in *The Life of Lord Kelvin* (1910) by Silvanus Phillips Thompson, which states "*I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be."* This theorem has been widely used and adapted by Edwards Deming the father and the pioneer of quality control asserting, "You can't manage what you can't measure" and Peter Drucker the father of modern management acknowledging, "You can't measure what you can't monitor." All works have meaning and relevance in the context of this thesis.

1.2 Problem Statement

Effectual energy evaluation methods are required now to enable the transition to understanding and delivering low energy buildings through appropriate design provision and accurate energy modeling. Building designers and users need to be more energy literate to reduce energy consumption, which may only happen if we 'make energy wastage socially unacceptable.' [14] It is crucial to evaluate the relevance of regulatory processes to exam if effectual energy evaluation and reporting are present. It is not clear how the complex dynamics of energy performance can be accurately predicted for comparison to measured and monitored data through the current framework, the Scottish Technical Handbooks or if a new framework for regulation or guidance should be implemented.

Theoretically an evaluation process, which sets down criteria by which the building can be tested against, that is sensitive to changes in occupancy factors, would help alleviate this problem. By April 2018, The UK Tenant Energy Efficiency Regulations[15] will come into force. Provisions set out in the Energy Act 2011, will make it unlawful to rent out an office below the stated minimum energy efficiency standards. Necessitating an initial retrofit of 22%[16] of offices in the UK, to enforce a proposed minimum Band E Rating.[15, 17, 18]The existing national energy reporting method does not categorise systemic variations in 'Patterns of Use', which occur between tenancies in its assessment. Leading to speculation whether the current energy performance evaluation framework is fit for purpose. To date, UK and European Union legislation focus on building energy use opposed to energy consumed by the building tenants. The absence of occupancy capacity related benchmarks is due to a "lack of robust, low-cost methods for collecting accurate density information, "potential for abuse" and "poor correlation between energy use and occupancy levels".[19] It has been recognised that a robust method of measuring and recording tenant density is required, however, benchmarking per m^2 is favoured by the Chartered Institute of Building Services Engineers [CIBSE], until a suitable method is developed.

There is an underlying reluctance in the construction industry to commit to what an office building's true energy performance should be. The reason given is that demonstration of energy performance is directly related to occupant behaviour and how the building is used and managed.[20] Building energy performance is currently articulated to comply with building codes and produce energy performance certificates. The main priorities of these procedures are to ensure we are designing buildings that use energy efficiently. Buildings are being reported to use up to three times more energy than predicted yet under the current energy performance evaluation route very little is communicated to the building user as to how the energy performance of the building was calculated.[7] Therefore there is no way for the tenant to determine if a building or part there off is not performing as expected, in relation to how the building was designed.[21] The Better Building Partnership intimated in 2009, "variations in energy consumptions due to patterns of use and occupancy should be recognised" and "building occupancy should be recorded and reviewed to reduce excessive consumption in periods of low occupancy," [22] however, to date little, if any, known research has been presented in this area. Thus, an alternative method should be explored to better communicate the effects of the tenant's 'Patterns of Use' on energy performance.

1.3 Structure of the thesis

The thesis follows the structure below to its conclusion:

Chapter 1	**Introduction Overview and Context** *Introduction to the Energy Performance Gap, Regulatory Framework, and Building Performance Evaluation.*
Chapter 2	**Literature Review, Gap and Methodology** *Defining the Gap, Problem Statement, Research Question (Can a method capturing POU in BEP assessment provide useful insight (a) at design stage, and (b) in the operational stage?)* *Research Methodology (The approach taken is to first make the hypothesis that such a BEP POU method could be developed, then to specify and develop such a method, and test it through application to appropriate case studies, and then assess the extent to which the hypothesis is shown to be correct), followed by a Chapter Overview.*
Chapter 3	**Specification, Scope, and Evaluation Plan for the Proposed New Method** *The Proposed New Method Outline Specification is described to include the scope, how it will be tested and evaluated.*
Chapter 4	**Development of the Proposed New Method** *The Development of the Proposed New Method through defining Variations in Patterns of Use and the New Methods Parameters and Ranges.*
Chapter 5	**Application of the Proposed New Method** *The Application of the Proposed New Method to a 'Real-life' Case Study.*
Chapter 6	**Application of the Proposed New Method** *The Application of the Proposed New Method to demonstrate the impact of Variations in Pattern of Use on Tenant Energy Performance.*
Chapter 7	**Analysis of the Proposed New Method** *The Review of the Proposed New Method against Evaluation Criteria.*
Chapter 8	**Discussion of Results and Proposed General Applications** *The Outcomes from the Thesis and more general New Method Applications.*
Chapter 9	**Conclusions** *The Hypothesis, Further work, Conclusions, and Contribution.*

1.4 Research Outline

This thesis presents a technical research study into the science of building energy performance design and evaluation processes by improving and supplementing energy benchmarking, monitoring and modeling techniques. The research focuses on three key areas: energy performance, building energy use and tenant energy use while reviewing their impact on the design and operational stages [Figure 1.3].

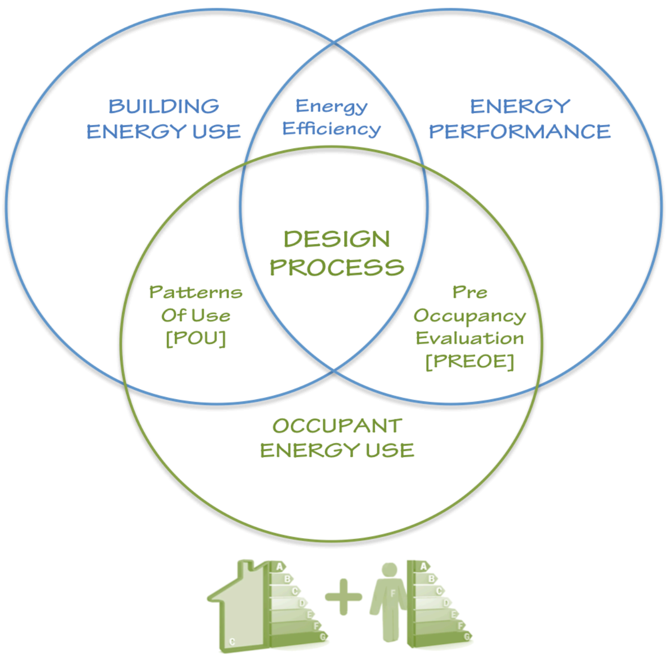

Figure 1.3 Research focus diagram showing the main research fields of interest.

This study is a systematic investigation into the impact of 'Patterns of Use' on energy performance, how this is represented in the existing energy performance compliance methods. The new method is developed through reviewing and testing a case study sample, then applying the new method using existing calculations and then critically evaluating the results and the appropriate measures needed to integrate the proposals into the existing building energy performance evaluation methodologies. The thesis works expand on existing research in the field carried out by Bill Bordass et al of the Usable Building Trust, who researched and authored the

Probe Studies and Soft Landings in association with BRSIA. The research also supplements TM54: Evaluating Energy Performance at Design stage researched and produced by David Cheshire and Anna Menzies of AECOM in conjunction with CIBSE.

1.5 Key Contributions

Variations in 'Patterns of Use' are tenant specific and present-day energy performance evaluation is building specific. Delivering bespoke energy assessments based on energy delivered per m^2 of floor area doesn't allow different tenants to evaluate or compare their impact on buildings performance in operation. The absence of occupancy benchmarks is a systemic problem throughout the building design and operation process. Including occupancy benchmarks and energy assessment on energy delivered per FTE could improve energy efficiency and help close the energy performance gap.

Thus, the main improvements to evaluating tenure opposed to building energy performance, and subsequently the contributions to knowledge are; the new method allows the tenant to (a) evaluate the impact of a tenure through detailing the aggregated energy use of a full-time employee; (b) evaluate the minimum and maximum 'Patterns of Use' scenarios to understand the impact of the tenant's 'Patterns of Use' on Tenant Energy Performance and Building Energy Performance; and (c) to understand if the building or the occupant's 'Patterns of Use' are inefficient, improving on best practice.

1.6 Research Background

The work was undertaken in 5 phases over the course of fours years, from 2010 to 2014. The project, which started in 2010, has been a collaborative venture between myself, the Ph.D. candidate, ESRU and the BRE, jointly funded by EPRSC and the BRE Trust. As a charity for research and education, the BRE Trust commissions 'for public benefit' research. It awards scholarships and bursaries to Ph.D.'s and provides financial support for the Chairs held by the Directors of the Centres that together form the ‘BRE-Universities Partnership'. The BRE Centre at the University of Strathclyde is concerned with Energy Utilisation. Hence the research falls within this field of research.

Chapter 2: Literature Review, Gap and Methodology

Defining the Gap, Problem Statement, Research Question, Methodology and Chapter Overview

2.0 Chapter Introduction

This chapter considers Building Energy Performance [BEP] evaluation within the wider context and provides a motivation for investigation of the research gap. This is followed by a critical review of previous work related to the gap and the relevance of the work in this thesis. This work is to be judged as a new method for evaluating the impact of variations in Patterns of Use on tenant energy performance.

2.1 Current Methods of BEP Evaluation

This literature review aims to demonstrate a working understanding of BEP, including the strengths and weaknesses of existing evaluation methods. This is achieved by defining the different types of energy performance gaps, stating current BEP definitions, and highlighting gaps in relevant case studies.

The last 20 years has seen a rapid change in the way we evaluate and record energy use in the built environment. Regulations on the Conservation of fuel and power came into effect in 1995, five years after privatisation of the electricity industry and 100 years after the first power station opened in the UK. A brief timeline of the history of energy legislation and energy performance guidance is illustrated in Figure 2.1. Awareness of our increasing environmental footprint has resulted in more stringent and binding European Union [EU] energy efficiency targets. Under the new Lisbon Treaty, the European Commission [EC] has established the Climate Change Action Directive (CCAD) to regulate development, energy, environment, research, and innovation. This new directorate is led by Members of the European Parliament (MEPs) and aims to deliver on climate action and regulate member states contributions. Moreover, new European regulation has filtered down into Scottish regulation; however, the quality of the law has been called into question. An example of this is the Climate Change (Scotland) Act 2009, which was invoked top-down from the EU Environment Directorate (Brussels) to national legislations.

According to Love[23], ‘The legal landscape has shifted; the EU previously set the bar, now nations, such as Scotland, are trying to improve on EC targets.’

1882	**Electric Lighting Act**
1891	First AC Power Station Opened
1947	**Electric Act**
1947	British Electric Authority and 15 UK regional boards established
1960	Watt adopted as unit of power
1990	Privatisation of Electricity Industry
1995	Building Regulations Part L, Conservation of Fuel and Power
1998	CIBSE Guide F: Energy Efficiency in Buildings
1998	CIBSE AM11: Building Energy and Environmental Modeling
1999	CIBSE TM22: Energy Assessment and Reporting Methodology
2003	**Energy Performance of Buildings Directive**
2003	UK Energy White Paper
2006	CIBSE TM31: Building Log Book Toolkit
2007	Energy Performance Certificates
2008	**Climate Change Act**
2008	Display Energy Certificates
2008	Landlord Energy Performance Certificates
2009	Better Building Partnership Green Lease Toolkit
2009	Soft Landings
2013	CIBSE TM54: Evaluating operational energy performance of buildings at the design stage

Figure 2.1 A brief history of energy legislation and energy performance guidance.

There are now three main areas of focus in EC climate change legislation, which are influencing building regulation in the United Kingdom. In general, these cover the carbon, energy and Life Cycle Analysis (LCA). The legislation seeks to minimise carbon emissions, minimise fossil-fuel-based energy consumption and reduce carbon attributed to the atmosphere. The EC directives, which provide the framework for energy regulation in European law, are illustrated in Table 2.1.

Table 2.1 Overarching EC Energy Regulatory Directives. Source: European Commission Joint Research Centre

Building Regulation Influence	EC Directives Shaping the EC Construction Sector and national regulation	
	Directive	**Directive Title**
Energy	2003/87/EC	Emission Allowance Trading Directive
	2006/842/EC	Regulation on Certain Fluorinated Greenhouse Gases
	2002/91/EC	Energy Performance of Buildings (EPBD)
	2005/32/EC	Eco-design of Energy-using Products (EuP)

The only climate change directive that applies specifically to buildings, and therefore EC nations' building legislation, is the EC Energy Performance of Buildings Directive [EPBD] (2002/91/EC).[24-27] The EPBD legislates a move to use less fossil-fuel-based energy in our buildings through regulatory measures and certification led by government economic incentives.[28] The directive promotes ambitious energy standards and increased renewable energy use by informing potential buyers and tenants about BEP through Energy Performance Certificates [EPC]. In 2002, the EC launched the Concerted Action (CA) EPBD to support the 29 EU member states in delivering the EPBD, and EPBD recast to promote dialogue and exchange of best practice of EPBD implementation. Irrespective of the current EPBD,[29] there is still considerable variation across the European Union regarding energy reduction methods, definitions and reported results.[30, 31]

The focus of UK building regulations since its inception has been health and safety. The introduction of the EPBD and member states' environmental climate change regulation has changed this focus to include environmental considerations. Achieving a standard of energy performance is now an integral part of building regulations in the UK. The current energy-related building legislation (2015), associated guidance; National Calculation Method [NCM] and certification for the UK and Scotland are presented in Table 2.2. The EPBD and EPC legislation apply to all UK buildings. The Directive is transposed down into the UK (England and Wales) building legislation in the form of the Approved Documents, Part L, 'Conservation of fuel and power' and cited in the Scottish Technical Handbooks, Section 6, energy use in domestic and nondomestic buildings (Table 2.2). Table 2.2 demonstrates that regulatory principles vary between domestic and non-domestic buildings as well as changing regulatory standards within the UK.

Table 2.2 Similarities and differences in the application of the current UK and Scottish building regulation and guidance for domestic and non-domestic buildings.

Energy-related Building Legislation[3] (2015) and associated guidance EC, UK and Scotland (energy)		Building Regulation United Kingdom[1]				Building Regulation Scotland			
		Domestic		Non Domestic		Domestic		Non Domestic	
		N	R	N	R	N	R	N	R
EC[2]	Energy Performance Building Directive (EPBD)	√	√	√	√	√	√	√	√
UK Building Regulation	Building Regulations Part L Approved Documents	√	?	√	?	×	×	×	×
	Scottish Technical Handbooks: Section 6	×	×	×	×	√	?	√	?
UK Building Guidance: Voluntary Standards	Code for Sustainable Homes (CSH)	√	×	×	×	×	×	×	×
	Building Research Establishment Energy Assessment Method (BREEAM)	×	×	√	√	×	×	√	√
UK National Calculation Method [NCM]	Standard Assessment Procedure (SAP)	√	√	×	×	√	√	×	×
	Simplified Building Energy Model (SBEM)	×	×	√	√	×	×	√	√
UK Building Certification	Energy Performance Certificate (EPC)	√	√	√	√	√	√	√	√

Key:

N: New Build **R**: Retrofit (energy reduction measures)

√: Regulation or guidance applies ×: Regulation or guidance does not apply ?: Not clear

[1] In this Instance referring to building regulations in England and Wales only

[2] European Committee Climate Change led Building legislation

[3] Building Legislation explicitly linked to Climate Change Action Directive, which promotes GHG reduction; thus currently energy reduction and carbon reduction measures only

This demonstrates that regulatory principles vary between domestic and non-domestic buildings and also that standards vary within the UK. EU Regulations only evaluate selected building energy loads, similar to the UK regulation system. Creating a barrier to reducing overall demand. Marsh *et al*.[29] state that over the last 30 years heat consumption has reduced, parallel to a rapid growth in electricity demand, which has dominated total energy use. Moreover, a reduction of only 50% in total energy consumption is forecast for our technology-reliant, knowledge-based society. Construction professionals could evaluate the effects of future climate changes on energy use and thermal comfort through improved regulation, reducing future energy demand realised in the early design process and achieving a balanced account of energy saving methods adaptable to future energy trends.[29] However, Roaf *et al.*[32] claim that current UK legislation results in increased, not decreased, emissions from buildings. New building regulations to target low energy buildings are proving ineffectual, as new buildings are typically more energy profligate year on year, attributed to increased mechanisation, poor building envelopes and, predominantly, variation in societal energy consumption patterns. There is guidance [Table 2.2 and Figure 2.1] provided to monitor and assess the energy performance of our buildings,[33-40] but not the impact of the building occupants. Therefore it 's hard to measure how much occupancy factors contribute to overall energy demand. Moreover, perceptions of thermal comfort have changed regarding how often and how much we heat and cool our buildings, resulting in higher energy use. Roaf *et al*.[32] and Tuohy[41] suggest that a radical approach is required to overhaul artificial air conditioning standards in the UK. Current building regulations are driving designers away from the less energy-intensive methods of natural ventilation systems by proposing new standards, to include proving the BEP in operation through the designers' remit and a new set of regulations to enforce the responsibility of building occupants to control and monitor their energy consumption. However, to engage building occupants to share responsibility, they first need to know how much energy they are using. Therefore, the EPBD and national building regulation has essentially created a barrier, limiting building occupants' understanding and assessment of their energy consumption patterns, as it 's hard for designers and building users to use less energy-intensive practices through enshrining only building and not occupant-related benchmarks in EU legislation. Thus, the first challenge is to design for changes in occupancy levels and communicate the effect of an occupancy load factor on energy performance to building users. By April 2016, The UK Tenant Energy Efficiency Regulations[15] will have come into force. Provisions set out in the Energy Act 2011 will make it unlawful to rent out an office below the stated minimum energy efficiency standards, necessitating an initial retrofit of 22%[16] of offices in the UK, to enforce a proposed minimum Band E Rating.[15, 17, 18] The existing national energy reporting method does not consider in its assessment the variations in occupancy patterns that occur between tenancies, leading to speculation as to whether the current energy performance evaluation framework is fit for purpose. The absence of occupancy capacity-related benchmarks is due to a 'lack of robust, low-cost methods for collecting accurate density information, 'potential for abuse' and 'poor correlation between energy use and occupancy levels'.[19] A robust method of measuring and recording occupant density is required, however benchmarking per m^2 is favoured by CIBSE until a suitable method is developed. The Better Building Partnership intimated in 2009 that 'variations in energy consumptions due to patterns of use and occupancy should be recognised' and 'building occupancy should be recorded and reviewed to reduce excessive consumption in periods of low occupancy'.[22] However, to date little, if any, known research has been presented in this area. Variations in occupancy patterns have been overlooked at the early stages of projects, resulting in inaccurate energy model predictions and subsequently inefficient mechanical and electrical installations. Presently, energy models only determine building regulation compliance and provide certification of the outcomes through benchmarking BEP. The absence of occupancy benchmarks is a systemic problem throughout the building design and operation process and should be understood to mitigate against changes in building use and operation. Including occupancy benchmarks could improve energy efficiency and help close the BEP gap. Adhering to EPBD legislation and building regulations do not ensure that the building is efficient in use; however, the introduction of occupancy benchmarks could provide a platform by which building designers and building tenants could both evaluate and deliver energy performance in practice. The lack of proving BEP in use is creating a knowledge gap between the predicted energy use submitted for building control compliance and the annual usage recorded by building energy meters.

When buildings do not perform as expected; the gap in measurement is referred to in the construction industry as the 'Energy Performance Gap'.[42, 7, 43, 9, 10, 44-48] Design assumptions, technical defects and operational issues all contribute to poor performance.[49] Different gaps contribute to errors in BEP throughout the lifecycle of the building. The gaps are further identified as a 'Policy Gap', a 'Perception Gap', a 'Measurement Gap' and an 'Occupancy Gap'.[7, 20] The predominant gap is the lack of EPBD requirement for designers to prove their design works in practice, making it difficult for the building tenants to challenge the building design and assess energy efficiency, referred to by Burman et al. as a 'Policy Gap'.[7] Tuohy *et al.*[41] suggested that a building services engineer's usual design remit covers the design and control of building mechanical systems; but the form, fabric, natural lighting and ventilation systems are under the supervision of the architect, and architects contractually do not hold responsibility for building performance. Moreover, architects do not observe how tenants use buildings and designers do not carry out research analysis. Designers create buildings based on self-judgments and site analysis, not operational analysis. Architects visualise how a building should work based on pre-determined regulation rather than independent research, which is substantiated in the Royal Institute of British Architects [RIBA] Plan of Work [POW].[50, 7, 51, 52, 49, 40] The work stages detail the architect's framework for designing and managing a building project. The POW sets down the key stages of the design process, with the primary drivers being efficiency and cost. The process is linear and attempts to address complex issues such as building performance and legislation. However, the employer's requirements and building performance are reviewed in detail after planning approval is achieved. There is no obligation to alter energy models to reflect design changes during the design, construction or operational phase of a building, which could result in a compliance resubmission and additional fees, abating BEP revisions being carried out. It is therefore at the client's discretion, beyond providing the tenant with an EPC, as to whether a strategy is put forward to monitor energy through Building Energy Modelling [BEM], Post Occupancy Evaluation [POE] or energy audits. Tuohy *et al.*[41]

state that the paradox between policy and responsibility is, in reality, a large pitfall in the production of low energy buildings. This suggests that building contracts may need to be altered or roles and responsibilities restructured to achieve high levels of BEP.

The RIBA led the way in post-occupancy evaluation (POE) with the inclusion of Stage M: Feedback within the RIBA plan of work in 1965.[53] However, its implementation has been patchy due to associated fees, insurance, liability, and its failure to be seen as an architect's responsibility.[54] As a result, the RIBA removed the Stage M part from their plan of work in the 70s. At that time, it was not compulsory, and clients did not want to pay fees for this service. Recently POE has been reintroduced as an optional service, together with the need to assist in the initial occupation of the building, in the new RIBA POW 2013. However, the current system will not resolve the earlier issues associated with fees, insurance and liability unless a more robust way of validating the performance of our buildings is introduced. The main problems with RIBA POW and design process are highlighted as:

- Environmental performance and targets dealt with late in the process.
- Post Occupancy Evaluation and initial occupation assistance are light-touch.
- Does not provide a robust method of design validation.
- Predicted design performance is rarely achieved.
- Design services and design team responsibilities diminish after the building is handed over.
- There is little interaction between the building users and the design team.
- Monitoring of buildings is a timely and expensive process, which is currently not part of an architect's remit.

Ensuring that designers are involved from the very start of a project through to post completion to ensure the building 'works' as intended is a sensible approach to Building Performance Evaluation. However, existing techniques such as POE are under-utilised and are not enforced through legislative processes. The only incentive to ensure performance is environmental accreditation or tenant preference. POE was introduced to assess tenants' opinion of the buildings they occupy. It was not designed as a BEP validation tool but loosely used as an umbrella to determine all building performance conditions. POE has benefits, but by and large, the process is too late, the building has been built, the design errors have been made, and changes will be costly. Once the building has been let, the landlord has no further incentive to pay for improvement measures, as they are not responsible for paying the running costs [Figure 2.2].

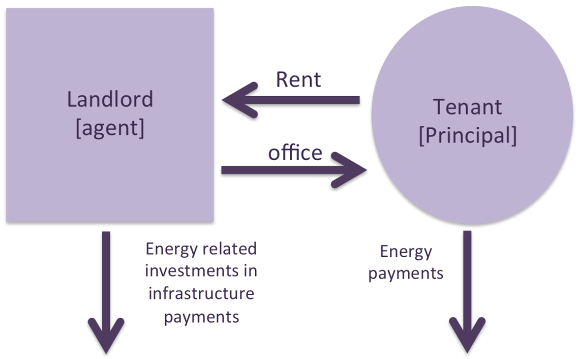

Figure 2.2 The 'who pays for energy improvements or energy efficiency' conundrum.[d]

According to Bentley *et al.,* 'the ultimate power of deciding how a place should be designed lies in the hands of whoever pays for it: the *patron.* Patronage is almost never controlled by the direct users'.[55] This creates a divergence between the building design and the building users, the design brief and the building operational usage patterns, and finally between the design brief energy predictions and actual energy performance. The natural reaction, when this happens, is for the building designers to blame the tenants for how they operate the building and for the tenants to blame the building design and difficulty of operation.[56] This highlights a need to (a) test the design intent against operational use in a simple, low-cost manner, (b) be able to separate tenant energy use from building energy use and (c)

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[d] Figure Source adapted from IEA Mind the gap: quantifying principal, agent problems in energy efficiency. Accessible at: http://www.iea.org/publications/freepublications/publication/mind_the_gap.pdf

promote early adoption of energy assessment criteria to avoid costly design changes. The idea of a pre-occupancy evaluation is not a new concept;[57-59] however, the evolution of a preoccupancy energy assessment criteria ‘to generate more suggestions for improving design solution during designer–client communication compared with traditional approach’[60] has not been adopted. The lack of an EPBD framework has abated introduction in existing regulation and compliance procedures. An attempt to tie post-occupancy evaluation back into the design process has been targeted through the introduction of the Soft Landings Framework authored by BSRIA and the Usable Buildings Trust.[61, 62] Soft Landings works in conjunction with existing procurement processes to define design targets; it also offers a natural route for feedback and post-occupancy evaluation at the handover stage.[61, 63] The aim is for industry to adopt and learn from a ‘no blame' situation while mitigating against repressing innovation. This soft approach is driven by ‘the expense of setting up a legally-defensible system, uncertainties about metrics, the difficulties in dividing any responsibility for outcomes between all parties concerned’[63] to include the occupiers and facility managers. The Soft Landing guidance stipulates that it is also driven by ‘the fact that the industry is as unfamiliar with the true in-use performance of buildings’ and ‘to make building design and construction more performance driven, and narrow the credibility gaps that often yawn between expectations and outcomes.’[63] This approach is well-intentioned and provides a high-level framework to improve overall building performance, but it does not set out a methodology to link design expectations to deliver BEP and ultimately meet challenging government targets. Thus, the aim of the approach is to raise ‘awareness of performance in use in the early design stages of briefing and feasibility’ and to ‘set realistic targets’, [63] which is critical but it still does not stipulate how this can be done and how improvements are realised. Janda states that ‘Architects need to seek ways of integrating user involvement in building performance’,[64] however a solution to the ‘Policy Gap' is hard to resolve unless proving design performance in operation is legislated for in the EPBD and designers and equipment held accountable. The ‘Policy Gap’ is heightened by the ‘Perception

Gap'[65, 10] that compliance and certification calculations represent all the energy use within a building and that compliance calculations and ratings are consistent. Predicted energy calculations rarely represent the operational energy performance, as they account only for the regulated building loads, which include heating, cooling, hot water, ventilation and lighting. They do not include unregulated energy use, as indicated in Figure 2.3.

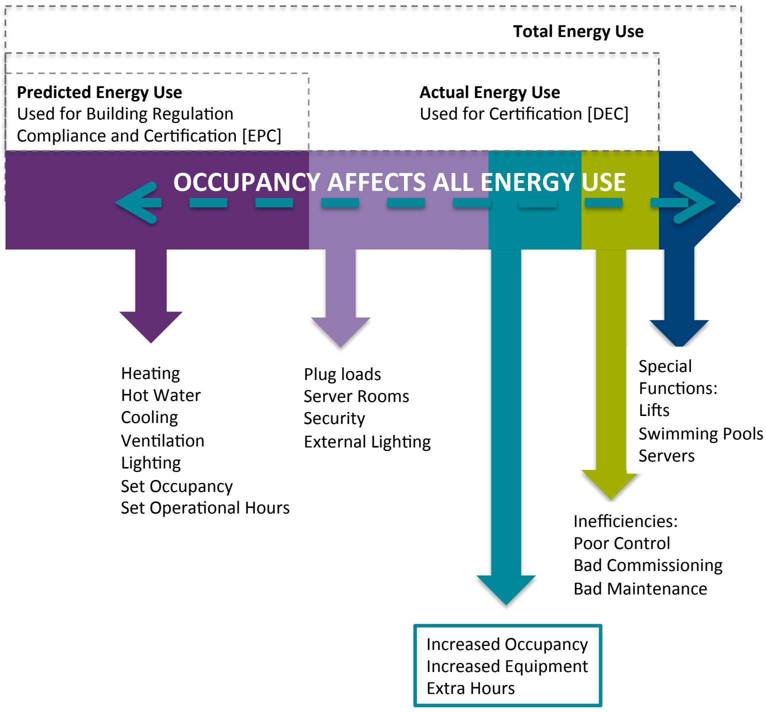


Figure 2.3 Design predictions issued for regulatory compliance do not account for all energy used in a building. Occupant factors can have an effect on all regulated and unregulated energy use. [Adapted from carbon buzz and carbon trust]

These include occupancy factors,[e] Inefficiencies from poor control, bad commissioning or inadequate maintenance, and special functions like lifts and swimming pools. It is clear that occupancy factors, as indicated in Figure 2.3, can affect all aspects of energy use and contribute to the energy performance gap, but

[e] 'Occupancy factors' are defined as variations in occupancy capacity, building hours of operation, IT and personal equipment, plug loads, server demand and the impact of these patterns of use on energy loads.

an exact value is difficult to quantify using existing methods. This is due to (a) the current metric being building-specific and (b) contributions to poor performance[49] beyond unregulated loads to include occupancy factors. There is also a 'measurement gap' where compliance-modelling tools are expected to be capable of predicting energy performance in use; however, these tools were not designed for this function. Compliance tools are limited to considering regulatory loads and standard operating conditions. Buildings Energy Modelling [BEM] commissioned specifically to evaluate and improve energy performance through fabric or operation can also create systemic gaps between the predicted BEM and actual energy use, due to building management, technical or design defects or variations in occupant usage patterns. This conundrum could be easily resolved if occupancy factors and non-regulatory loads were embedded in the EPBD process. Tenants need to be able to measure the impact of occupancy factors on BEP to enforce energy responsibility buildings. The 'measurement gap' occurs as the EPBD and energy rating system recognises kW.h/m^2, which represents energy delivered per unit of area and is building-specific. This does not account for occupancy capacities or extended hours of operation, which would necessitate an evaluation of kW.h/person or kW.h/person/hour. If tenants cannot measure performance, tenants cannot effectively manage performance, and Soft Landings will not bring the building's performance any closer to the predicted values. Hubbard states, 'If a measurement matters at all, it is because it must have some conceivable effect on decisions and behaviour. If we can't identify a decision that could be affected by a proposed measurement and how it could change those decisions, then the measurement simply has no value.'[66] This is apparent in the enactment of measurement for measurement sake without repercussion or effect on decisions or behaviour within the existing BEP evaluation process. This approach adds no value. Regarding the 'Policy Gap', it is essential to re-evaluate the current energy performance process to allow effective measurement, improve performance and actively engage the design team and the building users through understanding the process of evaluation, the building design limitations and how the occupants impact on BEP. Burman *et al*. and Ekins state that, if the EPBD and UK continue to assess performance based on theoretical measurements, the UK energy targets will not be achieved.[26] [7] According to Carbon Buzz[54] and the Carbon Trust RIBA, CIBSE and BRE [2014] published energy performance gap figures for 240 UK offices. The results indicate that offices in the UK use on average double the predicted energy use [Figure 2.4] while the Carbon Trust have reported up to five times the predicted calculations.[48]

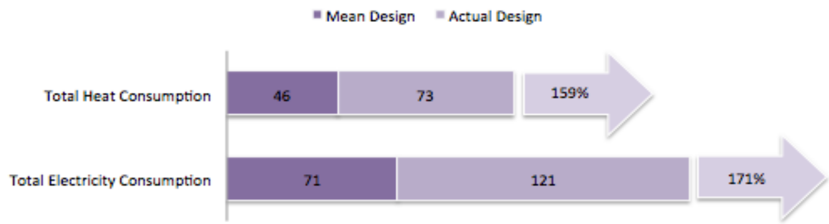


Figure 2.4 Mean Energy performance gap of 240 UK offices [kW.h/m^2 per year].[f]

EPBD, UK regulation and policy focus is centred on design and technical defects. Table 2.3 shows the life cycle phase of a building from design through to operation and includes the technical causes of the energy performance gap, the proposed gap reduction measures, and the percentage gap before and after remediation measures are put in place. Operational issues are speculated to create the biggest gap between predicted and actual use, with a range of 30%-120% increase while Building Management Systems [BMS] and control audits to ensure the building is running efficiently only close this gap by 20%. This highlights that design simplifications, value engineering and building systems are not operating as designed nor are they correctly modelled due to wear and tear, maintenance issues or poor setup, which contribute to increased energy use and a disparity between predicted and actual energy cost. Gaps also arise between the building 'as designed' and the building 'as constructed' regarding continuity in achieving fabric values and airtightness.[67]

[f] Figure Source: Summary of Audits performed on Carbon Buzz by the UCL Energy Institute accessed at:/ <http://www.carbonbuzz.org/downloads/PerformanceGap.pdf>

Building Phase	Causes of the Energy Performance Gap	% of Gap	Energy Performance Gap reduction measures	Comments	% of Gap
Design	• Simplifications and inaccurate assumptions in design process • Design modelling naïve • Assumed perfect controls	≈ +10-20%	Assumptions in design process reflect real anticipated operation	• Feedback to briefing and early design is crucial. • Energy models reflects practice including use and the nuances in controls	≈ +0-10%
Construction	• Value engineering design changes and poor quality of construction • Contractor designed elements	≈ +10-30%	Implications of design changes on energy use considered	• Test proposed changes as to their effect on eventual building performance.	≈ +0-15%
Commissioning	• Inadequate or incomplete commissioning of systems • BMS controls not working as intended	≈ +15-30%	Systems are commissioned appropriately	• Complete and rigorous commissioning – in some instances seasonal commissioning	≈ +0-15%
Operation	• Systems not operated as intended/envisaged • Unmanageable complexity of systems • User over-ride of BMS • Poor energy management	≈ +30-120%	Buildings are managed for minimum energy use	• BMS and control audits to ensure once the building is running at its optimum & it stays there	≈ +0-20%
Accumulated increase in energy consumption [total]		**65% - 200%**	**Accumulated decrease in energy consumption [total]**		**0-60%**

Table 2.3 The nature of the energy performance gap: Contributing Factors and Reduction Measures. Sourced from the Green Construction Board Buildings Working Group.

While technical and design defects are currently recognised and contributory factors, the impact of occupants on energy performance is still not understood, and it is unclear to what extent the 'occupancy gap' contributes to the overall gap. Wilde *et al*.[10] have stated that due to current EPBD practices we are 'less well-placed to develop buildings that are resilient and robust toward further changes in use' and 'bridging the gap becomes even more necessary if the industry intends to "occupant proof" buildings.' Therefore, to deliver energy targets and resilient buildings, the occupancy aspects of energy performance need to be clearly identified, measured and verified against the design intent so that the building tenants can achieve their building's performance potential. A UK building's energy performance is reported through an EPC, as collated by Department of Energy & Climate Change [DECC] to portray national building sector emissions to the EU under EPBD and to be reported at an international level to the International Energy Agency [IEA]. The IEA reports on the pledge of 39 nationalities to slow international growth of energy sector emissions. While this is an effective tool for national reporting, it has proven ineffective in reducing energy use in practice. Janda and Yudelson suggest that 'Buildings don't use energy, people do',[64, 68]. Hence if we targeted the energy use of people while the building was in operation, this would give an alternative method of assessing BEP.

To understand the impact of tenants on BEP, we first need to know how 'occupancy' is considered within the construction industry and building regulation. Under current UK Building Regulation Standards, it is necessary to calculate the appropriate number of building occupants for normal circumstances, which assumes a maximum number of occupants facilitating the building at any given time. A building's occupancy levels and how a building is used can vary significantly over its lifetime. Within the context of the construction industry and building regulation, 'occupancy' refers to the use, or intended use of a building or part thereof by one or more occupants or tenants. An 'occupant' refers to a single person inhabiting a building at any one time, and a 'tenant' refers to a person or group of people who are leasing a building or part thereof. ‘Occupancy load factor’ (Table 2.4 b) and ‘occupancy capacity’ (Table 2.4 a) are terms defined in the Scottish technical handbooks to describe the number of building occupants and used for facilitating design requirements. Occupancy capacity is estimated by assigning an average floor area per occupant called the occupancy load factor. Relatively, the building occupancy capacity is calculated by dividing the building floor area in square meters by the occupancy load factor. The Scottish technical handbooks allocate an office occupancy load factor of $6m^2$ per person as a guide for safe passage in the event of a fire.[69] NCM Standard occupancy (Table 2.4 c) is used to determine the proposed energy performance of a building calculated and issued under an EPC, resulting in a narrow view of how the building will perform in operation. The current method of using a single *standard* occupancy pattern does not recognise that various tenant groups may differ in terms of occupied floor space, the number of full-time employees, patterns of operation and hours of use, which all have an effect on energy loads identified in Figure 2.2 and total building energy use. Moreover, a tenant’s occupancy pattern will have a direct effect on the operation and intensity of use of IT and HVAC equipment. Thus, the NCM method is a best-guess rather than a demonstration of predicted energy performance. BEP is specific to tenant usage patterns, and present-day energy performance evaluation in its current form is building-specific. Delivering energy assessment tools based on energy delivered by floor area does not allow for different tenants to compare their impact on BEP in operation.

Table 2.4 Occupancy terms and definitions

Term	Definition
a) Occupancy Capacity (persons)[69]	Calculation of the appropriate number of occupants in a building or each space for normal circumstances [calculated for building regulation purposes and the client's requirements]. The occupancy capacity can be estimated by assigning a floor area per occupant [called the occupancy load factor (m^2/person)]. The occupancy capacity of a room or space can then be obtained by dividing the area in square meters by the relevant occupancy load factor. [69]
b) Occupancy Load Factor (m^2/person)[69]	A designation of area per person (m^2/person) based upon fire safety regulation. It is used to determine a maximum 'occupancy capacity' by dividing the occupancy load factor by the overall square footage of a habitable area. The recommended occupancy limit for an office building is based on an 'occupancy load factor' of 6.0. [69]
c) NCM Standard Occupancy (standard m^2/person plus associated profiles)[70, 33, 71]	The NCM Activity Database provides 'standard occupancy,' temperature set-points, outdoor air rates, and heat gain profiles based on standard occupancy for each type of space in the buildings, so that buildings with the same mix of activities differ only in terms of their geometry, construction, building services and weather location. This makes it possible for the Section 6 compliance checks and EPCs to compare buildings by their intrinsic potential performance, regardless of how they are used in practice. The NCM 'Standard Occupancy' of an office is 9m^2 per person. [71]
d) Occupant Density[70, 33, 71]	A designation of square metres per person in the NCM BEM software SBEM used to determine the Occupant Load Average. 'Occupant density' can be designated either 'standard occupancy' or 'tailored occupancy.'
e) Tailored Occupancy	The occupancy capacity used to predict energy performance for building regulation and certification purposes reflects the occupancy capacity in use.
f) Occupant Load Average [72, 73]	Average predicted internal heat or power load due to occupants, lights and equipment [Watts] used to calculate heating and cooling requirements in BEMs.
g) Actual Occupancy Load[73]	Operational internal heat or power load due to occupants, lights and equipment [Watts] used to calculate tailored heating and cooling requirements in building BEMs to compare the energy use of HVAC in operation.
h) Occupant's Variations in 'Patterns of Use' [POU]	Referred to in the thesis as: Variations in a tenant's occupied floor space, the number of full-time employees, patterns of operation, hours of use and intensity of equipment use. All of which affects overall energy use and deviates from the 'standard occupancy' and 'Occupant Load Average' used in NCM and approved BEMs.
i) Occupancy Factors	Defined as variations in occupancy capacity, building hours of operation, IT and personal equipment, plug loads, server demand and the impact of these patterns of use on energy loads.

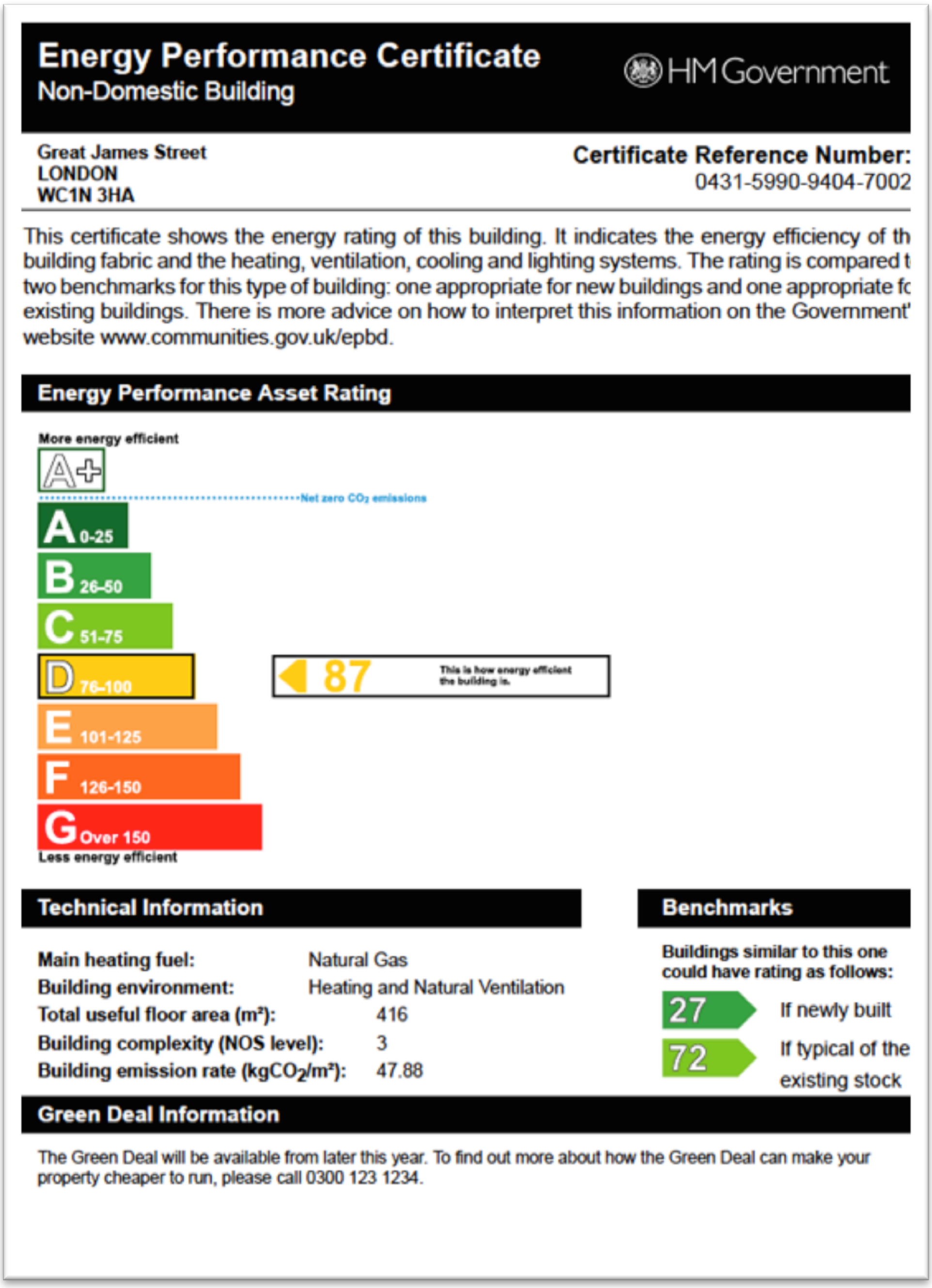
The building owner proposes a ‘standard occupancy’ determined by budget determining a specific number of occupants and ’standard occupancy’ is used to define the proposed energy performance of a building calculated by NCM and issued under an EPC. It would be of benefit if this could be adjusted to show how the building would perform under different usage pattern scenarios to better inform the tenant of their impact on BEP. Moreover, there is sufficient CIBSE guidance for all aspects of BEP except for occupancy factors (Table 2.4 i) and the impact of variations in patterns of use on BEP (Table 2.4 h). To understand the impact of occupancy on energy performance, we first need to define how the existing compliance framework operates.

2.1.1 Critical Evaluation of BEP Evaluation Methods

This section evaluates the limitations of the current BEP methods in including occupancy factors. Aspects under consideration are the limitations of (a) energy certification,[74] (b) Building Energy Management Systems, (c) the accuracy of energy models,[75-78] (d) energy performance guidance and (e) the designer’s remit. Limitations of building regulation calculation methods are discussed in Chapter 4.

2.1.1.1 Limitations of Certification

International energy accreditation methods such as Energy Star, Energy Performance Certificates and the National Australian Built Environment Rating System [NABERS] are primarily concerned with obtaining achievement through ‘a comparative label or a positive endorsement label.’[79] EU Energy Performance Certificates [EPC] and Display Energy Certificates [DEC] mimic international methods of displaying and comparing BEP rather than suggesting areas for improvement. In the UK, an EPC is a ‘communication tool that informs tenants or owners how the building is expected to perform’,[80] and is aimed at influencing demand for energy efficient buildings and owners to refurbish their buildings correctly.[80] An example of a UK EPC is shown in Figure 2.5. The certificate shows the energy rating of a



Energy Performance Certificate
Non-Domestic Building

HM Government

Great James Street
LONDON
WC1N 3HA

Certificate Reference Number:
0431-5990-9404-7002

This certificate shows the energy rating of this building. It indicates the energy efficiency of th building fabric and the heating, ventilation, cooling and lighting systems. The rating is compared t two benchmarks for this type of building: one appropriate for new buildings and one appropriate fc existing buildings. There is more advice on how to interpret this information on the Government' website www.communities.gov.uk/epbd.

Energy Performance Asset Rating

More energy efficient
A+
Net zero CO_2 emissions
A 0-25
B 26-50
C 51-75
D 76-100
E 101-125
F 126-150
G Over 150
Less energy efficient

87 This is how energy efficient the building is.

Technical Information

Main heating fuel:	Natural Gas
Building environment:	Heating and Natural Ventilation
Total useful floor area (m^2):	416
Building complexity (NOS level):	3
Building emission rate ($kgCO_2/m^2$):	47.88

Benchmarks

Buildings similar to this one could have rating as follows:

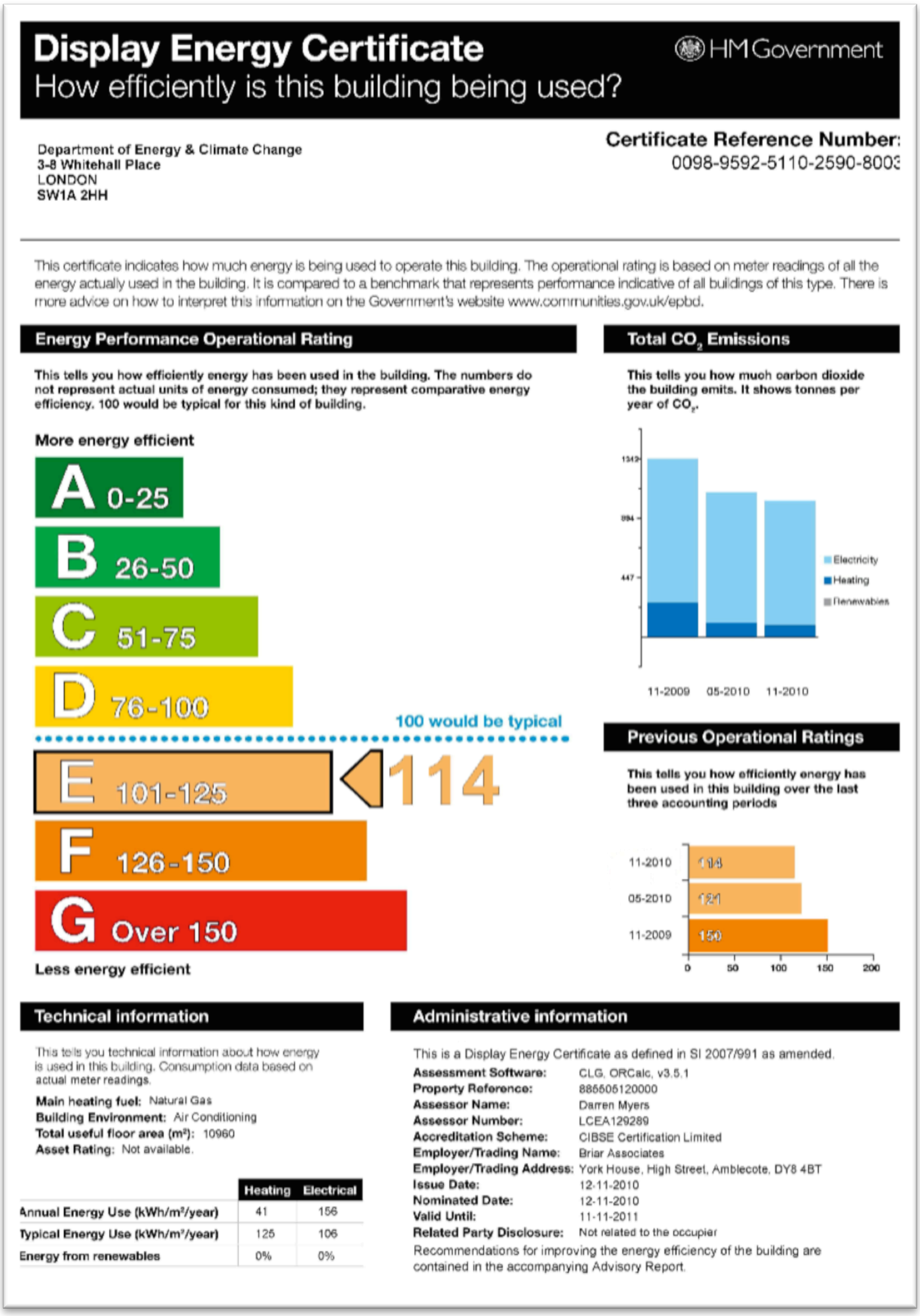
27 If newly built

72 If typical of the existing stock

Green Deal Information

The Green Deal will be available from later this year. To find out more about how the Green Deal can make your property cheaper to run, please call 0300 123 1234.

Figure 2.5 Example of an UK Energy Performance Certificate



Display Energy Certificate

How efficiently is this building being used?

HM Government

Department of Energy & Climate Change
3-8 Whitehall Place
LONDON
SW1A 2HH

Certificate Reference Number:
0098-9592-5110-2590-800?

This certificate indicates how much energy is being used to operate this building. The operational rating is based on meter readings of all the energy actually used in the building. It is compared to a benchmark that represents performance indicative of all buildings of this type. There is more advice on how to interpret this information on the Government's website www.communities.gov.uk/epbd.

Energy Performance Operational Rating

This tells you how efficiently energy has been used in the building. The numbers do not represent actual units of energy consumed; they represent comparative energy efficiency. 100 would be typical for this kind of building.

More energy efficient

A 0-25
B 26-50
C 51-75
D 76-100

100 would be typical

E 101-125 — 114
F 126-150
G Over 150

Less energy efficient

Total CO_2 Emissions

This tells you how much carbon dioxide the building emits. It shows tonnes per year of CO_2.

Previous Operational Ratings

This tells you how efficiently energy has been used in this building over the last three accounting periods

Technical information

This tells you technical information about how energy is used in this building. Consumption data based on actual meter readings.

Main heating fuel: Natural Gas
Building Environment: Air Conditioning
Total useful floor area (m^2): 10960
Asset Rating: Not available.

	Heating	Electrical
Annual Energy Use (kWh/m²/year)	41	156
Typical Energy Use (kWh/m²/year)	125	106
Energy from renewables	0%	0%

Administrative information

This is a Display Energy Certificate as defined in SI 2007/991 as amended.

Assessment Software: CLG, ORCalc, v3.5.1
Property Reference: 885505120000
Assessor Name: Darren Myers
Assessor Number: LCEA129289
Accreditation Scheme: CIBSE Certification Limited
Employer/Trading Name: Briar Associates
Employer/Trading Address: York House, High Street, Amblecote, DY8 4BT
Issue Date: 12-11-2010
Nominated Date: 12-11-2010
Valid Until: 11-11-2011
Related Party Disclosure: Not related to the occupier

Recommendations for improving the energy efficiency of the building are contained in the accompanying Advisory Report.

Figure 2.6 Example of an UK Energy Performance Certificate

building compared to two benchmarks for a similar type building. Figure 2.6 shows an example of a UK display energy certificate [DEC]. The first benchmark compares the predicted Asset Rating to a newly built building with similar characteristics, concerning regulated building activities and building area. The second benchmark provides a comparison of building energy efficiency with regards to a typical existing building that was built in a similar year. This certificate is valid for ten years and must be finalised before the building is inhabited. Non-domestic EPCs have been around since 2008 and are required if a new property is within a particular area, or when letting or selling a building. The requirements of an EPC are highlighted in Figure 2.7.

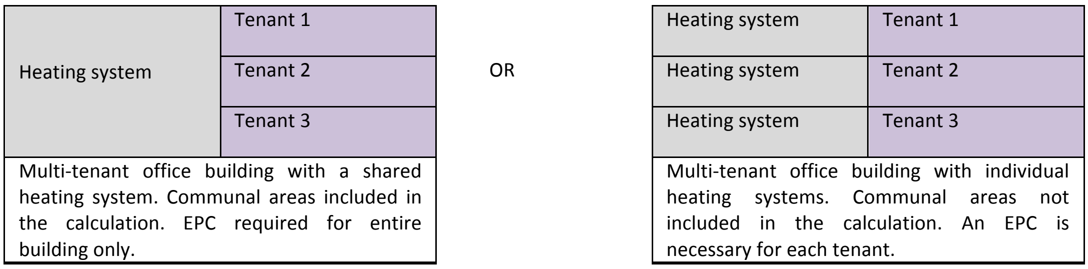


Figure 2.7 The current EPC requirement options for a multi-tenanted office building.[7]

'An EPC for a simple unit within a building may be based on an assessment of a similar representative unit or apartment in the same block.' [39] Therefore, the evaluation is a speculative estimate rather than a client specific evaluation. Moreover, it depends on how many different tenant groups a building can accommodate. The effectiveness of this method to deliver EU energy reduction targets has been called into question. The Concerted Action EPBD working group published reports[81] on the weakness of the EPBD recast and certification, highlighting issues including:

- Only 50% of building owners or tenants regard competitive EPC ratings an

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[7] Figure Source: Adapted from 25. [EU]., E.U., *Impact Assessment (IA) Recast of the Energy Performance of Buildings Regulations*, Department for Communities and Local Government, Editor 2012, EU: Department for Communities and Local Government.

advantage.[82]

- Financial savings and potential impacts of measures are not realised due to the lack of proper monitoring and feedback of procedures.[83]
- The detail of EPCs is very general regarding energy audits preventing them from being used for funding applications or comparison to monitoring exercises.[80]
- Mandatory uptake of both a certificate for part building occupation and full building occupation options has been abated by the financial implications of providing more than one report.[83]

Therefore, EPBD legislation is seen as a front-end tool to inspire building owners and tenants to be more energy conscious through financial gain. However, the lack of proving the performance of a building in use in comparison to regulation and compliance calculations has undermined the directive and building regulation. Besides, any financial gain from saving energy is marginal and is further offset against the cost of implementing, monitoring and incorporating EPC recommendations for building improvements to fabric and building HVAC systems.

DECs differ from an EPC in that they display only the operational rating of the building from the last year and are only required if the whole of a building or part thereof is designed or altered to be used as a public building. DECs are displayed with an aim to raise public awareness of energy use.[19, 36] Two types of ratings are used as a means of determining certification: (a) the asset rating based on building data derived from building inspections, drawings and building specification and (b) the operational rating based on actual metered data. The ratings are typically used independently. Characteristic asset ratings are used for new buildings, and operational ratings are used for existing buildings, which prove more complex in operation, with differences occurring between calculating compliance and rating criteria.[67] Moreover, EPC *ratings* differ from DEC ratings even though they use the same rated values; on an A to G scale. However, while the scales look comparable, this does not mean that a building will operate on the same energy efficiency or at reduced CO_2 emission levels. The baseline criteria for certification and compliance are very different, resulting in buildings, which in principle can achieve the same reduction in emissions, while achieving different EPC and DEC scores. Also, compliance calculations are also referenced against a notional building, which allows regulations to evolve to achieve greater efficiency, while technology and techniques improve. However, EPCs are assessed against a reference building based on building type. This makes the process of regulation confusing, resulting in a discredited compliance and rating systems.[67] This supports the opinion of the construction industry that energy efficiency recommendations rather than ratings mobilise the market to deliver energy saving measures.[79, 84] Therefore, there is scope to reassess the rating systems and how they are applied throughout the design process and building life. Pérez-Lombard *et al*. reviewed benchmarking, rating and labelling concepts,[74] highlighting three key limitations:

1. Asset rating calculations are based on standard usage patterns and climatic conditions.
2. Asset ratings do not consider tenant behaviour, actual weather and indoor conditions.
3. Asset ratings are designed to rate the building and not the occupant.

It is readily observable that irrespective of a tenant's patterns of use variations in occupancy[85], associated with energy use patterns and hours of operation, will result in EPCs with generic energy ratings whether a building is efficiently operated or not. Similarly, DECs may allow for a more useful review of year-on-year building performance; they cannot be used to determine if the building is achieving the design intents speculated performance due to differences in how performance is calculated. Various UK building energy certification scheme energy ratings are defined in Table 2.5. The information provided in the table confirms the diversity and (current) characteristics of each of the energy rating methods and highlights scope to synthesise and improve the approaches. All ratings shown in the table are based on building energy use.

Table 2.5 Definitions of Energy Ratings. Adapted from A review of benchmarking, rating and labelling concepts within the framework of building energy certifications schemes. [74]

Rating Method	Rating Type	Rating Subtype	Based on	Pattern of use	Project stage
EPC	Asset [standard]	Design	Calculations	Standard	Design
EPC	Asset [standard]	As built	Calculations	Standard	Built
TM54*	Tailored	Design	Calculations	Non-Standard	Design
Green Deal*	Tailored	As built	Calculations	Non-Standard	Built
DEC	Operational [measured]	As built	Metered data	Actual	Built
*Please note TM54 and Green deal are just guidance tools.					

Mandatory monitoring and certification has been implemented by the Danish Energy Authority since 1997.[79, 86] Problems highlighted include complications in adopting a uniform certification system and benchmarking through a comparison of building types, which have been difficult to implement due to the complexity of the system. Moreover, if certification and monitoring could be tested against design intent, there would be no need to compare building types and delivered performance could be used to drive energy efficiency rather than inaccurate, partially calculated building ratings. For example, if a combined asset and operational rating equate to a proposed 75% reduction in energy based on 2008 standards by 2020 (without benchmarking criteria), it is reasonable to expect further reduction with occupancy benchmarks in place if deliverable performance is the key driver. Furthermore, if tenant energy use goes up to 70% of the overall building use, then incorporating tenant behaviour and the impact of occupancy factors on BEP could be considered as part of the certification and rating system to improve energy efficiency. Pérez-Lombard *et al*. predict that 'Intelligent tools capable to automatically explore different options and even to select an optimum are part of the coming future. Meanwhile, results based analysis tools to guide the user in the improvement process could be of great help'.[74] These tools should incorporate 'scale sensitivity' and 'the ability to improve the energy label of a given building',[74] with the result being an improved energy performance and energy saving. Furthermore, this highlights the lack of an analysis tool that building users can use to judge improvement measures and an integrated sensitivity analysis, which can be utilised throughout the building lifecycle.

2.1.1.2 Limitations of Building Energy Models

Energy Certification alone does not result in lower energy consumption; other measures are needed to support reduced energy demand.[79, 87] This section explains the limited scope of the NCM BEMs with consideration to the effect of occupancy on energy performance and how energy loads associated with 'occupant density'[8] (Table 2.4 d) are calculated and how NCM calculations are limited to predicting building energy usage patterns for a 'standard occupancy' or 'tailored occupancy' (Table 2.4 e) profile. The Scottish Building Standards Agency has employed advanced building energy modelling and simulation tools in a pragmatic approach to determine the impact of building upgrades and renewable energy systems within a generated Energy Model for use as a policy tool.[88] This model establishes a rated carbon performance of individual dwellings under the EPBD. Existing policy-related tools that rely on simple calculation methods have been shown to have limited ability to representing the dynamic interconnectedness of technology options or the impact of future changes in occupant behaviour.[88, 89] Table 2.6 defines and compares the attributes of commercial, research and compliance based building energy simulation software tools.

[8] A designation of a square meter per person in the NCM BEM software SBEM used to determine the Occupant Load Average. 'Occupant density' can be designated either 'standard occupancy' or 'tailored occupancy.'

Table 2.6 A Comparison of Building Energy Simulation Software Tools, adapted and sourced from 'Energy Simulation Software for buildings: Review and Comparison' Joana Sousa, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal. [90]

Calculation Method	**SBEM**	**ESP-r**	**IDA ICE**	**Energy Plus**	**IES***	**TRNSYS**
Quasi-steady state calculation	X					
Monthly energy balance and annual energy results	X					
Dynamic Building Simulation		X	X	X	X	X
User-specified time steps		X	X	X	X	X
Simulation Solution						
Simulation of loads, systems and solutions	X	X	X	X	X	X
Iterative solution of nonlinear systems	X	X	X	X	X	X
Extent of Time Calculations						
Variable time intervals per zone for interaction of HVAC		X		X		
Simultaneous selection of building systems and user	X	X			X	X
Dynamic variables tested		X	X	X		
Variable time intervals per zone for occupancy factors		X				
Variable time intervals per zone for climate control systems		X		X		
Complete Geometric Description						
Walls, roofs and floors	X	X	X	X	X	X
Windows, skylights, doors and external cladding	X	X	X	X	X	X
Building geometry imports from CAD software	X	X	X	X	X	X
Building geometry exports from CAD software		X	X	X		
Import/ export of simulation model programs	X	X	X	X	X	
Thermal balance calculation	X	X	X	X	X	X
Internal thermal mass	X	X	X	X	X	X
Human thermal comfort	X	X	X	X	X	X
Solar analysis				X		X
Analysis of Isolation	X	X	X	X	X	X
Advanced Fenestration	X	X	X	X	X	X
General building calculations	X	X		X	X	X
Surface temperature of zones	X	X	X	X	X	X
Airflow through the windows	X	X	X	X	X	X
Driving surfaces	X	X	X	X	X	X
Heat transfer from the soil	X	X	X	X	X	X
Thermo-physical variables			X			
Day-lighting and lighting controls	X	X	X	X	X	
Infiltration of a zone	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients	X				X	
Natural ventilation		X	X	X		X
Natural and mechanical ventilation	X				X	
Control of openings for natural ventilation		X	X	X		X
Air leaks in multiple zones		X	X	X		X
Electrical Systems and Equipment						
Energy production through renewable energy		X		X		X
Distribution and management of electric power loads		X		X		X
Electricity generators				X		X
Network connection		X		X		X
HVAC Systems						
HVAC idealised	X	X	X	X	X	X
Possible configuration of HVAC systems	X	X	X	X	X	X
Repetitions of air cycles	X	X	X	X	X	X
Distribution systems	X	X	X	X	X	X
Modelling CO_2	X		X		X	X
Singular distribution of air per area	X	X	X	X	X	X
Forced air unit per zone	X	X	X	X	X	X
Equipment unit	X	X		X	X	X
Climate Data						
Monthly climate data of 14 UK cities	X					
CIBSE Test Reference Year and Design Summer Year		X			X	X
Orientation						
8 orientations [N, S, E, W, NW, NE, SW, SE]	X					
Unlimited orientations		X	X	X	X	X
*IES also represents TAS and HEVACOMP software as they fundamentally are aligned to a dynamic simulation tool used for compliance calculations and certifiable outputs.						

These tools differ in capabilities and approach [Table 2.6] to simulating energy performance and the user interface. For example, some allow you to create a geometric model together with the mathematical model and others vary in calculation scope. The main difference between the UK NCM calculation tool, SBEM and alternative building energy models is that SBEM is a quasi-steady state calculation. It calculates monthly energy balance and annual energy results, while other energy models are capable of more detailed dynamic simulation of user-specific time-steps down to minute intervals. Moreover, research-oriented tools (Table 2.6) that are capable of demonstrating the impact of occupancy factors on energy use are limited and deemed unsuitable for direct use by policy-makers, practitioners or building occupiers; adopting occupancy principles has not been indoctrinated in BEP legislation and abated by BEP implementation costs. Thus, modeling tools with the exception of ESP-r, do not provide a method of reviewing occupant's variations in POU. Figure 2.8 illustrates the key steps NCM methodology for predicting and reporting BEP for office buildings. The NCM utilises a building energy model to calculate expected building energy loads. The calculations of the actual building are compared to the performance of a notional building of size, typology and expected performance in line with building regulations of that period. If the actual building performance is better than the notional building, the energy performance of the building is approved by building control. The outputs of the study are recorded in a report submitted to building control and in an EPC. This is then given to the building tenant as a record of the buildings expected performance. The EPC is revised either after ten years or if improvements measures have been carried out to the building increasing the building's performance and marketability. Building energy models provide a limited scope for comparing the design data to actual monitored data when a building is in operation.

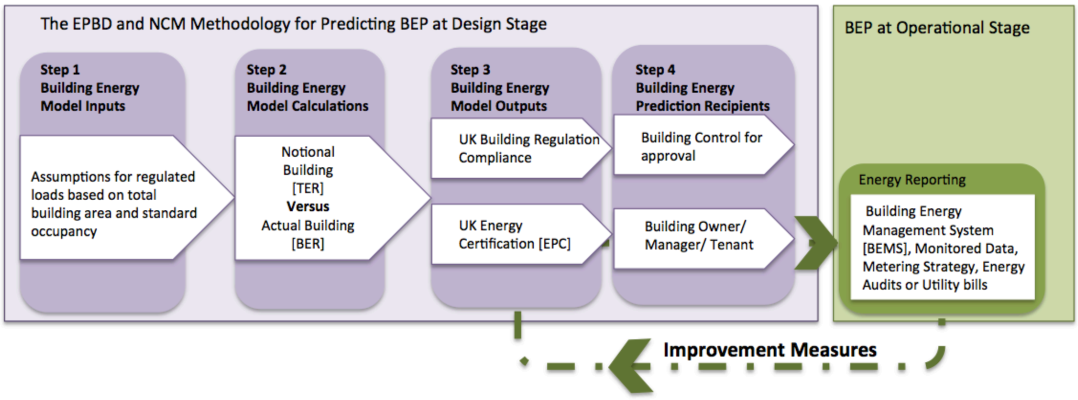


Figure 2.8 UK method for predicting and reporting energy performance.

SBEM is primarily a compliance tool rather than a design tool for variations in operating conditions to be considered. As such, predicted performance does not necessarily meet the tenant's energy performance aspirations. Tenants' primary concerns are annual utility bills, savings on consumption year on year and how savings can be used to invest in assets. Tenants and clients need to understand the implications of the brief through the transparency of the calculations and statements of design assumptions to understand how the building will perform under their influence. The current system compromises tenants if calculations are wrong. Definitive figures are dangerous for designers due to a threat of litigation and financially for tenants. It is important to highlight the sensitivities of the building in operation to the users so they can fairly assess their personal performance. Supporting the hypothesis that there is a gap for a new method to be created whereby variation in POU are considered and scope for the existing NCM tools to be redesigned.

An SBEM or approved dynamic simulation model is used to predict the BEP of office buildings in the UK. Some usage patterns that affect energy demand are standardised to regulate and compare energy use. These include; heating and cooling set points during occupied or unoccupied hours, ventilation and infiltration rates, lighting levels, standard occupancy day schedules [weekday, weekend and holiday profiles], hot water and heat gains, occupants' appliances and lighting]. Standard activities are predefined in the NCM database, which applies a rule of thumb, for occupant densities and the associated internal room heat gains, with factors representing a standardised intended usage pattern rather than physical design constraints.[91] These profiles are intended to be typical and do not attempt to represent variations that may exist between tenants. To carry out this analysis, the latest version of SBEM (iSBEM_v5.0.c) was reviewed. This software was previously used to conduct Part L 2013 Building Regulations Compliance check, EPC and Green Deal Assessment.[92] When an SBEM user assigns an activity to a room or space, this automatically assigns parameters within the activity space, to include; occupant density [Figure 2.9] and associated gains, which are prescriptive.[91] The limited scope of the NCM methods allows for prediction of a tailored energy use profile. Moreover, a tailored profile is a successful way of predicting and monitoring energy use if the building and the behaviours of building tenants are known and are effectively managed by a building energy management system. 'Standard occupancy' is the most common method of estimating building performance, as the actual nature of the tenancy is not always known at the design stage. Both standard and tailored profiles can be calculated within SBEM and the outcome documented in an EPC, for reference when the building is operation. However, assumptions regarding (a) occupancy capacity and (b) hours of operation parameters entered into SBEM to determine a building energy loads are not recorded or published in an EPC. Fundamentally, a lack transparency calculating energy performance and EPC results makes it difficult to reference design data once the building is handed over and ensure the building is functioning as intended. As such, understanding or comparing BEP when the building is in use is problematic unless an energy assessor, facilities managers or building tenant were actively involved with the building design process and know the parameters chosen to demonstrate their buildings operation performance.

SBEM (iSBEM_v5.0.c) enables redefinition of a buildings baseline assessment to include more accurate operational data and appropriate green deal measures. Allowing a precise definition of the actual operating regime as opposed to the design intent submitted for building control compliance. Operational data can be tailored to include detailed observations of occupant density, airflow rate and daily schedules, etc. of occupancy for previously specified activity areas within the building model, as shown in Figures 2.9 and 2.10. Although a more detailed assessment of occupancy can be carried out compared to previous SBEM versions, it is still very limited and does not allow for an accurate portrayal of tenant usage patterns. For example, the tool does not allow for different occupancy profiles for different days of the week, even though weekend usage patterns could vary substantially from weekday use. Currently, this energy model cannot be used to evaluate the impacts of the occupancy load factor (referred to as occupant density) on energy efficiency, as SBEM (iSBEM_v5.0.c) is specifically tailored to improving the performance of buildings through green deal measures.

Although it allows a comparison between 'as designed' and 'as managed', SBEM was not intended as a design tool; therefore, it does not simulate the effect of variations in POU between tenants, occupancy capacity or hours of operation preferences on BEP. SBEM (iSBEM_v5.0.c) calculates building energy efficiency based on energy delivered by floor area and total BEP, creating a barrier to measuring the effect of individual tenants, who through variation in user preferences, may vary in intensity of energy use. The calculation '*factors in'* occupancy gains on a monthly basis, regarding kW.h/m^2, for inclusion in the overall building energy performance rating. The tailoring function in SBEM (iSBEM_v5.0.c) allows different densities to be compared for energy efficiency measures. Thus, SBEM simulates the effects of hourly weekday occupancy, however, if the tool analyses energy efficiency on kW.h/m^2 per year, variations in occupancy has little or no effect on the calculations output. In conclusion, the primary purpose is of the current SBEM (iSBEM_v5.0.c) is to indicate if Green Deal measures will improve BEP. Furthermore, the tool was reviewed to identify *if* SBEM is capable of conducting these calculations in its current form and it has been shown to be incapable at present.

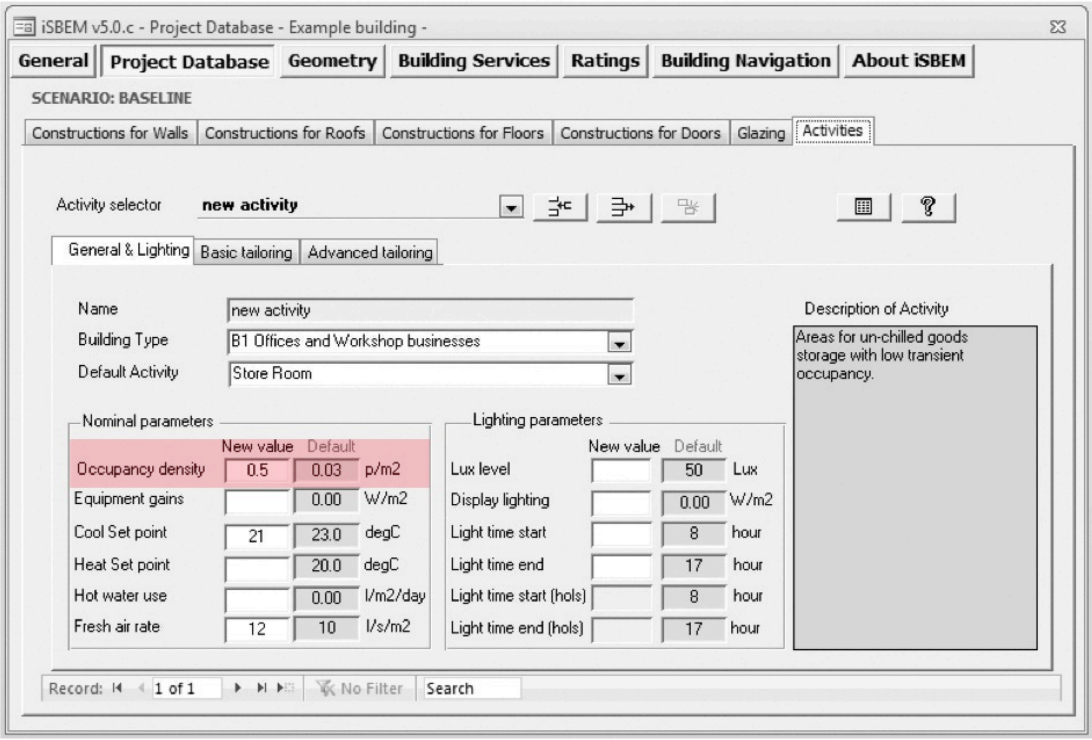


Figure 2.9 Illustrates how occupant density is articulated in SBEM.

The impact of occupant density and its relation to BEP is not depicted as a tool output. Therefore the tool is not capable of illustrating that a building will (i) perform over a range dependent on tenant usage patterns or (ii) perform when the building activities are out of range. Overall, the method of representing improvements is too generic (Figures 2.10 and 2.11). Moreover, this demonstrates that a BEP range under different user profile scenarios would enhance and strengthen the non-domestic tool.

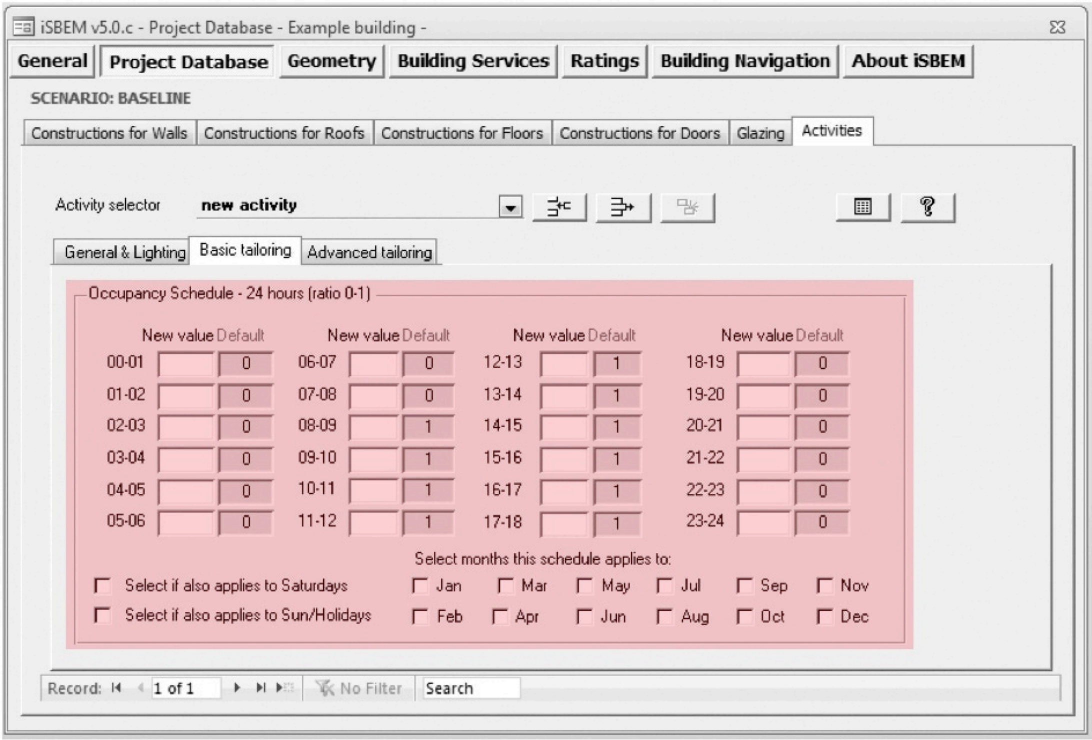


Figure 2.10 Illustrates limited representation of the occupancy in SBEM.

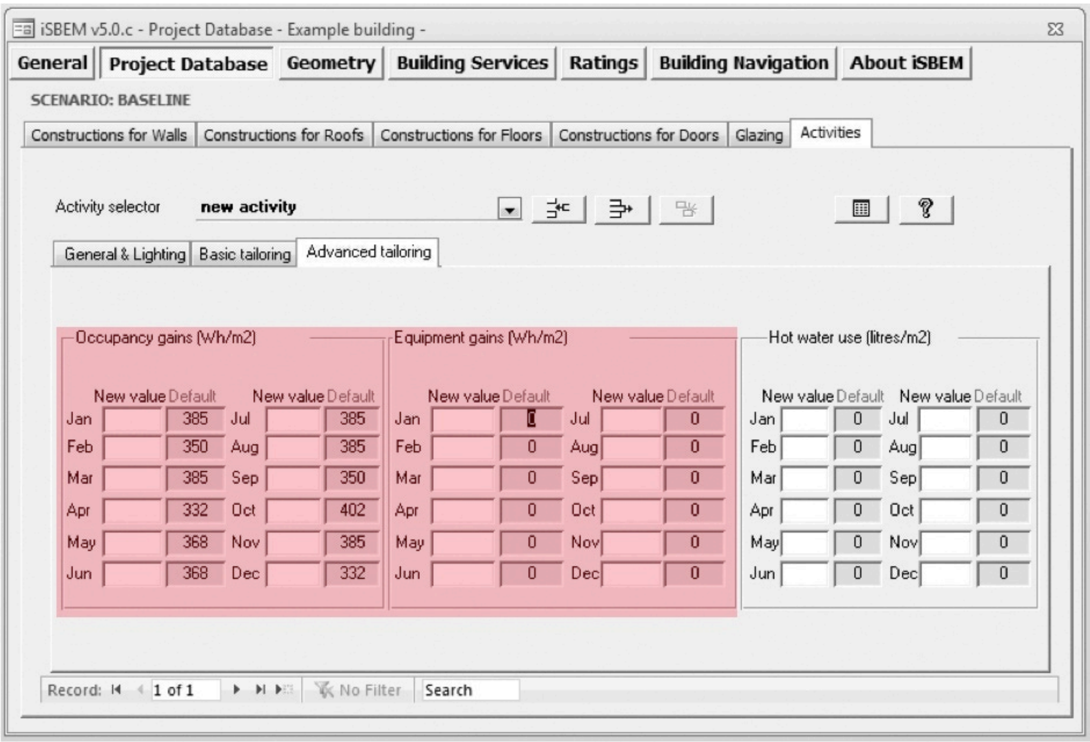


Figure 2.11 Illustrates further limited representation of the occupancy in SBEM.

The SBEM (iSBEM_v5.0.c) assessment advice report consists of two parts: the EPC and the tenant assessment. Therefore, the tenant assessment is an evaluation of the building as managed against the asset rating submitted for design compliance purposes. A new assessment could include detailed energy data from monitored data or energy bills if available. Furthermore, SBEM (iSBEM_v5.0.c) could incorporate variations in occupant density and hours of operation in the baseline analysis to simulate changes in POU between building tenants for more accurate energy load profiling. There is, therefore, the potential for the tool to be altered to allow tenants to evaluate the building area under their control and allow a breakdown of building activity energy use to highlight potential operational problems. The next section discussed the limitations of building management systems.

2.1.1.3 Limitations of Building Management Systems

Building Management Systems [BMS] or Building Energy Management Systems [BEMS] are used to manage BEP. BEP certification is issued to the building tenants or facilities manager following the establishment of the BEM, which informs building regulation compliance and building certification. BEMS are computer-based systems that help manage, control and monitor building technical services, and the energy consumption of devices used by the building that can be accessed over the internet. The main selling point of BEMS is greater control and comfort together with cost savings.[93] Moreover, they provide the information and the tools required by building managers to understand the energy usage of their buildings and to control and improve their buildings' energy performance.[94] BEMS monitor the operation of HVAC equipment throughout the building, to include boilers, pumps, fans, motors and lighting. Through sensors and controls, they can respond to changing conditions in temperature, lighting levels and hours of operation. If managed correctly, BEMS are capable of reducing energy costs by up to 10%.[94] However, BEMS are only effective if the people who manage them know the system. Furthermore, they require regular maintenance of the sensors, [95] actuators and controllers[93] to optimise the energy efficiency of monitored building activities. In this regard, it 's hard to understand a subtenant's individual impact and how significant savings can be made on energy bills, as subtenants often do not have control of BEM. Building occupiers also need the resources and expertise to manage and maintain a micro-BEMS system. Furthermore, BEMS provide increased energy data. However, current automation systems are poor in generating actionable energy data to end-users.[96] Sensors have been used to measure occupancy levels with an estimated accuracy of 87% for a single-person and 78% in a multi-person office.[97] An average occupancy energy use can be calculated by dividing the total energy use by the predicted number of building occupants to give a kW.h/FTE. However, this will vary between occupancy groups and would not benefit a subtenant, unless it could be applied to their independent energy use and be comparable in terms of energy use per m^2 and energy use per person for self-assessment. Nonetheless, BEMS have not been used in tandem with occupancy related energy forecasts, which could assist in defining whether or not high-energy usage patterns are correlated with high occupancy levels. Moreover, occupancy factors could hypothetically be adapted into certifications and BEMS systems, thereby identifying a further research gap that can be used to assess the importance of the impact of occupancy factors on energy performance data to the end user and how this should be integrated into existing procedures. Beyond the practical approaches of BEP tools, there is a wealth of UK national guidance on energy performance measures provided by CIBSE that support the building services industry and provide energy assessment methods by which the industry can calculate and report energy performance.

2.1.1.4 Limitations of Guidance

The UK Chartered Institute of Building Services Engineers [CIBSE] provides energy benchmarking guidance in support of UK building regulation. This guide is also used to help building designers, owners and facilities managers to monitor their usage under EPBD legislative requirements. The guidelines that relate to energy benchmarking are TM46 Energy Benchmarks, TM22 Energy Assessment and Reporting Method and TM39 Building Energy Metering. CIBSE states that:

> ‘Benchmarking is a comparison of the energy consumed within a building to industry-standard benchmarks from similar buildings within the sector. The simplest benchmarking compiles kW.h per annum (p.a.), or kW.h/m^2 p.a. for each fuel used in the building (e.g. gas and electricity) and compares this with industry-standard benchmarks, such as those found in CIBSE TM46.'

and

> ‘Some benchmarks, such as those found in CIBSE Guide F,[98] which provide a breakdown by end-use. Provided each of these items was sub-metered then a direct comparison could be made such that the actual kW.h used for lighting versus the ‘good practice’ and ‘typical’ benchmark values for lighting. In particular, within existing buildings, there is often no sub-metering by end-use, so it is simply the heating fuel and electricity figures that are compared with the benchmark’.[34]

This approach is based on 100-year-old energy benchmarks and is basically out of date.[98] The benchmarks are based on building area and compare similar buildings that are useful at a national level to aid government policy. However, they do not give accurate benchmarking of the building's design intent, which the building could be assessed against. The use of ‘tree diagrams’ (Figure 2.12) is promoted as a good way of analysing BEP and service provision; however, these support kW.h/m^2 as their preferred metric. Also, hours of operation are considered, but there is no consideration as to how different occupancy usage patterns affect overall performance or individual building activities, such as lighting and ventilation. Therefore, accurate sub-metering and detailed analysis of energy consumption patterns are essential for efficient building management, but they do not personally engage building users to reduce consumption patterns, as they cannot measure the impact personal usage.

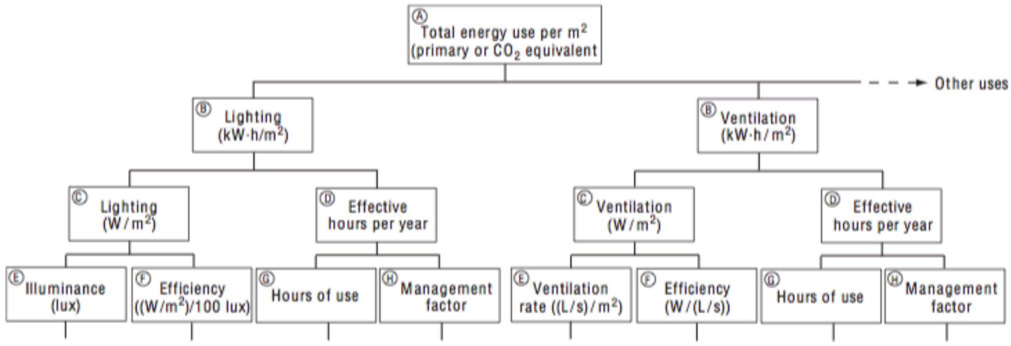


Figure 18 Analysis of building energy consumption and service provision (reproduced from CIBSE TM22[(4)])

Figure 2.12 Analysis of building energy consumption and service provision [sourced from TM22]

2.1.1.5 Limitations of the Designer's Remit

Typically, 'how the building has been designed' is poorly documented. This results in detailed POE exercises being compared against a set of unrealistic baseline data. Furthermore, documentation of design changes such as occupancy levels, operational times and operational requirements, utilisation of spaces, equipment and specification of equipment, the performance of M&E equipment and building fabric all affect the validity of BEP data. Collecting data is expensive and can be ineffective unless the data is relevant, informative and helpful. Therefore, accurate contextual information of how the building compares between 'as designed' and 'as constructed' is key to attaining a clear indication of how the building should perform in operation. Currently, there is no requirement for the design team to accurately define changes to BEP benchmark criteria, as POE is not enforced through the RIBA POW and is not always carried out by the design team as part of the building contract. This results in a disconnected design process in which it is unclear who should conduct and pay for POE.

2.1.2 Occupancy Case Studies

This section critically evaluates case studies relating to (a) offices and (b) occupancy, to identify and articulate the knowledge gap that is to be investigated in this work. The Post Occupancy Review of Building Engineering [PROBE] studies[99-102] refer to a seven-year research project funded, in 1995, by the UK Government and The Builder Group [now the CIBSE journal] and carried out by the Energy for Sustainable Development, William Bordass Associates, Building Use Studies and Target Energy Services. CIBSE demonstrated through 23 PROBE case studies that POE 'is a proven tool for delivering better building performance and value for money.'[103] The first case study, PROBE 1, measured actual energy use against industry benchmarks. Five subsequent office studies have examined if the office Building Performance Evaluations have met expectations and have been carried out correctly to provide insight into assessing building performance.[104] Furthermore, the studies engaged with occupants through POE surveys. However, the approach varied from prior POE exercises and focused on the likes and dislikes of users. This was done in three ways:[102] (a) each office was benchmarked in comparison with the other PROBE studies, (b) the survey was combined with energy reports, occupiers' activities and details of how the building was designed and managed, and (c) the results of the known buildings were published. The report results indicated that POE could deliver data on running costs, energy use, space utilisation and maintenance through feedback and not just occupant comfort or satisfaction. Moreover, the energy use of 16 buildings fluctuated over a massive range when measuring energy use per square metre or if the energy use was expressed per tenant for the building, which had a greater variation. The study concluded that energy use delivered by a unit of area was a more reliable benchmarking measurement than occupancy until an industry standard that separated area and occupancy into assessable amounts could be agreed. A suitable method to improve regulation and the design process through to in use has not been considered since 2001. The only benchmarks relevant for offices are to be found in the Energy Consumption Guide 19, ECON 19.

The PROBE studies attribute increased energy use to extended hours of operation, unregulated loads [not considered in the design estimates] and subordinate operational efficiency of HVAC equipment. A relationship between peak occupancy and increased energy use was not deemed significant over the portfolio of buildings. However, this was before onerous regulation of insulated envelopes and advancement of technological equipment and stresses on servers [which may also have an impact on energy use patterns].

The UK launched the TSB Building Performance Evaluation [BPE] programme[105] of 101 domestic and non-domestic case studies to address the performance gap in new buildings in 2010, following these studies. The TSB BPE programme[105] researched the causes of underperformance across all building sectors over a period of five years. This was to define methods applicable to help close the gap in future. The programme highlighted the 'poor or non-existent visibility of total operational energy use during design and fit-out.' It was found that buildings were routinely handed over with a limited assessment of how they would perform in use. Moreover, energy intensive equipment was being installed without question. Quantitative evidence was collated for the BEP; a split of regulated and unregulated loads and a split between electricity consumed within hours of operation and 'out of hours'. The study data illustrated that emissions for office buildings ranged between 2-3 times the predicted performance, unregulated loads accounted for between 25% and 65% of total energy consumption, and out of hours electricity accounted for 45% of the daily use. However, this last point was not considered in current energy performance calculations. Thus, future methods of assessing BEP should include unregulated loads and record the nature of 'out of hours' operation. Besides, the BPE programme identified that rigorous collection of data was needed to inform design, modelling and benchmarking, which could lead to improved BPE through feedback to briefing and operation.[65] The 2050 Low Carbon Construction Route-map for the Built Environment[5] and EPBD[24] suggests that all new private and public buildings must be nearly zero-energy by 2025. Therefore, methods to enable feedback and evaluation of virtually zero buildings need to be realised and delivered within ten years.

The Innovate UK Building Performance Evaluation programme[21] monitored the building performance of 48 non-domestic projects. The study disclosed problems monitoring energy performance within building management systems due to (i) the systems being installed as a tick-box exercise to comply with building regulations rather than provide sufficient information that would be useful to the building user, (ii) problems configuring and optimising the system, (iii) reports of building heating and cooling systems fighting each other, (iv) lack of clarity to monitor energy use and intervene in problems associated with building controls and management practices, and (v) the monitoring system working on simplified averages creating difficulties for the facilities manager to interpret or gain anything meaningful from the performance data. The report presented more problems than solutions; highlighting issues evaluating building performance, such as:

- Building logbooks and building user guides presented at handover stage were bulky documents with no clear focus and not given to tenants.
- Difficulties proving that the building has a defect in operation due to the complexity of evaluating building management systems and equipment in operation.
- Energy meters are often difficult for non-specialists to monitor and interpret.

Furthermore, the disconnect between energy monitoring, building management systems and the ability for building users to understand complex systems makes the realisation of energy performance evaluation worse. Austin speculates that ‘We can only indicate the order of magnitude of the variations and which are first order and high priority areas to address in the design construction and operation of buildings.'[65] However, there is a lack of research that looks at how variations occur between tenants and what the key priorities are to deliver low-energy buildings for both building designers and building users. As part of the TSB Retrofit for future projects, a report was published on tenant-centred retrofit; engagement and communication,[106] which details lessons learned from engaging and communicating with housing tenants after installing new technology for improving energy performance. The report identified that 'landlords and designers have a responsibility to help tenants understand technology to achieve energy reduction measures.' Moreover, 'feedback is crucial for ensuring systems are fit for purpose' and 'collaboration in monitoring and evaluation is key to understanding and sustaining the energy-saving performance'.[30] The TSB study established that different users, within similar households, had very different patterns of use and internal temperature preferences. Moreover, unrealistic baselines, systemic in UK NCM assessment tools, result in poor energy predictions and poor performance that disengages the user. An alternative is to 'profile tenants' behaviour patterns to set a more realistic baseline. A method of 'profiling tenants' behaviour' and its impact on unregulated energy use, together with 'out of hours operation' would be of use to engage occupants in using the building as intended and also provide useful feedback to designers. Agha-Hossein *et al*.[107] studies showed that lighting sensors and a building management system to helped reduce energy consumption, however, the actual energy use was still three times that of the predicted calculations. This gap in measurement was partly qualified, as unregulated loads were not accounted for in design calculations. To overcome this, Agha-Hossein *et al.*[107] suggest operating hours, accounting for occupant-related energy use and better space utilisation could also reduce consumption.

Menezes et al.,[45] carried out a study in 2012 investigating the relationship between occupancy profiles and electricity demand. A comparison of predicted and actual energy performance, together with occupancy levels, was reported from half-hourly office walkthrough's.

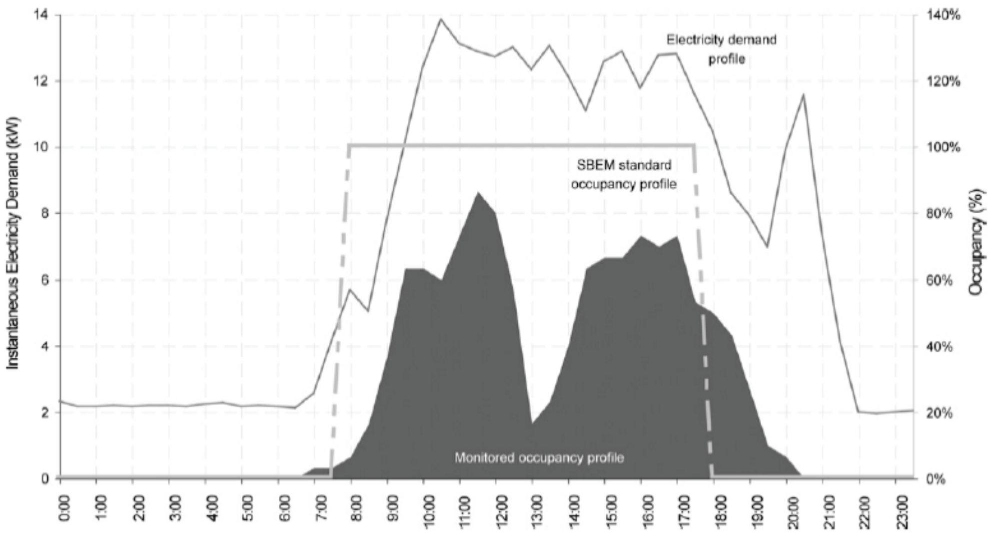


Figure 2.13 24-hour comparison of electricity demand and occupancy profiles.

Figure 2.13 indicates that SBEM 'standard' occupancy profile is in no way representative of the monitored occupancy profile of the office. The aim of the analysis was to assert the effectiveness of predictive modeling tools in predicting energy performance when tailored POU were known. Results from the monitoring exercise were fed directly into energy models with the aim to produce more accurate predictions. Menezes *et al*. argue that post occupancy evaluation data can be used to create specific dynamic simulation models within 3% of actual energy-use figures and later produced the TM54 evaluating energy performance at design stage. However, benchmarks for occupancy are not set out in the guidance; rather, a building energy performance range expressed in terms of energy delivered per unit of area is proposed.[108] This approach focused on evaluating the building energy performance instead of tenant energy performance. Therefore a gap in predicted performance remains unless the 'actual' tailored occupancy is known for the entire building, the office building is 'singular' occupancy, and the tenants behave in the exact way that the calculations specify. Barclay[85] argues that alternative approaches to both predicted and measured energy reporting would be of benefit to designers and facilities managers; moreover, an energy consumption metric per occupant could reward intelligent space utilisation and accommodating POU. Analysis of building performance evaluation has concentrated on typical user behaviour scenarios characterised by energy delivered by unit of area or per year [kW.h/m^2][109, 110, 52, 111, 75] as the methods and tools by which to assess building performance evaluation. Therefore, we need to understand how a building responds to different usage patterns by carrying out a sensitivity test. From this, we can gain a better understanding of how to better design our buildings to deal with these fluctuations.

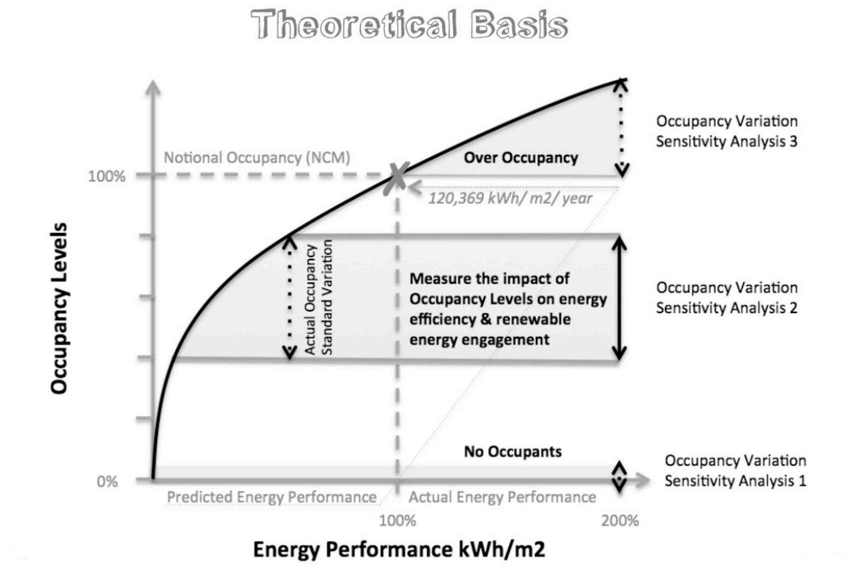


Figure 2.14 Theoretical sensitivity analysis: impact of occupancy capacity variation on BEP.

Figure 2.14 illustrates a potential energy performance scale, which could be used to compare tenant energy consumption. The building energy performance focus would then evolve from being building-centric to occupant-and-building-centric. This would allow tenants to understand and assess their energy use patterns. The

EPBD currently creates a barrier to this process by only enshrining building-related benchmarks in EU legislation, making it difficult for designers and building users to assess energy intensive practices. Agha-Hossien *et al.,*[107] Barclay[85] and Diamond *et al.*[67] all confirm a distinct gap in the lack of a method to assess the impact of occupancy on energy performance. This is further substantiated by CIBSE guidance, which is provided for all aspects of technical defects and associated impacts on building energy performance except operational variations due to changes in tenant preferences and work patterns.

2.2 Problem Statement

This chapter has reviewed the current legislation that promotes low energy building practices, top-down from the European Commission [EC] to national level, through a review of building regulation and policy in order to determine how much the energy performance gap is attributed to the existing building design and regulation processes referencing relevant work in the Building Energy Performance [BEP] field.

The literature review, as outlined, has clearly stated and given evidence that current BEP methods assume that different building tenants will all use the building in the same way whether they (i) occupy the gross floor area or part thereof (ii) have a high or low number of staff and equipment per m^2 or (iii) have longer or shorter operating hours than the proposed NCM standard usage patterns. The NCM does not consider different tenant groups vary in their patterns of use resulting in various operational and energy requirements. Variations in POU, as defined in the thesis works, is determined by a tenant's rentable area, number of full-time employees and hours of operation, which contribute to the intensity of use of all energy loads. For instance; the heating and cooling loads will vary depending on (i) the extent of rentable area they are accommodating and hours of operation required (ii) the internal heat gains from people and equipment [due to the density of people per m^2] (iii) the tenants preference for HVAC operation hours and (iv) internal temperature preferences.

To address the knowledge gap, the work in this thesis proposes a new method for supporting tenant groups, building designers, owner-occupiers and facility managers to understand the effect of variations in POU on BEP. A critical evaluation of the existing BEP assessment methods provides the following hypotheses: (a) the absence of POU benchmarks creates a barrier to understanding the impact of variations in tenants rentable area, number of full-time employees and hours of operation on building energy use, and (b) POU benchmarks are needed to meet energy reduction targets and new imminent energy performance legislation, as the current standard method of measurement does not demonstrate the impact of variations in POU on BEP.

2.3 Research Question

The research question devised was: 'Can a new method be developed to capture POU in BEP assessment and provide useful insights if adopted at (a) the design stage, and (b) the operational stage?'

2.4 Methodology

The approach taken was first to hypothesise that such a BEP POU method could be developed. The next stage was to specify and develop such a method and test it through application with appropriate case studies and then to assess the extent to which the hypothesis is shown to be correct. The thesis is structured around the following key steps:

(i) The new method is clearly defined to include the scope, how it will be tested and evaluated. [Chapter 3]

(ii) The new method is developed through a desktop study (i) reviewing how patterns of use are captured in existing regulatory and industry processes (ii) demonstrating actual variations in POU that exist between three building tenancies of a case study building (iii) reviewing input parameters required for BEP evaluation to determine new suitable POU BEP input parameters and POU benchmarks. [Chapter 4]

(iii) The new method is tested in application through case study scenarios to ascertain if it's useful. The impact of variations in POU on BEP is tested through (i) collating data on energy use and (ii) observing of tenants' occupancy levels, hours of operation and occupied area to gather evidence that POU varies between tenants and those variations in POU impact on BEP. [Chapter 5]

(iv) The new method is tested in application to demonstrate the impact of variations in Patterns of Use [POU] on tenant energy performance. The new method is tested and considered through defining a tenant's POU parameters, ranges, benchmarks and scenarios in a building energy model [ESP-r] and using the existing TM54 methodology. The resultant calculations demonstrate the predicted effect of POU on energy loads and overall energy performance using the new method metrics. The usefulness of reporting and evaluating variations in POU and a tenure energy performance range is then proven in practice. [Chapter 6]

(v) The robustness of the new method and POU results is tested by comparing the predicted POU to the operational 'actual' tenant energy use, collated and monitored in the real life case study. [Chapter 7]

(vi) Outcomes from the thesis and the new method application are discussed.

The new method is evaluated to determine the ease of use and benefits at the design and operational stages, through review of integration with existing BEP techniques. [Chapter 8]

(vii) The final chapter concludes with a discussion on the results of the application of the new method and states the hypothesis, contribution and potential opportunity for future work. [Chapter 9]

2.5 Justifications for the research

The research is justified by its assertion that variations in POU are not demonstrated under the current UK reporting measures. This discovery adds to and enriches BEP evaluation by providing building tenants with 'a method that estimates likely energy use that can compare with actual consumption'. Moreover, the proposed new method will allow for changes in POU to be assessed while the building is in occupation and to understand the impact of building design alterations or improvements to serve tenants' needs better. During the progress of this PhD, and potentially directly influenced by outputs from this PhD,[112] there has been some move towards tailored energy performance assessment as described in this chapter, however, this still falls short of what is proposed, elaborated and demonstrated in this PhD thesis, as will be outlined in the next chapter.

2.6 Chapter Summary

Empirical evidence was sought through investigating the existing measures and calculations. Methods have been used to demonstrate building energy performance and to review state of the art in the field. This allowed for an informed argument that existing BEP approaches and procedures have fundamental limitations. These are:

(i) The current compliance standards are determined by a set of standard usage patterns, which does not reflect how an office building will perform in use;

(ii) A detailed analysis showing the effects of variations in POU that can occur between office building users has not been documented;

(iii) The most cost-effective time to implement energy efficient measures and demand side management protocols is at the outset of a building project. Once the building is complete, changes will be costly. It is, therefore, imperative to include certification protocols, aims and objectives at the design stage and implement them throughout the design process; and

(iv) Currently a method does not exist that outlines a set of BEP POU benchmarks that establishes performance criteria by which an office building can be tested against.

Chapter 3: Outline of New Method

Specification and description of the new method: also how it is to be tested and evaluated.

3.0 Chapter Introduction

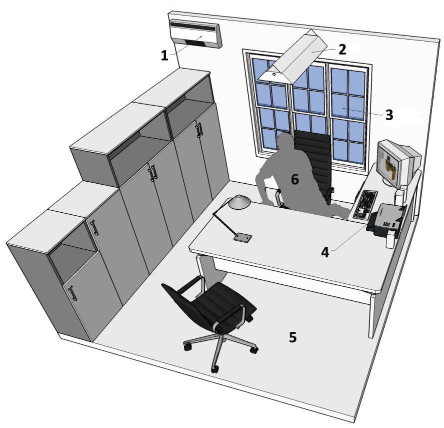
This chapter describes how the gap identified in Chapter 2 is to be addressed. This is to be achieved through (i) outlining the new method specification (ii) defining how the new method will be developed, tested and evaluated and (iii) describing the new method steps, templates, and processes. The parameters chosen to represent the new method are then introduced and justified. The new method summary provides a clear and justified Patterns of Use [POU] definition, a description of how it is to be applied to the design and operational stage, and a list of the intended key users.

3.1 New Method Description

The aim of building energy performance evaluation is to improve energy efficiency in operation. To attain efficiency accurate tools are vital to evaluate energy use to measure and improve performance in practice. The new method provides the potential to predict, record and monitor building energy performance by taking POU into account, giving advantages over current methodologies [Table 3.1]. The new method focuses on energy delivered per person [FTE] and uses tenure specific 'occupancy load factor' benchmarks. The new method improves upon current best practice, by including high, low, standard and tailored POU scenarios early in the design process, and by capturing these POU dependencies in the information given to the building operators. Building operation can then be comprehended through specific tenure 'occupancy load factor' benchmarks and given a realistic appraisal of performance and correct assessment of potential energy reduction measures. Presently, as shown in Table 3.1, standard practice, such as that used in the National Calculation Method [NCM], estimates an office building's likely energy use through (a) modeling the physical building parameters [the construction of the building fabric [u-values], orientation, climate, geometry and floor area] and then (b) assigning the operational parameters [HVAC, lighting, occupancy hours, occupant density, equipment gains and set points] as shown in Figure 3.1. The model assumes a standardised POU based on building activity type.

Table 3.1 How POU are captured at design stage in existing Building Energy Models and Building Energy Performance calculations and the refinements of the new method

Methodology	Patterns of Use [POU]	Area	Occupancy [OLF]	Operational Hours	BEP Measurement
Standard Practice	Standard	Gross Building Area Defined [m^2]	Standard [9m^2/person]	Standard [Monday to Friday 9am - 5pm]	Energy Delivered by unit of area [kWh/m^2] relative to Building Occupancy Load Factor's
	Tailored	Gross Building Area Defined [m^2]	Tailored [m^2/person]	Tailored [Set Hours Monday – Friday + Weekend]	Energy Delivered by unit of area [kWh/m^2] relative to Building Occupancy Load Factor's
Best Practice	Tailored Scenarios/ Building Energy Performance Range	Gross Building Area Defined [m^2]	Tailored Range of occupant densities scenarios m^2 or m^2/person	Tailored [Set operational hour scenarios] [Monday – Friday + weekend]	Energy Delivered by unit of area [kWh/m^2] relative to Building Occupancy Load Factor's
New Method	Benchmarked Scenarios/ Building Energy Performance & Tenant Energy Performance Range	Gross Building or Tenant Area Defined [m^2]	Range of Occupancy Load Factor Benchmarks: Min, Max, NCM, Tailored and Design Standard	Tenant Tailored [Set Operational hours scenarios to include swing shift calculations [Monday – Friday + weekend]]	Energy Delivered by unit of area [kWh/m^2] relative to Tenure Occupancy Load Factor's **and** Energy Delivered per person [fte] relative to Tenure Occupancy Load Factor's [kWh/ fte]



1. HVAC [Heating, Ventilation, Air-conditioning and Cooling Systems]
2. Lighting [Heat gains and usage]
3. Solar Gains, Weather and Natural Ventilation
4. IT and workstation Equipment [heat gains and usage]
5. Occupancy Load Factor [Area Allocated per person]
6. Occupant POU [hours of operation, thermal comfort, space standards, personal energy use.

Figure 3.1: Generic Operational Parameters used to calculate Office Building Energy Use.

The limitations of ‘Standard Practice’ used for building energy performance compliance [RIBA work-stage 4-6] and Energy Performance Certificates [EP] [RIBA work-stage 6-7] is that calculations either assess (a) an entire buildings building energy performance provided the office building is facilitated through a shared heating system or (b) if tenants have individual heating systems; the calculations are based on the relevant heating system and do not include the common areas. Both methodologies are based on the standard NCM ‘occupancy load factor’ and presented as energy delivered per m^2. Allowing EPC's to be based on an assessment of a similar office in the same block. This results in compliance calculations and EPC predictions which are generic and limited in scope, which create a barrier to building users understanding the impact of their POU, or determining if the building is functioning as intended, and if the tenant's POU varies from the NCM calculations.

The current best practice is encapsulated in CIBSE TM54.[108] TM54 recommends that building scenarios include a range of potential occupant densities and hours of operation to show the impact on internal heat gains and small power loads represented ‘per person’ where appropriate. While this standard makes a recommendation as to what should be done; it does not put forward a method for how this can be done, and also how it can be usefully integrated into building design, certification and operational processes. Therefore, the specification, development and demonstration of such a method is the focus and contribution of this thesis. Thus, the contribution to knowledge is a new method to convey (a) the impact of variations in occupancy load factors and hours of operation on building energy performance (b) an acceptable building energy performance range and (c) how can this be captured at the design and operational stage, which is useful to designers and building users. At the core of the new method is the creation of new tenure benchmarks, the capture of tenant operation hours with a swing shift allowance, and the apprehension of the impact of these parameters on both design and operational stages. The new method provides a platform to project likely variations in tenant patterns of use with a greater level of accuracy by determining (i) the impacts of a tenants POU on internal heat gains and energy loads (ii) when equipment is not working as intended (iii) intensive energy use within working hours and (iv) and potential energy savings out of regular office hours. Tenant Energy Performance is evaluated through the proposed new method design stage Occupancy Load Factor benchmarks [Maximum, Minimum, NCM, Tailored and Design] either defined as demonstrated in the thesis by industry standards or by stating what the tenants expected occupancy load factor would be for each of the proposed benchmarks. Then comparing the design stage benchmarks against the 'actual' operational performance.

Table 3.2 Building Performance Evaluation Standard Practice, Best Practice and New Method Summary Detailing the main differences and improvements

Methodology	RIBA POW Stage		Assessment Name	Procedure	Study Scope	Application in Operational Phase
Standard Practice	**Design**	**Stage 4: Technical Design**	National Calculation Method for EPBD [NCM]	Demonstrating compliance with the building [energy] regulations	Entire Office building	N/A
	Operation	**Stage 6: Handover**	Energy Performance Certificate [EPC]	Demonstrating predicted building energy use	Entire building unless subtenants have different heating systems then an EPC required for each tenant based on standard usage patterns	Certificate reports Predicted NCM standard annual energy usage pattern for regulated energy loads i.e. lighting, hot water, space heating, cooling and fans/ pumps/ controls, for comparison to monitored energy use. Certificate lasts 10 years
Best Practice [Standard practice plus]	**Design**	**Stage 4: Technical Design**	CIBSE TM54: Evaluating operational energy performance of buildings at design stage	Demonstrating low and high end scenarios for regulated and unregulated energy loads	Entire building unless subtenants have different heating systems then an assessment required for each tenant with scenarios based on variations of standard usage patterns and OLF	POE study carried out to establish if building is performing within the scope identified in the TM54 study.
	Operation	**Stage 7: In Use**	POE, BMS and Energy monitoring [TM22]	Recording Detailed Energy Use Data	Varies	POE study carried out to establish if building is performing within the scope identified in either EPC or TM54 or recorded data [TM22]
New Method [Standard and best practice plus revised certification]	**Design**	**Stage 1-3: Preparation & Brief**	The Tenant Energy Reporting Method [TERM] is established. The BEIA templates are populated.	Recording detailed design data to include the expected POU: OLF benchmarks and operational hours.	Office Tenure [either entire building or part thereof]	BEIA records and documents expected building performance under different predicted POU for the TER and TEC at design stage for comparison to monitored operational data either POE or BMS studies.
		Stage 4: Technical Design	Building Energy Impact Assessment [BEIA]	Demonstrate predicted tenant energy use with OLF benchmarks and operating hour scenarios	Office Tenure [either entire building or part thereof]	BEIA records and documents expected building performance under different predicted POU for the TER and TEC at design stage for comparison to monitored operational data either POE or BMS studies.
	Operation	**Stage 6: Handover**	Tenant Energy Report [TER]	The BEIA data is recorded in a report and a energy performance range is established for the building tenure/s	Office Tenure [either entire building or part thereof]	TER is issued to building owner and tenant to describe how the building will perform under different POU.
		Stage 7: In Use	Tenant Energy Certificate [TEC]	Annual tenant energy reporting using OLF benchmarks and detailing operating hour	Office Tenure [either entire building or part thereof]	Reports Tenant Energy Performance to understand when HVAC or building management is not operating effectively at chosen intervals and for comparison to other tenants POU.

Table 3.2 illustrates current building performance evaluation 'Standard Practice', 'Best Practice' and gives a 'New Method Summary' describing the main differences and improvements. The new method combines and enhances the current evaluation process by providing guidance on how to integrate energy performance evaluation in the design and operation stages. Presently, energy performance evaluation at the design stage is not communicated or connected to performance in use. EPCs provide recommendations for improvement measures, however, if a building is sublet then as the building user pays for bills and not building owner then, as discussed in Chapter 2, there is little reason for actioning improvement measures. However, if

the tenant can compare and understand if the equipment is failing or their operation patterns is inefficient, this then allows them to make informed decisions about equipment use, operation times and the level of efficiency they expect from their chosen patterns of use, accommodation and HVAC.

Design Stage	The Design Team compiles the BEIA to include expected POU occupancy levels, OLF benchmarks, operational hours, typical appliance schedules and appliance energy ratings.
	The Design Team use a building energy model to simulate the predicted energy use scenarios using the OLF benchmarks and BEIA data to determine an expected performance range for building certification purposes & complete the BEIA.
	The BEIA and building energy model outputs are used to generate the Tenant Energy Report [TER]
Operational Stage	The Building owner or previous tenant issue new tenants with TER showing the impact of different POU
	Tenant uses TER to compare and improve energy performance of building and occupants and TER is used for the basis of energy reporting Tenant Energy Certificate [TEC]
	TEC is used for comparing tenant energy use to offices with similar TEC profiles & benchmarking UK energy use

Figure 3.2 Proposed changes to the design process at design and operational stage

The steps, roles and responsibilities of the new method at the design and operational stages are summarised in Figure 3.2. The new method brings together best practice techniques and processes to better explain and improve tenants POU and highlight why the building may not perform as anticipated by explaining how the designers expect the building to function. The new method does two things – it allows building performance to be tested and evaluated in-use by the building users to establish best practice under their individual POU and it also allows building designers to learn what is effective in low energy design. The new method integrates energy performance evaluation throughout the building lifecycle [in design and operation] through (a) defining a method to benchmark minimum and maximum intensity of use [determined by occupancy load factors, occupancy capacity and occupied floor area], which can be used to record, test, report and evaluate energy performance and (b) demonstrating how variations in hours of operation affects building energy performance.

3.1.1 New Method Background

In the 1920s a maximum number of people, who could occupy a room or building, was defined in international building regulation[9] to determine a safety exit code for office buildings. Data was collated in Philadelphia and New York for 12 office buildings to review a maximum building population through measuring the number of people entering and leaving the building, then recording the difference, to determine the actual number of building occupants at any one time. The study collated insufficient data for an exact office business occupancy load factor, however, $100ft^2$ [$9m^2$] per person was recommended. [113] The Committee on Safety to Life stated 'that gross area rather than rentable area was selected for calculation as rentable area varies and because there is a fairly constant ratio between gross and rentable area.' [114] This representation of office space standards has been adopted by the NCM to predict building energy performance and compare buildings like for like. The current method of predicting an office building energy performance is calculated by assuming a single tenant occupies the gross building area, with an occupancy load factor of $100ft^2$/person and operates the building between the hours of 9-5pm, Monday to Friday. In reality, occupancy load factors will vary by tenure either (i) between different building user groups or (ii) overtime in a single tenancy as staff numbers rise and fall or (ii) the company changes their lettable area. The occupancy load factor affects the intensity of the building population, known as the occupancy capacity, and therefore the intensity of energy use needed to support the building population.

Variations in 'Patterns of Use', as defined in this thesis, arise through the influence of a building's tenure [conditions under which the building is occupied] on tenant energy loads and performance; in particular, through their chosen floor area, occupancy capacity, resultant occupancy load factor and hours of operation [Figure 3.3].

[9] The Life Safety Code and Building Construction Safety Code.

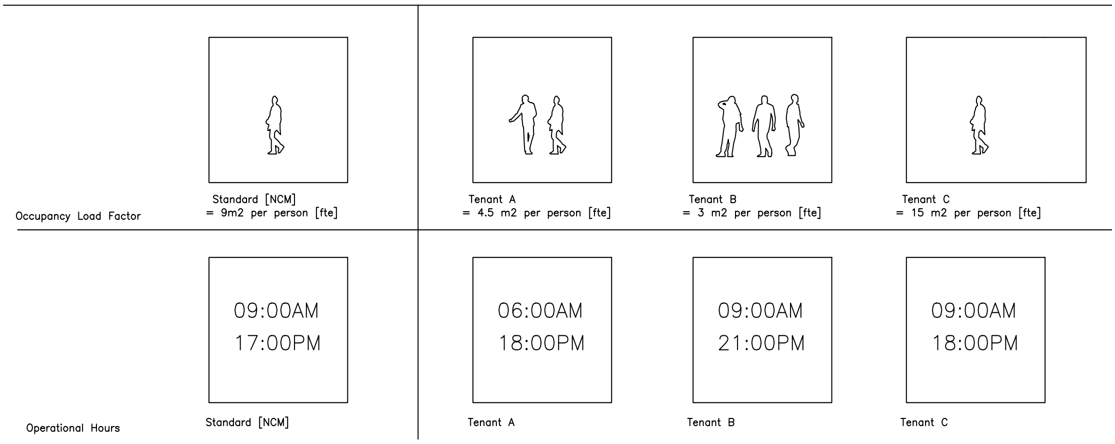


Figure 3.3 Diagram illustrating how building tenants occupying the same building can vary in their Patterns of Use

3.1.2 New Method Calculations

As stated, conventional building energy performance *prediction* calculations assume that all buildings operate under one standard operating condition throughout the building's lifecycle, whether they are accommodating a single tenant or multiple tenancies. The predicted occupancy load factor and operating hours speculated at design stage remain constant and are used to estimate the building energy loads and internal heat gains while the building is in operation. In reality, different building tenants will operate and inhabit the building differently; affecting the occupancy load factor and operating hours and subsequently the balance of the power loads, heat gains and overall building energy performance calculations. The existing approved methodology to calculate annual building energy performance deliver by a unit of area or per person is illustrated in Box 3.1. The calculations outline that energy performance can be speculated either using the NCM or a tailored usage pattern to determine energy performance. The calculation is based on a generic tenure with the total energy use divided by the building area or a total number of occupants.

Box 3.1 Conventional *Building* Energy Performance Calculations [energy use per m and per person]:

Building $_{[NCM\ or\ tailored]}$ *Annual* Energy Performance [kW.h /m^2] = Building $_{[NCM\ or\ tailored]}$ *Annual* Energy Use [kW.h] / Building Area [m^2]

Building $_{[NCM\ or\ tailored]}$ *Annual* Energy Performance per occupant [kW.h /person] = Building $_{[NCM\ or\ tailored]}$ *Annual* Energy Use [kW.h] / Total number of full-time equivalent building occupants $_{[NCM\ or\ tailored]}$

The new method [Box 3.2] allows tenants occupying, either the whole or part of the building, to test and evaluate the energy performance of the building area under their tenure through demonstrating (i) their tailored POU based on the occupancy load factor [established from the tenants occupied area and number of full-time employees] and (ii) the impact of varying their POU under different operating conditions defined by minimum and maximum 'occupancy load factor' benchmarks, in addition to the existing design or NCM standard, to align with existing methodologies.

Box 3.2 New Method *Tenant* Energy Performance Calculations [energy use per m^2 and per FTE]:

Tenant $_{tailored}$ *Annual* Energy Performance [kW.h /m^2] = Tenant $_{tailored}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]

Tenant $_{minimum}$ *Annual* Energy Performance [kW.h /m^2] = Tenant $_{minimum}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]

Tenant $_{[NCM\ or\ design]}$ *Annual* Energy Performance [kW.h /m^2] = Tenant $_{[NCM\ or\ design]}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]

Tenant $_{maximum}$ *Annual* Energy Performance [kW.h /m^2] = Tenant $_{maximum}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]

Tenant $_{tailored}$ *Annual* Energy Performance per [kW.h /FTE] = [Tenant $_{tailored}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]] x tenant occupancy load factor $_{tailored}$

Tenant $_{minimum}$ *Annual* Energy Performance per [kW.h /FTE] = [Tenant $_{minimum}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]] x tenant occupancy load factor $_{minimum}$

Tenant $_{[NCM\ or\ design]}$ *Annual* Energy Performance per [kW.h /FTE] = [Tenant $_{[NCM\ or\ design]}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]] x tenant occupancy load factor $_{[NCM\ or\ design]}$

Tenant $_{maximum}$ *Annual* Energy Performance per [kW.h /FTE] = [Tenant $_{maximum}$ *Annual* Energy Use [kW.h] / Tenant Area [m^2]] x tenant occupancy load factor $_{maximum}$

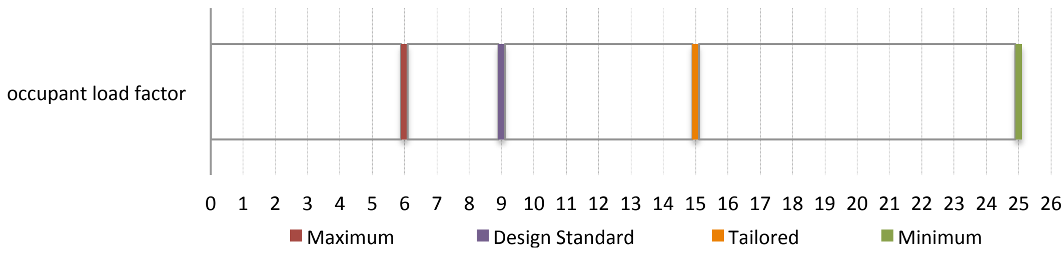


Figure 3.4 New Method Occupancy Load Factor Benchmarks [Area allocated per FTE]

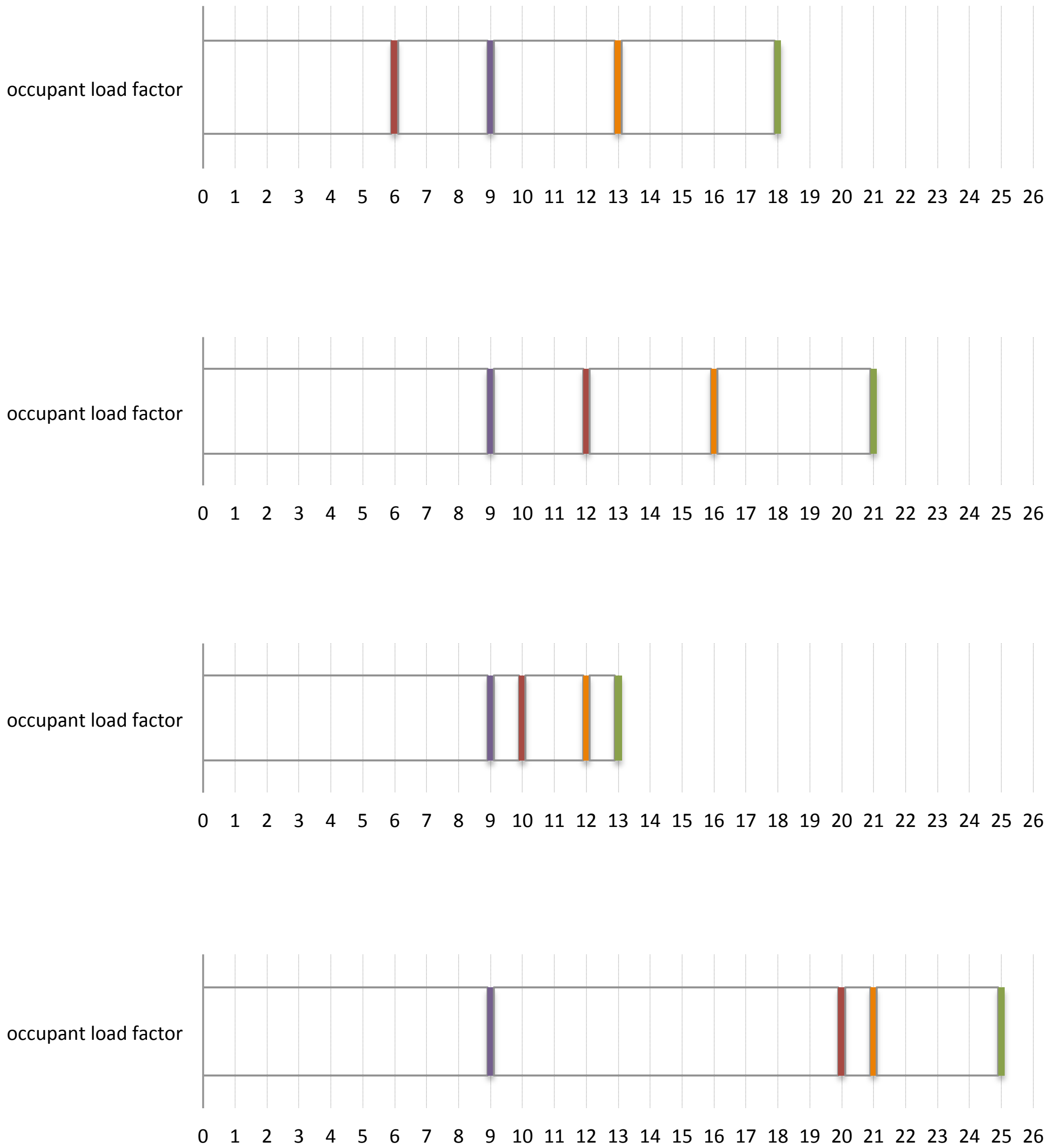


Figure 3.5 Demonstration of Possible Variations in Occupancy Load Factor Benchmarks

This enhancement assists tenant energy performance evaluation by creating a new method whereby (i) a tenant can more accurately predict their office's energy performance specific to their patterns of use (ii) tenants can set office operational limits by defining minimum and maximum operating conditions through the proposed new method 'occupancy load factor' benchmarks [Figure 3.4] or minimum and maximum benchmarks established by the tenants themselves [Figure 3.5] or (iii) building managers, designers and owners can provide guidance on an optimum building energy performance and range based on the new 'occupancy load factor' benchmarks. Figure 3.5 demonstrates that the predicted range of the 'occupancy load factor' benchmarks will affect the predicted operating range of energy loads, therefore, in theory, the more accurate the occupancy range *is,* the more accurate the projected energy performance of the activities will be, and subsequently it will be easier to determine if equipment of building operation isn't working or being managed as it should. 'Occupancy load factors' affect internal heat gains, small power loads and other energy uses. The new defines a tenure energy performance range at the design stage. It does this by calculating the expected tenures minimum, and maximum internal heat gains [using a suitable building energy model], small power loads and other energy uses to determine an energy performance range for all tenant activities, for the tenants chosen office hours and occupancy load factor [based on tenure area and occupancy capacity], that can be used to compared the tenants 'actual' energy use in operation. Energy use is measured delivered per FTE and per m^2 allowing an assessment of intensive energy use assuming all the building activities are individually metered. Likewise, the new method illustrates how occupancy influences energy loads and how different energy loads relate to each other. Furthermore, the aggregated tenant energy performance delivered per full-time employee and per m^2 is targeted at engaging tenants of multi-tenanted buildings to allow subtenants to understand and compare tenant energy use to (i) other tenants within the same building or to other similar office buildings (ii) and the design or NCM standard, whereby the building was designed to function. Moreover, this allows tenants and facilities manager to target and reduce both the energy consumption of the building and occupants in tandem. A building or room's occupancy load factor is calculated by dividing the occupancy capacity [maximum building population] by the gross building or room area, as shown in Box 3.3.

Box 3.3 Calculating Occupancy Load Factor [OLF]
Occupancy Load Factor [area [m^2] per person [FTE]] = Occupancy Capacity [number of people in a room or building] / Occupied Area [either the whole building or part thereof [m^2]]

The new method recognises that several different POU could be operating in a building at any time, impacting on both tenant and *overall* building energy use. The 'occupancy load factor' benchmarks test the robustness and sensitivity of the tenant energy performance under differing operating conditions. The new method enhances existing building energy performance evaluation methods by defining an intended occupancy load factor range for all office buildings. However, this technique could be applied to other building types. The new method also assesses other variations in POU, such as (i) the impact of extended hours of operation, and (ii) energy use in periods of transition where offices maybe using increased energy consumption in the run-up time prior to or post-occupation. The energy performance range is defined using the 'occupancy load factor' minimum and maximum benchmarks and then following the steps outlined in TM54 to generate the results. The 'occupancy load factor' benchmarks and operational hour scenarios provide the basis for a new energy rating [kW.h/FTE] and can be compared to the current building energy rating [kW.h/m^2] to target both energy delivered per unit of area and per person. Box 3.2 indicates the benchmarks used to calculate total annual energy use. The benchmarks can be tailored to compare all energy loads including; HVAC loads, lighting, IT server loads, plug loads and special functions against sub-metered data, at any time step to include annual consumption, as shown in Figure 3.6. The flexibility of the new method allows tenant energy-reporting method to be adapted to the tenant and building management requirements.

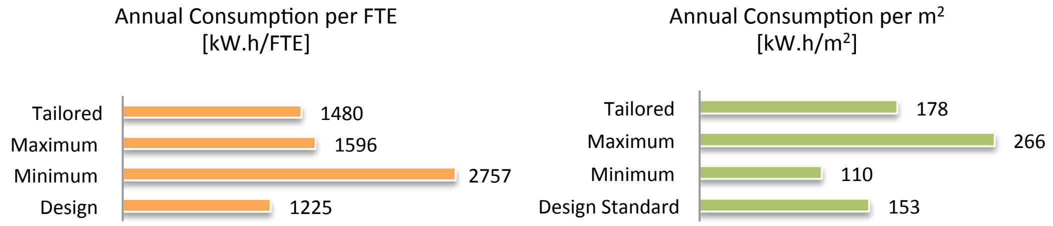


Figure 3.6 Demonstration of occupancy load factors applied to annual energy use delivered per FTE and per m^2.

3.1.3 New Method Principles

The new method used to predict and compare the impact of tenants POU on tenant energy performance, as applied at the design stage is named the 'Building Energy Impact Assessment' and at the operational stage the 'Tenant Energy Reporting Method', as illustrated in Figure 3.7.

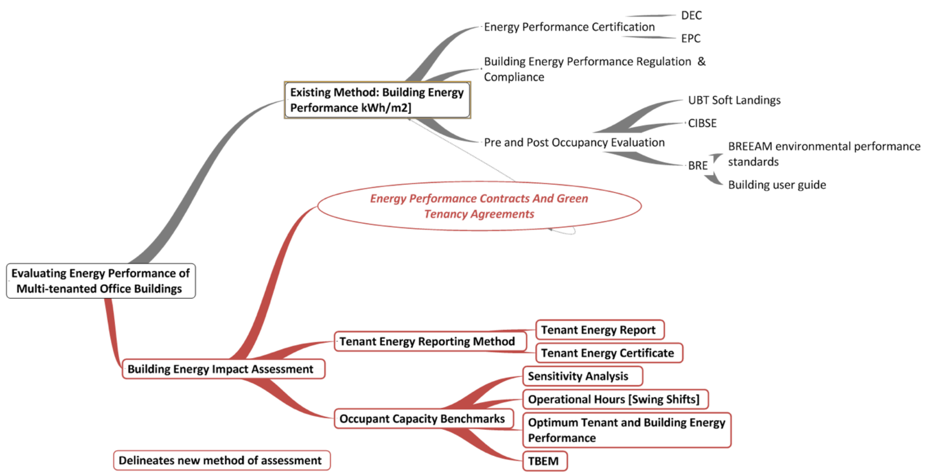


Figure 3.7 'Building Energy Impact Assessment' and 'Tenant Energy Reporting Method' Energy Performance Map

The 'Building Energy Impact Assessment' occupancy load factor benchmarks, determined at the design stage provide a platform for tenants to test operational performance using the 'Tenant Energy Reporting Method'. The 'Building Energy Impact Assessment' considers the energy performance criteria [kW.h] against the net floor area [m^2] (current compliance method) together with the 'occupancy load factor' benchmarks for each sub-tenanted office. The energy performance can be calculated for daily, weekly, yearly, monthly or daily comparisons. Box 3.4 outlines the key principles used to predict the energy performance range of a building or tenure for comparison to operational data.

Box 3.4 Defining an Energy Performance Range through Tenant Energy Performance 'occupancy load factor' [OLF] Benchmarks

(a) Calculate TEP OLF maximum and minimum values of the '*as designed*' regulated and unregulated loads:

$TEP_{D\ Min}$ = [kW.h/ NFA_T] x O_{Min}
Where $O_{LF\ Min}$ = NFA/ O_{Min}

$TEP_{D\ Max}$ = [kW.h/ NFA_T] x O_{Max}
Where O_{Max} = NFA/ $O_{LF\ Max}$

(b) Define the 'as *designed'* building subtenant $O_{LF}B$ performance range:

TEP_{Ra} = $TEP_{D\ Min}$ - $TEP_{D\ Max}$

$TEP_{D\ Min}$	Designed minimum energy performance value
$TEP_{D\ Max}$	Designed maximum energy performance value
TEP_{Ra}	Designed energy performance range
$TEP_{LF\ Min}$	Designed minimum occupancy load factor
$TEP_{LF\ Max}$	Designed maximum occupancy load factor
O_{Min}	Established from Occupancy Capacity
O_{Max}	Established from Occupancy Capacity
NFA	Net floor area [m^2]
NFA_T	Net floor area of the subtenant [m^2]

(c) Calculate the $O_{LF}B$ performance of the *in use* regulated and unregulated loads:

TEP_A = [kW.h/ NFA_T] x O_{LFA}
Where O_{LFA} = NFA/ O_A

O_{LFA}	Actual Occupancy [Aggregated energy use per full-time employee]
O_A	Actual Performance

(d) If the *actual* TEP regulated or unregulated loads fall within the *designed* TEP parameters, then the office energy performance is performing as expected. The closer the energy performance indicator is to the benchmark the more efficient the office utilities are in use.

The new method enhances the current TM54 method by defining extreme POU rather than loosely defined scenarios. The first principal (a) is to define the expected minimum and maximum occupancy of the building and the resulting ‘occupancy load factor’ benchmarks. The benchmarks are followed by a calculation of the impact of the different POU scenarios on building or tenant energy performance. The second principal (b) determines the energy performance range for the total energy use and specific energy loads. The third principal (c) allows the tenant's energy performance to be calculated for each energy load [kW.h/FTE]. The final principal (d) demonstrates whether or not the *actual* measured performance falls within the *designed* parameters. The energy load is shown to be performing as expected if the measured energy use falls within the defined range. Thus, the closer the energy performance indicator is to the benchmark the more efficient the office facilities are in use. However, if the measured performance falls outside the speculative range further investigation is required to determine the cause.

The ‘Building Energy Impact Assessment’ is only effective through the implementation of ‘Tenant Energy Reporting Method', ‘Tenant Energy Report' and ‘Tenant Energy Certificate’. The detail of the ‘Building Energy Impact Assessment’ is put forward as an ideal or best practice approach. A detailed operational energy assessment of a building's energy loads is only achievable if the tenure is adequately sub-metered or a detailed monitoring strategy is deployed through a building management system. The new method templates, described in the next section, illustrate the data required to evaluate variations in POU and their impact on energy performance.

The ‘Building Energy Impact Assessment’ and ‘Tenant Energy Reporting Method’ templates[10] serve as a standard outline of the collective documentation needed to

[10] The BEIA template is based on the Carbon Buzz template with data collection scales, 'occupancy load factor' benchmarks and comparison strategies added. The template was revised after the results of the case study were reviewed, and the 'Tenant Energy Report' and 'Tenant Energy Certificate' templates were visualised. The 'occupancy load factor' benchmarks and metrics were added as an outcome of the research presented in this thesis

compare design and operational performance. This includes the data to be accrued from 'Tenant Energy Reporting Method' and monitoring exercises. The 'Building Energy Impact Assessment Templates outline the building data required for the tenant building energy model and the proposed tenant energy performance range. The 'Building Energy Impact Assessment' requires more work at the design stage to predict the POU in a simulation model environment; however, the outcome helps minimise the need for intrusive and costly post occupancy evaluation exercises post completion – for example, when the balance of operational and management details are not known. Moreover, the 'Building Energy Impact Assessment' can be introduced retrospectively after an energy certificate is awarded, but the scale and cost of this work increase as indicated in Figure 3.8.

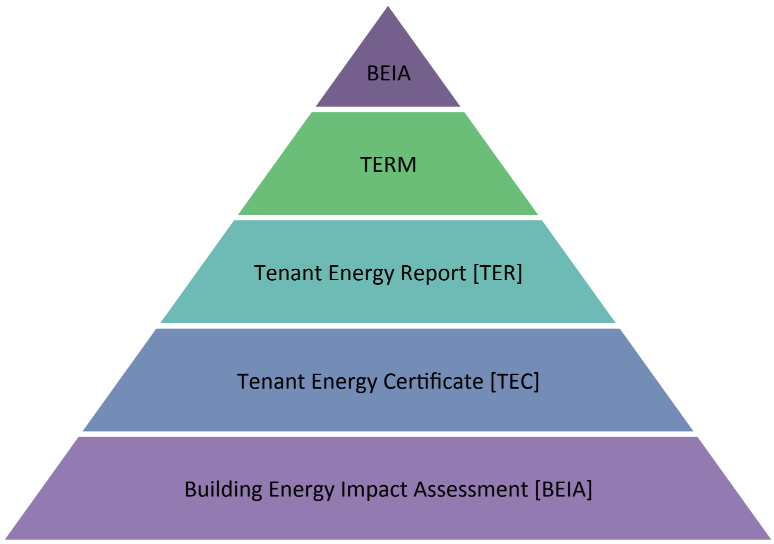


Figure 3.8 Hierarchy of the new Tenant Energy Reporting Method.

The 'Tenant Energy Report Method' replicates the 'Building Energy Impact Assessment' principles to compile annual operational energy use data. The data is gathered when the building has been occupied for a year, similar to the standard post-occupancy evaluation exclusion period. The 'Tenant Energy Report Method' and the 'Building Energy Impact Assessment' templates are the proposed foundation of post-occupancy evaluation assessments and articulate scales of how the post occupancy evaluation data could be recorded through measuring activity energy use at hourly or daily time steps.

Moreover, the templates identify best practice to record and compare the results of the pre- and post-occupancy data. The 'Tenant Energy Report Method' report can be revised if there is a change in tenant; accommodation area or a post-occupancy evaluation exercise is required and aligns with the existing national building energy certification scheme.

The next section explains how the new method key steps are (i) incorporated into the design stages of the Royal Institute of British Architect [RIBA] Plan of Work and (ii) coordinated with building energy models, TM54 calculations and operational reporting measures. The 'Building Energy Impact Assessment' and 'Tenant Energy Report Method' templates are introduced together with what the new certificates could look like [Figure 3.9].

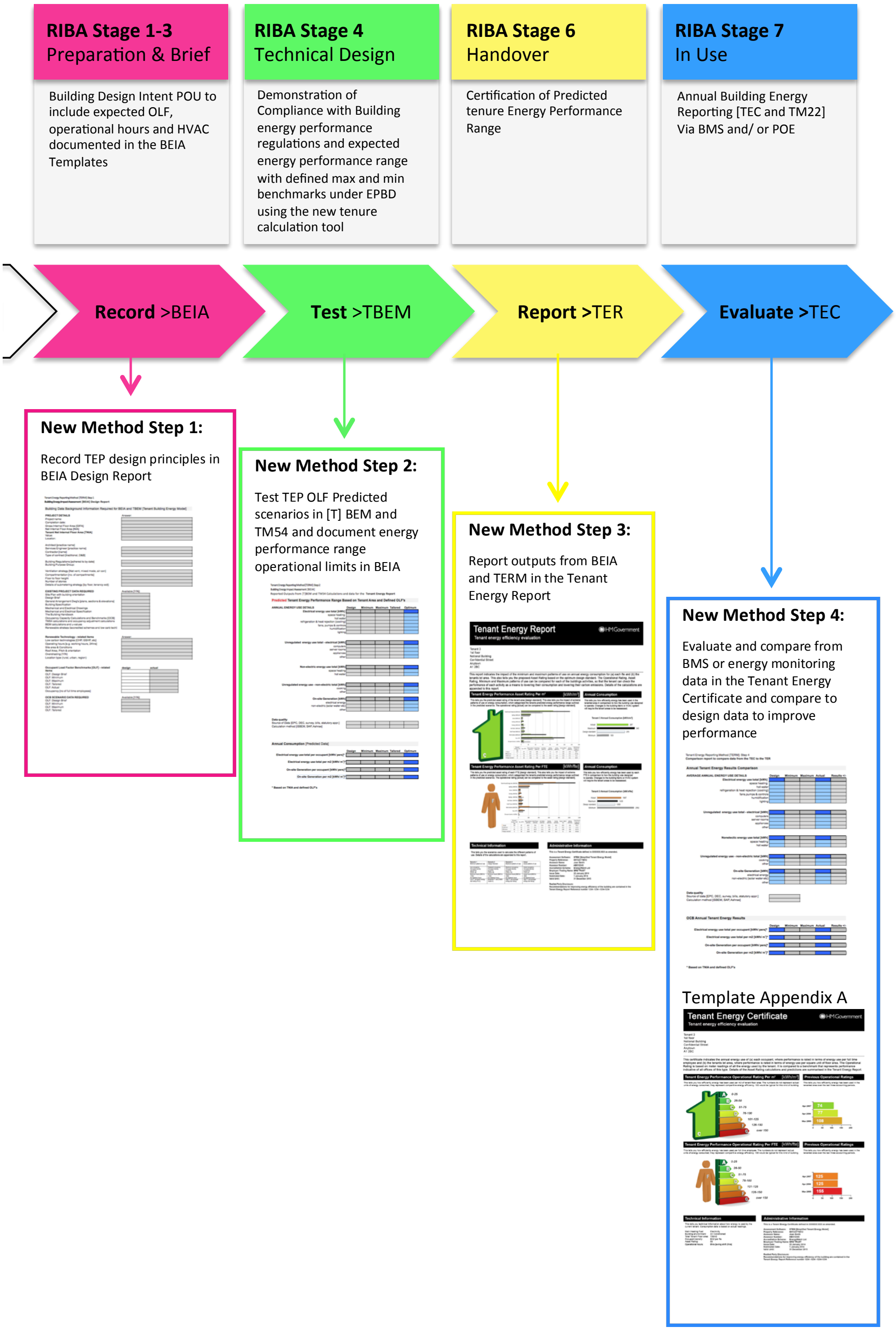


Figure 3.9 New Method Process Diagram

3.2 New Method Key Steps

The new method consists of 4 steps. The Project Architect carries out the first step, at RIBA stages 1-3, recording the information required for the 'Building Energy Impact Assessment'. The Project Engineer carries out the second step, at RIBA Stage 4, to record the necessary calculations for the POU parameters and establish an energy performance range for the tenure and to generate the 'Tenant Energy Report' in Step 3. The Facilities or Office Manager via a building management system, if applicable, carries out the final step at RIBA Stage 7 or commissions an Energy Assessor to assess the energy performance of the tenure in operation, records the outcome in the 'Tenant Energy Reporting Method' and then reports the finding's in the 'Tenant Energy Certificate'.

The 'Tenant Energy Reporting Method' and 'Tenant Energy Certificate' is compared back to the design data compiled the 'Building Energy Impact Assessment' and 'Tenant Energy Report' to understand if the building or tenure is operating as expected and highlight improvement measures. The content and aim of each part of each template is now discussed.

3.2.1 Step 1: Record the Tenant Energy Performance Details

The project details, project documentation, site conditions and predicted patterns of use parameters are recorded at design stage, in the 'Building Energy Impact Assessment'. The project architect fills in the four parts of Template 1, illustrated in Figure 3.10.

3.2.2 Part 1: Project Details

The 'Project Details' [Template 1: Part 1] are collated to give a record of the building and design team contact details to support the collection of the Project Documentation.

TEMPLATE 1: BUILDING ENERGY IMPACT ASSESSMENT [BEIA]

PART 1: PROJECT DETAILS	Answer:
Project name:	
Completion date:	
Gross Internal Floor Area [GIFA]	
Net Internal Floor Area [NIA]	
Tenant Net Internal Floor Area [TNIA]	
Value:	
Location:	
Architect [practice name]	
Services Engineer [practice name]	
Contractor [name]	
Type of contract [traditional, D&B]	
Building Regulations [adhered to by date]	
Building Purpose Group:	
Ventilation strategy [Nat vent, mixed mode, air con]	
Compartmentation [no. of compartments]	
Floor to floor height	
Number of stories	
Details of submetering strategy [by floor, tenancy ect]:	

PART 2: PROJECT DOCUMENTATION	Available [Y/N]:
Site Plan with building orientation	
Design Brief	
General Arrangement Dwg's [plans, sections & elevations]	
Building Specification	
Mechanical and Electrical Specification	
The Building Handbook	
Occupancy Capacity Calculations and Benchmarks [OCB]	
TM54 calculations and occupancy adjustment calculations	
BEM calculations and u-values	
Renewable strategy [accredited schemes and low carb tech]	
Low carbon technologies [CHP, GSHP, etc]	

PART 3: SITE CONDITIONS	Answer:
Site area & Conditions	
Roof Area, Pitch & orientation	
Overshading (Y/N)	
Location type (rural, urban, region)	

PART 4: Occupancy Load Factor [OLF] and Occupancy Capacity [OC]	OLF	OC
Occupancy Load Factor Benchmark: Design		
Occupancy Load Factor Benchmark: Minimum		
Occupancy Load Factor Benchmark: Maximum		
Occupancy Load Factor Benchmark: Tailored		
Occupancy Load Factor Benchmark: NCM		
Occupancy Load Factor Benchmark: Actual		

PART 5: Hours of Operation Scenarios	[00:00-00:00]	[09:00-17:00]	[06:00-18:00]	[06:00-21:00]	[00:00-24:00]

Figure 3.10 Template 1

3.2.3 Part 2: Project Documentation

The aim of the 'Project Documentation' [Template 1: Part 2] is to record the design information to enable the future energy performance evaluation exercises to be compared to the information recorded in the 'building energy impact assessment' and the 'tenant energy reporting method' with integrity and accuracy. The documentation includes the key design team drawings to establish details of the building's design and operation, building and HVAC specification, details of the building envelope [u-values] and renewable technologies.

3.2.4 Part 3: Site Conditions

The aim of collating the 'Site Condition' details [Template 1: Part 3] is to record the necessary building energy model information on the site area, co-ordinates, orientation, site conditions, location and over-shading, which have been used in calculating the energy model outputs.

3.2.5 Part 4: Occupancy load factor benchmarks and occupancy capacity

The aim of the 'occupancy load factor benchmarks' [Template 1: Part 4] and 'occupancy capacity' [together with the hours of operation] is to provide the mathematical data necessary to enable the project engineer to generate the building energy model and the TM54 calculations. Then to establish an energy performance range for the tenure or tenant energy loads, based on the minimum and maximum expected 'Patterns of Use,' for the project. Please note whether the building energy inputs in Template 2 [e.g. temperature set points or airflows] differ for each of the occupancy load factor benchmarks or if the parameters are constant for the exercise. If the model inputs vary for each benchmark, then a separate template defining the inputs into the building energy model will be required.

The method of calculating the occupancy capacity based on the occupancy load factor benchmarks is shown in Box 3.5. The design occupancy load factor [if different from the NCM standard] and tailored benchmarks are to be confirmed by the building user. The 'maximum' occupancy load factor is defined from fire safety regulation, as stated in Chapter 4, Table 4.1.5. The British Council for Offices study, as stated in Table 4.10, defines the 'minimum' occupancy load factor. The design team defines the 'design' occupancy load factor if the proposed POU differ at design stage from the NCM standard. The 'tailored' occupancy load factor is determined if the tenant expected occupancy is known at design stage. The 'NCM' occupancy load factor is determined by the energy standards as defined in Table 4.1.6. The occupant capacity can then be calculated as shown in Box 3.5.

Box 3.5 Worked example: Occupancy Load Factor Benchmarks and Occupancy Capacity

Input data:

Maximum OLF	= $6m^2$/FTE
Minimum OLF	= $25m^2$/FTE
Design [Optimum]	= Xm^2/FTE
Tailored OLF	= Xm^2/FTE
NCM OLF	= $9m^2$/FTE

Minimum Occupancy Capacity	= [NLA/ minimum occupancy load factor]
Maximum Occupancy Capacity	= [NLA/ maximum occupancy load factor]
Designed Occupancy Capacity	= [NLA/ designed standard occupancy load factor]
NCM Occupancy Capacity	= [NLA/ NCM standard occupancy load factor]

Table 3.3 Proposed function of occupancy load factor [OLF] benchmarks in tenant or building energy performance evaluation

OLF Benchmark		Description of Use
1	Maximum	Sets upper limit of energy loads
2	Minimum	Sets lower limit on energy loads
3	Design [optimum]	Maximise letting potential, efficiency and cost for the building
5	Tailored	Accurate reporting of individual POU for specific tenure
6	NCM	Comparison to existing CIBSE benchmarks and EPC documentation
7	Actual	Allows TEP reporting and improvements in efficiency and cost

Benchmarks 1-5 can be project specific if required, as shown in Table 3.3. As stated the minimum and maximum 'occupancy load factor' benchmarks set the limits for testing operational performance of POU and HVAC equipment. The design benchmark is aimed at (i) maximising letting potential for the building owner (ii) efficient design, construction and operational costs (ii) and can be used by the building tenants to compare how the building is being operated in use in comparison to how the building was designed to function and sets the target for optimal building performance based on ideal operational parameters. The design benchmark is only used if the designed POU do not replicate the NCM or tailored 'occupancy load factor'. A tailored 'occupancy load factor' can be used if part of the building has been designed at briefing stage to suit the needs of a specific tenant. The NCM standard is used to allow the existing compliance methodology to be carried out in tandem with the new method of reporting at the design and operational stage. In addition, the actual 'occupancy load factor' is reported in the 'Tenant Energy Certificate', when the building is in operation for comparison to the predicted 'occupancy load factor' benchmarks 1-6 and to compare to other buildings with similar building classification, specification and POU or other tenures sharing the same building.

3.2.6 Part 5: Establishing Operational Hour Scenarios

The operational hour scenarios are selected based on the building expected POU if known. Typical operational hour scenarios are shown in Table 3.4, which include 00:00-24:00, for a 24-hour facility. Once the 'occupancy load factor' benchmarks and operating hours have been established the TM54 calculations and a building energy model can be used to predict the impacts of variations in POU on Tenant or Building Energy Performance.

Table 3.4 Proposed Tenant Operational Time scenarios

	Minimum	NCM	Maximum	Tailored	24hr
Operational Times Scenarios:	**[09:00-17:00]**	**[09:00-17:00]**	**[06:00-18:00]**	**[06:00-18:30]**	**[00:00-24:00]**

3.2.7 Step 2: Test the Tenant Energy Performance Predictions

The project engineer fills in the four parts of Template 2, illustrated in Figures 3.11 and 3.12. The expected Building or Tenure Energy Performance 'Pattern of Use' Scenarios are calculated using an approved building energy model, capable of modeling tenant's POU parameters to include occupancy load factors, occupant capacity, tenant area and hours of operation and also using TM54.

3.2.8 Part 1A: Inputs into BEM: Internal Heat Gains

Quantifying and simulating the impact of variations in 'occupancy load factors' and 'hours of operation' on building activities through their relationship to one another in a building energy model requires a level of detailed information and planning. The building energy model assumptions are detailed in Template 2, Figure 3.11. This process is documented, as the transparency of the calculations are imperative to the overall method; however, the articulation of this information is not under review as part of this thesis and is given for clarity to frame how POU can be represented in a building energy model environment. The engineer calculates the heating and cooling loads in a building energy model by manually inputting occupancy schedules, lighting loads, small power, airflows and heating set points data, which the engineer has determined suitable for the project.

Template 2 [Figure 3.11] records the expected internal heat gain inputs into the Building Energy Model. The templates are recorded for each of the study scope 'Patterns of Use' scenarios based on the tenant's occupied area, occupancy load factor and hours of operation. Recording the model inputs provides clarity on how the heating and cooling loads have been calculated within the building energy model and also gives clarity to the building users of what the predicted POU were at the design stage and the expected heat gains from each, for comparison to the building in operation.

Template 2: INPUTS INTO BEM [Internal Heat Gains] Amend all values as Appropriate

Study Scope: [Minimum/ Maximum/ Design/ Tailored] patterns of use

Occupancy Load Factor: XXm^2/FTE Occupied Area: XXm^2 FTE'S: XX

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	09:00	0	0	0
09:00	17:00	0	0	0
17:00	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	09:00	0	0	0
09:00	17:00	0	0	0
17:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [$W.m^{-2}$]	Radiant heat	Convective heat
00:00	09:00	0	0	0
09:00	17:00	0	0	0
17:00	00:00	0	0	0

Assumptions:
Small power includes computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
**Equipment heat gains based on 25m^2/ person speculated based on results in Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.*

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [Ac/h]
00:00	09:00	-	-
09:00	17:00	-	-
17:00	00:00	-	-

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 15 people @ 12 l/s = 180 l/s assumed for hours of operation [180 x 0.001 = 0.180].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^oC]	Cooling Set point [^oC]
00:00	09:00	0	0	0
09:00	17:00	0	0	0
17:00	00:00	0	0	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

<u>DSM Results [DSM OUTPUTS Defined in Template 3: Part 5]</u>

Heating: X kW.h per year *estimated*
Cooling: X kW.h per year *estimated*

Figure 3.11 Template 2

TEMPLATE 3: BUILDING ENERGY IMPACT ASSESSMENT [BEIA] TEMPLATE 3

PART 1B: DATA QUALITY	
Source of Data [EPC, DEC, survey, bills, statutory appr.]	
Calculation method [iSBEM, SAP, Ashrae]	

PART 2: TOTAL ELECTRIC ENERGY USE					
Hours of Operation Scenarios [hrs]		[09:00-17:00]	[06:00-18:00]	[06:00-21:00]	[00:00-24:00]
Annual Total Energy Use [kWh/m2]	Maximum				
	Minimum				
	Design				
	Tailored				
Annual Total Energy Use [kWh/FTE]	Maximum				
	Minimum				
	Design				
	Tailored				

PART 3: NON-ELECTRIC ENERGY USE	NCM	Minimum	Maximum	Tailored	Design
Non-electric energy use total [kWh/m2]					
space heating					
hot water					
Non-electric energy use total [kWh/fte]					
space heating					
hot water					

Part 4: ON-SITE GENERATION	NCM	Minimum	Maximum	Tailored	Design
On-site Generation [kWh/m2]					
electrical energy					
non-electric (solar water etc)					
On-site Generation [kWh/fte]					
electrical energy					
non-electric (solar water etc)					

PART 5: SUB-METERED ENERGY USE	NCM	Minimum	Maximum	Tailored	Design
Electrical energy use total [kWh/m2]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					
Electrical energy use total [kWh/fte]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					

Energy Perfromance Range

Figure 3.12 Template 3

3.2.9 Part 1B: Data Quality

In Template 3: Part 1b [Figure 3.12], the project engineer records the source of data and the calculation methodology. Recording the methodology provides transparency to the building users as to how the building performance was calculated and allows the building management systems, and future energy monitoring or post occupancy evaluation exercises to be compared and linked with the 'Building Energy Impact Assessment' data.

3.2.10 Part 2: Total Electrical Energy Use

The 'Total Electrical Energy Use' [Template 3: Part 2] is recorded for each of the occupancy load factor benchmarks: Minimum, Maximum, Design, Tailored, and NCM expressed as kW.h/m^2 and kW.h/FTE, noting the hours of operation and predicted variations in energy use for each of the benchmarks and operational hour scenarios. The 'Total Electrical Energy Use' energy performance range and subsequently operational limits are defined from the minimum and maximum values shown in the columns highlighted in red. The new method of demonstrating variations in POU on tenant energy performance uses the existing TM54 methodology calculations shown in Box 3.6 for minimum POU. The calculations are repeated for each of the chosen scenarios shown in the matrix in Part 2 of Template 3. Box 3.6 highlights in red the parts of the calculation that can be updated to represent each of the scenarios to reflect changes in 'occupancy load factor'. The days of operation can also be adjusted if required. The hours of operation are affected in the TM54 calculations for each of the building activities e.g. work stations and within the building energy model calculations, which is not obvious from the worked example shown, however, this is better defined in Chapter 6 when the new method is shown applied to the real life case study scenario.

The total energy use can be recorded in the template for the timescale required by the building management system e.g. daily, weekly, monthly or annual measured in energy delivered by unit of area [m^2] or occupant [FTE].

The collective minimum 'hours of operation scenario' and minimum 'occupancy load factor' benchmarks are used to determine the lower range for the calculations in Parts 3, 4 and 5 of Template 3. Similarly the collective maximum 'hours of operation scenario' and maximum 'occupancy load factor' benchmarks are used to determine the upper range for the calculations in Parts 3, 4 and 5. The Tailored and Design POU determine the Tailored and Design Benchmarks, respectively. The minimum and maximum values generate the energy performance range for the tenure or building. The predicted design data is used to compare and evaluate how the building is performing in use to the actual monitored data in the 'Tenant Energy Reporting Method' in Step 3 and 4.

Box 3.6 Worked Example: Total Electrical Energy Use [Minimum/ Maximum/ Design / Tailored] patterns of use [Hourly/ Daily/ Monthly/ Annual]

Minimum patterns of use Annual Input data:

Days of operation = 5 days x 52 weeks = 260 days
Tenant Area = 726m^2
Tenant occupancy load factor $_{minimum}$ = 6m^2/ FTE

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 3725 + 22 585 [26310 – 3725] + 17589 + 17722 + 1834 +4742 +9306 + 1850 + 704
= 80 057 kW.h/year

Tenant annual $_{minimum}$ energy use per m^2 = Tenant annual energy use/ tenant area
= 80057/ 726
= 110 kW.h/m^2

Tenant annual $_{minimum}$ energy use per FTE = (tenant annual energy use/ tenant area) x Tenant occupancy load factor $_{minimum}$)
= [80057/ 726] x 6
= 661 kW.h/FTE

Repeat Calculations for maximum, design and tailored patterns of use and fill in Template 3: Part 2a with the results.

3.2.11 Part 2: Calculating the Swing Shift Allowance

Working out with normal hours of business is considered 'a swing shift requirement' in the new method. TM54 methodology does not currently allow for swing shift periods, which imitate the ramp up and ramp down in energy out with usual working hours where occupants start to inhabit the building or leave resulting in increased energy consumption from heating, lighting and plug loads etc. A worked example showing how this can be integrated into the new method is calculated for small power, indicated in Box 3.7. The building operations should account for the offices hours of business to include weekday, weeknight or weekend shifts, as required. The occupancy of the building and efficient working hours and practices can then be altered to suit individual tenants needs. This concludes the information required for Template 1.

Box 3.7 Worked Example for small power loads [adapted from TM54]

<u>Communal small power consumption</u>

Input data:

Typical equipment installed (a)	= 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers
Average power demand	= 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200 W/ fridge + 345 W/vending + 80 W/ cooler = 2445W
Swing shift power demand	= 2445W/2 = 1222.5W
Sleep mode power demand	= 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler = 374
Hours of operation	
[Occupied hours]	= 7 days x 8 hours x 52 weeks = 2912 hours
[Swing shift hours 0600-0900]	= [7 days x 3 hours x 52 weeks]/2 = 546 hours
[**Swing shift hours 1700-1800]**	= [7 days x 1 hours x 52 weeks]/2 = 182 hours
	= 2912 + 1274 + 546 = 4732 hours
Total hours per year	= 8760 hours

Annual energy consumption for tenant 3 communal small power [kW-h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (1222.5 x 546) + (1222.5 x 182) + (374 x (8760 – 4732))]/1000
= [7 119 840 + 667 485 + 222 495 + 1 506 472] /1000
= 9 516 kW-h/year

3.2.12 Part 3: Non-Electrical Energy Use

Part 3 of Template 3 records the predicted total non-electrical energy use for the building or tenure, as required. The calculations for the Non-electric energy use follow the same principles as the worked example for the Total Electrical Energy Use.

3.2.13 Part 4: On-site Generation

Part 4 of Template 3 records the predicted total on-site energy use for the building or tenure, as required. The calculations for the 'Non-electric Energy Use' follow the same principles as the worked example for the 'Electrical Energy Use'. The data can be used for BREEAM assessments[115] and post occupancy evaluation studies as required.[116]

3.2.14 Part 5: Sub-metered Electrical Energy Use

Part 5 of Template 3 records the predicted sub-metered electrical energy use, for each individual energy load, for the building or tenure, as required. The predicted sub-metered energy use can be recorded for the timescale required for the building management system e.g. daily, weekly, monthly or annual measured in energy delivered by unit of area [m^2] or occupant [FTE], as required. The predicted design data is used to compare and evaluate how the building is performing in operation documented in the 'Tenant Energy Reporting Method', in Step 3 and 4. The calculations out with a building energy model using the existing TM54 methodology are demonstrated for minimum POU for: hot water [Box 3.8], workstations [Box 3.9], server room [Box 3.10] and communal small power [Box 3.11]. Additional worked examples for calculating lighting, lifts and escalators, catering and other equipment can be sourced in the TM54 guidance.[108] The results presented in the 'Building Energy Impact Assessment' Template 3 can then be presented in the tenant energy report discussed in the next section.

Box 3.8 Worked Example: Hot water_[Minimum/ Maximum/ Design/ Tailored] patterns of use [Hourly/ Daily/ Monthly/ Annual]

Minimum patterns of use Annual Input data:

Daily hot water consumption per person	= 8 litre/person
Number of occupants $_{minimum}$	= 28
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 58 240 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 58 240 x 1 = 58 240 kg
Supply temperature of domestic hot water	= 65^{o}C
Return temperature of domestic hot water	= 10^{o}C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water (Cρ)	= 4.187 kJ/kg.K

Annual energy consumption (kW.h/year) = mass of water (kg) x ΔT (K) x Cρ (kJ/kg.K) /3600
= 58 240 x 55 x 4.187 / 3600
= 3725 kW.h/year

Tenant annual $_{minimum}$ energy use per m^2	= Tenant annual energy use/ tenant area = 3725/ 726 = 5 kW.h/m^2
Tenant annual $_{minimum}$ energy use per FTE	= (tenant annual energy use/ tenant area) x Tenant occupancy load factor $_{minimum}$) = [3725/ 726] x 6 = 30 kW.h/FTE

Repeat Calculations for maximum, design, and tailored patterns of use and fill in Template 3: Part 2a with the results.

Box 3.9 Worked Example: <u>Workstation Energy consumption</u> [Minimum/ Maximum/ Design/ Tailored] patterns of use [Hourly/ Daily/ Monthly/ Annual]

Minimum patterns of use Annual Input data:

Number of workstations $_{minimum}$	= 28
Workstation equipment	= 1 desktop + 1 screen + 1 phone
Average power demand	= 40 W/desktop + 30 W/ screen + 5 W/ phone = 75
Sleep mode power demand	= 2 W/desktop = 2W
Hours of operation	= 5 days x 8 hours x 52 weeks = 2080 hours
Total hours in a year	= 8760 hours

Annual energy consumption for tenant 3 workstations [kW.h/year] = number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {28 x [(75 x 2080)+ (2 x (8760-2080))]} /1000

= {28 x [156 000 + 13 360]}/ 1000

= **4742** kW.h/year

Tenant annual $_{minimum}$ energy use per m^2 = Tenant annual energy use/ tenant area
= 4742/ 726
= 6.5 kW.h/m^2

Tenant annual $_{minimum}$ energy use per FTE = (tenant annual energy use/ tenant area) x Tenant occupancy load factor $_{minimum}$)
= [4742/ 726] x 6
= 39 kW.h/FTE

Repeat Calculations for maximum, design and tailored patterns of use and fill in Template 3: Part 2a with the results.

Box 3.10 Worked Example: Small server room with no cooling

Input data:

Number of server rooms	= 1
Rated power demand of servers	= 1.2 kW [3 x 0.4 server]
Ratio of rated to operational demand	= 67%
Hours of operation	= 24 hours x 7 days x 52 weeks = 8760 hours

Annual energy consumption for small server rooms (kW.h/year) = (number of rooms x rated power demand (kW) x ratio of rated to operational power demand x hours of operation)

= (1 x 1.2 x 0.067 x 8760)
= 704 kW.h/year *estimated*

Tenant annual $_{minimum}$ energy use per m^2 = Tenant annual energy use/ tenant area
= 704 /726
= 0.9 kW.h/m^2

Tenant annual $_{minimum}$ energy use per FTE = (tenant annual energy use/ tenant area) x Tenant occupancy load factor $_{minimum}$)
= [704/ 726] x 6
= 5.8 kW.h/FTE

Repeat Calculations for maximum, design and tailored patterns of use and fill in Template 3: Part 2a with the results.

Box 3.11 Worked Example: Communal Small Power Consumption [Minimum/ Maximum/ Design / Tailored] patterns of use [Hourly/ Daily/ Monthly/ Annual]

Minimum patterns of use Annual Input data:

Typical equipment installed (a) = 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers

Average power demand = 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200

W/ fridge + 345 W/vending + 80 W/ cooler = 2445W

Sleep mode power demand = 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler= 374W

Hours of operation = 7 days x 8 hours x 52 weeks = 2912 hours

Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (374 x (8760 – 2912))]/1000

= [7 119 840 + 2 187 152] /1000

= 9306 kW.h/year

Other equipment installed = *2 radio [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 2 microwave [700W] + 1 coffee machine [670W] + 1 water kettle [2800W] + 1 television [190W]* + 1 video entrance system [20W] + 1 smart board [275] + 1 network hub [20W] + 1 mechanical lifter for smart board [1800W] + 1 task light [50W]

Average power demand = 10915 W *estimated*

Sleep mode power demand = 50W *estimated*

Hours of operation = 5 days x 0.5 hours x 52 weeks = 130 hours *estimated*

Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(10915x 130) + (50 x (8760 – 130))]/1000

= [1 418 950 + 431 500] /1000

= 1850 kW.h/year *estimated*

Tenant annual $_{minimum}$ energy use per m^2 = Tenant annual energy use/ tenant area

= 11156/ 726

= 15.4 kW.h/m^2

Tenant annual $_{minimum}$ energy use per FTE = (tenant annual energy use/ tenant area) x Tenant occupancy load factor $_{minimum}$)

= [11156/ 726] x 6

= 92 kW.h/FTE

Repeat Calculations for maximum, design and tailored patterns of use and fill in Template 3: Part 2a with the results.

3.2.15 Step 3: The Tenant Energy Report

The new 'Tenant Energy Report' would replace a non-domestic EPC to show the Asset Rating[91] for (a) the building by tenure measured in energy use delivered per unit of area [kW.h/m^2] and (b) the occupant by tenure measured in energy use delivered per FTE [kW.h/FTE] at building handover. The 'Tenant Energy Report' also demonstrates the impact of variations in POU for the 'occupancy load factor' and 'hours of operation' defined in the 'Building Energy Impact Assessment' for annual consumption of (a) the total energy use and (b) the predicted energy loads for each building activity. The aim of the new 'Tenant Energy Report' is to communicate the energy performance calculations used to inform the building design and gain building compliance prior to building occupation to the end user, the tenant.

Retrospectively, a 'Tenant Energy Report' could be compiled to engage the tenant or landlord in energy improvement measures and compare energy performance to another subtenant's office with similar POU. The detailed information in the report is aimed at empowering the tenant to understand how to target suitable energy reduction measures and determine if the building is functioning as expected and who should pay for changes to the building fabric or HVAC systems, the tenant or the landlord. The 'Tenant Energy Report' communicates the energy performance range defined by the 'Building Energy Impact Assessment' and design information sets operational limits on building activities highlighting areas within or out of range. As stated previously, if the energy load is out of range the POU calculations can be investigated to ascertain the operating patterns need to change or if the HVAC is not operating effectively.

The 'Tenant Energy Report' could form the basis of an online dynamic version of an EPC, which updates the building performance data inline with meter readings, the building management system, monitored energy use, and occupancy data.

Tenant Energy Report

HM Government

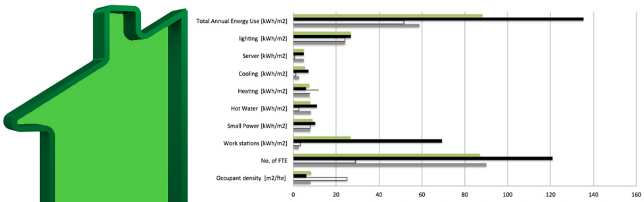
Tenant energy efficiency evaluation

1st floor
Notional Building
Confidential Street
Anytown
A1 2BC

This report indicates the impact of the minimum and maximum patterns of use on annual energy consumption for (a) each fte and (b) the tenants let area. This also tells you the proposed Asset Rating based on the optimum design standard. The Operational Rating, Asset Rating, Minimum and Maximum patterns of use can be compared for each of the buildings activities, so that the tenant can check the performance of each activity as a means to lowering their consumption and lowering their carbon emissions. Details of the calculations are appended to this report.

Tenant Energy Performance Asset Rating [kWh/m²]

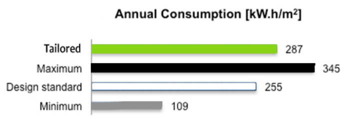
This tells you the predicted asset rating of the tenant area [design standard]. This also tells you the impact of extreme patterns of use on energy consumption, which categorized the tenants predicted energy performance range outlined in the predicted scenarios. The operational rating [actual] can be compared to the asset rating [design standard].



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/m2]	Small Power [kWh/m2]	Hot Water [kWh/m2]	Heating [kWh/m2]	Cooling [kWh/m2]	Server [kWh/m2]	lighting [kWh/m2]	Total Annual Energy Use [kWh/m2]
Actual	8.3	87	26.6	8.95	7.9	7.5	5.57	4.88	26.8	88.2
Maximum	6	121	69.4	10.3	11	5.9	7	4.88	26.9	135.38
Minimum	25	29	3.24	7.9	2.55	12.1	1.23	0.48	24.1	51.6
Design standard	8	90	2.48	7.92	8.19	8.47	2.68	4.95	24.1	58.79

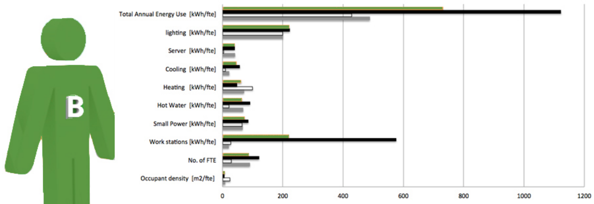
Annual Consumption

This tells you how efficiently energy has been used in the tenanted area in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed.



Tenant Energy Performance Asset Rating [kWh/fte]

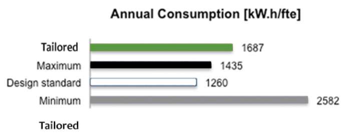
This tells you the predicted asset rating of each FTE [design standard]. This also tells you the impact of extreme patterns of use on energy consumption, which categorized the tenants predicted energy performance range outlined in the predicted scenarios. The operational rating [actual] can be compared to the asset rating [design standard].



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/fte]	Small Power [kWh/fte]	Hot Water [kWh/fte]	Heating [kWh/fte]	Cooling [kWh/fte]	Server [kWh/fte]	lighting [kWh/fte]	Total Annual Energy Use [kWh/fte]
Actual	8.3	87	220.7	74.2	65.6	62.3	46.2	40.5	222	731.5
Maximum	6	121	576	85.5	91.3	48.9	58	40.5	223	1123.2
Minimum	25	29	26.8	65.57	21.2	100	10.2	3.98	200	427.75
Design standard	8	90	20.58	65.7	67.9	70.3	22.2	41	200	487.68

Annual Consumption

This tells you how efficiently energy has been used by each FTE in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed.



Technical Information

This tells you the scenarios used to calculate the different patterns of use. Details of the calculations are appended to this report.

Scenario 1 Minimum patterns of use	**Scenario 2** Design Standard	**Scenario 3** Maximum patterns of use	**Actual** Actual patterns of use
Low occupancy Occupant density: 25m2/FTE FTE'S: 29	Designed occupancy Occupant density: 8m2/FTE FTE'S: 90	Maximum occupancy Occupant density: 6m2/FTE FTE'S: 121	Actual occupancy Occupant density: 8.3m2/FTE FTE'S: 87
Minimum hours [0900 to 1700] No weekend hours	Minimum hours [0900 to 1700] No weekend hours	Maximum hours [0600 to 1800] No weekend hours	Actual hours [0600 to 1800] No weekend hours
Low IT use [good energy star rating of 4.0].	Moderate IT use [CIBSE Guide A].	High IT use [average energy star rating].	High IT use [average energy star rating].

Administrative information

This is a Tenant Energy Report as defined in SI2007:991 as amended.

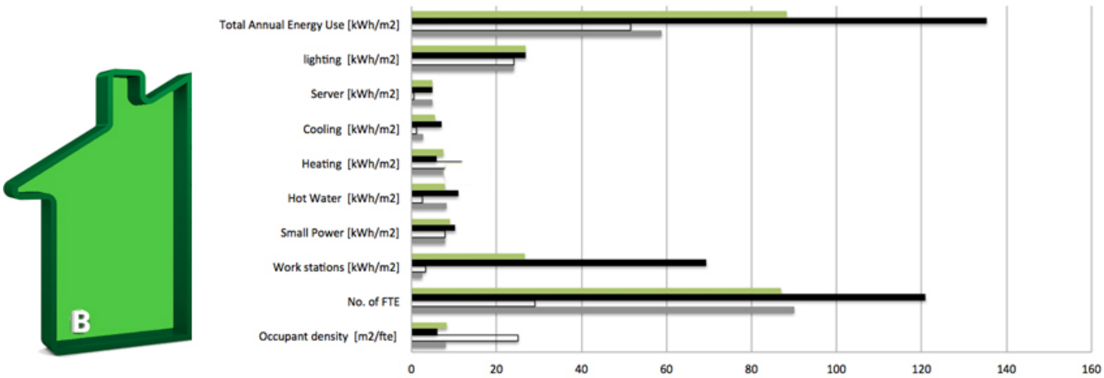
Assessment Software:
Property Reference: 891123776612
Assessor Name: John Smith
Assessor Number: ABC12345
Accreditation Scheme: ABC Accreditation Ltd
Employer/Trading Name: EnergyWatch Ltd
Employer/Trading Address: Alpha House, New Way, Birmingham, B2 1AA
Issue Date: 12 May 2007
Nominated Date: 01 Apr 2007
Valid Until: 31 Mar 2008
Related Party Disclosure:
Recommendations for improving the energy efficiency of the building are contained in Report Reference Number 1234-1234-1234-1234

Figure 3.13 Example of Proposed Tenant Energy Report

The Asset Rating would be derived either from the 'NCM standard or design' POU and would represent optimal performance in the 'Tenant Energy Report'. Articulating the predicted energy use under standard conditions as the optimum design condition allows tenants to understand that the predicted energy usage outlined in the report would only be achievable if the POU, working hours, internal and external environment mimicked the design brief POU. This helps the users to consider how they are operating the building differently and to calculate their tailored POU. Although the benchmark is renamed to give more clarity as to what it represents, the old method of calculation is sustained to allow easy reference to the existing EPCs. Therefore the potential for improvement will be accountable to the variations in POU specific to tenant requirements.

The 'Tenant Energy Report' example illustrated in Figure 3.13 indicates the impact of occupancy benchmarks on annual energy consumption for (a) each FTE and (b) the Tenants let area. This also indicates the proposed Asset Rating based on the optimum design standard. The design [Asset Rating], minimum, maximum and tailored POU can be compared for each of the building activities, so that the tenant can check the performance of each activity as a means to lowering their consumption and their carbon emission.

The 'Tenant Energy Performance Asset Rating' [kW.h/m^2] section of the report [Figure 3.14] indicates the predicted Asset Rating [Design or NCM standard] of the tenant delivered by area. This also indicates the impact of occupancy benchmarks on energy consumption categorised by the tenants predicted energy performance range outlined in the predicted scenarios. The tailored POU can be compared to the Asset Rating [design or NCM standard] to determine how the tenant is using the building in comparison as to how it was designed to function. This enhances the current NCM method by predicting each of the tenants activities performance range. If the building is sub-metered to give readings for all or some of the building activities they can be checked to see if the building is performing as predicted. The results shown here are for yearly calculations.



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/m2]	Small Power [kWh/m2]	Hot Water [kWh/m2]	Heating [kWh/m2]	Cooling [kWh/m2]	Server [kWh/m2]	lighting [kWh/m2]	Total Annual Energy Use [kWh/m2]
Actual	8.3	87	26.6	8.95	7.9	7.5	5.57	4.88	26.8	88.2
Maximum	6	121	69.4	10.3	11	5.9	7	4.88	26.9	135.38
Minimum	25	29	3.24	7.9	2.55	12.1	1.23	0.48	24.1	51.6
Design standard	8	90	2.48	7.92	8.19	8.47	2.68	4.95	24.1	58.79

Figure 3.14 Tenant Energy Performance Asset Rating per m^2 [kW.h/m^2]

The 'Annual Consumption' [kW.h/m^2] section of the report [Figure 3.15] indicates the total tenant tailored energy use, which is used to define the tenant energy rating delivered by area. This shows how efficiently energy has been used in the tenanted area in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed. If the tailored POU are not known or calculated the asset rating will be used to determine the buildings energy rating. This measure enhances the existing EPC by reporting how the tenanted area is expected to perform over its performance range aligned with the TM54 method adjustments.

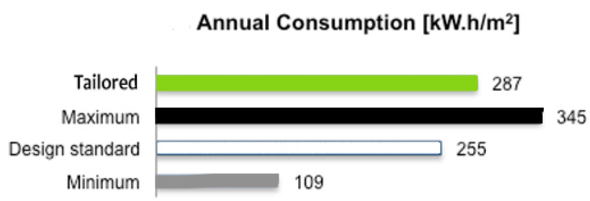
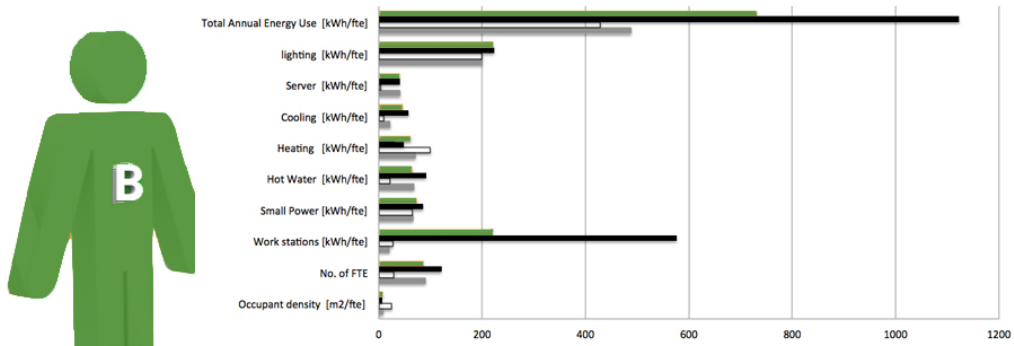


Figure 3.15 Annual Consumption [kW.h/m^2]

The 'Tenant Energy Performance Asset Rating' [kW.h/FTE] section of the report [Figure 3.16] indicates the predicted asset rating of an FTE [design or NCM standard].

This also indicates the impact of extreme POU on energy consumption, which categorized the tenants, predicted energy range outlined in the predicted scenarios. The tailored POU can be compared to the Asset Rating or ‘design’ standard. This measure enhances the existing EPC by reporting the impact of occupant behaviour on energy performance.



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/fte]	Small Power [kWh/fte]	Hot Water [kWh/fte]	Heating [kWh/fte]	Cooling [kWh/fte]	Server [kWh/fte]	lighting [kWh/fte]	Total Annual Energy Use [kWh/fte]
Actual	8.3	87	220.7	74.2	65.6	62.3	46.2	40.5	222	731.5
Maximum	6	121	576	85.5	91.3	48.9	58	40.5	223	1123.2
Minimum	25	29	26.8	65.57	21.2	100	10.2	3.98	200	427.75
Design standard	8	90	20.58	65.7	67.9	70.3	22.2	41	200	487.68

Figure 3.16 Tenant Energy Performance Asset Rating per FTE [kW.h/FTE]

Annual Consumption [kW.h/FTE] section of the report [Figure 3.17] indicates how efficiently energy has been used by an FTE in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed. This measure enhances the existing EPC by reporting the impact of occupant behaviour on energy performance and how the tenanted area is expected to perform over its performance range inline with the TM54 method. The Technical Information section of the report indicates the scenarios used to calculate the different POU. Details of the calculations would be appended in the ‘Building Energy Impact Assessment’ report.

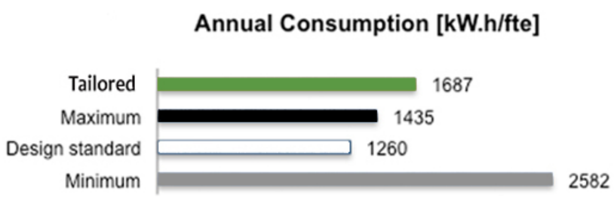


Figure 3.17 Annual Consumption [kW.h/FTE]

The proposed outcome is an occupant led annual consumption energy performance range calculation determined by the occupancy load factor benchmarks, which can be compared to similar buildings as identified in the EPC or can be compared to other tenants occupying the same building.

3.2.16 Step 4: Report Operational Energy Use

The aim of template 4 [Figure 3.18] is to report the operational energy performance of the building or tenure to compare actual energy consumption with predicted 'Patterns of Use', in the 'Tenant Energy Reporting Method'.

3.2.17 Part 1: Data Quality

Template 4: Part 1 records the source of operational data by an energy survey, energy bills, building management system or monitoring etc. and notes the reporting method.

3.2.18 Part 2: Actual Total Electric Energy Use

Template 4: Part 2 records the operational 'actual' total electric energy use, at the required time intervals of the building users. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.19 Part 3: Non-electric Energy Use

Template 4: Part 3 records the operational non-electric energy use, at the required time intervals of the building users. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.20 Part 4: On-site Generation

Template 4: Part 4 records the operational energy use of all on-site generation, at the required time intervals of the building users. This can be recorded for yearly, monthly, weekly or daily comparisons.

TEMPLATE 4: TENANT ENERGY REPORTING METHOD [TERM]
Specify Energy Reporting Timescales: [Daily/ Weekly/ Monthly/ Annual]

PART 1: DATA QUALITY	
Source of Data [survey, bills,BMS.monitoring]	
reporting method [TM22, BMS, EPC, DEC]	

PART 2: ACTUAL TOTAL ELECTRIC ENERGY USE					
Electrical energy use total per occupant [kWh/fte]					
Electrical energy use total per m2 [kWh/m^2]					

PART 3: NON-ELECTRIC ENERGY USE					
Non-electric energy use total [kWh/m2]					
space heating					
hot water					
Non-electric energy use total [kWh/fte]					
space heating					
hot water					

Part 4: ON-SITE GENERATION					
On-site Generation [kWh/m2]					
electrical energy					
non-electric (solar water etc)					
On-site Generation [kWh/fte]					
electrical energy					
non-electric (solar water etc)					

PART 5: SUB-METERED ENERGY USE					
Electrical energy use total [kWh/m2]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					
Electrical energy use total [kWh/fte]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					

Figure 3.18 Template 4

3.2.21 Part 5: Sub-metered Energy Use

Template 4: Part 5 records the operational sub-metered energy use of all building activities, at the required time intervals of the building users. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.22 Evaluate Operational Performance against the Design Predictions

The aim of Template 5 [Figure 3.19] is to report the operational tenure energy performance against the design data captured in Template 3 and 4 to evaluate operational efficiency. The template can be used to generate a 'Tenant Energy Certificate', and compare data from the building management system or commissioned energy monitoring exercises. The template is used to determine if the tenure energy performance is improving or not and can be linked back to the traditional energy ratings in the 'tenant energy report' and 'tenant energy certificate' to target improvements for both the building rating and the occupant rating.

3.2.23 Part 1: Data Quality

Template 5: Part 1 [Figure 3.19] records the source of operational data by an energy survey, energy bills, building management system or monitoring etc. and notes the reporting method. Recording the design and operational data provides the baseline knowledge for targeted future energy monitoring or post occupancy evaluation exercises to be established, which is linked with the 'Building Energy Impact Assessment'.

3.2.24 Part 2: Actual Total Electric Energy Use

Template 5: Part 2 records the actual total electric energy use predicted at design stage and evaluates the proposed performance against the 'actual' operational data to assessment improvement or not. This can be recorded for yearly, monthly, weekly or daily comparisons.

TEMPLATE 5: TENANT ENERGY REPORTING METHOD [TERM]

PART 1: DATA QUALITY	
Source of Data [survey, bills,BMS.monitoring]	
reporting method [TM22, BMS, EPC, DEC]	

PART 2: ACTUAL TOTAL ELECTRIC ENERGY USE	Design	Minimum	Maximum	Actual	Results +/-
Electrical energy use total per occupant [kWh/fte]					
Electrical energy use total per m2 [kWh/m^2]					

PART 3: NON-ELECTRIC ENERGY USE	Design	Minimum	Maximum	Actual	Results +/-
Non-electric energy use total [kWh/m2]					
space heating					
hot water					
Non-electric energy use total [kWh/fte]					
space heating					
hot water					

Part 4: ON-SITE GENERATION	Design	Minimum	Maximum	Actual	Results +/-
On-site Generation [kWh/m2]					
electrical energy					
non-electric (solar water etc)					
On-site Generation [kWh/fte]					
electrical energy					
non-electric (solar water etc)					

PART 5: SUB-METERED ENERGY USE	Design	Minimum	Maximum	Actual	Results +/-
Electrical energy use total [kWh/m2]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					
Electrical energy use total [kWh/fte]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					

Energy Perfromance Range

Figure 3.19 Template 5

3.2.25 Part 3: Non-electric Energy Use

Template 5: Part 3 records the non-electric energy use predicted at design stage and evaluates the proposed performance against the 'actual' operational data to assessment improvement or not. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.26 Part 4: On-site Generation

Template 5: Part 4 records the on-site generation of all building activities predicted at design stage and evaluates the proposed performance against the 'actual' operational data to assessment improvement or not. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.27 Part 5: Sub-metered Energy Use

Template 5: Part 4 records the sub-metered energy use of all building activities predicted at design stage and evaluates the proposed performance against the data 'actual' operational to assessment improvement or not. This can be recorded for yearly, monthly, weekly or daily comparisons.

3.2.28 The Tenant Energy Certificate

The new 'Tenant Energy Certificate' [Figure 3.20] would be created when the building was in occupation for a year, similar to how a Display Energy Certificate [DEC] is used for depicting a public buildings energy rating in use. The 'Tenant Energy Certificate' is used in conjunction with the 'Tenant Energy Report.' The 'Tenant Energy Certificate' replicates the DEC in terms of showing the buildings operational energy efficiency rating, which could be calculated from detailed energy monitoring information if available or meter readings if not. As shown in the certificate in Figure 3.20, the 'Tenant Energy Certificate' indicates the annual energy use of (a) each occupant, where performance is rated in terms of energy use per full time employee and (b) in terms of energy use per square unit of floor area, for a tenant specific let area.

Tenant Energy Certificate

Tenant energy efficiency evaluation

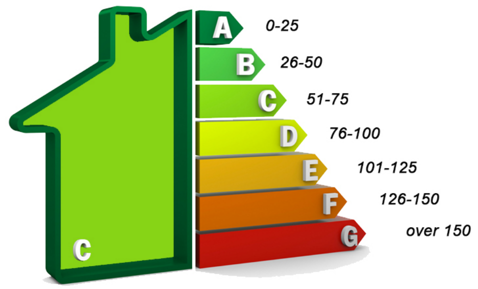
HM Government

1st floor
Notional Building
Confidential Street
Anytown
A1 2BC

This certificate indicates the annual energy use of (a) each occupant, where performance is rated in terms of energy use per full time employee and (b) the tenants let area, where performance is rated in terms of energy use per square unit of floor area. The Operational Rating is based on meter readings of all the energy used by the tenant. It is compared to a benchmark that represents performance indicative of all offices of this type. Details of the Asset Rating calculations and predictions are summarised in the Tenant Energy Report.

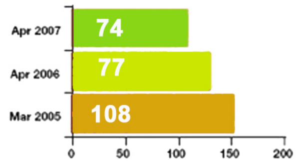
Tenant Energy Performance Operational Rating [kWh/m²]

This tells you how efficiently energy has been used per m2 of tenant floor area. The numbers do not represent actual units of energy consumed; they represent comparitive energy efficiency. 100 would be typical for this kind of building.



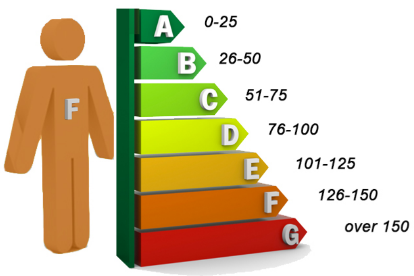
Previous Operational Ratings

This tells you how efficiently energy has been used in the tenanted area over the last three accounting periods.



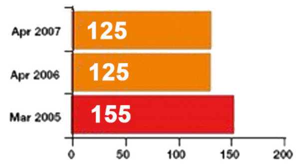
Tenant Energy Performance Operational Rating [kWh/fte]

This tells you how efficiently energy has been used per full time employee. The numbers do not represent actual units of energy consumed; they represent comparitive energy efficiency. 100 would be typical for this kind of building.



Previous Operational Ratings

This tells you how efficiently energy has been used in the tenanted area over the last three accounting periods.



Technical information

This tells you technical information about how energy is used by the current tenant. Consumption data is based on actual readings.

Main Heating Fuel: Electricity
Building environment: Air Conditioned
Total Tenant Floor area: 726m2
Occupant density: 8m2 per fte
Asset Rating: 50

	Heating	Electrical
Annual Energy Use (kWh/m²/year)	126	129
Typical Energy Use (kWh/m²/year)	120	95
Energy from renewables	0%	20%

Figure 3.20 Example of Proposed Tenant Energy Certificate

The Operational Rating is based on meter readings of all the energy used by the tenant. It is compared to a benchmark that represents performance indicative of all offices of this type. Details of the Asset Rating calculations and predictions are summarised in the Tenant Energy Report' section.

The 'Tenant Energy Performance Operational Rating' per m^2 [$kW.h/m^2$] section of the report [Figure 3.21] indicates how efficiently energy has been used per m^2 of tenant floor area. The numbers do not represent actual units of energy consumed; they represent comparative energy efficiency. 100 would be typical for this kind of building. This emulates how a current DEC is presented.

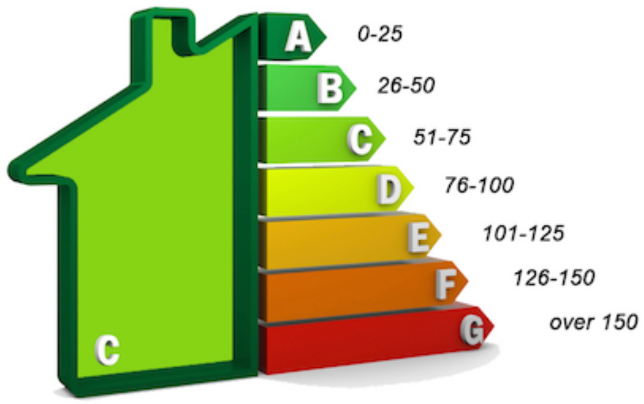


Figure 3.21 Tenant Energy Performance Operational Rating per m^2 [$kW.h/m^2$]

The Previous Operational Ratings per m^2 [$kW.h/m^2$] section of the report [Figure 3.22] indicates how efficiently energy has been used in the tenanted area over the last three accounting periods. This also emulates how a current DEC is presented.

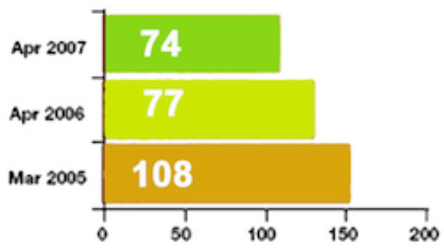


Figure 3.22 Previous Operational Ratings per m^2 [$kW.h/m^2$]

The Tenant Energy Performance Operational Rating per FTE [kW.h/FTE] section of the report [Figure 3.23] indicates how efficiently energy has been used per full time employee. The numbers do not represent actual units of energy consumed; they represent comparative energy efficiency. 100 would be typical for this kind of building. This measure enhances a DEC by presenting the annual energy rating by reporting the impact of POU on energy performance.

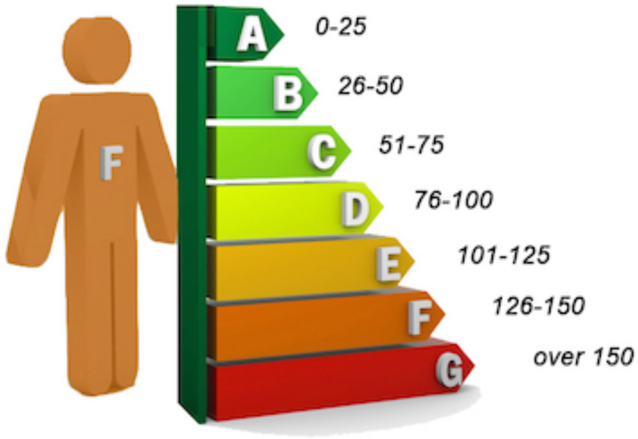


Figure 3.23 Tenant Energy Performance Operational Rating per FTE [kW.h/FTE]

The 'Previous Operational Ratings per FTE' [kW.h/FTE] section of the report [Figure 3.24] indicates how efficiently energy has been used in the tenanted area over the last three accounting periods. This measure also enhances a DEC by presenting the annual energy rating by reporting the impact of POU on energy performance.

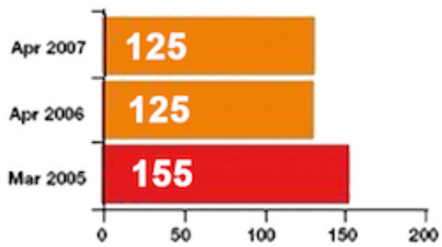
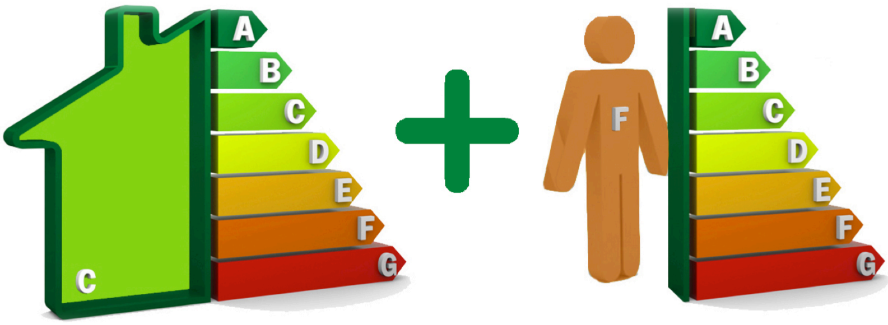


Figure 3.24 Previous Operational Ratings per FTE [kW.h/FTE]

The Technical Information section of the report indicates technical information about how energy is used by the current tenant. Consumption is based on actual readings. This also emulates how a current DEC is presented.



Annual Energy Consumption per m^2 [kW.h/m^2]

Annual Energy Consumption per FTE [kW.h/FTE]

Figure 3.25 Demonstrating the Energy Rating Method per m^2 and per FTE.

Figure 3.25 Shows that annual energy consumption could be calculated using kW.h/FTE using accurate information on occupancy load factors, which considers floor area allocated per person in relation to the sublet area, which differs from the current view of an approximate occupancy load factor for the entire building. Using the two metrics is a powerful tool when used together. Considering both occupant and buildings energy use clearly identifies efficient buildings but inefficient tenants or vice versa through targeting both regulated and unregulated energy use.

3.3 Intended Impacts and Benefits

The newly introduced method enhances building energy performance scope beyond what is currently required for compliance and certification, through (a) measuring the impact of occupant factors on energy efficiency, (b) providing detailed analysis of multi-tenant buildings [as opposed to a representation or evaluation of the buildings as a whole], (c) enabling assessment of the building's operational limits and extremes of low and high occupancy and POU by tethering occupant energy demand [kW.h/FTE] to building energy demand [kW.h/m^2] and (d) identifying inefficient working hours, equipment or management strategies. The benefit of producing a 'Tenant Energy Report' with the supplementary 'Tenant Energy reporting Method' calculations is the clarification of how a building is expected to operate. This can also be scaled to represent any sublet part of an occupied building, given the right building energy model is used to articulate the heating and cooling requirements. The new methods strategy of integrating the use of 'occupancy load factor' benchmarks and 'operational hour scenarios' from design stage through to evaluating the building in operation provides a necessary narrative and best practice guide, which energy monitoring and post occupancy evaluation exercises, such as building management systems and TM22, can be judged providing useful feedback. The intended users of the new method include building designers, owners, tenants, and facilities managers [Figure 3.26].

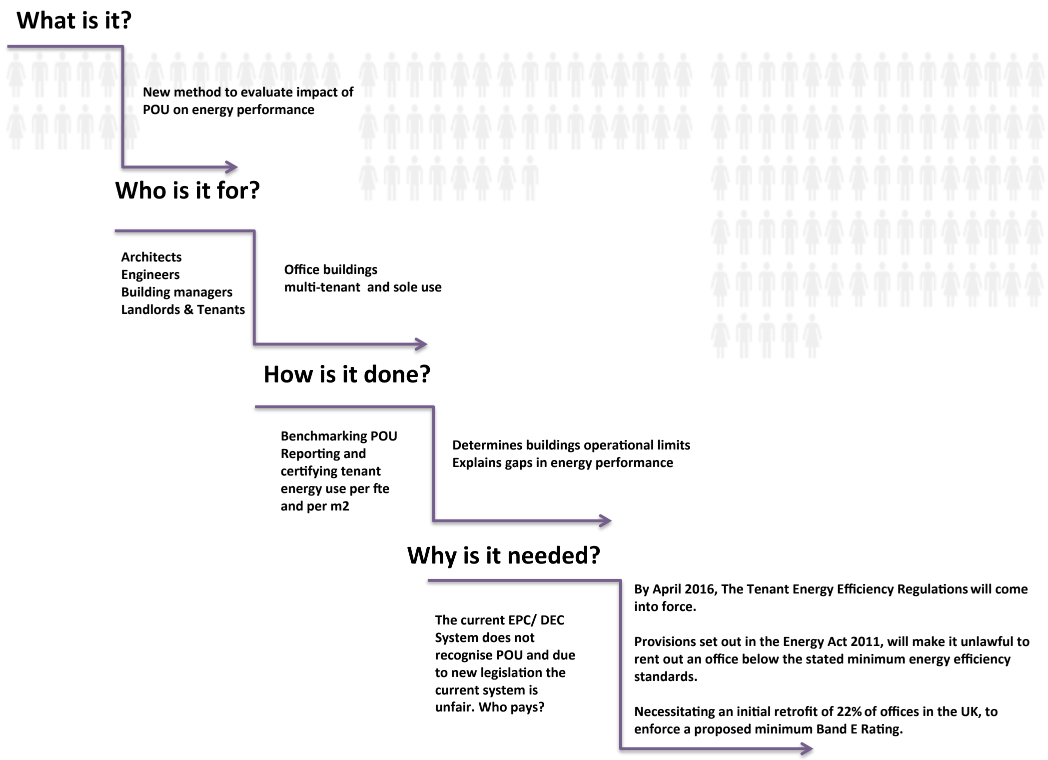


Figure 3.26 Method Summary showing intended Impacts, Benefits and Users

The new method allows designers and tenants to learn the effect of POU on performance, understand the relationships between different energy loads and provide detailed building energy performance reporting of the building area under their ownership. The method also allows designers, owners, facilities managers and tenants to monitor and improve the relationship between building and occupant performance, reduce bills, mitigate the impact of buildings on the environment, promote building energy performance improvement measures and market building operational efficiencies to clients. The method will support the application of the Tenant Energy Efficiency Regulations enabling a fair assessment of minimum energy efficiency standards.

3.4 Integration with Industry State of the Art.

The new POU method enhances the current state-of-the-art processes used by Carbon Buzz and TM54 in the design and operation phases, as identified in Figure 3.27 to describe the impact of POU in more detail.

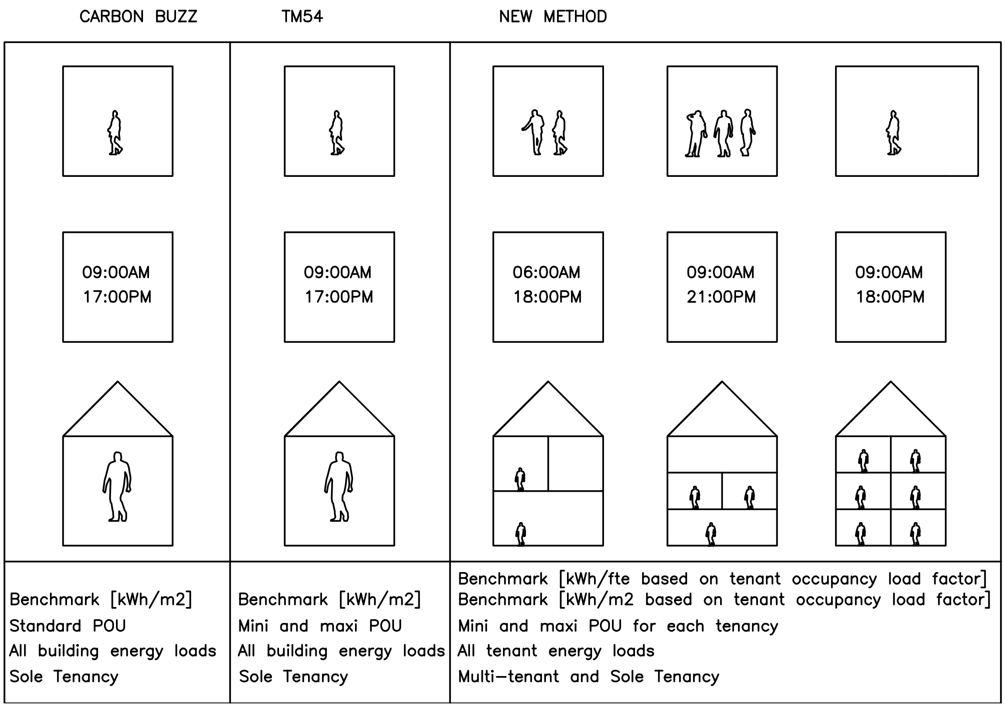


Figure 3.27 Illustration of how the new method compares to the existing carbon buzz and TM54 methodologies.

The new method enhances the existing NCM method by maintaining standard usage patterns as one of the occupancy load factor benchmarks and promotes using the A-G rating and kW.h/m^2 used in EPC's to certify tenant energy performance. Similarly, the calculations used to define building energy performance in TM54 are used as a platform to calculate the different tenant energy performance POU scenarios together with a 'Tenant Building Energy Model'. This allows easy transfer to the new method while maintaining the benefits of the old system. The main difference between evaluating building energy performance versus tenant energy performance is the new method allows the tenant to (a) evaluate the impact of a sub-tenant through detailing the aggregated energy use of a full-time employee; (b) evaluate the minimum and maximum POU scenarios to understand the impact of the tenant's POU on tenant and building energy performance; and (c) to understand if the building or the occupant's POU are inefficient, improving on best practice.

3.5 New Method Test and Evaluation

The approach taken to develop the new method is first to demonstrate the effect of POU on energy performance by measuring variations in POU between tenants in an office building. This is followed by determining whether the hypothesis is correct that POU differs from tenant to tenant and that a new method to capture the effect of POU on building energy performance could be developed.

3.6 Chapter Summary

This Chapter has outlined how the gap defined in Chapter 2 will be addressed through specifying the building energy performance method to be developed, outlining how POU will be tested and evaluated then reviewing how POU can be better defined to improve the existing methods of assessment and giving a step-by-step account of the new method. The next chapter develops the proposed method through further defining the parameters and ranges to be used.

Chapter 4: Development of the Proposed New Method

Development of the Proposed New Method through defining Variations in Patterns of Use Parameters and Ranges

4.0 Chapter Introduction.

This chapter defines and justifies the parameters, benchmarks, metric and ranges chosen to represent variations in Patterns of Use [POU] in the new method. The new method is developed through an investigation of (i) how POU are captured in existing building regulation and office guidance (Section 4.1), (ii) how variations in POU exist between building tenures and clarifying how this could be developed (Section 4.2) and (iii) how parameters, benchmarks and metrics used by building regulation and office guidance could be altered or improved for use in the new method (Section 4.3). A case study building was used to illustrate the current processes and methods to be investigated and the key parameters and ranges identified.

4.1 Establishing how variations in POU are captured in Building Regulation

This section defines how occupancy load factors and occupancy capacity calculations differ across building compliance standards by demonstrating that (i) occupancy load factor and occupancy capacity is specific to occupied area (ii) Tenant Energy Performance [TEP] values vary depending on a subtenant's chosen POU and (iii) how current compliance methods fall short of defining the impact of POU on Building Energy Performance [BEP]. How existing compliance and occupancy calculations could be used to determine occupancy load factor benchmarks and the effects of occupancy factors on BEP, are then defined.

Building Regulation exists to ensure that all buildings are constructed to national and european standards. Building regulation is developed by government and approved by parliament. In Scotland, the building regulation standards are cited in the Scottish Technical Handbooks. The standards driven by occupancy calculations include Section 3: Ventilation and Sanitary Provision, Section 4: Fire Safety and Section 6: Energy. To demonstrate compliance with the standards it is necessary to calculate the total number of occupants to be accommodated in the building defined as either (a) a maximum building occupancy capacity or (b) a building occupancy load factor (categorised by the building's purpose group). The calculations establish suitable and safe building facilities to include: a fire evacuation strategy, sanitary provision, and HVAC requirements. With the exception of the fire standards, the occupancy calculations estimate rather than demonstrate likely building occupancy in operation.

The National Calculation Method [NCM], ensures consistent comparison of similar building types by predicting how the building will perform through defining a schedule of building activities.[71] As stated in Chapter 2, a number of factors that affect energy demand [heating and cooling set points during unoccupied or occupied hours, ventilation and infiltration rates, lighting levels, standard occupancy day schedules, hot water and heat gains] are standardised [per m^2 of treated floor area], in order to regulate and compare energy use. The NCM database applies standard profiles, for the occupancy load factor, hours of operation and the associated internal room heat gains. The building energy performance calculations assume that all buildings operate under a standard operating condition throughout the building's lifecycle, irrespective of the buildings future physical conditions or design constraints. [91] Conversely, within the Scottish Technical Non-Domestic Handbook standards 3, 4 and 6 the building occupancy load factor and occupancy capacity can vary in design intent depending on which of the standard you are demonstrating. This is because, beyond the scope of the building energy performance evaluation, buildings are designed to accommodate different occupancy capacities over the lifespan of the building, but may be designed to tenants requirements in the short term.

Figure 4.1 The Case Study Building.

The Scottish Technical Non-Domestic Handbook[117] were reviewed [based on the 2007 edition of the standards], in addition to the architects [Appendix A] and engineers drawings [Appendix B] and Section 6 compliance report [Appendix C] to determine the proposed occupancy levels, for a sample case study building.

4.1.1 Identification of the Case Study Building

A suitable case study office building required four key compulsory characteristics to allow it to provide the necessary data:

1. To be a multi-tenanted with a minimum of three different tenants.
2. Each tenants energy use required to be sub-metered.
3. The building needed to be occupied for at least 2-3 years post-handover. This was to ensure the building was out with the defects liability and settling in period; the building systems were in full operation, and the building had completed a full seasonal cycle.[116]
4. Permissions, availability and access to allow collation of detailed occupant data on all the tenants including their behaviour in entering and leaving their office accommodation, in tandem with monitoring of the energy use data.

The Orion building was identified, partly occupied by the BRE, as fulfilling the above requirements. The resident tenant groups office managers and their employees were approached to gain permission to study their offices POU and permission was granted. The intention was to use a building, which was simple to observe, to gain credible insights, as opposed to getting lost in the data of a larger more complex project. The chosen case study methodology could be repeated on a grander scale if the resources and financial commitment could be met. The selected case study building proved to be a good example, for the thesis, by clearly demonstrating the hypothesis that variations in patterns of use exist between different tenant groups, sharing the same building.

The case study building [Figure 4.1, 4.2] consists of office space accessed from a central double height glass atrium, which leads to 2 adjacent office wings on the ground and first floor. The building houses three different tenants, one tenant in each of the wings at ground floor and one tenant who occupies both wings at the upper level.

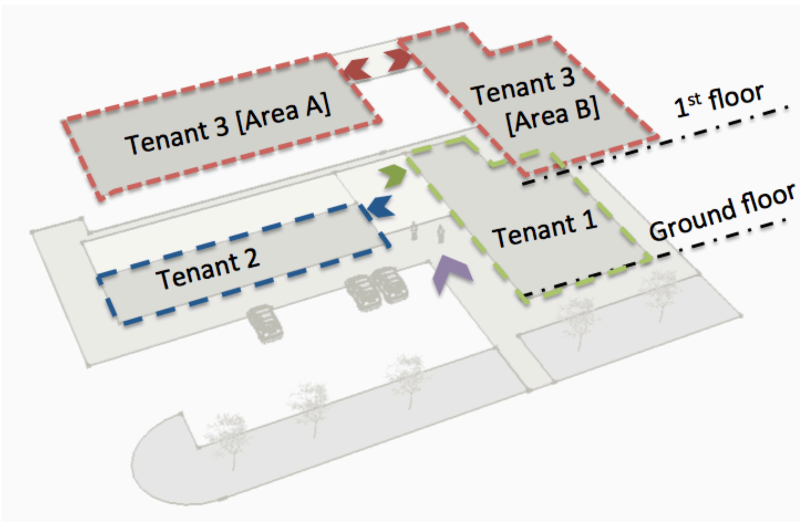


Figure 4.2 Building Schematic showing office locations and entrance points for tenants 1,2 and 3.

The architect's drawings [Figure 4.3 and 4.4] were requested to gain information on the building and tenant areas as a means of calculating the occupancy capacity allowed for each tenancy under the 2007 building regulations.

Figure 4.3. Orion Building Elevations

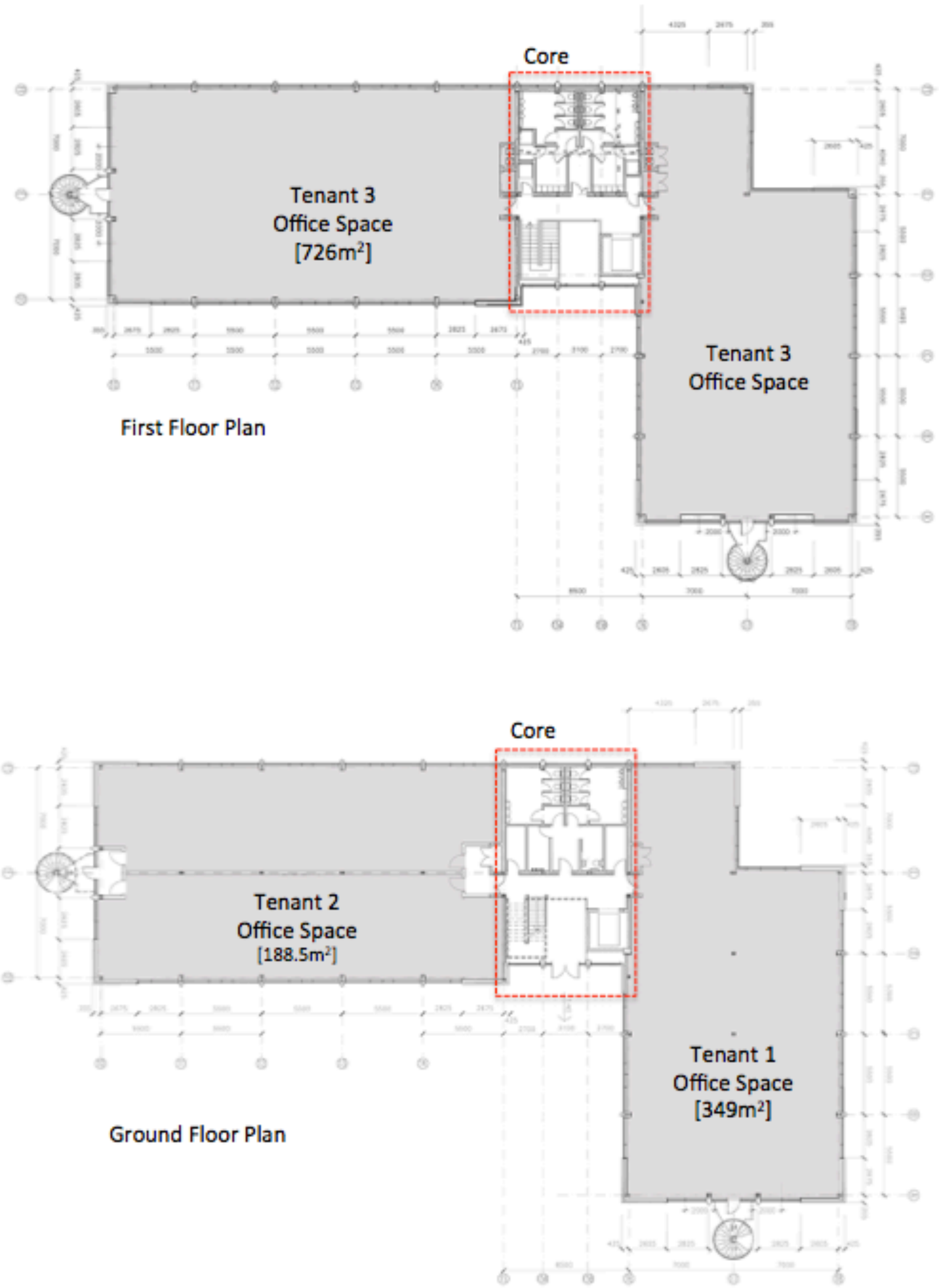


Figure 4.4. Orion Building Floor Plans

The area occupied by each tenant is shown in Table 4.1. The drawings also provided information on the building fabric [Appendix A] and u-values in Table 4.2.

Table 4.1 Tenancy Net Lettable Area Breakdown

Tenancy	Tenant 1	Tenant 2	Tenant 3	Single Tenure
Building Area [m^2]	349m^2	188.5m^2	726m^2	1452m^2

Table 4.2 Building Fabric U-values used in simulation [taken from architects drawings]

Building Fabric Element	**U-value ($W/m^2.K$)**
External walls	0.2896
Ground	0.2533
Roof	0.2498
Glazing (North and East)	1.40
Glazing (South and West)	1.40
Internal ceiling	0.4102
Internal partition	1.7341

The drawings [Figures 4.3 and 4.4] illustrate the clear separation between the different tenant group's office space and the shared services within the building core accessed from a central atrium. The building core contains the toilets, building management facility computer room, electrical cupboard housing all the tenant's electric metres and general cleaning storage. As the core area is a shared facility and out with each tenants net lettable area the tenant energy performance calculations for the operation of this area was not included in the study. The building management facility comprised of a small room with a computer, which records the hours of operation of the building through a swipe card entry system and security camera footage, solely for the security of the building. The building management facility did not record building energy performance at the time of the case study.

All areas accept the plant rooms, toilets and stores were heated using a Variable Refrigerant Flow [VRF] multi-split air conditioning system with heat recovery, which comprises of three external heat pumps [one per tenant group] and internal ceiling mounted heat recovery units to each room, which provide both heating and cooling operated via a wired remote controller. The technology enables individual climate control of air conditioning zones. The toilets were heated using electric panel heaters, and electric immersion heaters supplied hot water alongside mechanical ventilation with heat recovery provided to all common areas. As the toilets were a shared facility the energy use of common areas were metered separately, and the running costs split between different tenant groups.

4.1.2 Calculating Occupancy Capacity at Design Stage

The Scottish Technical Handbook regulatory standards were used to retrospectively calculate the predicted occupancy capacity at design stage for each tenant group within the case study building; firstly, to test how occupancy varies within the standards and secondly, how this compares in reality to the occupancy levels recorded in the case study sample. The relevant Building Standard examples are summarised in Boxes 4.1– 4.5. The calculations are typical of all building control submissions for a building of this nature to meet building warrant approval. The calculations are based on an occupancy load factor defined by the tenant group area and the number of full-time employee's according to each office manager. Each tenant group intimated set working hours of 8 hours a day per person despite variations in employee start and finish times. Thus, for the purpose of the calculations carried out in this section and the thesis a full-time employee is defined as someone who works 40 hours every week, for 260 days every year.

4.1.3 Calculating Occupancy Capacity via the Ventilation Standards

The Scottish Technical Handbooks Section 3.14: Ventilation standards [118] are met by demonstrating an appropriate air change rate calculated as litre per second per person, to ensure the air quality within the building is maintained at an acceptable level. Working back, an expected occupancy for the tenant accommodation can be calculated when the airflow for each tenant is known. The total airflow used to calculate the occupancy capacity assumed in ventilation compliance calculations was derived by a back-calculation from the engineer's drawings submitted for approval [Appendix B]. The occupancy capacity for each tenant group's office area, identified in figure 4.2, is illustrated in Box 4.1.

Box 4.1 Worked example: Maximum number of building occupants assumed in ventilation regulation standard calculations.

Occupancy Capacity = total airflow/airflow rate per person

Tenant 1

Total Airflow: 504 l/s @ 12 l/s/p

Occupancy Capacity = [504/ 12] = 42 people

Tenant 2

Total Airflow: 428 l/s @ 12 l/s/p

Occupancy Capacity = [428/ 12] = 35 people

Tenant 3

Total Airflow: 1470 [720 + 750] l/s @ 12 l/s/p

Occupancy Capacity = [1470/ 12] = 122 people

The ventilation calculations are shown for each of the three different offices within the case study building. Please note although the net internal floor area for the upper and lower floors are identical [Figure 4.4] the engineer has allowed for a more generous total airflow [Appendix B] for tenant 3. It is unclear why the accommodation has been designed in this way; however, the occupancy capacity of this office is denser than tenant 1 and 2. This highlights that a change in occupancy beyond the specified design limit in either tenant area 1 or 2 would have an effect on the air quality of this office.

4.1.4 Calculating Occupancy Capacity via the Sanitary Provision Standards

The Scottish Technical Handbooks Section 3.12.1: Sanitary Provision Standards[118] are met by calculating the proposed number of occupants and then providing sanitary provision as outlined in the standard. Working back from the sanitary accommodation provided, the number of occupant serving each office could be derived as shown in Box 4.2. Tenant X represents a part of the case study building, which is sublet and not part of the research study.

Box 4.2 Worked example: Maximum number of building occupants to comply with sanitary provision standards

Occupancy Capacity = tenant area [m^2] /occupancy load factor [$6m^2$ per person]

Where provision of toilets and wash hand basins is 1 for 1 to 5 occupants, 2 for 6 to 25 occupants and one additional for every additional 25 occupants.

From the architect's drawings the following sanitary provisions were noted:

Ground Floor

3 male WC and 3 female WC plus 1 unisex disabled toilet

Assuming a provision of 6 toilets on a 50: 50 split male and female

1 to 25 occupants = 2 WC and 1 WC for every 25 occupants thereafter =

125 occupants

Based on area; Tenant 1 occupy 48% [$349m^2/726m^2$] of the space and Tenant 2 26% and Tenant 26% respectively

Tenant 1 = 60 occupants, Tenant 2 = 32 occupants and Tenant X = 32 occupants

First Floor:

3 male WC, 2 urinals = 46 - 60 occupants

3 female WC = 50 occupants

Tenant 3 = 110 occupants

4.1.5 Calculating Occupancy Capacity via the Fire Safety Standards

The Scottish Technical Handbooks Section 4: Fire Safety Standards[69] are met by applying an occupancy load factor for the entire office building stated in standard 2.9.2 of the technical handbooks 2007 as $6m^2$ per person. The calculations for a sole tenant and subsequently the three actual tenants are shown in Box 4.3. This demonstrates the maximum number of building occupants who can safely escape in the event of a fire.

Box 4.3 Worked example: Maximum number of building occupants to comply with fire regulation safety standards Occupancy Capacity = tenant area [m^2] /occupancy load factor [$6m^2$ per person]	
Sole Tenant	=1452/6 =242 occupants
Tenant 1	= 349/6 = 58 occupants
Tenant 2	= 188.5/6 = 31.5 occupants
Tenant 3	= 726/6 = 121 occupants

4.1.6 Calculating Occupancy Capacity via the Energy Standards

The Scottish Technical Handbooks Section 6: Energy Standards[119] data was extracted from the iSBEM model software and represents a standard occupancy load factor used by the NCM for open plan office space to comply with section 6 of the Scottish Technical Handbooks. Each tenancy in the Orion Building consists of open plan office space; therefore the occupancy load factor allocated is described as 0.11 people per m^2 or $9m^2$ per person. The proposed occupancy capacity calculation for each of the tenants is shown in Box 4.4.

Box 4.4 Worked example: Maximum number of building FTE to comply with energy regulation Occupancy Capacity = tenant area [m^2] /occupancy load factor [$9m^2$ per person]	
Sole Tenant	=1452/9 =161 occupants
Tenant 1	= 349/9 = 38 occupants
Tenant 2	= 188.5/9 = 20 occupants
Tenant 3	= 726/9 = 80 occupants

4.1.7 Calculating Occupancy Capacity via British Council for Offices Standards

In addition to building regulation standards, there is also the UK British Council for Offices [BCO] Standards.[120] The BCO standards recommend $100ft^2$ per person as standard occupancy load factor for offices, which equals 9.3m^2 per person. This concludes the review of the predicted occupancy calculations for the case study building, shown in Box 4.5.

Box 4.5 Worked example: Maximum number of building occupants to comply BCO recommended minimum office standards

Occupancy Capacity = tenant area [m^2] /occupancy load factor [9.3m^2 per person]

Sole Tenant	=1452/9.3
	=156 occupants
Tenant 1	= 349/9.3
	= 37 occupants
Tenant 2	= 188.5/9.3
	= 20 occupants
Tenant 3	= 726/9.3
	= 78 occupants

The variations in occupancy load factor originated from the various predicted occupancy scenarios calculated from the building standards are listed in Table 4.3 and 4.4. The occupancy load factor's shown in the Table refer to the expected number of occupants [FTE] per m^2 of net lettable floor area and occupancy capacity refers to the total number of occupants [FTE] expected within each office tenure.

Table 4.3 Variations in Occupancy Load Factor [depending on the occupancy standard used)

	Occupancy Load Factor of Each Tenancy [m^2 per occupant]			
Occupancy Standard	**Tenant 1**	**Tenant 2**	**Tenant 3**	**Sole Occupancy**
Energy	9	9	9	9
Sanitary Facilities	5.8	5.8	6.6	6.2
Ventilation	8.3	5.3	5.9	6.2
Fire	6	6	6	6
BCO standard	9.3	9.3	9.3	9.3
Actual Occupancy	**19.3**	**18.8**	**8.3**	**12.6**

Table 4.4 Variations in Occupancy Capacity [depending on the occupancy standard used)

	Occupancy Capacity of Each Tenancy [No of occupants/ FTE]			
Occupancy Standard	**Tenant 1**	**Tenant 2**	**Tenant 3**	**Sole Occupancy**
Energy	38	20	80	161
Sanitary Facilities	60	32	110	235
Ventilation	42	35	122	235
Fire	58	31	121	242
BCO standard	37	20	78	156
Actual Occupancy	**18**	**10**	**87**	**115**

Reviewing the building regulatory standards demonstrates the extent of the variation present in the case study sample. The research highlights systemic discrepancies between occupancy load factors calculated as a tool for design intent and occupancy load factors calculated by the NCM to deliver energy performance predictions. What's interesting is that not one of the actual tenant occupancy capacity matched up with the occupancy predicted and portrayed in the Section 6 Compliance Report, which is the indicator of predicted energy performance. Tenant 1 and Tenant 2 occupancy capacity is very low in comparison to Tenant 3. Tenant 1 and Tenant 2 indicate the highest number of proposed occupants using the sanitary provision standard calculations. This level of occupancy would not be expected as it's beyond the occupancy that could be accommodated for safe evacuation in the event of a fire. The higher sanitary provision is likely to be a client request so this upper limit can be quickly discounted. From the analysis, the actual occupancy of tenant 1 and 2 was much lower than predicted. If prediction models are being used as a benchmark for energy use then the offices with low occupancy loads and low capacity have double the energy allowance in comparison to tenant 3 who would have to be slightly more economical with their energy consumption to meet the predicted energy use, as they have a higher occupancy capacity than predicted.

The outcome of the study has demonstrated that the fire safety standard is a good indicator of the maximum number of tenants the building can be expected to cope with at any one time, setting a sensible upper limit and a maximum benchmark for each office. However, it is hard to set the lowest occupancy benchmark based on the study sample survey data.

4.1.8 Defining Occupancy Capacity used in NCM approved Building Energy Models

A review of the building standards occupancy calculations confirmed the expected occupancy of a building differs depending on what standard or guidance the calculation is demonstrating. The NCM calculates design stage building performance by assuming an entire office building is a single tenure with specific POU, operating under a standardised occupancy load factor of $9m^2$ per FTE and standardised weekday operating hours of 9 am to 5 pm unless a tailored POU is defined at design stage. The occupancy capacity determines how the building will respond with this amount of people and their prescribed allocation of IT equipment, ventilation requirements and thermal comfort. This method allows a Building Energy Model to carry out calculations and compare how buildings of different sizes, locations, orientation and fabrics will respond to our climate. The Building Energy Model calculates the building energy use through considering the building geometries, climate and orientation alongside the buildings technical specification. The generic calculation makes it impossible for subtenants to understand the impact of their individual POU on Tenant Energy Performance or the collective impact of several differing tenant POU on BEP.

Subsequently, the current methodology of evaluating predicted occupancy, in the NCM methodology and Building Energy Models, are an approximation rather than a likely representation of building or tenant energy performance. Also, due to increasing sensitivities of a building’s heating, cooling and energy requirements to the effect of the occupant’s operational requirements, the NCM methodology represents a very narrow view of energy performance.

There is scope and capability to demonstrate how a building may perform under different tenant groups POU to give facilities managers and building users a better understanding of their operational patterns on performance. All of the above occupancy calculations are based on regulatory standards to be applied in the design stage. The outcome of the review of building regulation identified conflicting calculations of occupancy capacity levels across the standards. The next section considers how occupancy capacity, occupancy load factor and operational times vary across each tenant in the case study building.

4.2 Variations in POU present in the Case Study Building

The actual occupancy load factor and occupancy capacity calculations for the Orion Building were then gained from each tenant group's office manager confirming the number of full-time employee's of each organisation, shown in Table 4.5. Also, each tenant group's hours of operation were also requested, shown in Table 4.6.

Table 4.5 Calculating the Actual Occupancy Load Factor for Each Tenant in the Case study Building

Tenancy	Area	Number of Full Time Employees [FTE]	Occupancy Load Factor [Area/FTE]
NCM	1452m^2	161	[1452/161] = 9m^2
Tenant 1	349m^2	18	[349/ 18] = 19.3m^2
Tenant 2	188.5m^2	10	[188.5/10] = 18.8m^2
Tenant 3	726m^2	87	[726/87] = 8.3 m^2

Table 4.6 NCM speculated hours of building operation and tenants regular hours of operation

Tenancy	Day	Regular hours of operation
NCM	Monday - Friday	09:00 – 17:00
Tenant 1	Monday - Friday	07:00 – 19:00
Tenant 2	Monday - Friday	06:30 – 18:00
Tenant 3	Monday - Friday	07:00 – 19:00

Occupancy load factor and hours of operation varied across each of the case study building tenant groups. Resulting in the hypothesis that in reality, different tenants operate the building with differing POU. Variations in occupancy load factor, hours of operation and related occupancy parameters, identified in chapter 3, will then have an effect on some the tenant's energy loads and the thermal performance of their portion of office space.

A method to determine the impacts of variations in POU could be developed through demonstrating likely patterns of use and their impact on tenant energy loads.

Figures 4.5 and 4.6 demonstrate the office area sublet to each tenant and how they vary in size. The combination of variations in occupancy load factor and occupied area makes it difficult for a tenant to compare their BEP as they only use a portion of the buildings overall energy use. As the area used by tenants varies significantly it makes sense that BEP is measured in energy delivered per unit of floor area. However, as occupancy load factors vary, it also makes sense to demonstrate BEP measured in energy use delivered per occupant, in the context of offices by FTE equivalent, concerning their predicted POU [based on tenant specific occupancy capacity and occupied area] and then asses the effect of POU on all building energy loads.

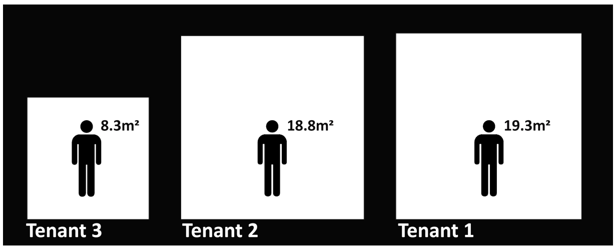


Figure 4.5 Diagram showing the proportional representations of variations in occupancy load factors (m^2 per person (FTE)) that exist between each tenant in the case study building.

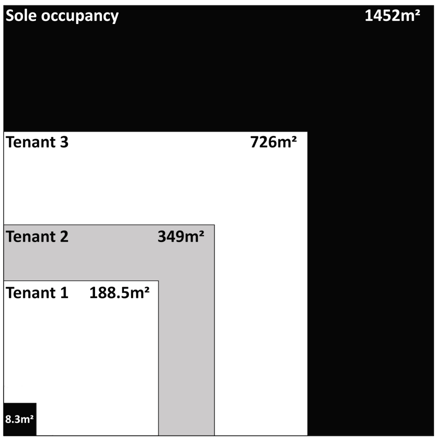


Figure 4.6 Proportional representation of variations in tenure area leased by each tenant group in the case study building.

4.2.1 Reporting NCM Annual and Monthly Building Energy Use

To prove the hypothesis that the impact of tenant POU on BEP is not captured in existing BEP compliance procedures the following calculations were derived from the

Orion Building Section 6 Compliance Report generated by the NCM methodology submitted for building warrant approval. The NCM calculations show the projected annual and monthly building energy use.

As shown in Table 4.7, the monthly energy usage in January is predicted at approximately 12.7MWh. This is then used to calculate a daily energy use for each tenant that can be compared to the actual monitored case study data.

Table 4.7 Predicted annual, monthly and January Energy Use

	Energy Use [MWh]		
Regulated Loads	**Annual**	**Monthly Average**	**January Average**
Heating	24	2	4
Cooling	8	0.7	0
Fans/ Pumps/ Controls	53	4.4	5.4
Lights	35	2.9	3.3
Total	**120**	**10**	**12.7**

The data in Table 4.7 was used to predict daily energy use and to calculate energy delivered per unit of floor area, as shown in Box 4.6 and Table 4.8.

Box 4.6 Worked example: Daily Energy Use in January

12.7MWh= 12,700kW.h

12,700 / 31 days = 577 kW.h per day

577kW.h per day/ buildings Net Internal Area [1452m^2] = 0.27 kW.h/m^2 per day

Table 4.8 Energy Use per unit of floor area

	Daily Predicted Energy Use in January of Each Tenancy [kW.h/m^2]			
NCM Standard	**Tenant 1**	**Tenant 2**	**Tenant**	**Sole Occupancy**
Energy Compliance	0.27	0.27	0.27	0.27

This proves that, under the current compliance method it does not matter what occupancy the building has (as the energy use is calculated per m^2), the energy use would be predicted to be the same, based on the building being occupied by one standard POU, hence, it assumes that all tenants will inhabit and use the floor space of their building in the same manner. The same occupant to floor space ratio and the same loads and the same hours of operation would be used. This methodology allows compliance calculations of the proposed building to be tested against the notional building benchmark that building control set to determine if the projected building's performance is good enough.

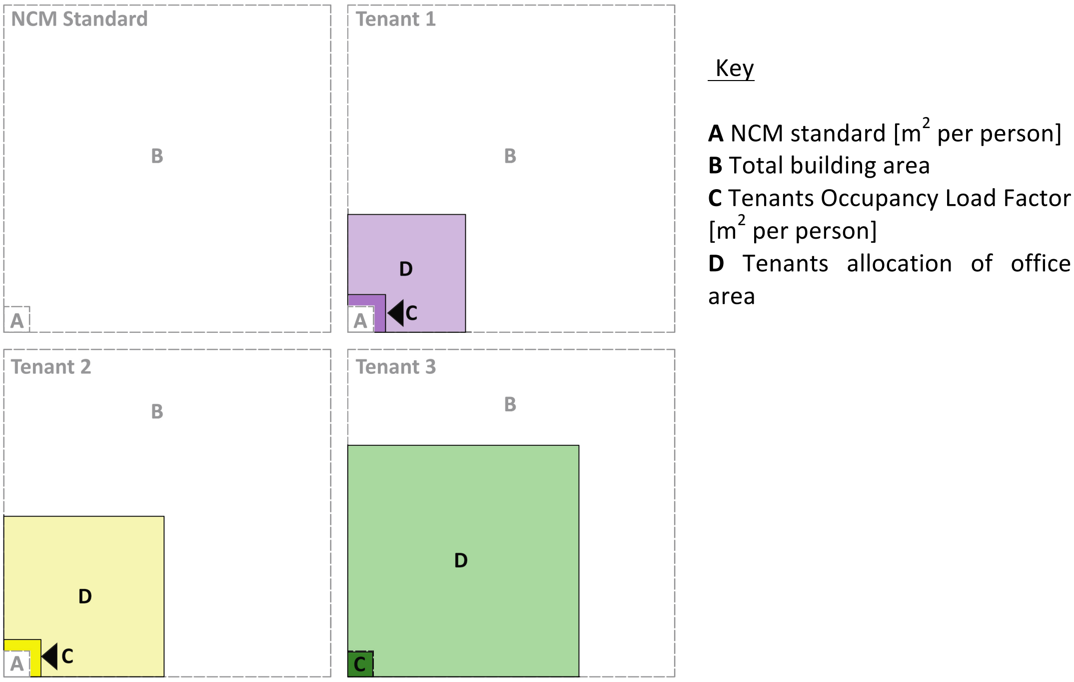


Figure 4.7 Proportional representation of how each of the tenants compares to the NCM standard occupancy load factor and proportionally how much area they accommodate in relation to the total building area.

Figure 4.7 shows proportionally how each of the tenant's occupancy load factor and area varies in comparison to the predicted NCM standard. Table 4.6 demonstrates that the hours of operation of each tenant vary from the NCM standard office hours used in the compliance calculations, which result in the overall building operation hours extending beyond 8 hours to 13. The results reveal variations between each tenant's occupancy load factor, occupied area and hours of operation, affecting the tenant's intensity of energy use. Subsequently, the tenant energy loads will differ in operation from calculations in the building energy model submitted for building regulation compliance or from the parameters used in TM54 calculations.

4.2.2 Defining Variations in Patterns of Use

It is not possible to simply apply a scale factor to calculate the energy use of each tenant group, as this would not consider variations in patterns of use between tenants in terms of variations in hours of occupancy and occupancy load factor during the occupied period and the cumulative effect of differing variations in POU on total building energy use. Nor is it accurate to calculate energy delivered per building occupant by dividing the total energy use by the total number of predicted building occupants as this also results in a standard POU assessment. The desktop study has identified that current compliance methods fall short of realising the impact of POU on BEP and that a new method could be developed that considers effects of different tenants variations in POU on building performance evaluation. It is not feasible to demonstrate every possible POU for every building. However, it would be beneficial to illustrate to the building users what the expected minimum and maximum POU could be to set limits on expected energy loads and tenant operation. Using variations in occupancy capacity, occupancy load factors and hours of operation factors as parameters to demonstrate the effect of occupancy factors on energy loads could better represent a BEP range and enhance existing BEP methodologies. 'Variations in POU', 'occupancy load factor' and 'occupancy capacity' have been shown to be key parameters in establishing realistic thresholds. Variations and assumptions across design standards have been illustrated. The next step is to look at how POU benchmarks and ranges could be defined in the new method.

4.2.3 Defining Occupancy Load Factor Benchmarks and Ranges

This section determines POU benchmarks and ranges through investigating the occupancy load factors used in building regulation and guidance. To define the occupancy load factor benchmarks by which the building and tenants energy use can be reasonably tested against a range of existing industry benchmarks were reviewed to set down the principles of maximum and lower design limits [see Table 4.9].

As discussed, the fire regulatory standard could set the maximum design limit. The British Council for Offices Occupancy Survey[120] was considered and could be adjusted to adopt a sensible lower limit of 25m^2 per person. The existing NCM benchmark used for determining expected energy use for EPC and DEC could be used to define a design standard benchmark, which could be substituted for a 'tailored building POU,' if used at design stage. This was adopted instead of the BCO work place density as the NCM occupancy load factor is integrated with existing building performance evaluation assessments tools and would allow comparison with the existing BEP evaluation methodology. The last benchmark represents the tenants POU, tailored to the tenants own occupancy load factor, based on actual occupancy levels, and allocated office area. This allows for an accurate comparison of the tenant predicted energy use to actual monitored data. The introduction of a design standard allows the building to be compared in a traditional sense to the CIBSE benchmarks and guidance.

Table 4.9 Existing OLF Benchmarks used for Building Regulation and Space Standards

Building Regulation Standard or Guidance	**Occupancy load factor**
Building Regulations Approved Document B [Fire safety]	$6m^2$/person
NCM office density	$9m^2$/ person
British Council for Offices: Workplace density	$10m^2$/person
British Council for Offices: Occupant density survey sensible lower limit	$23m^2$/person

Table 4.10 Adopted New Method OLF Energy Performance Benchmarks

	Building Regulation Standard or Guidance	**Occupancy load factor**
Maximum	Building Regulations Approved Document B [Fire safety]	$6m^2$/person
Design	'Building' occupancy load factor at design stage	Xm^2 /person
NCM	NCM standard occupancy load factor	
Minimum	British Council for Offices: 2008 occupant density survey sensible lower limit	$25m^2$/person
Tailored	Tenant's POU at operational stage	Xm^2/ person

The proposed benchmarking method and range is identified in Table 4.10. The maximum occupancy load factor benchmark is defined as $6m^2$/person [FTE] and the minimum occupancy load factor benchmark is defined as $25m^2$/person [FTE]. This sets the operational range of the tenure occupancy. The NCM occupancy load factor benchmark is defined as $9m^2$/person [FTE] creating a design target. The design and tailored occupancy load factor benchmark would be defined project by project. The hours of operation range defined in Chapter 3, Table 3.4, Illustrates NCM operation hours to be 9am-5pm and maximum operational hours to be a 24-hour building but other scenarios would be defined project by project. Therefore the tenure POU range is established from the collective impact of maximum occupancy load factor benchmark and maximum operational hours and minimum occupancy load factor benchmark and minimum operational hours on tenant energy loads.

This section has described and justified the selection of occupancy load factor and hours of operation to demonstrate variations in POU, which exist between building tenant groups. The next section defines the parameters used to test BEP at the design stage and in the operation stages. Then assesses how variations in POU parameters are currently addressed.

4.3 Parameters and sensitivity analysis from literature and compliance models

In this section, the selection of existing parameters, benchmarks and metrics used for building performance evaluation and best practice[71, 108, 121, 122] are identified. The criteria chosen to represent variations in POU is reviewed and justified in relation to the thesis works. The parameters, benchmarks and metrics are tested, compared and reviewed against existing regulatory and industry processes to determine the advantages of using the new methods parameters, benchmarks, metrics and ranges in practice.

4.3.1 Building Energy Performance [BEP] Parameters

Predicting building activity energy loads and total energy use is well covered by existing methods of assessment. The current industry methods to evaluate BEP, to include: Carbon Buzz,[46, 47] TM54, [108] TM22[121] and the NCM,[71] are reviewed for their inclusion of the POU parameters (i) occupancy load factor [area and occupancy capacity] and (ii) hours of operation. The objective is first to understand the differences between the parameters selected in the methodologies and then to evaluate if the calculations could be used to define variations in energy loads based on POU parameters and ultimately an energy performance range for each. Furthermore, existing BEP metrics are reviewed as a method of evaluating the impact of POU on BEP. The analysis discovers that parameters relating to physical systems are well covered, but the POU-specific parameters to determine variation in POU are found lacking. The parameters used to measure and compare BEP equal the building energy loads, which are grouped and categorised in Table 4.11.

Table 4.11 The parameters used to measure and compare BEP

BEP Evaluation Parameters	**BEP Assessment Methodology**			
	Carbon Buzz	**TM22**	**TM54**	**NCM**
Total Energy Use	✓	✓	✓	✓
Total Electric Energy Use	✓			✓
Total Non-Electric Energy Use	✓			✓
On-site generation	✓			✓
Building Activity Energy Loads	**Carbon Buzz**	**TM22**	**TM54**	**NCM**
Equipment (small power)		✓	✓	✓
Lighting	✓	✓	✓	✓
Pumps and controls	✓	✓	✓	✓
Fans	✓	✓	✓	✓
Cooling	✓	✓	✓	✓
Hot water	✓	✓	✓	✓
Heating	✓	✓	✓	✓
Workstations (Computers)	✓		✓	
Server Rooms	✓		✓	
Appliances (small power)	✓		✓	
Catering (small power)	✓		✓	
Lifts			✓	

The parameters used to measure and compare BEP consist of total electric energy use, non-electric energy use, onsite generation and individual building activity energy loads e.g. hot water and lifts. The parameters vary in scope and depth depending on the BEP methodology used and the extent of the energy evaluation. On reviewing the current methodologies, Carbon Buzz and TM54 assess the greatest amount of BEP parameters. Carbon Buzz is aimed at comparing detailed BEP trends in non-domestic buildings, and TM54 is a new methodology aimed at demonstrating an energy performance range for each building activity. Therefore, the most robust way to document BEP would be to record POU, similar to Carbon buzz principles for reporting BEP to industry and prove POU performance similar to TM54 principles, which could be adopted in the NCM and TM22 methodologies. The next section reviews 'TM54: Evaluating Operational Energy Performance of Buildings at the Design Stage' to determine which BEP parameters are affected by variations in POU parameters to include: occupancy load factor, occupancy capacity, occupied building area and operation hours. Then describes the existing benchmarks and metrics used to define BEP. The parameters identified in table 4.11 are used to populate the Building Energy Impact Assessment and Tenant Energy Reporting method: Part 5 of Templates 3, 4 and 5 in Chapter 3.

4.3.2 BEP Parameters affected by Occupancy Capacity

BEP predicted energy load calculations, cited in the TM54 methodology, directly affected by occupancy capacity involve hot water and lifts. The calculations are currently based on (i) a predicted number of building occupants for energy use generated from hot water use or (ii) the number of lift trips generated by occupancy for the energy use associated with lifts, as shown in Table 4.12.

Table 4.12 BEP calculations affected by occupancy capacity

Parameter	Direct	Indirect	Comments	Calculation Method
Hot water	✓		Hot water use is predicted on litres used per occupant.	Annual mass of water (kg) = (**Daily hot water consumption per person x number of occupants** x number of occupied days per year) x water density at ambient temperature. Then Annual energy consumption (kW.h/year) = mass of water (kg) x temperature difference (55K) x specific heat capacity of water (4.187 kj/kgK/ 3600
Lifts	✓		Increased pedestrian traffic and occupants POU affect the intensity that lifts are used.	Annual Lift Energy Use (kW.h/year) = (the **number of starts per year** x the drive motor rating (kW) x time to travel all floors / 4) + the standby energy used by a single lift per year.

The calculations could be repeated to show expected variations in hot water and lift energy use, determined by variations in occupancy capacity, for either the entire building or individual tenure. The impacts of POU could be clearly calculated and demonstrated for each of the occupancy load factor benchmarks, indicated in section 4.2.3, to generate an energy performance range for the lift and hot water energy use.

4.3.3 BEP Parameters affected by Occupancy Capacity and Hours of Operation

Work-station energy load calculations, cited in the TM54 methodology, are directly affected by occupancy capacity and hours of operation. The calculations are currently based on a predicted number of workstations provided per building occupants for the required hours of operation, as shown in Table 4.13.

Table 4.13 BEP calculations affected by occupancy capacity and hours of operation

Parameter	Direct	Indirect	Comments	Calculation Method
Workstations (Computers)	✓		Workstation equipment to include desktop computers will be directly linked to occupancy. Shared equipment will also have an increase in usage due to the frequency of use with less or more occupants. Also, the hours of use of workstation equipment are under control of the occupants.	Annual energy consumption for workstations (kW.h/year) = **number of workstations** × {[average power demand during operation × hours of operation] + [sleep mode power demand × (8760 – hours of operation)]}

The calculations could be repeated to show expected variations in the equipment and workstations provided alongside the tenant's hours of operation, for either the entire building or individual tenure. The impacts of POU could be simply calculated and demonstrated for each of the occupancy load factor benchmarks, indicated in section 4.2.3, to generate a workstation energy performance range.

4.3.4 Parameters affected by Occupancy Capacity, Area and Hours of Operation

BEP energy load calculations, cited in the TM54 methodology, affected by occupancy capacity, building area and hours of operation are shown in Table 4.14, which include the buildings fan, pumps and controls and the building heating and cooling systems. The calculations are complex and undertaken by a building energy model.

Table 4.14 BEP calculations affected by occupancy capacity, building area and hours of operation

Parameter	Direct	Indirect	Comments	Calculation Method
Fans, Pumps and controls		✓	HVAC pumps and controls are indirectly affected by occupancy due to users requirements out with office hours or user preferences.	An estimate of the energy use for space heating cooling, fans and pumps is undertaken by using a DSM model with the National Calculation Methodology

Heating and Cooling	✓	✓	Heating and Cooling is directly affected by building users, as proven in the case study, as occupant's preferences and POU determine when and how often cooling is required. Cooling is also necessary in relation to increased heat from increased IT kit, which can be related to increased occupancy.	An estimate of the energy use for space heating cooling, fans and pumps is undertaken by using a DSM model with the National Calculation Methodology

Occupancy, tenure area and hours of operation could be modeled to determine tailored usage patterns but could also be used to project the occupancy load factor benchmarks proposed, with the right building energy model. The impacts of POU could be clearly calculated and demonstrated for each of the occupancy load factor benchmarks, indicated in section 4.2.3, to generate an energy performance range for each parameter shown in Table 4.11.

4.3.5 BEP Evaluation Parameters affected by Hours of Operation

BEP energy load calculations, cited in the TM54 methodology, affected by occupants preferred operational times are shown in Table 4.15. It would be possible to demonstrate variations in hours of operation using current TM54 calculations methods and reflect individual tenant groups POU through demonstrating variations in proposed working hours.

Table 4.15 BEP calculations affected by occupants preferred hours of operation

Parameter	Direct	Indirect	Comments	Calculation Method
Small Power: Equipment, Appliances and Catering	✓	✓	Shared equipment will increase in usage due to the frequency of use with less or more occupants. Besides the hours of use of equipment are under control of the occupants.	Annual energy consumption (kW.h/year) (communal small power) = number of floors × [(power demand during operation × **hours of operation**) + (out of hours power demand × (8760 – hours of operation)]
Server Rooms		✓	Server rooms are sized on expected IT usage and also the number of people the equipment is to facilitate.	Annual energy consumption for large cooled server rooms (kW.h/year) = (number of rooms × rated power demand (kW) × ratio of rated to operational power demand × **hours of operation**) × 1.7
Lighting	✓	✓	Task lighting is in direct control of occupants	Energy consumption used for illumination (kW.h/year) = [(total

			together with operational times. Security lighting and general lighting will be under the influence of building operation requirements.	installed power x constant illumination factor) x (daylight **usage time** x occupancy dependency factor x daylight dependency factor) + (non-daylight **time usage** x occupancy dependency factor)]/ 1000 plus the parasitic energy consumption

The calculations could be repeated to show expected variations in a tenant's hours of operation, for either the entire building or individual tenure to generate an energy performance range for each parameter shown in Table 4.11.

A review of the TM54 methodology has clearly demonstrated that the TM54 calculations could be used to define the impact of variations in POU on building or tenant energy loads based on POU parameters and ultimately an energy performance range could be established for each, if the calculations were repeated for variations in hours of operation and occupancy load factor benchmark scenarios. The review has highlighted all BEP parameters are affected by POU parameters and should be included in the new method.

4.3.6 BEP Evaluation Benchmarks and Metrics

In addition to the BEP parameters, there is also variation across BEP evaluation methodologies regarding how BEP is benchmarked and measured, detailed in Table 4.16. Please note that the preferred measurement of BEP is energy delivered per unit of area and energy delivered per person is not required for building regulation compliance or overarching legislative requirement. Each methodology uses a different set of benchmarks to compare energy performance.

Table 4.16 Variation in how BEP is measured

Energy Use Benchmarks and Metric	Carbon Buzz	TM22	EPC/ DEC	TM54	NCM
Actual [kW.h]	✓				
Design [kW.h]	✓				
Notional [kW.h/m^2]					✓
Actual$_1$ [kW.h/m^2]					✓
Actual$_2$ [kW.h/m^2]		✓		✓	
Adjusted [kW.h/m^2]		✓		✓	
Good Practice [kW.h/m^2]		✓		✓	
Typical [kW.h/m^2]		✓		✓	
TM54 Estimate [kW.h/m^2] low-end				✓	
TM54 Estimate [kW.h/m^2] mid-range				✓	
TM54 Estimate [kW.h/m^2] high-end				✓	
Operational rating [kW.h/m^2]			✓		

Note:
Actual$_1$: The NCM refers to the 'actual' building as being the predicted building criteria for comparison to the standards set by a 'notional' building by which BEP is judged against.
Actual$_2$: Carbon Buzz, TM22 and TM54 refer to the 'actual' BEP being the actual measured BEP when the building is in operation.

Carbon Buzz compares the buildings predicted 'design' performance against the 'actual' operational performance. Building Regulation compliance calculations compare the 'actual' building as designed against a 'notional' building with the current legislated BEP requirements. If the building design surpasses the notional requirements set by building regulation, then the building complies. This assessment is not verified against how the building performance in operation. TM22 compares 'actual' operational use against typical and best practice benchmarks established by CIBSE. TM54 estimates how the building will perform under differing operating scenarios and benchmarks the building energy performance range against TM22 benchmarks. An EPC or DEC benchmarks the operational rating of the building with improvements measures for an EPC or year on year performance for a DEC. All the BEP benchmarking methodologies look at building energy use for comparison to similar buildings. The existing benchmarks and metrics do not currently provide the necessary detail to evaluate the impact of variations in POU through assessing the impacts of variations in occupancy load factors or hours of operation.

Both kW.h per person[107, 123] and kW.h per m^2 [79, 71] are used in industry [71, 108, 121, 122] to evaluate the annual building energy, as shown in Box 4.7, however, the calculations are based on the building annual energy use divided by the total number of full-time employees giving a standardised energy use per person applicable to a tenant who occupies the whole building under a singular POU.

Box 4.7 Worked example: Annual Energy Performance per m^2 and FTE
Building X is 2,000m^2 Building X has 175 occupants Building X energy use is 197,100 kW.h/year approximated from metered data Building X annual energy use per m^2 is 197,100/ 2000 = 98.5 kW.h/m^2 Building X annual energy use per FTE occupant is 197,100/ 175 = 1126 kW.h/FTE

This technique is not used to predict and compare tenure energy use. To do this, you need details of the exact tenant net lettable area, the number of full-time employees, the buildings hours of operation and the typical working days within the week. The exact information is not always known at design stage, but this technique could be used to determine an occupancy range and subsequently a performance range for the building, as discussed in the new method outline in Chapter 3, the new method used for calculating the predicted tenant energy use from the compliance data is shown in Box 4.8.

Box 4.8 Calculating variations in tenant energy use per m^2 and per FTE
Tenant energy use [kW.h/m^2] = [tenant energy use/ tenant area] Tenant energy use [kW.h/FTE] = [tenant energy use/ tenant area] x occupancy load factor

The new method and metric would allow for detailed reporting of energy performance for all energy loads. Reporting the impact of POU on energy performance would also allow occupant related POU and building POU to be assessed independently. The benefit of monitoring both metrics would be that the tenants can target energy use directly under their control, and facility managers can assess total energy use and building activity energy loads separately. A method to evaluate energy use in periods of low or high occupancy enables the building base load and efficiency of hours of operation and parasitic energy loads to be addressed, and as a result, highlight technical defects more easily. The new method metric also addresses the current problem in BEP that low occupancy may result in low energy readings if energy use is evaluated as energy delivered per unit of area. Creating a new method to analyse high and low occupancy capacity on energy demand alleviates this problem.

4.3.7 Testing the effect of occupancy load factor and capacity on energy use

The building regulation standards and the predicted annual energy use given in the report submitted for Section 6: Energy Compliance [Appendix C], for the case study building, was used to test the probable impact of occupancy on energy use. The 'actual' daily energy use per FTE is based on the daily occupancy of each tenancy given by each tenant office manager, Table 4.5. The building regulation standards occupancy capacity assumptions detailed in Section 4.1 were used to evaluate if occupancy would have an impact on operational building performance, shown in Table 4.17. This exemplifies that the energy performance per FTE varies depending on what standard you are demonstrating, confirming that variation in occupancy capacity affects energy performance. This tabulated data can now be used to test the actual data accrued from the monitoring exercise, against the predicted performance stated in the design calculations and validate the predicted POU in the forthcoming chapters. A sensible approach to BEP evaluation would be to project building and occupant energy use in tandem to encourage and engage building users to lower their consumption patterns and report on figures. The energy use per FTE shown for Tenant 1 is high as this tenant has the lowest number of occupants and therefore the highest amount of floor area per person, resulting in a higher rate of energy use predicted per person. This highlights that BEP inefficiencies in low occupancy could go unnoticed in current BEP evaluation techniques unless energy use per FTE is used.

Table 4.17 Energy Use per Occupant [FTE] depending on the building regulation standard used

	Daily Predicted Energy Use in January of Each Tenancy [kW.h/FTE]			
Occupancy Standard	**Tenant 1**	**Tenant 2**	**Tenant 3**	**Sole Occupancy**
Energy	2.4	2.4	2.4	2.4
Sanitary Facilities	1.5	1.5	1.8	1.6
Ventilation	2.2	1.4	1.6	1.6
Fire	1.6	1.6	1.6	1.6
BCO standard	2.4	2.4	2.4	2.4
Actual Occupancy	5.1	5	2.2	3.4

4.4 Justification of the POU parameters, benchmarks, metric and range to be applied in the proposed new method.

The application and results of the case study sample are reviewed providing evidence that the proposed POU parameters and ranges are useful and necessary to predict the effects of POU on BEP. The results of the case study sample prove that occupancy patterns and operating hours differ between building tenant groups. However, existing BEP methodologies evaluate BEP on predetermined standard POU. The case study sample has proven that existing industry standards can provide necessary BEP occupancy load factor benchmarks to establish realistic variations in POU and an energy performance range, which could be predicted and measured at design and operational stage to determine how effective a building is being operated in use to enhance best practice measures. The parameters chosen to predict and evaluate variations in POU and their impact on tenant energy loads in the new method are:

1. Tenure Hours of Operation
2. Tenure Occupancy Load Factors
3. Tenure Occupancy Capacity
4. Tenure Area

The next chapter tests the impact of variations in POU by demonstrating the effects of high and low occupancy through using a BEM and TM54 methodology.

4.5 Chapter Summary

Comparing the projected and actual occupancy capacity of a case study building tested the impact of occupancy on BEP. Theoretically, this technique is biased, as it does not consider variations in POU determined by occupancy factors. This technique creates a barrier to tenants understanding their impact on TEP. Tenants POU vary and even if tailored calculations have been calculated for the tenant, in retrospect, it is very difficult to understand what the design assumptions were unless they have been accurately recorded and passed on to the building users. Presently, there is no framework to accurately record the impact of tenant POU in the design process.

The analysis also focused on how different regulatory standards can affect energy performance formulating a further hypothesis that the existing energy performance evaluation technique is limited and theoretically is susceptible to abuse. The compliance calculations are a high-level evaluation of occupancy based on full occupancy during the specified occupancy periods of 9 am to 5 pm. The occupancy figures of the recorded number of full-time and part-time employees show how each tenant's occupancy compares to the predicted occupancy capacity. However they do not illustrate how the building is occupied in reality, as occupancy levels may fluctuate over the course of the day, the occupants may not adhere to regular working hours, and this may have an effect on BEP.

This study reviewed the NCM calculations submitted to building control, demonstrating that set POU do not accurately convey expected tenure energy loads. This study examined how the current BEP system works and identified how it fails, which has gained valuable insight into how the impact of building occupants POU on BEP could be recorded and conveyed. BEP examination must apply the most effective analytical tools to guarantee efficient building design and practical use by the building users by setting limits on operation through demonstrating expected POU and then proving performance in practice. The outcome of the case study sample has highlighted that a building is inherently designed to operate over a range influenced by POU and that this should be communicated to building users for efficient building operation.

Chapter 5: Application of the Proposed New Method

Application of the Proposed New Method to Case Study Scenarios

5.0 Chapter Introduction

Tenure 'Occupancy load factor', 'occupant capacity' 'area' and 'hours of operation' were identified as key variations in POU parameters in the last chapter, and specific 'Patterns of Use' [POU] parameters and ranges, together with a proposed POU metric, was put forward based on a review of the existing methods. The aim of this chapter is to gain further insights into these key POU parameters and their impact on energy use through a detailed monitoring study of a 'real-life' case study building.

At present, there is a research gap that quantifies (i) how varied POU can be between tenants sharing the same building (ii) the impact on BEP and (iii) if tenants operational POU replicate the design brief assumptions. Comparing real-time monitored data to the design intent calculations tests the hypothesis that variations in POU exist and effect BEP. Both the hypothesis and the new method are tested in application to learn if this hypothesis is correct and establish if a new method to capture the effect of variations in POU could be useful and effective. The method is directed at promoting change in the design process, occupant behaviours and how efficiently a building is utilised.

The chapter is split into three sections. Initially, the case study evaluation process is defined; explaining how the real-time occupancy observations and energy use monitoring was achieved in unison. Secondly, the variations in POU observed in the 'real life' case study building are presented and discussed in the context of the new method outlined in Chapter 3. Lastly, the results of monitoring study are compared to the NCM standard energy performance calculations. Then the implications for the new method of the case study findings are critically reviewed.

5.1 Patterns of Use Applied to a 'Real-life' Case Study Building

Office space is the highest use of non-residential floor area in the UK.[124] Hence, to test the impact of variation in POU on building and tenant energy use a multi-tenanted office building was monitored over a six-week period. Variations in POU is reviewed through testing the relationship between occupancy capacity, and energy use then comparing the aggregated predicted energy use, attained from the Section 6 Compliance Report [Appendix C] to each tenant's energy use profile for a typical day. The study results demonstrate POU could be used to improve the design and BEP evaluation process by highlighting the effect of tenant behaviour on energy loads. The study reaffirms the importance of sub-metering building activities to inform the building user if activities are not performing as expected.

The case study building, evaluation methodology, had the following key steps:

1. Placing and confirmation of case study permissions and information requests.
2. A desktop study evaluation of the proposed building occupancy and speculated energy performance at the design stage.
3. Observation of three tenants occupancies and their energy use.
4. Comparison of the design data to the in-use data.
5. Evaluation of evidence supporting the hypothesis.

The key steps are now discussed in detail starting with the permission and placing request procedure. The research study was initiated by contacting the building owner to grant permission to carry out the study. This was followed by a presentation to the building tenants detailing the scope of the investigation to gain their approval and consent. After approval had been granted, access and information were requested. A request was placed with the building managers to monitor the electrical energy use of each of the three tenants, the shared electricity meter and the ASHP serving the three office units. Permission was granted to install an energy monitor, to measure energy use at minute intervals, on the electric meter of each office, within the electrical cupboard situated on the ground floor of the property.

Carbon Buzz[46] and TM22[121] guided the case study methodology. The aim of the study was to test (i) the effect of several different tenant groups POU on operating hours, occupancy capacity, thermal comfort and overall energy use and (ii) compare the NCM predicted performance calculations to the actual observed energy performance in use, to see how each tenant group compares. The methods were adapted to test the relationship between tenant occupancy and energy load profiles by simultaneously recording each tenants energy meter [three-phase electrical supply], manually observing occupancy levels, indoor and outdoor temperature, all logged at minute intervals.

The initial study period was over a 6-week period during January and February. A second data sample was taken at the same time the following year to investigate repeatability. A winter sample was opted for as it shows how the heating system responds, the preferred indoor temperature of the occupants and the heating demand. Furthermore, the building is mechanically and naturally ventilated, therefore in winter there is less chance of occupants opening the windows resulting in the ambiguity between the building energy model and actual recorded data in Chapter 6.

The Orion building uses electricity from the grid without on-site renewables or CHP. The building's energy use was reported based on a TM22 methodology analysis, which assesses the use of electric and non-electric use separately using the metric $kW.h/m^2$, allowing conventional benchmarking of energy delivered to the building. TM22 aims to understand the roots of energy consumption of installed equipment, annual hours of use and the buildings core hours of occupancy, where half or quarterly-hour data is available. The TM22 methodology does not exemplify how variations in POU differ between tenant groups and their effect on energy use. TM22 benchmarks currently compare BEP by energy delivered by floor area 'in design' and 'in use' for 'standard' POU only. The case study measures the impact of POU on energy use by documenting the differences between each tenant by recording their individual (i) 'occupancy load factor' (ii) daily 'energy usage pattern' and (iii) 'hours of operation'. Energy monitoring focused solely on individual tenant energy use. The energy use measurements were carried out for each one of the three offices by taking meter reading thrice daily and by data loggers measuring the three-phase supply of each tenant's electric meters, at minute intervals. The study excluded the electrical consumption for the unoccupied common areas. The sum of each tenants energy load was reported, as tenants did not have a sub-metering facility to measure the breakdown of their individual loads.

To calculate likely plug loads without sub-metering available an appliance schedule was recorded for each of the offices by conducting an office walk through and manually documenting all the visible kit that was being used to include the number of IT servers and supporting equipment, the workspace IT allocation and general office equipment and all the kitchen appliances. Office meeting room equipment and ancillary items are all noted on a room-by-room basis. If the power consumption was labeled on the appliance, this was also recorded. If the power consumption information was not available, the specification was gained by referencing online resources. Personal equipment is not reviewed dually as (i) it is unclear how this would affect IT energy loads as most modern equipment is charged through a desktop computer and (ii) the irregular frequency of use for each occupant makes it difficult to quantify within the remit of the thesis works. The appliance schedule and office hours of operation, provided by each office manager, gave an indication of the total appliance loads for each office. The appliance schedule and office hours of operation were compared to the NCM calculations, based on CIBSE Guide F. The inventory was used to calculate the workstation and office equipment energy loads and subsequently the heating and cooling loads and energy performance range based on each appliance load, discussed in Chapter 6.

Smart meters measuring real-time tenant energy consumption were in use in 2 out of the 3 offices. The use of this equipment was quickly discounted as it would be difficult to coordinate between varying levels of equipment accuracy and therefore the results would be questionable. Instead, reliable Eltek data logging equipment and an associated software package was used, which is widely used in the UK by academics and industry to carry out long-term monitoring exercises [see Box 5.1].

The monitoring equipment consisted of a data logger, which recorded the data from a series of study dependent sensors. A three-phases electrical supply is measured in the same way as three single installations, a voltage monitor is applied to each phase and the total power use is the sum of the three readings. The data logger software was uploaded to a laptop. Allowing the sensors to be programmed to uplift data required at predetermined time increments. Once the sensors are programmed the sensors can be located at the monitoring site and the data logger records the data, which can be downloaded for analysis. The sensors measured the current [amps] travelling through each of the phases by connecting a clamp around each phase supply cable. Each sensor has two clamp ports enabling a single sensor to take two readings. Each sensor and port was labeled so that it was clear which office meter was being monitored, as shown in Figure 5.1.

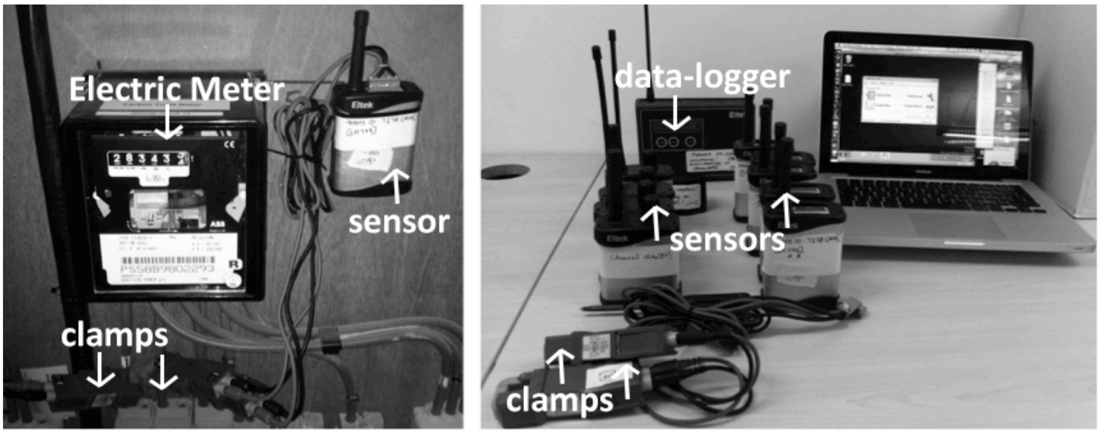


Figure 5.1 Monitoring equipment installed: Sensor measuring the current passing through each three-phase electrical supply [left] and the sample of the monitoring equipment used [right].

All sensors were regularly checked to see if the batteries were still functioning and data was downloaded and checked at 4.45pm to make sure data was not lost and the previous 24 hours were downloaded as a checking exercise. The logger remained in operation over the entire monitoring period, so that the data would still log from the start date, Monday the 9th January. A detailed schedule of the monitoring equipment used and housekeeping items are listed in Box 5.1.

Box 5.1. Energy use and Temperature Monitoring Equipment

The Monitoring Equipment Required to measure three-phase electrical supply to monitor electrical consumption to each office unit and the external and internal temperatures are as follows:

Data logger
Eltek SQ 1000 series squirrel [radio telemetry] data logger and power adapter
Type RX250AL
Eltek LC-TX3 cable connects the sensor to the PC
Eltek LC-68 cable connects the data logger to the PC

Data logger software
Eltek Darca 3.1

Sensors [number of sensors study dependent]
4 x *Eltek* GC05 Temperature sensors
5 x *Eltek* GS42 Current/ voltage sensors with 2 clamp ports
9 x *Eltek* M2.5 100A to 1v dc clamps
9 x *Eltek* clamp lead sets

House keeping
USB to RS232 cable [to convert PC serial port to USB for recording data to a laptop]
AA batteries [for sensors] 46 in total for this study
Cross head screwdriver [for removing sensor base plate to connect sensor to pc]
Small flat head screwdriver [for fixing clamp leads to clamps]
25 x 25mm self-adhesive cable tie mounts
295mm cable ties
50mm cable ties
Plastic container to provide a waterproof enclosure for temperature sensor located outdoors.

For kit installation, please refer to the Installation Guide

The data logger also recorded the internal and external temperatures measured in degrees centigrade through placing three temperature sensors in the main area of each office and one externally. The external sensor was placed on an external fire escape stair in a damp proof container to prevent damage. The aim of the internal sensors was to ascertain the office temperature and the desired level of comfort of the office occupants. The sensor temperature was compared to the thermostats in each of the office's rooms. This information was collated when the appliance schedule was noted. The office manager was also asked to confirm if this was the typical thermostat settings and therefore typical office temperature, which was confirmed verbally. The aim of the external temperature sensor was to record the external temperature in relation to the energy use inside each of the offices. The external temperature explained any radical heating or cooling drops within the building and confirmed any extreme changes in temperature over the course of the day. The temperature sensors were used as a tool to understand better the tenants POU and energy loads opposed to a detailed comparison of predicted and in use weather patterns. The next section discusses how occupancy capacity was observed and recorded.

There are many methods used by industry for observing occupancy patterns. There is no set guidance provided by the construction industry to monitor energy use against occupancy capacity as energy performance is benchmarked and compared in energy use per unit of floor area. Some methods noted in Table 5.1 were reviewed.

Table 5.1 The pros and cons of occupancy study methods
[Adapted from: WCO Guide to occupancy to utilisation and occupancy studies].

Method	Cost	Scalability	Accuracy	Granularity	Invasiveness	Comments
Paper-based observation studies	OK	OK	GD	GD	PR	Good back up of data. Processing data delays delivery of results. More detailed data than walkthrough body count.
Electronic observation studies	OK	PR	GD	GD	PR	Longer and more expensive than paper study No budget for this kit and proposed study over a short period & therefore cannot justify costs.
Walk through Body Count	GD	OK	PR	PR	OK	Least time consuming but will not give detailed analysis of occupancy patterns
Swipe-card or security data	GD	GD	PR	PR	GD	Prone to inaccuracy as more than one person can access or egress the building without being counted. The data may not be available at the time of monitoring.
People counters	PR	OK	PR	PR	GD	Devices are not available on site.
IP/PC/VOIP monitoring	PR	GD	OK	PR	PR	Lack of PC processing activity does not give an accurate reading of how many occupants are in the office building.
PIR sensor systems	PR	OK	GD	OK	OK	Expensive to set up but cost effective for long term monitoring, therefore not suitable for this study.
People tracking	PR	PR	PR	OK	PR	Unreliable as sensors not always carried by occupants, considered obtrusive and a privacy infringement.

PR – poor, GD – good, OK – okay.

Swipe-cards and security cameras were used on the site. Observation from security cameras located was reviewed as a means of the collection but ruled out early in the process. Weekly data was available from the security company on site computer by downloading a weekly schedule of the entries and exits to the building. However, the property factor declined this request as an infringement of security measures. Use of the security camera to monitor occupants entering and leaving was discounted, as it is not possible to detect which personnel were entering each office from the equipment available. Additional surveillance equipment could be installed to survey this more accurately but due to the budget, duration of the project and issues with privacy this was discounted. The building occupants movements were ordinarily monitored via employee building access swipe cards. This data is recorded for each calendar week by the building manager for security purposes and backed up to a computer on site. The occupancy data enables the number of staff in each office per day to be checked and to validate the occupancy data, as shown in Figure 5.2.

All events this week
Site: [redacted]
Date: 27 January 2012 16:54

Date/time	User	Where	Event	Details
27/01/2012 16:52:14		[redacted] Reception	Door opened	With exit button
27/01/2012 16:52:04		[redacted] Reception	Door opened	With exit button
27/01/2012 16:51:52	[redacted]		Operator	Logon
27/01/2012 16:50:30		[redacted]	Door opened	With exit button
27/01/2012 16:49:52		Front Door	Door opened	With exit button
27/01/2012 16:49:40		Front Door	Door opened	With exit button
27/01/2012 16:49:39		Front Door	Door opened	With exit button
27/01/2012 16:49:34		[redacted] Reception	Door opened	With exit button
27/01/2012 16:49:22		[redacted] Reception	Door opened	With exit button
27/01/2012 16:49:12		Front Door	Door opened	With exit button
27/01/2012 16:49:05		[redacted]	Door opened	With exit button
27/01/2012 16:49:01		[redacted] Reception	Door opened	With exit button
27/01/2012 16:48:59		Ground Floor LHS Main Door	Door opened	With exit button
27/01/2012 16:48:55		[redacted] D/S LHS	Door opened	With exit button

Figure 5.2 Example of door push data received from the building management security software [Areas blanked out for privacy reasons].

The door push data indicates the date and time of every swipe card or exit button strike, the user code, the location of entry and the event details. The event details indicate how the door was opened by swipe card [permitted access], by reception or by utilising the exit button. The data also gives details of time and location of access for individual occupants.

An initial observation of swipe card use confirmed that often more than one person could access the main entrance door and office entrance areas with a single swipe of a card or leave with the single use of the door release button; therefore, the data was unreliable. Within regular working hours, while the building is heavily trafficked, it would not be possible to monitor accurately the number of occupants entering and leaving the building using this method. This could, however, document POU of each tenant to determine (i) their true hours of operation by recording the exact time of the first people to arrive and the last people to leave the office (ii) tenants unoccupied energy use when the offices are empty overnight and (iii) low occupancy hours. This also gave an indication of occupancy traffic of all offices over the weekend, as occupancy was minimal at these times. Walk-throughs were also reviewed and not adopted, as simultaneous manual recording was not possible. The only way to observe the occupancy traffic simultaneously between the three offices was to monitor each at the same time, which was essential to the study to attain meaningful real-time POU data for comparison to energy use.

Other electronic and sensor-based systems to record occupancy where reviewed but they were discounted due to the availability of the equipment on site or due to cost. Based on the assessment of the methods tabulated, a combination of paper-based observation and swipe card data were chosen to collate and check tenant occupancy, through real-time observation of the occupants arriving and leaving the building within working hours, reviewing visitor books, taking body counts from the entry card system and intermittent video, while meter readings were taken. The combined monitoring method achieved the necessary real-time simultaneous data of the tenants POU by recording occupancy levels, energy use, and hours of operation, as required. This data was then used to calculate how much energy (i) the occupants use (FTE) (ii) the building uses (kW.h/m^2) and (iii) Tenant use in comparison to the predicted calculations. Paper–based Real-time Observation were possible on this project due to the building design. Notably because (a) the three different offices were accessed from a common glazed atrium, which enabled clear observation of the occupants accessing and leaving all the offices (b) the office entrances were visibly separated from each other [with one exception, which was later discounted from the study] and (c) there were in total about 120 employees, which made observation by one person manageable for the duration of analysis. The occupant's movements were monitored passively by watching the flow of staff to determine, which office they were entering. This would not be possible if visibility was poor or there was more than one entry or exit door. A paper entry was manually recorded in a Table [Table 5.2] between 7:00 am and 6:30 pm, Monday to Friday.

Table 5.2 The method of occupancy documentation: the occupancy levels were noted for the total amount of occupants and the number of occupants entering and leaving the building shown as [Tenant 3] in or out and Tenant 3, which represents the running occupancy total.

Time	Number	In	Out	Total	visitor	T3 In	T3 Out	T 3	T2 In	T2 Out	T 2	T1 In	T1 Out	T 1
07:39	1	1		1		1		1			0			0
07:50	1		1	0			1	0			0			0
08:07	1	1		1		1		1			0			0
08:07	1	1		2		1		2			0			0
08:08	1	1		3		1		3			0			0
08:08	2	2		5		2		5			0			0
08:09	1	1		6		1		6			0			0
08:11	1		1	5			1	5			0			0
08:12	1	1		6		1		6			0			0
08:13	1	1		7				6	1		1			0
08:14	3	3		10		1		7			1	2		2
08:16	2	2		12		2		9			1			2
08:17	1		1	11			1	8			1			2
08:17	1	1		12				8			1	1		3
08:17	2	2		14		2		10			1			3

The occupancy data was recorded live and the access and egress recorded to the nearest minute. The survey data was later entered into a spreadsheet for analysis where the data from the occupancy levels could be compared to the tenant energy use patterns. Post entry data delays the results and can be subject to observations errors or incorrect data entry. A number of checks were carried out to ensure the data collected was accurate: (i) each tenant's, full and part time equivalent, staff numbers were collected (ii) an overall count of the staff was recorded in addition to the office count to ensure both tallied up and (iii) swipe-card and door push data was used to check the observed data sample, which proved effective.

Syncing the recording equipment and time steps of both monitoring exercises at minutely intervals allowed easy and accurate comparison of the data. The data logger clock was synced with the clock on the laptop, which was also synced with a smartphone. The smartphone was used to record footage when it was necessary to leave the observation area e.g. to take the meter readings and also as the clock used to record the occupant access and egress times.

The study sample was repeated in January the following year to confirm the occupancy, weather and energy use patterns were consistent with the previous year, validating the data as typical. The data was checked to ensure the data observed was not out of context with normal working POU and normal energy consumption patterns within the winter period. The data was taken randomly for three consecutive days. The checks also proved that the study was repeatable and was nonintrusive to the occupants, who agreed that further study could take place. Problems arose from the reliability of operation of the building electricity meters. Tenant 3's meter did not work in the first year resulting in no data collection, and Tenant 2's meter was reset before the second data sample was taken, discussed in Chapter 7. As a result annual electricity use was not available from the electric energy meters for two of the offices. To overcome this, a comparison was made from the energy consumption over a 24-hour period and checked back to the POU from the previous year to confirm the energy data was consistent. The occupancy patterns were also compared to the previous year, and it was found that each office had a similar POU and energy use.

5.2 Observed Variations in POU Parameters.

The next section presents the results of the case study highlighting (i) variations in 'occupancy load factor', 'occupant capacity' and 'hours of operation' (ii) the impact of 'occupancy capacity' on BEP (iii) the effect of using an occupancy metric [kW.h/FTE] and (iv) assessing POU parameters against building activities e.g. tenant preferred internal temperatures. Furthermore, the practicalities of implementing occupancy monitoring are critically reviewed.

At the outset of the study, the Eltek temperature sensors were tested to ensure the reading coupled with the thermostat and the office managers were asked to give details of the set operational times of the heating controls and the preferred internal temperature, outlined in Table 5.3. Each room was independently zoned to have its thermostat control.

All three internal temperature sensors were located in each tenant's main communal office space. For Tenant 1 and Tenant 2 this was a large open plan office, and for Tenant 3 this was the main hub of the office where all the staff congregated. The sensor was consistently placed in a central office location to minimise the effect of cool spots or drafts next to windows.

Table 5.3 HVAC control days and hours of operation and internal temperatures.

Tenant	Day	Set hours of operation	Thermostat setting
1	Monday - Friday	07:00 – 19:00	18-21
	Saturday - Sunday	OFF	
2	Monday	06:30 – 18:00	21-22
	Tuesday - Friday	07:00 – 20:00	
	Saturday - Sunday	OFF	
3	Monday - Friday	07:00 – 19:00	21-25
	Saturday - Sunday	OFF	

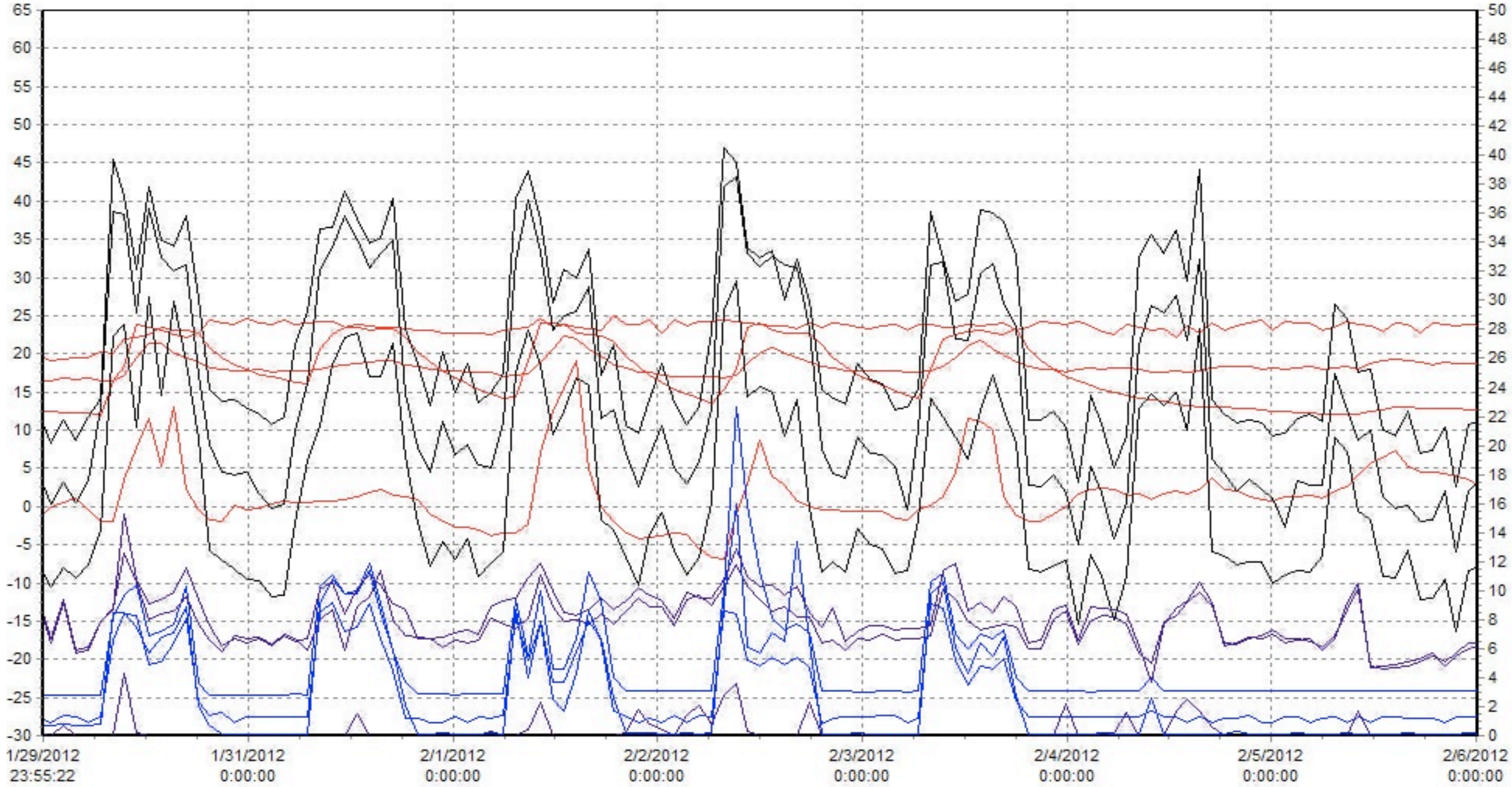


Figure 5.3 Trends in energy consumption showing variation in energy use between the different tenants during the winter months of January and February. The graph also shows the internal office temperatures [upper three red lines] and the external temperature [lower red line]. The graphs show three lines, one for each of the three phases of a single tenants electrical usage.

The results of the temperature study revealed all tenant groups thermostats constantly set to 21 degree's or higher whether the room was in regular use or not. Tenant 1 programmed their thermostat so that the office temperature would not fall below 10 degrees during the night and allowed for a preoccupancy warm up period so that the office would be warm for staff arriving resulting in an energy base-load out of hours [Figure 5.3]. Tenant 2 had Optimum Start[11] installed to achieve the desired internal office temperature within working hours. The temperature readings confirmed the internal office temperature drops during the night parallel to outside temperatures [Figure 5.3] contributing to very minimal or no overnight energy base-load. Tenant 3 had a pre-programmed operation period; however, the controls were manually overridden to heat the office overnight, and the thermostats in the open plan office space were set at 23 degrees contributing to a base-load of more than double the other offices overnight. The study demonstrates each tenants preference for heating control and internal temperature effect's their energy use and the building performance. Illustrating the value of monitoring performance and assessing the effect of variations in POU on building activity energy loads, such as heating and cooling. Reviewing the effect of POU parameters on energy consumption is an effective tool to show the effect of simple management procedures on energy performance, together with potential cost savings. A more specific and client based study would deploy temperature sensors in each room to monitor the relationship between heat emitted from IT and if this had an impact on internal comfort temperatures in the winter and summer. This study focuses on variation in POU between tenants, and therefore this level of detail was not required.

Each tenant group was asked to give details of the number of staff operating out of each office. The tenant and building occupancy capacity were established from the total number of full or part-time equivalent employees given by each office

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[11] Optimum start is a heating sensor control system to allow the heating system time to reach the desired temperature, so the office space is heated correctly and efficiently in the programmed hours of operation, in this case before the staff arrives in the morning.

manager. The office manager also confirmed office operating hours and if the offices were used at the weekend, shown in Table 5.4, alongside the NCM assumptions.

Table 5.4 Tenants Occupancy and Hours of Operation

Tenancy	Area	Number of FTE	Hours of Operation	
NCM	1452m^2	161 FTE	Monday – Friday	09.00 – 17.00
			Saturday & Sunday	None
Tenant 1	349m^2	17 FTE	Monday – Friday	08.00 - 17.30
			Saturday & Sunday	Varies at staff discretion
Tenant 2	188.5m^2	10 FTE	Monday – Friday	08.30 – 18.00
			Saturday & Sunday	Minimal
Tenant 3	726m^2	83 FTE 4 PTE	Monday – Friday	06.00 - 17.30
			Saturday & Sunday	Varies with staff training

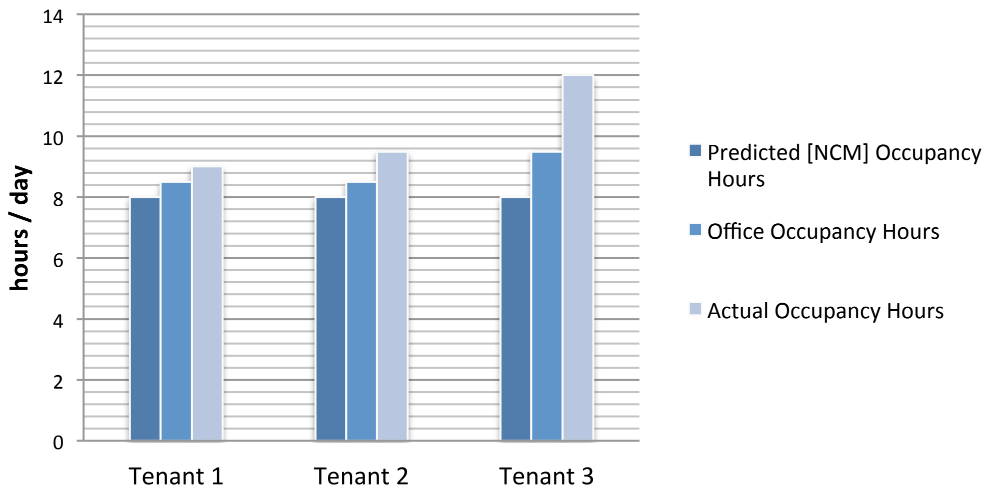


Figure 5.4 Variation in POU: Typical Week-day Occupancy hours

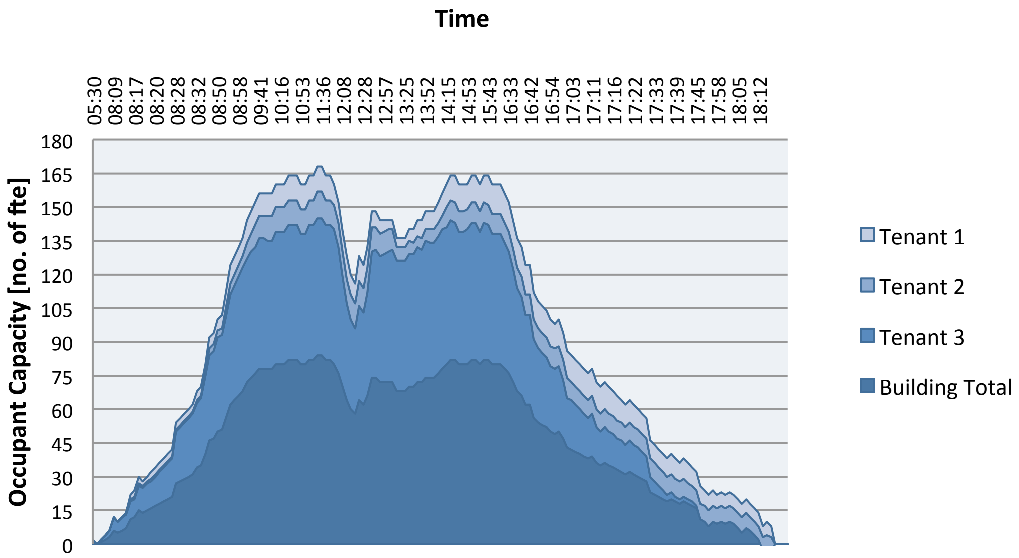


Figure 5.5 Variations in POU: Typical Workday Occupancy Hours

The monitoring results of the occupancy study demonstrated that the predicted building hours of operation, of a 9.00 to 5.00 pm 5-day working week did not reflect the tenant's typical weekday occupancy hours, shown in Table 5.4. Also, each tenant group regularly worked out with the office managers perceived office hours. The collective impact of variations in tenant POU increases the case study buildings weekday hours of operation from 8 hours [9.00 am to 5.00 pm] to 13hrs [5.30 am to 6.30 pm] illustrated in Figure 5.4, and in extreme cases up to 15 hours over the study duration. The increased office hours are primarily due to Tenant 3's cleaner arriving at 5.30 am and working until 8.00 am, and a member of staff who starts at 6.00 am. Most staff arrive between 8.00 am, and 9.00 am, as shown in Figure 5.5, then leave between 4.30 pm and 5.30 pm. The occupancy of the other offices is low in comparison to Tenant 3. Typical office hours for Tenant 1 and 2 are between 9.00 am and 5.30 pm, however, some Tenant 2 staff arrive at 8.00 am and stay in until 6.30 pm to avoid peak commuter traffic. Tenant 3 has employees that occupy the building until 8.30pm if they have been out of the office during the day and are catching up with the workload. At 10.30 am the building reaches peak occupancy of approximately 88 staff after Tenant 3 has a smoker's break roughly about 10.00 am to 10.30 am. Tenant 3's lunch break starts at midday until around 1.00 pm and Tenant's 1 and 2 have lunch between 12.00 pm and 2.00 pm, reflected in Figure 5.5. The flexible working hours of the building increased energy use in each of the offices in periods of very low occupancy. The results of increased offices hours on BEP will be discussed at the end of the chapter. The case study tested variations in working hours between each of the office tenant groups. The results demonstrate that although office hours are regularly defined as 9.00 am - 5.30 pm, each of the tenant's POU varies from design expectations and each of the tenants hours of operation extends beyond regular working hours. In particular Tenant 3's POU extend tenant and building hours of operation from NCM predictions by 40%. The next section will discuss the impact of occupancy and variations in POU on Energy Use.

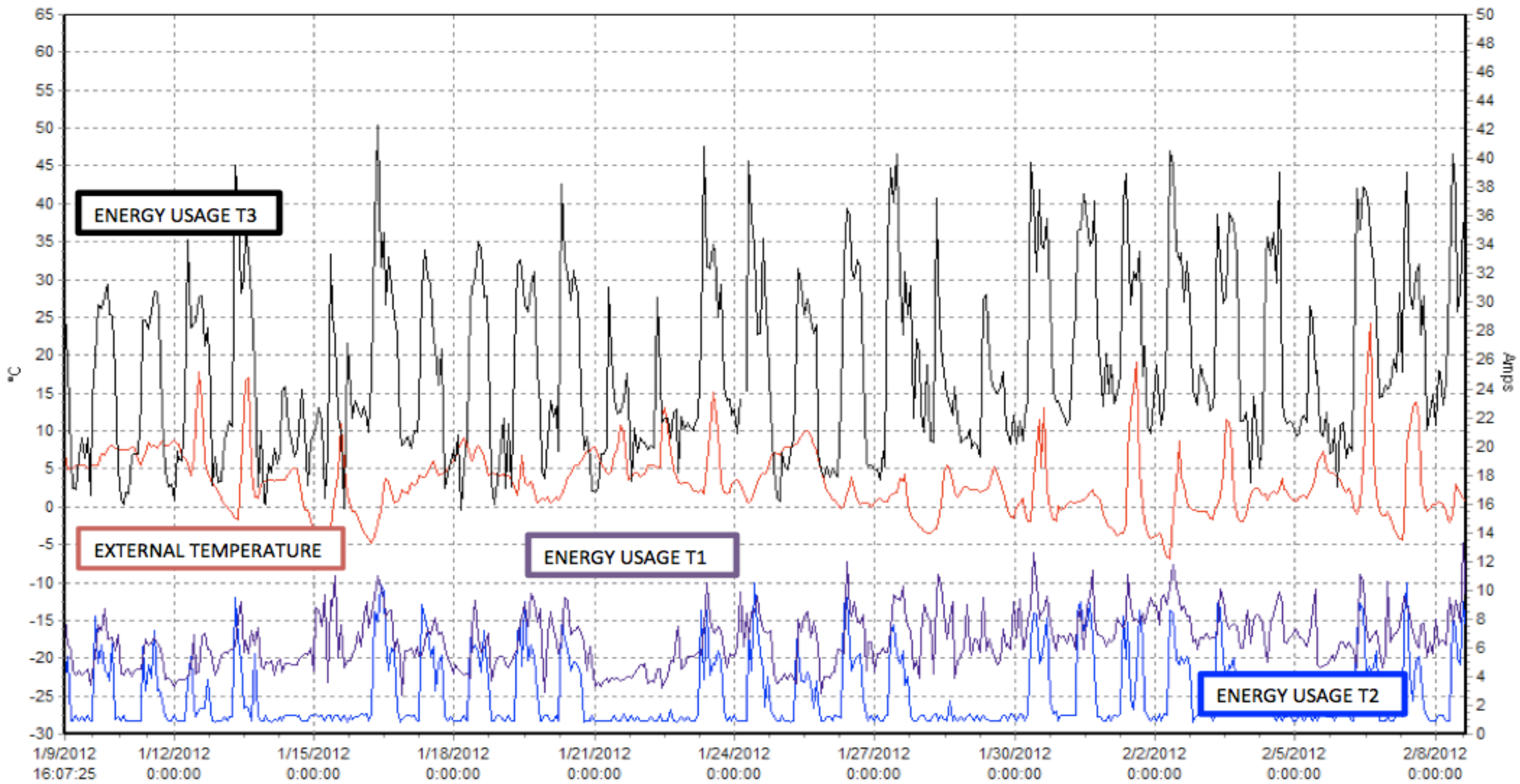


Figure 5.6 Trends in energy consumption showing variation in energy use between the different tenants during a full winter month [January to February]. The graph also confirms the external temperature.

5.3 Test the impact of Occupancy Capacity on BEP

The impact of occupancy capacity on BEP was tested through simultaneously monitoring each tenant group's occupancy profile with their energy use profile. The results demonstrate that there is a clear relationship between increases and decreases in tenant occupancy capacity and tenant energy use over a 24-hour cycle. The results also show a significant variation in POU between tenants to include (i) peak energy usage times (ii) total daily energy use and (iii) significantly different energy consumption patterns out of office hours, as indicated in Figure 5.6 and 5.7.

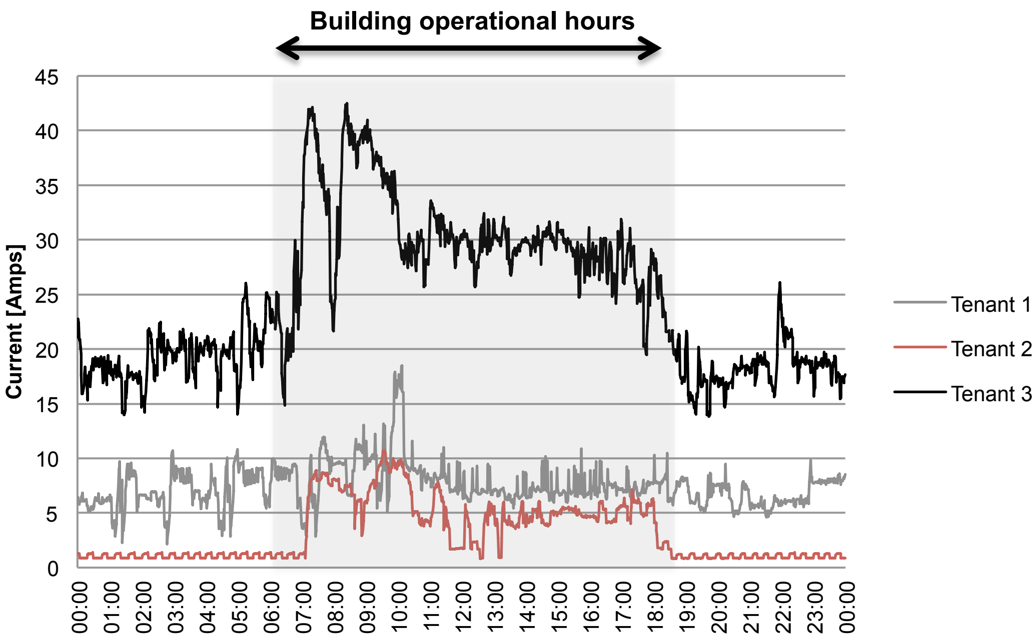


Figure 5.7 Monitored energy consumption data over a 24hr period in January, showing variations in patterns of energy use between building tenants.

The case study exemplifies that monitoring occupancy in tandem with energy use is a powerful tool to understand better the impact of tenants preferred POU on BEP. The case study revealed tenant occupancy capacity and POU preferences affect the intensity and usage times of building energy loads. Tenant 1 has a higher office base-load when the building is unoccupied and a more erratic energy use profile than Tenant 2. Tenant 3's out of hours energy use is higher than the sum of Tenant 1 and 2's daytime profile with a much higher energy use during the full working week. Figure 5.7 illustrates that Tenant 2 has the lowest occupancy and a regular daily energy use profile with very low energy consumption out with office hours compared to the other tenants. Tenant 2's energy load clearly ramps up in initial hours of occupation showing a clear dip in energy use at lunch and when the office is in low occupancy in the afternoon. It is clear the office energy loads increase when the building is in occupation. However, it is unclear *why* each tenants POU differs so greatly and if this solely attributed to variations in tenants POU or if other management and technical defects attribute to the performance from monitoring the overall energy use. The overnight behaviour shown in Figure 5.7, when the building is unoccupied, is very different [T1 approx. 80%, T2 approx. 5%, T3 approx. 60%] and not related to occupancy, so could be attributed to preferred internal temperature and the heating being left on overnight. Whether modeling variations in heating and cooling set points and sub-metering building activities can capture, this is discussed in the next chapter. Therefore to understand the impact of occupancy on energy use further analysis is required to determine the impact of POU on individual loads [Chapter 6].

A daily average energy use per FTE was calculated in Chapter 4 [Table 4.17] relative to the tenant's occupancy load factor, as indicated in Figure 5.8. The daily energy use demonstrates that trends in energy consumption mimic the occupancy patterns of the building during working hours, shown in Figure 5.9. The relationship is most noticeable in the most densely occupied office, Tenant 3. The energy use of the three-phase supply rises sharply with the number of FTE, falls during lunch hours and rises and falls during the afternoon and then when everyone leaves. There is also a fluctuation in Tenant 3's energy use during the night, which could be attributed to the heating is left on at a set temperature of 23 degrees. Also, to back up servers operating during the night and associated cooling and a greater amount of IT equipment being left on but it's not clear from the data presented.

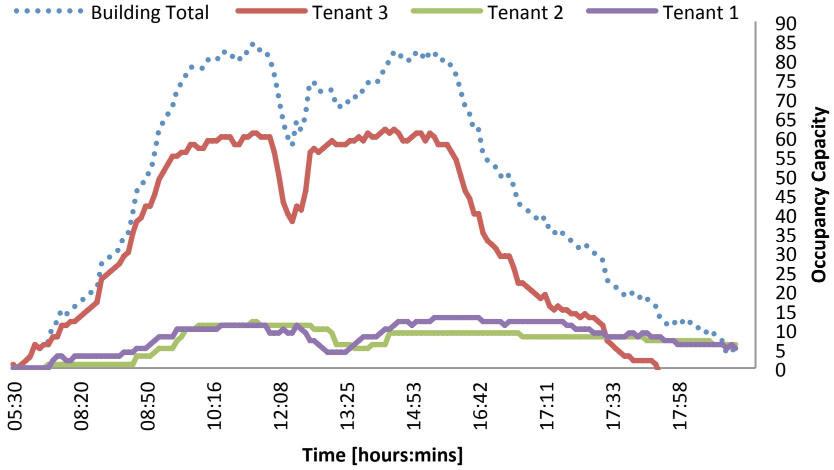


Figure 5.8 Typical Weekday Occupancy Pattern

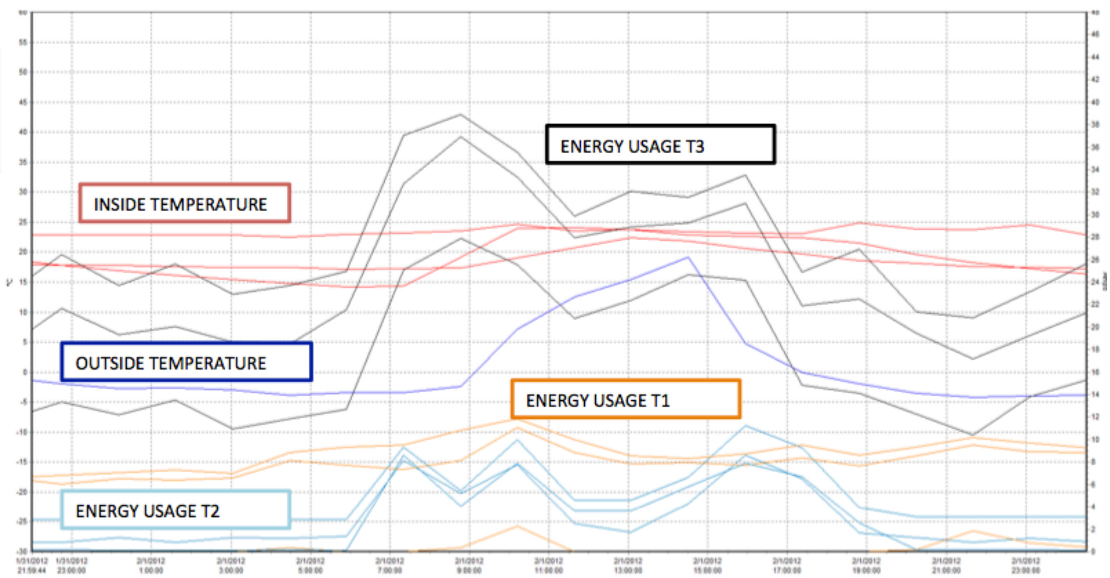


Figure 5.9 Trends in energy consumption [over a typical 24 hour period] mimic the occupancy patterns of the building during working hours, shown in Figure 5.8.

The monitoring exercise highlighted that the energy demand of the high capacity office space, which is close to the designed occupancy load factor, can be reduced more easily than the energy demand of the low capacity office space through simple management measures. The internal and external temperature is plotted to show that there is no apparent relationship to the increase in energy use shown. The monitored data has allowed insight into the tenure energy use patterns and tenure occupancy patterns of each of the three offices to include; the actual energy use, patterns in consumption periods over a 24 hours cycle, the working week and at the weekend, peak consumption times and identified that variations in occupant energy loads are significant over the course of the day, as shown in Figure 5.9.

The case study has proven the impact variations in POU on energy use is difficult for a tenant to measure due to the incompatibility of current monitoring and reporting systems available to monitor both energy use and occupancy together, in addition to a level of expertise to analyse the data.

An initial appraisal of predicted POU to include occupancy capacity and hours of operation is adequate to carry out a projected tenant energy use calculation. The most significant information extracted from the data was not proof that a relationship between energy use and occupancy exists but the significance of variations in POU that exist between tenants and how this could be better defined and demonstrated in line with current energy evaluation practices. To develop the proposed method, a means of accurately representing tenure POU in TEP using appropriate metrics via the case study data was reviewed. The appropriate metrics are discussed in the next section.

5.4 Test the impact of using an occupancy metric in BEP

To test the usefulness of the occupancy data acquired from the case study, each tenancies POU is measured, in terms of aggregated energy use per occupant [defined as a full-time employee], in relation to each tenant groups occupied area. The occupancy data is then compared to the current compliance methods of evaluation to critically evaluate the usefulness of the newly proposed metric. This section explains how a new metric and benchmarks could express accurately how a building operates in use.

The results of the monitoring exercise are used to explain further what the actual implications of variations in POU have and to demonstrate how this new knowledge could be useful to the end users.

The metric adopted by the EPBD, EPC and the NCM is articulated as "*delivered energy used per unit of floor area (kW.h/m^2).”* This metric is used to calculate both electrical and fossil fuel energy consumption. Display Energy Certificates [DEC] evaluate a building's energy use based on real energy consumption data. The current metric is used to establish energy benchmarks to compare buildings of a similar nature. TM46 allows two adjustments to the benchmarks, firstly, an adjustment to degree-day data, to give a more accurate response to climate, which is not relevant to this study. The second is an occupancy adjustment, which is only carried out if the buildings annual hours are confirmed to exceed the standard benchmark values. It does not consider other factors that affect a tenant’s POU to include occupancy and occupied area. Therefore it is not possible to evaluate the impact of high or low occupancy capacity.

To calculate variations in tenant energy use the case study measured and compared variations in each tenant's Net Lettable Area [NLA], occupancy load factor and operational hours by comparing kW.h/FTE and kW.h/m^2, in design and in use, as shown in Chapter 3 Box 3.1. Figure 5.10 illustrates the tenant energy use for (a) the predicted compliance report assumptions used to calculate the predicted regulated occupancy loads and energy use for a typical 24-hour day in January [Note, the same occupancy load calculation is used irrespective of the tenants intended POU] (b) the predicted tenants regulated and unregulated loads [in this instance an allowance for additional office equipment, catering equipment and IT servers is included] and (c) the actual monitored operational data.

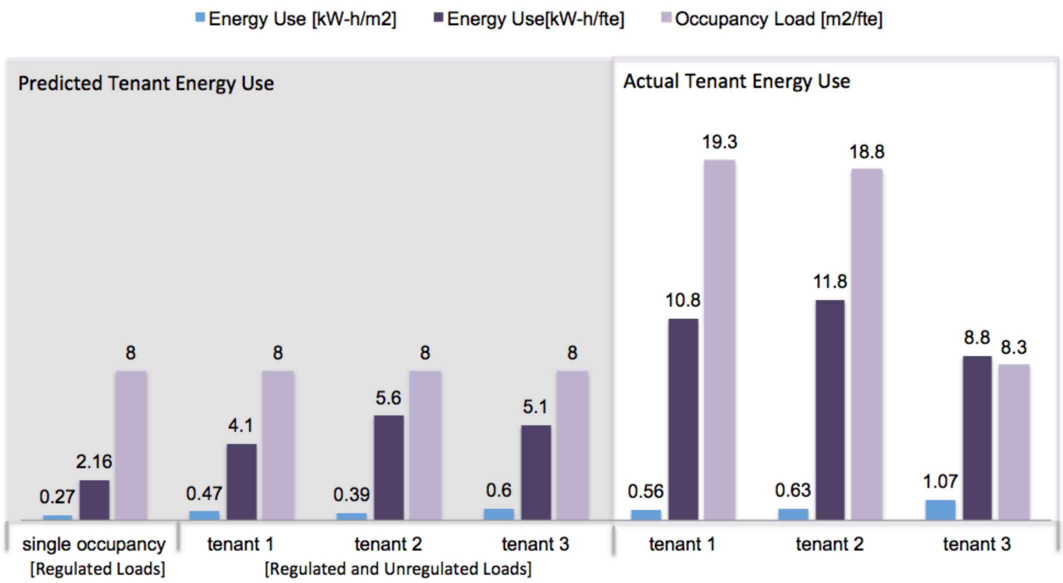


Figure 5.10 Predicted and actual total tenant energy use over a 24-hour period in January

There is a large disparity between the 'Predicted Tenant Energy Use' sourced from the compliance report [Figure 5.10] and the 'Actual Tenant Energy Use' sourced from the monitored data. This is due to variations in POU, which exists between the building tenants. The occupancy load factor varies between 8m^2 and 19.3m^2 per FTE. The NCM uses kW.h/m^2 as a reliable way to assess and compare BEP. However, if you consider the occupancy load factor, Tenant 2 has the lowest number of staff but the highest energy use per FTE. Illustrating that low occupancy [Tenant 2] and high occupancy [Tenant 3] can be misrepresented under the current calculation method, highlighting a potential area of concern under the current EPC benchmarking method.

Variations in POU account for up to a 44% increase in energy use per m^2 and 112% increase per FTE. Figure 5.11 illustrates that the current method of predicting energy consumption patterns based on fixed occupancy and set hours of operation for a sole tenant is misleading and allows for a large margin of uncertainty unless the exact POU can be established or are known at the design stage. The predicted energy use of the design brief occupancy should, therefore, be explicitly an optimum building design standard rather than a demonstration of predicted tenant energy performance by which tenant energy efficiency is assessed against.

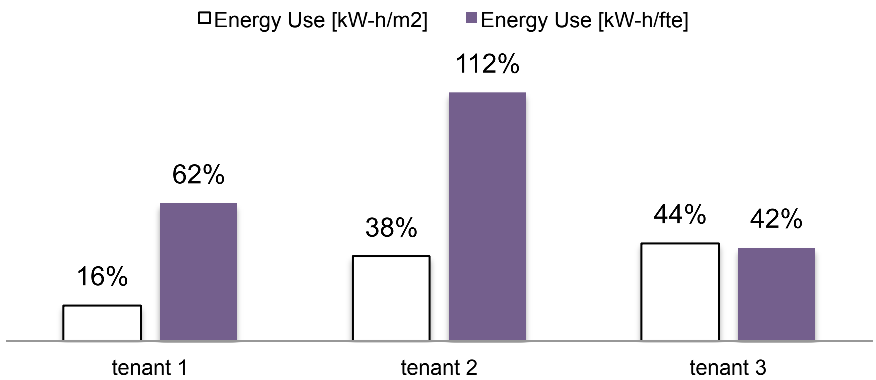


Figure 5.11 Percentage increase in tenant energy use from design estimates to actual tenant energy use over a 24-hour period in January.

Evaluating the monitored data from first principles gained new knowledge on the variations in POU between tenants and the impact on energy use, which significantly varied from the design assumptions in the Compliance Report, Appendix C. The monitoring exercise has tested and proved the hypothesis that variations in POU exist and can be measured by quantification of the tenant parameters: 'occupancy load factor' [determined by tenure area and occupancy capacity] and 'hours of operation'. The method of calculating the POU parameters is demonstrated in the next chapter. The results support the hypothesis that a new method could be developed that captures variations in POU, which would better convey the impact of high and low occupancy patterns on BEP to tenants, which could measure and compare by dually evaluating energy delivered per FTE and kW.h/m^2.

5.5 Critical Review of Implementing Occupancy Monitoring

The security system equipment installed in the building gives useful data on building hours of operation for each tenant, which could be paired with sub-metering data. From this data set, peak occupancy hours, hours of minimum occupancy and zero occupancy hours could be reported in tandem with energy use. Targeting operational hours could reduce energy use in zero and low occupancy hours. Providing a means to extract this data in tandem with energy use data could be useful to the building managers.

The methodology used in this study provided thorough data on POU and building operations that could not be attained from building walk-throughs. This method also afforded simultaneous real-time analysis between the three different tenants, which could be used to directly compare their energy performance over varying time increments, over an hour, day or year. Real-time occupancy and energy monitoring informs building users of actual energy loads and operating hours, opposed to the EPC method of conjecture. The case study demonstrated it is also useful to determine effective working patterns, highlights energy consumption when the building is unoccupied and gives an annual value to this for comparison to standard usage.

5.5 Chapter Summary

The aim of the case study was to deliver a sensitivity analysis of the building to understand how the building operates under variations in POU, its effect on energy demand due to speculation over why energy performance gaps occur. The following outcomes are concluded:

(i) Monitoring energy use alone through smart meters or data logging equipment without monitoring other occupancy factors gives an incredibly narrow view of building energy performance.

(ii) Regulated and unregulated loads should be considered to inform the users of what the BEP should be with details of the assumptions calculated.

(iii) Design brief occupancy should be defined explicitly as *an optimum design standard* rather than a demonstration of *predicted energy performance*.

(iv) The study supports the hypothesis that the current NCM process is an unfair demonstration of energy performance, as it does not recognise the impact of low or high occupancy on energy demand or projected minimum and maximum POU and that a method could be developed to capture a predicted BEP building performance range.

(v) It would be beneficial to demonstrate the impact of 'occupancy load factor' and 'hours of occupancy' in the design and operational phases to communicate how a building performs under variations in POU, pre and post–occupancy, to the end user.

This outcome of the case study motivates the hypothesis: to document and monitor variations in POU allows the tenant to evaluate their impact on BEP to engage the occupants in possible energy efficiency measures.

Chapter 6: Application of the Proposed New Method

Application of the Proposed New Method to demonstrate the impact of Variations in Patterns of Use on Tenant Energy Performance

6.0 Chapter Introduction

In this Chapter the new method is tested in application to demonstrate the impact of variations in Patterns of Use [POU] on tenant energy performance. The new method is tested and considered through defining a tenant's POU parameters, ranges, benchmarks and scenarios in a building energy model [ESP-r][125] and using the existing TM54 methodology.[108] The resultant calculations demonstrate the predicted effect of POU on energy loads and overall energy performance using the new method metrics. The usefulness of reporting and evaluating variations in POU and a tenure energy performance range is then proven in practice. The new method is demonstrated in application by conveying how one of the case study tenants [Tenant 3] will perform under variations in POU, using the proposed 'occupancy load factor benchmarks' and 'occupancy capacity' defined in Chapter 4 together with variations in hours of operation scenarios, determined from the case study observations in Chapter 5. Minimum and maximum POU are calculated for each of the tenant energy loads and POU parameters identified in the 'Building Energy Impact Assessment' and 'Tenant Energy Reporting Method.' The results exemplify the benefits of using the new method metrics to explain tenant energy performance. The next section explains the building energy model [ESP-r] selection and the model planning essential to predicting energy use patterns akin with the POU stipulated for the case study building and the tenant group selected.

6.1 Building Energy Model Selection

The building energy model ESP-r was selected and used to model tenant 3's POU. The benefits of using this particular building energy model is that tenant specific data can be inputted into the model for the building hours of operation, occupancy loads, lighting, small power, airflows and set points, which are tenant and not building specific while other variables such as the building envelope specification, climate files and orientation were notably consistent within the confines of the model and the program used, with each simulation being instantly comparable. Other building energy model's were considered but they didn't allow the freedom to explore POU in this manner [Chapter 2: Table 2.6].

Quantifying and simulating the impact of occupancy capacity on building activities and their relationship to one another for the POU assessment requires a level of detailed information and model planning. This process is documented, as the transparency of the calculations is key to the overall method; however, the articulations of the parameters inherent in the building energy model environment are not under review as part of this thesis, as stated in Chapter 3. Details of the building energy model inputs are given for clarity to frame how POU can be represented in a BEM [ESP-r] environment.

6.1.1 Building Energy Model Assumptions

The case study building Orion House, is located at the Scottish Enterprise Technology Park in East Kilbride. The building geographical co-ordinates are Latitude: 55.7566, Longitude: -4.1699 and the building is orientated facing South East.

The following building energy model assumptions were made to replicate the data collected from the monitoring exercise and ensure the data gained from the building energy model was a true representation and accurate. The simulation time period was six-weeks from the beginning of January to mid February. Analysis was performed over the period: 1st January – 31st December for an operational occupancy of Monday to Friday between 09:00 and 17:00, 06:00 and 18:00, 09:00 and 18:30. The model was calibrated by comparing the energy demand represented in the building simulation with actual monitored data for the three individual offices over the 4-week time period. Model continuity was retained as each tenant area was modeled with the same building structure, fabric and detail assumptions. The quantity of model information is limited so that the model calculations retain integrity and the energy performance is easy to understand. The building energy model inputs and 'Building Energy Impact Assessment' is recorded so that the energy performance simulation can be repeated. The existing simulation time step period is based on performance calculations data at in 30-minute incremental time steps. For the ESP-r simulation all areas are air conditioned except the toilets, stores and changing areas. All areas are heated and cooled with a VRF multi split air conditioning system with heat recovery and an air source heat pump with electric heaters servicing all other areas. The building u-values [Table 4.2] and ventilation rates [Table 6.1] assumed for the case study building and inputted into the building energy model.

Table 6.1 Operational Characteristics [Assumed in Building Energy Model]

Room Type	**Max Power Consumption (W/m2)**	**Infiltration Rate (ach)**	**Small Power (W/m2)**
Open Plan Offices	12	0.25	25
Toilet	12	0.25	0
Stores	12	0.25	0
Kitchen/ Canteen	12	0.25	25
Meeting Rooms	12	0.25	25
General Offices	12	0.25	25
Circulation	12	0.25	0

The next section reintroduces and applies the new method steps discussed in Chapter 3 to Tenant 3 and explains why Tenant 3 was selected.

6.2 New Method Steps Restated

As stated in Chapter 3 the new method provides the potential to record, test, report and evaluate tenant energy performance [Figure 3.9] by conveying the impact of variations in pattern of use, improving on current methodologies by defining a tenure specific energy performance range and setting limits on operation. The new method improves on best practice by capturing the impact of occupancy load factors and hours of operation on tenant energy usage patterns at design stage in the 'Building Energy Impact Assessment' and then monitoring the operational energy performance and recording the results in the 'Tenant Energy Reporting Method.' The new method was introduced in Chapter 3 outlining the new method calculations [Section 3.1.2], principles [Section 3.1.3], key steps, templates and energy performance calculations [Section 3.2] summarised in Figure 6.1.

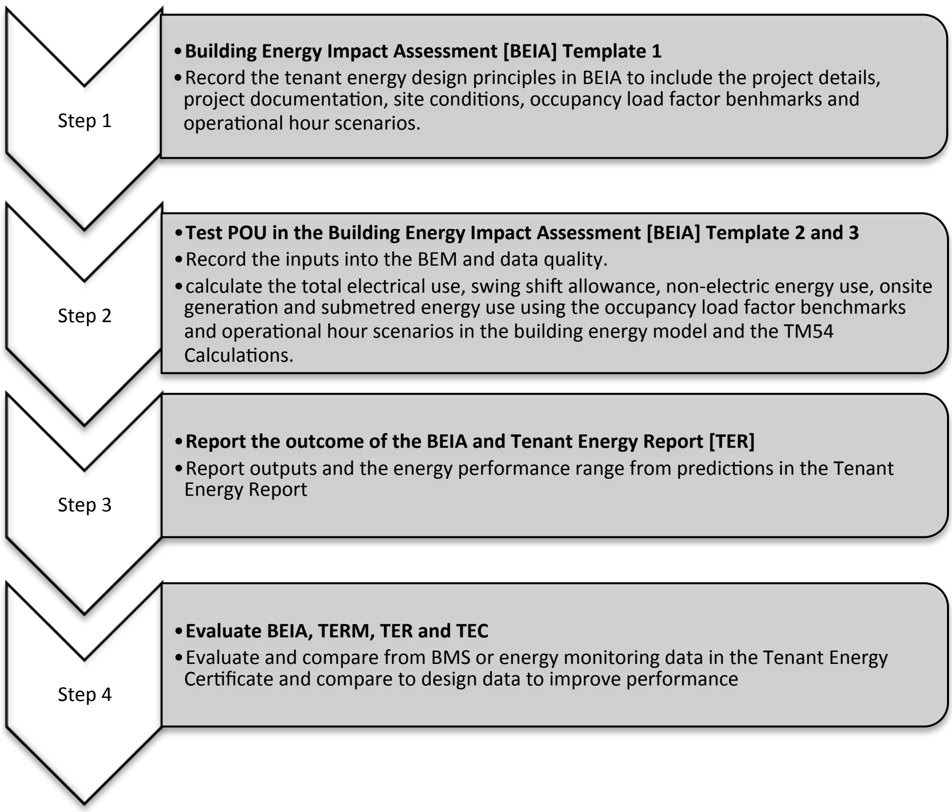


Figure 6.1 New Method Key Steps Summary.

TEMPLATE 1: BUILDING ENERGY IMPACT ASSESSMENT [BEIA]

PART 1: PROJECT DETAILS	Answer:
Project name:	ORION BUILDING
Completion date:	2008
Gross Internal Floor Area [GIFA]	1645M2
Net Internal Floor Area [NIA]	1452M2
Tenant Net Internal Floor Area [TNIA]	349 +377 = 726M2
Value:	
Location:	EAST KILBRIDE
Architect [practice name]	
Services Engineer [practice name]	
Contractor [name]	
Type of contract [traditional, D&B]	DESIGN AND BUILD
Building Regulations [adhered to by date]	2007 SCOTTISH TECHNICAL HANDBOOKS
Building Purpose Group:	OFFICE BUILDING
Ventilation strategy [Nat vent, mixed mode, air con]	MIXED MODE
Compartmentation [no. of compartments]	ONE
Floor to floor height	3725M
Number of stories	2
Details of submetering strategy [by floor, tenancy ect]:	BY TENANT - TOTAL ELECTRICAL USE ONLY

PART 2: PROJECT DOCUMENTATION	Available [Y/N]:
Site Plan with building orientation	APPENDIX A
Design Brief	NO
General Arrangement Dwg's [plans, sections & elevations]	APPENDIX A
Building Specification	NO
Mechanical and Electrical Specification	APPENDIX B
The Building Handbook	NO
Occupancy Capacity Calculations and Benchmarks [OCB]	NO
TM54 calculations and occupancy adjustment calculations	NO
BEM calculations and u-values	U-VALUES
Renewable strategy [accredited schemes and low carb tech]	NO
Low carbon technologies [CHP, GSHP, etc]	ASHP

PART 3: SITE CONDITIONS	Answer:
Site area & Conditions	APPENDIX A
Roof Area, Pitch & orientation	APPENDIX A
Overshading (Y/N)	N
Location type (rural, urban, region)	URBAN

PART 4: Occupancy Load Factor [OLF] and Occupancy Capacity [OC]	**OLF**	**OC**
Occupancy Load Factor Benchmark: Design	9M2	91
Occupancy Load Factor Benchmark: Minimum	25M2	29
Occupancy Load Factor Benchmark: Maximum	6M2	121
Occupancy Load Factor Benchmark: Tailored	8.3M2	87
Occupancy Load Factor Benchmark: NCM	9M2	91
Occupancy Load Factor Benchmark: Actual	8.3M2	87

PART 5: Hours of Operation Scenarios		**[09:00-17:00]**	**[06:00-18:00]**	**[06:00-18:30]**	**[00:00-24:00]**

Figure 6.2 BEIA: Template 1: Tenant 3

6.2.1 The New Method Applied to Tenant 3

Tenant 3 was selected to demonstrate the new method due to the ‘actual’ operational occupancy load factor [8.3m^2 per FTE] being the closest example to the design or National Calculation Method [NCM][71] occupancy load factor [9m^2 per FTE] and therefore illustrating to what extent POU could fall out with perceived normal operating conditions and project beyond Energy Performance Certificate [EPC][38] predictions and the NCM standard POU.

6.2.2 Step 1: Record

Tenant 3’s details are recorded in the ‘Building Energy Impact Assessment’ [Figure 6.2] in Template 1: Parts: 1-5. The elements recorded are the project details, the project documentation, the site conditions, the occupancy load factors and the operational hour scenarios. The project documentation can be referenced in Appendix A [architects drawings] and Appendix B [engineers drawings]. The next section illustrates the tenure area and occupancy capacity calculations and defines the occupancy load factor benchmarks.

6.2.3 Occupancy Load Factors, Calculating Tenure Area and Occupancy Capacity

Tenant 3 occupies the top floor of the Orion Building spanning over two wings [Area A and Area B] either side of a central atrium, as shown in Figure 6.3. The sum of the office areas under the influence of Tenant 3 is shown in Box 6.1.

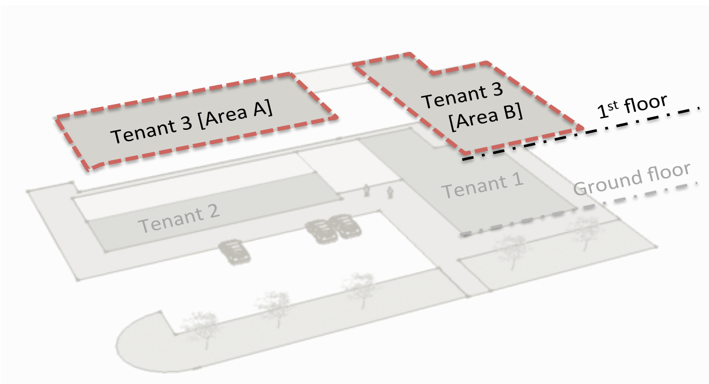


Figure. 6.3 illustrates the area of the building occupied by Tenant 3.

Box 6.1 Worked Example: Area Calculation.	
Tenant 3 Total NLA	= Area A [NLA] + Area B [NLA]
	= 377 + 349
	= 726m^2

The occupancy load factor benchmarks used to demonstrate Tenant 3's POU are stated in Table 6.2 and the tenure area [Box 6.1] is used to determine the occupancy capacity [Box 6.2] by dividing the tenant area by the proposed range of occupancy load factor benchmarks, as indicated. The next step is to determine the operational hour scenarios to represent Tenant 3.

Table 6.2: The occupancy load factor benchmarks and source of selection

Occupancy Load Factor Benchmark		Source	Thesis Reference
Maximum	= 6m^2/FTE	Fire Safety Standard	Section 4.1.5
Minimum	= 25m^2/FTE	British Council for Offices	Table 4.10
Design [Optimum]	= 9m^2/FTE	Energy Standard	Section 4.1.5
Tailored	= 8.3m^2/FTE	Tenant Specific [Case Study]	Table 4.5
NCM	= 9m^2/FTE	Energy Standard	Section 4.1.5

Box 6.2 Worked Example: Occupancy Capacity	
Minimum Occupancy Capacity	= [NLA/ minimum occupancy load factor]
	= [726/ 25]
	= 29 FTE
Maximum Occupancy Capacity	= [NLA/ maximum occupancy load factor]
	= [726/ 6]
	= 121
Designed Occupancy Capacity	= [NLA/ designed occupancy load factor]
	=[726/ 8]
	= 91
NCM Occupancy Capacity	= [NLA/ NCM standard occupancy load factor] =726/9
	= 81

6.2.4 Tenant 3 Operational Hour Scenarios

The operational hour scenarios chosen to represent the tenants POU where based on the field data collated in the case study for tenant 3 [Chapter 5], which generally showed office hours of 09:00am to 17:00pm, however, the tenant had FTE that worked shifts which extended the overall hours of operation of their tenure to 06:00-18:00 and on occasion from 06:00-18:30pm. Once the occupancy load factor benchmarks and operating hours have been established the TM54 and a building energy model can be used to calculate the predicted impacts on tenant or building energy performance. This data is then recorded together with the occupancy capacity and occupancy load factor benchmarks in Template 1 of the 'Building Energy Impact Assessment'.

Table 6.3. Proposed Tenant Operational Time scenarios: Tenant 3

	Minimum, Design & NCM	Maximum	Tailored
Hours of Operation Scenarios:	**[09:00-17:00]**	**[06:00-18:00]**	**[06:00-18:30]**

The next step in the 'Building Energy Impact Assessment' gathers data to demonstrate Tenant 3's predicted POU using mathematical calculations from TM54 and the building energy model ESP-r, which is then validated against the monitored data from the field study in the Tenant Energy Reporting Method.

6.2.5 Step 2: Test

The impact of variations in patterns of use is tested and predicted by running the calculation adjustments for each of Tenant 3's occupant load factor benchmarks and the selected Tenant 3's operational hour scenarios, initially in ESP-r to generate the expected heating and cooling loads, and then using the TM54 methodology to establish energy load calculations for Tenant 3's total electric use and sub-metered energy use. The case study building does not have a source of non-electric energy use, nor does the building have on-site generation, therefore these calculations are not applied or demonstrated. The sub-metered energy use is predicted for all the building activity parameters listed in Template 3: Part 5, to demonstrate the potential of the new method to predict energy performance in detail for comparison to the sub-metered operational data. The results are presented as energy delivered by unit of area and per FTE, as discussed in Chapter 3. The inputs into the building energy model are recorded for each of Tenant 3's POU scenarios. The POU scenarios selected [Table 6.2 and 6.3] are:

Design [NCM] POU: Illustrates the heating and cooling requirements of Tenant 3's office space with standard working hours [0900 to1700], with no weekend hours, with design occupancy load factor of $9m^2$ per FTE based on the tenant's actual occupied area of $726m^2$.

Minimum POU: This scenario looks at minimum occupancy load factor of $25m^2$/FTE based on an occupied Area of $726m^2$, minimum hours [0900 to 1700]. This scenario Illustrates the heating and cooling requirements of the individual office space with Standard working hours [9.00 to17.00] and no weekend hours.

Maximum POU: Tenant 3's office is modeled to show the impact of maximum POU on the tenant's energy demand with an occupancy load factor of $6m^2$ and an occupied floor area of $726m^2$. This scenario looks at high occupancy, maximum hours of operation [0600 to 1800] Monday to Friday. The working hours are 0600 to 1800 with no weekend hours.

Tailored POU: The tailored occupancy load factor is $8.3m^2$/FTE based on an occupied area of $726m^2$. The actual tenant working hours [0600 to1830] are modeled with no weekend hours.

6.2.6 Tenant 3: Inputs into Building Energy Model [ESP-r]

The building energy model [ESP-r] calculates the heating and cooling loads based on the criteria established by the project engineer, which represent how the building is envisaged to operate. The project engineer manually inputs the occupancy schedules, lighting loads, small power, airflows and set points data. The lighting loads and the airflows detailed [Figures 6.4-6.11] were derived from the engineer's drawings [Appendix B]. The small power load is based on the occupancy load factor and associated heat gains identified in CIBSE Guide A. The occupancy schedule is based on the occupancy load factor and hours of operation reflecting the four differing POU scenarios. Only four scenarios are presented, as the design and NCM patterns of Use are identical.

A template has been filled in for each wings of the building, as indicated in Figure 6.3. The building energy model [ESP-r] calculates the energy loads for each of the building wings separately, therefore it was easier to record and transfer the data into the model by presenting the data in this manner. The results of the heating and cooling calculations for the two wings of the building were then added together. The tenant's energy use was metered collectively for the whole area under their ownership and therefore there was no benefit gained from the energy model generating separate calculations.

Template 2: INPUTS INTO BEM
Study Scope: Design Patterns of Use, Tenant 3 [Area A]
Occupancy load factor: 8m^2/FTE **Occupied Area:** 349m^2 **FTE'S:** 43

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	09:00	0	0	0
09:00	17:00	43	3225	2365
17:00	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	09:00	0	0	0
09:00	17:00	5816	0.3	0.7
17:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	09:00	0	0	0
09:00	17:00	20*	0.4	0.6
17:00	00:00	0	0	0

Assumptions:
Small power includes computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 8m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
09:00	17:00	0.516	-
17:00	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 43 people @ 12 l/s = 516 l/s assumed for hours of operation [516 x 0.001 = 0.516].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	09:00	50	10	0
09:00	17:00	50	18	26
17:00	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Figure. 6.4 Template 3: Tenant 3 Design POU [Area A]

Template 2: INPUTS INTO BEM
Study Scope: Design Patterns of Use, Tenant 3 [Area B]
Occupancy load factor: 8m^2/FTE **Occupied Area:** 377m^2 **FTE'S:** 47

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	09:00	0	0	0
09:00	17:00	47	3525	2585
17:00	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	09:00	0	0	0
09:00	17:00	6808	0.3	0.7
17:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	09:00	0	0	0
09:00	17:00	20*	0.4	0.6
17:00	00:00	0	0	0

Assumptions:
Small power includes computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 8m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
09:00	17:00	0.564	-
17:00	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 47 people @ 12 l/s = 564 l/s assumed for hours of operation [564 x 0.001 = 0.564].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	09:00	50	10	0
09:00	17:00	50	18	26
17:00	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Figure. 6.5 Template 3: Tenant 3 Design POU [Area B]

Template 2: INPUTS INTO BEM
Study Scope: Minimum patterns of use, Tenant 3 [Area A]
Occupancy load factor: 25m^2/FTE **Occupied Area:** 349m^2 **FTE'S:** 13

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	09:00	0	0	0
09:00	17:00	13	975	715
17:00	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	09:00	0	0	0
09:00	17:00	5816	0.3	0.7
17:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	09:00	0	0	0
09:00	17:00	8*	0.4	0.6
17:00	00:00	0	0	0

Assumptions:
Small power includes computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
**Equipment heat gains based on 25m^2/ person speculated based on results in Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.*

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
09:00	17:00	0.156	-
17:00	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 13 people @ 12 l/s = 156 l/s assumed for hours of operation [156 x 0.001 = 0.156].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	09:00	50	10	0
09:00	17:00	50	18	26
17:00	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Figure. 6.6 Template 3: Tenant 3 Minimum POU [Area A]

Template 2: INPUTS INTO BEM
Study Scope: Minimum patterns of use, Tenant 3 [Area B]
Occupancy load factor: 25m^2/FTE **Occupied Area:** 377m^2 **FTE'S:** 15

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	09:00	0	0	0
09:00	17:00	15	1125	825
17:00	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	09:00	0	0	0
09:00	17:00	6808	0.3	0.7
17:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	09:00	0	0	0
09:00	17:00	8*	0.4	0.6
17:00	00:00	0	0	0

Assumptions:
Small power includes computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
**Equipment heat gains based on 25m^2/ person speculated based on results in Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.*

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
09:00	17:00	0.180	-
17:00	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 15 people @ 12 l/s = 180 l/s assumed for hours of operation [180 x 0.001 = 0.180].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	09:00	50	10	0
09:00	17:00	50	18	26
17:00	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Figure. 6.7 Template 3: Tenant 3 Minimum POU [Area B]

Template 2: INPUTS INTO BEM
Study Scope: Maximum patterns of use, Tenant 3 [Area A]
Occupancy load factor: 6m^2/person **Occupied Area:** 349m^2 **FTE'S:** 58

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	06:00	0	0	0
06:00	08:00	2	150	110
08:00	09:00	5	375	275
09:00	13:00	58	4350	3190
13:00	14:00	29	2175	1595
14:00	16:30	58	4350	3190
16.30	17.00	29	2175	1595
17:00	18:00	10	750	550
18:00	00:00	0	0	0

*Assumptions: *Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	06:00	0	0	0
06:00	18:00	5816	0.3	0.7
18:00	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:00	22.5*	0.4	0.6
18:00	00:00	0	0	0

Assumptions: Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads. *Equipment heat gains based on 6m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
06:00	18:00	0.696	-
18:00	00:00	-	0.25

Assumptions: Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 58 people @ 12 l/s = 696 l/s assumed for hours of operation [696 x 0.001 = 0.696].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	06:00	50	23	26
06:00	18:00	50	23	26
18:00	00:00	50	23	26

Assumptions: There is a constant internal temperature of 23^{o}C maintained.

Figure. 6.8 Template 3: Tenant 3 Maximum POU [Area A]

Template 2: INPUTS INTO BEM
Study Scope: Maximum patterns of use, Tenant 3 [Area B]
Occupancy load factor: 6m^2/person **Occupied Area:** 377m^2 **FTE'S:** 63

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	06:00	0	0	0
06:00	08:00	2	150	110
08:00	09:00	5	375	275
09:00	13:00	63	4725	3465
13:00	14:00	32	2400	1760
14:00	16:30	63	4725	3465
16.30	17.00	32	2400	1760
17:00	18:00	10	750	550
18:00	00:00	0	0	0

*Assumptions: *Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	06:00	0	0	0
06:00	18:00	6808	0.3	0.7
18:00	00:00	0	0	0

Assumptions: Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:00	22.5*	0.4	0.6
18:00	00:00	0	0	0

Assumptions:
Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 6m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
06:00	18:00	0.756	-
18:00	00:00	-	0.25

Assumptions: Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 63 people @ 12 l/s = 756 l/s assumed for hours of operation [756 x 0.001 = 0.756].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	06:00	50	23	26
06:00	18:00	50	23	26
18:00	00:00	50	23	26

Assumptions: There is a constant internal temperature of 23^{o}C maintained.

Figure. 6.9 Template 3: Tenant 3 Maximum POU [Area B]

Template 2: INPUTS INTO BEM
Study Scope: Tailored patterns of use, Tenant 3 [Area A]
Occupancy load factor: 8.3m^2/person **Occupied Area:** 349m^2 **FTE'S:** 42

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy	Sensible heat*	Latent heat*
00:00	06:00	0	0	0
06:00	08:00	2	150	110
08:00	09:00	5	375	275
09:00	13:00	42	3150	2310
13:00	14:00	21	1575	1155
14:00	16:30	42	3150	2310
16.30	17.00	21	1575	1155
17:00	18:30	10	750	550
18:30	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load	Radiant heat	Convective heat
00:00	06:00	0	0	0
06:00	18:30	5816	0.3	0.7
18:30	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:30	20*	0.4	0.6
18:30	00:00	0	0	0

Assumptions:
Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 8m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
06:00	18:30	0.504	-
18:30	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 42 people @ 12 l/s = 504 l/s assumed for hours of operation [504 x 0.001 = 0.504].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	06:00	50	23	23
06:00	18:30	50	23	23
18:30	00:00	50	23	23

Assumptions: There is a constant internal temperature of 23^{o}C maintained.

Figure. 6.10 Template 3: Tenant 3 Tailored POU [Area A]

Template 2: INPUTS INTO BEM
Study Scope: Tailored patterns of use, Tenant 3 [Area B]

Occupancy load factor: 8.3m^2/person **Occupied Area:** 377m^2 **FTE'S:** 45

Occupancy Schedule [Week days]

Building Hours of Operation		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	06:00	0	0	0
06:00	08:00	2	150	110
08:00	09:00	5	375	275
09:00	13:00	45	3375	2475
13:00	14:00	23	1725	1265
14:00	16:30	45	3375	2475
16.30	17.00	23	1725	1265
17:00	18:30	10	750	550
18:30	00:00	0	0	0

*Assumptions: *Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Hours of Operation		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	06:00	0	0	0
06:00	18:30	6808	0.3	0.7
18:00	00:00	0	0	0

Assumptions: Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Hours of Operation		Appliance load [W.m^{-2}]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:30	20*	0.4	0.6
18:30	00:00	0	0	0

Assumptions: Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads. *Equipment heat gains based on 8m^2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Hours of Operation		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
06:00	18:30	0.54	-
18:30	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 45 people @ 12 l/s = 540 l/s assumed for hours of operation [540 x 0.001 = 0.54].

Set points [Week days]

Building Hours of Operation		Capacity [kW]	Heating Set point [^{o}C]	Cooling Set point [^{o}C]
00:00	06:00	50	23	23
06:00	18:30	50	23	23
18:30	00:00	50	23	23

Assumptions: There is a constant internal temperature of 23^{o}C maintained

Figure. 6.11 Template 3: Tenant 3 Tailored POU [Area B]

The results of the heating and cooling loads calculations for each of the occupancy load factor benchmarks using the building energy model [ESP-r] simulation are shown in Table 6.4. The results are used to calculate the total predicted energy use in the next section, Box 6.3. The results are inputted into Template 3: Part 5 of the 'Building Energy Impact Assessment' to illustrate the impact of the chosen scenarios on Tenant 3 energy performance and show the expected energy performance range.

Table 6.4 Tenant 3 Predicted Heating and Cooling Loads Calculated in ESP-r

Occupancy load factor benchmark		**Hours of Operation scenarios**	**Design DSM Results [kW-h/year]**	
			Heating	**Cooling**
Maximum	= 6m^2/FTE	0600 – 1800	8595	10283
Minimum	= 25m^2/FTE	0900 - 1700	17722	1834
Design [Optimum]	= 9m^2/FTE	0900 - 1700	12342	3993
Tailored	= 8.3m^2/FTE	0600 – 1830	10949	8198
NCM	= 9m^2/FTE	0900 - 1700	12342	3993

The next section shows how the TM54 methodology calculations are used to determine Tenant 3's annual electrical energy use then the results are recorded in the 'Building Energy Impact Assessment' in Template 3, Figure 6.12.

6.2.7 Predicting Tenant 3's Total Electric Energy Use

The new method of calculation total annual electric energy use for each of Tenant 3's predicted POU is illustrated in Box 6.3. This is repeated for all Tenant 3 scenarios. This exercise is repeated to calculate the impact of design [NCM], maximum, minimum and tailored POU for Tenant 3's predicted energy use and stipulating what the design and calculation assumptions are, which are then later reported in the Tenant Energy Report.

Box 6.3 Worked Example: Tenant 3 Total Annual Electric Energy Use

Design [NCM] POU:

Input data:

Days of operation = 5 days x 52 weeks = 260 days

Tenant Area = 726m^2

Tenant Occupancy load factor = $8m^2$/ FTE

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 11 974 + 14 336 [26 310 – 11 974] + 32 616 + 9 306 + 1 850 + 7183 + 17 589 + 12 327 + 3 958
= 111 139 kW-h/year *estimate*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 153 kW-h/m^2/year

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor)
= 1225 kW-h/FTE/year

NB The results show that predictions need to account for swing shifts [operation out with normalised working hours] to demonstrate energy performance and the impacts of patterns of use.

Minimum POU:

Input data:
Days of operation = 5 days x 52 weeks = 260 days
Tenant Area = $726m^2$
Tenant occupancy load factor = $6m^2$/ FTE

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 3725 + 22 585 [26310 – 3725] + 17589 + 17722 + 1834 +4742 +9306 + 1850 + 704
= 80 057 kW.h/year

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 110 kW.h/m^2

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor)
= 2756 kW.h/FTE

Maximum POU:

Input data:
Days of operation = 5 days x 52 weeks = 260 days
Tenant Area = $726m^2$
Tenant occupancy load factor = $6m^2$/ FTE

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 16099 + 10 211 [26310 – 16099] + 24625 + 100 914 +15255 + 7183 + 8595 + 10283

= **193 165 kW.h/year**

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area

= 266 kW.h/m^2

Tenant annual energy use per FTE occupancy load factor) = (tenant annual energy use/ tenant area) x tenant **= 1596 kW.h/FTE**

Tailored POU:

Input data:

Days of operation = 5 days x 52 weeks = 260 days

Tenant Area = 726m^2

Tenant occupancy load factor = 8.3m^2/ FTE

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 11 575 + 14 735 [26 310 – 11 575] + 38 761 + 10 853 + 2 556 + 7183 + 24 625 +10 949 + 8198

= 129 435 kW-h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area

= 178 kW.h/m^2

Tenant annual energy use per FTE occupancy load factor) = (tenant annual energy use/ tenant area) x tenant **= 1480 kW.h/FTE**

The full range of Tenant 3's predicted results using the TM54 calculations to determine the effect of POU on tenant 3's energy performance is illustrated in Figure 6.12, Template 3: Part 2. The results incorporate the new method adjustments to show the proposed energy delivered per FTE and per m^2. The next section explains how the swing shift can be incorporated into the TM54 calculations to account for periods of occupancy beyond regular hours of operation.

TEMPLATE 3: BUILDING ENERGY IMPACT ASSESSMENT [BEIA] TEMPLATE 3

PART 1B: DATA QUALITY	
Source of Data [EPC, DEC, survey, bills, statutory appr.]	Statutory Approval
Calculation method [iSBEM, SAP, Ashrae]	TM54 and BEM [ESP-r]

PART 2: TOTAL ELECTRIC ENERGY USE					
Hours of Operation Scenarios [hrs]		[09:00-17:00]	[06:00-18:00]	[06:00-18:30]	[00:00-24:00]
Annual Total Energy Use [kWh/m2]	Maximum	203	**266**	271	532
	Minimum	**110**	136	138	272
	Design	**153**	178	181	356
	Tailored	153	178	**181**	356
Annual Total Energy Use [kWh/fte]	Maximum	1218	**1596**	1626	3192
	Minimum	**2750**	3400	3450	6800
	Design	**1377**	1602	1629	3204
	Tailored	1269	1477	**1502**	2954

PART 3: NON-ELECTRIC ENERGY USE	NCM	Minimum	Maximum	Tailored	Design
Non-electric energy use total [kWh/m2]					
space heating					
hot water					
Non-electric energy use total [kWh/fte]					
space heating					
hot water					

Part 4: ON-SITE GENERATION	NCM	Minimum	Maximum	Tailored	Design
On-site Generation [kWh/m2]					
electrical energy					
non-electric (solar water etc)					
On-site Generation [kWh/fte]					
electrical energy					
non-electric (solar water etc)					

PART 5: SUB-METERED ENERGY USE	NCM	Minimum	Maximum	Tailored	Design
Electrical energy use total [kWh/m2]	**153**	**110**	**266**	**181**	**153**
space heating	17	24	12	15	17
hot water	16	5	22	16	16
refrigeration & heat rejection (cooling)	5	3	28	11	5
fans, pumps & controls	20	31	14	20	20
lighting	24	24	34	34	24
Workstations	45	7	139	53	45
server rooms	10	1	10	10	10
small power	15.4	15.4	21	18.5	15.4
Electrical energy use total [kWh/fte]	**1225**	**2750**	**1596**	**1502**	**1225**
space heating	136	610	71	125	136
hot water	132	128	133	132	132
refrigeration & heat rejection (cooling)	44	63	170	94	44
fans, pumps & controls	158	778	84	168	158
lighting	194	606	204	282	194
workstations	359	163	834	443	359
server rooms	79	24	59	82	79
small power	123	384	126	153	123

Figure 6.12 BEIA Template 3

6.2.8 Tenant 3 Swing Shift Allowance

Chapter 3 [Section 3.2.11] identified three main occupancy periods: the typical hours of operation, the swing shift and the twilight shift. Tenant 3's normal operating hours were from 09:00-17:00, however due to some full time employee's working different shifts and the office cleaner, the building operated a swing shift of 06:00-09:00 and 17:00-18:00 and subsequently the tenure has a twilight shift of 18:00-06:00, as shown in Figure 6.13. TM54 allows for a base-load, referred to as the 'sleep mode power demand' calculation [Box 6.6 and Box 6.7] to cover the energy use over the twilight period, however, TM54 does not account for energy consumed within a swing shift.

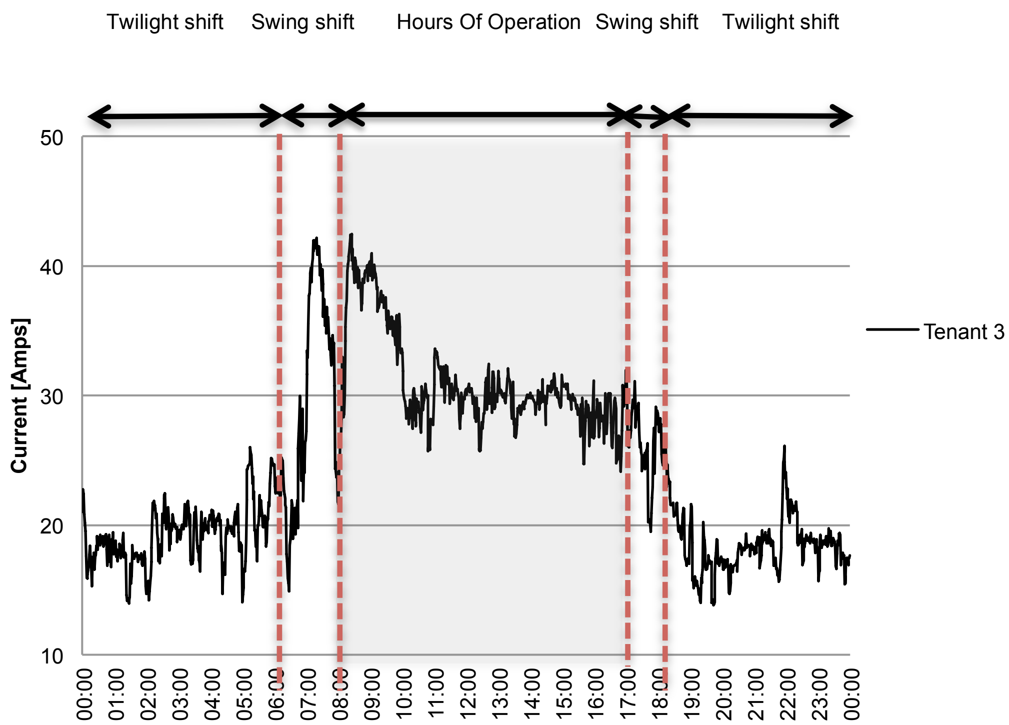


Figure 6.13 Tenant 3: Illustration of energy use over a typical 24hr period in winter.

A worked example showing how this can be integrated into TM54 calculations is demonstrated for small power loads indicated in Box 6.4. The next section illustrates Tenant 3's sub-metered calculations. The extended hours of operation and occupant capacity are considered in the building energy model, as shown in Figures 6.8 and 6.9. An allowance was also considered for increased periods of lighting, however, workstations, server rooms, hot water, fans, pumps and controls could all be considered. As the loads for these items were for one person and were minimal they were discounted from the calculations. The calculations associated with the cleaners energy use was also difficult to quantify from existing TM54 calculations and from the case study data and therefore this was also discounted from the calculations.

Box 6.4 Worked example for small power loads [adapted from TM54]

<u>Communal small power consumption [Tenant 3]</u>

Input data:

Typical equipment installed (a)	= 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers
Average power demand	= 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200 W/ fridge + 345 W/vending + 80 W/ cooler = 2445W
Swing shift power demand	= 2445W/2 = 1222.5W
Sleep mode power demand	= 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler = 374
Hours of operation	
[Occupied hours]	= 7 days x 8 hours x 52 weeks = 2912 hours
[Swing shift hours 0600-0900]	= [7 days x 3 hours x 52 weeks]/2 = 546 hours
[**Swing shift hours 1700-1800]**	= [7 days x 1 hours x 52 weeks]/2 = 182 hours
	= 2912 + 1274 + 546 = 4732 hours
Total hours per year	= 8760 hours

Annual energy consumption for tenant 3 communal small power [kW-h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (1222.5 x 546) + (1222.5 x 182) + (374 x (8760 – 4732))]/1000
= [7 119 840 + 667 485 + 222 495 + 1 506 472] /1000
= 9 516 kW-h/year

6.2.9 Tenant 3 Sub-metered Electrical Energy Use

The calculations for Figure 6.12 [template 3: part 5] are illustrated in boxes 6.5 to 6.7. The calculations are illustrated for Tenant 3 occupancy load factor benchmarks for hot water, workstations, small power, and server rooms. The calculations for lighting were taken from the engineer's drawings in Appendix B and variations calculated for the relevant operational hour scenarios. The fans, pumps and controls energy load was taken from the Section 6 Compliance Report in Appendix C and calculated to represent the operational hour scenarios. This concludes Part 5 of the Building Energy Impact Assessment: Template 3.

Box 6.5. Worked Example: Tenant 3 Predicted Hot water Calculations using TM54

Design [NCM] POU:

Input data:

Daily hot water consumption per person	= 8 l/person
Number of occupants	= 90
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 187 200 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 187 200 x 1 = 187 200 kg
Supply temperature of domestic hot water	=65^{o}C
Return temperature of domestic hot water	= 10^{o}C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water ($C\rho$)	= 4.187 kJ/kg.K
Annual energy consumption (kW.h/year)	= mass of water (kg) x ΔT (K) x $C\rho$ (kJ/kg.K) /3600
	= 187 200 x 55 x 4.187 / 3600
	= 11 974 kW-h/year
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area
	= 16.5 kW.h/m^2
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant
	= 131.9 kW.h/FTE

Minimum POU:

Input data:

Daily hot water consumption per person	= 8 l/person
Number of occupants	= 28
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 58 240 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 58 240 x 1 = 58 240 kg
Supply temperature of domestic hot water	= 65^{o}C
Return temperature of domestic hot water	= 10^{o}C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water ($C\rho$)	= 4.187 kJ/kg.K

Annual energy consumption (kW.h/year)	= mass of water (kg) x ΔT (K) x Cρ (kJ/kg.K) /3600 = 58 240 x 55 x 4.187 / 3600 = 3725 kW.h/year
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 5.1 kW.h/m^2**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 128.3 kW.h/FTE**
Maximum POU:	
Input data:	
Daily hot water consumption per person	= 8 l/person
Number of occupants	= 121
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 251 680 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 58 240 x 1 = 251 680 kg
Supply temperature of domestic hot water	= 65°C
Return temperature of domestic hot water	= 10°C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water (Cρ)	= 4.187 kJ/kg.K
Annual energy consumption (kW.h/year)	= mass of water (kg) x ΔT (K) x Cρ (kJ/kg.K) /3600 = 251 680 x 55 x 4.187 / 3600 **= 16 099 kW.h/year**
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 22.2 kW.h/m^2**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 133 kW.h/FTE**
Tailored POU:	
Input data:	
Daily hot water consumption per person	= 8 l/person
Number of occupants	= 87
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 180 960 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 187 200 x 1 = 187 200 kg
Supply temperature of domestic hot water	= 65°C
Return temperature of domestic hot water	= 10°C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water (Cρ)	= 4.187 kJ/kg.K
Annual energy consumption (kW.h/year)	= mass of water (kg) x ΔT (K) x Cρ (kJ/kg.K) /3600 = 180 960 x 55 x 4.187 / 3600

	= 11 575 kW-h/year
	[44 kW.h/day[11 944/ 260 = 46]]
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area
	= 15 kW.h/m^2
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant
	= 132 kW.h/FTE

Box 6.6. Worked Example: Tenant 3 Predicted Workstation energy consumption Calculations using TM54

Design POU:

Input data:

Number of workstations	= 90
Workstation equipment	= 1 desktop + 1 screen
Average power demand	= 65 W/desktop + 30 W/ screen + 15 W/ Misc* = 110
Sleep mode power demand	= 20 W/desktop = 20
Hours of operation	= 5 days x 8 hours x 52 weeks = 2080 hours
Total hours in a year	= 8760 hours

*Occasional desktop printer, chargers, desk fans, speakers etc.

Annual energy consumption for tenant 3 workstations [kW.h/year] = number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {90 x [(110 x 2080)+ (20 x (8760-2080))]} /1000

= {90 x [228 800 + 133 600]}/ 1000

= **32 616** kW-h/year

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor) **= 133 kW.h/FTE**

Minimum: POU

Input data:

Number of workstations	= 28
Workstation equipment	= 1 desktop + 1 screen + 1 phone
Average power demand	= 40 W/desktop + 30 W/ screen + 5 W/ phone = 75
Sleep mode power demand	= 2 W/desktop = 2W

Hours of operation = 5 days x 8 hours x 52 weeks = 2080 hours
Total hours in a year = 8760 hours

Annual energy consumption for tenant 3 workstations [kW.h/year] = number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {28 x [(75 x 2080)+ (2 x (8760-2080))]} /1000

= {28 x [156 000 + 13 360]}/ 1000

= **4742** kW.h/year

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor) **= 133 kW.h/FTE**

Maximum POU

Input data:
Number of workstations = 121
Workstation equipment = 1 desktop + 2 screen + 1 laptop + 1 phone
Average power demand = 80 W/desktop + 30 W/ screen + 35 laptop + 5 W/phone + 15 W/ misc*
= [(1 x 80) + (2 x 30) + (1 x 35) + 20 = 195W
Sleep mode power demand = 40 W/desktop + 0 W/ screen + 0 W/ laptop + 0 W/phone
= 40
Hours of operation = 5 days x 12 hours x 52 weeks = 3120 hours
Total hours in a year = 8760 hours

**Occasional laptop dock, chargers, speakers etc.*

Annual energy consumption for tenant 2 workstations [kW.h/year]= number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {121 x [(195 x 3120)+ (40 x (8760-3120))]} /1000
= {121 x [608 400 + 225 600]}/ 1000
= 100 914 kW.h/year

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE load factor)	= (tenant annual energy use/ tenant area) x tenant occupancy **= 133 kW.h/FTE**

<u>Tailored POU:</u>

Input data:

Number of workstations	= 87
Workstation equipment	= 0.75 desktop + 1.4 screen + 0.36 laptop + 1 phone
Average power demand	= 80 W/desktop + 30 W/ screen + 35 laptop + 5 W/phone + 15 W/ misc*
	= [(0.75 x 80) + (1.4 x 30) + (0.36 x 35) + 20 = 135W
Swing Shift power demand	= 135W /2 = 67.5W
Sleep mode power demand	= 20 W/desktop + 0 W/ screen + 0 W/ laptop + 0 W/phone = 20
Hours of operation	
[Occupied hours]	= 5 days x 8 hours x 52 weeks = 2080 hours
[Swing shift hours 0600-0900]	= 5 days x 3 hours x 52 weeks = 780 hours
[Swing shift hours 1700-1830]	= 5 days x 1.5 hours x 52 weeks = 390 hours
	= 2080 + 780 + 390 = 4472 hours
Total hours in a year	= 8760 hours
Sleep mode power demand	= 20 W/desktop + 0 W/ screen + 15 W/dock + 0 W/phone = 35W

**Occasional laptop dock, chargers, speakers etc.*

Annual energy consumption for tenant 2 workstations [kW.h/year]= number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {87 x [(135 x 2080) + (67.5 x 780) + (67.5 x 390) + (20 x (8760-4472))]} /1000
= {87 x [280 800 + 52 650 + 26 325 + 85 760]}/ 1000
= **38 761** kW-h/year

Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 22.2 kW.h/m^2**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 133 kW.h/FTE**

Box 6.7. Worked Example: Tenant 3 Predicted Communal small power consumption calculations using TM54

Design POU:

Input data:

Typical equipment installed (a) = 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers

Average power demand = 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200 W/ fridge + 345 W/vending + 80 W/ cooler = 2445W
Sleep mode power demand = 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler= 374W
Hours of operation = 7 days x 8 hours x 52 weeks = 2912 hours
Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (374 x (8760 – 2912))]/1000
= [7 119 840 + 2 187 152] /1000
= 9 306 kW-h/year

Other equipment installed *= 2 radio [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 2 microwave [700W] + 1 coffee machine [670W] + 1 water kettle [2800W] + 1 television [190W]* + 1 video entrance system [20W] + 1 smart board [275] + 1 network hub [20W] + 1 mechanical lifter for smart board [1800W] + 1 task light [50W]

Average power demand = 10915 W *estimated*
Sleep mode power demand = 50W *estimated*
Hours of operation = 5 days x 0.5 hours x 52 weeks = 130 hours *estimated*
Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(10915x 130) + (50 x (8760 – 130))]/1000
= [1 418 950 + 431 500] /1000
= 1 850 kW-h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor)
= 133 kW.h/FTE

<u>Minimum POU :</u>

Input data:

Typical equipment installed (a) = 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers

Average power demand = 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200 W/ fridge + 345 W/vending + 80 W/ cooler = 2445W
Sleep mode power demand = 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler= 374W
Hours of operation = 5 days x 8 hours x 52 weeks = 2912 hours
Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (374 x (8760 – 2912))]/1000
= [7 119 840 + 2 187 152] /1000
= 9306 kW.h/year

Other equipment installed *= 2 radio [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 2 microwave [700W] + 1 coffee machine [670W] + 1 water kettle [2800W] + 1 television [190W]* + 1 video entrance system [20W] + 1 smart board [275] + 1 network hub [20W] + 1 mechanical lifter for smart board [1800W] + 1 task light [50W]

Average power demand = 10915 W *estimated*
Sleep mode power demand = 50W *estimated*
Hours of operation = 5 days x 0.5 hours x 52 weeks = 130 hours *estimated*
Total hours per year = 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(10915x 130) + (50 x (8760 – 130))]/1000

= [1 418 950 + 431 500] /1000
= 1850 kW.h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE occupancy load factor) = (tenant annual energy use/ tenant area) x tenant
= 133 kW.h/FTE

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000
= [(2445 x 4550) + (374 x (8760 – 4550))]/1000
= [11 124 750 + 1 574 540] /1000
= 12 699 kW.h/year

Other equipment installed *= 2 radio [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 2 microwave [700W] + 1 coffee machine [670W] + 1 water kettle [2800W] + 1 television [190W]* + 1 video entrance system [20W] + 1 smart board [275] + 1 network hub [20W] + 1 mechanical lifter for smart board [1800W] + 1 task light [50W]

Average power demand = 10915 W *estimate*
Sleep mode power demand = 50W *estimate*
Hours of operation = 5 days x 0.75* hours x 52 weeks = 195 hours *estimated*
Total hours per year = 8760 hours

**50% increase from design based occupancy = [4550 - 2912 = 1638/2912 x 100] = 56%*

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000
= [(10915x 195) + (50 x (8760 – 195))]/1000
= [2 128 425 + 428 250] /1000
= 2556 kW.h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE occupancy load factor) = (tenant annual energy use/ tenant area) x tenant
= 133 kW.h/FTE

Tailored POU:

Input data:

Typical equipment installed (a) = 1 photocopier + 2 printers + 1 counter fridge + 1 Fridge + 2 vending machines + 4 water coolers

Average power demand	= 250 W/photocopier + 460 W/ printer + 65 W/ fridge + 200 W/ fridge + 345 W/vending + 80 W/ cooler = 2445W
Swing shift power demand	= 2445W/2 = 1222.5W
Sleep mode power demand	= 40 W/photocopier + 17 W/ printer + 10 W/ fridge + 25 W/ vending + 5 W/ cooler= 374W
Hours of operation	
[Occupied hours]	= 5 days x 8 hours x 52 weeks = 2912 hours
[Swing shift hours 0600-0900]	= 5 days x 3.5 hours x 52 weeks = 1274 hours
[Swing shift hours 1700-1830]	= 5 days x 1.5 hours x 52 weeks = 546 hours
	= 2912 + 1274 + 546 = 4732 hours
Total hours per year	= 8760 hours

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(2445 x 2912) + (1222.5 x 1274) + (1222.5 x 546) + (374 x (8760 – 4732))]/1000
= [7 119 840 + 1 557 465 + 669 123 + 1 506 472] /1000
= 10 853 kW-h/year

Other equipment installed	= *2 radio [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 2 microwave [700W] + 1 coffee machine [670W] + 1 water kettle [2800W] + 1 television [190W]* + 1 video entrance system [20W] + 1 smart board [275] + 1 network hub [20W] + 1 mechanical lifter for smart board [1800W] + 1 task light [50W]
Average power demand	= 10915 W *estimated*
Sleep mode power demand	= 50W *estimated*
Hours of operation	= 5 days x 0.75* hours x 52 weeks = 195 hours *estimated*
Total hours per year	= 8760 hours

**50% increase from design based occupancy = [4550-2912 = 1638/2912 x 100] = 56%*

Annual energy consumption for tenant 3 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(10915x 195) + (50 x (8760 – 195))]/1000

= [2 128 425 + 428 250] /1000
= 2556 kW-h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2/year

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor)
= 133 kW.h/FTE/year

Box 6.8. Worked Example: Tenant 3 Predicted Large server room with local cooling calculations using TM54

Design, Maximum & Tailored POU:

Input data:

Number of server rooms	= 1
Rated power demand of servers	= 7.2 kW [18 x 0.4 server]
Ratio of rated to operational demand	= 67%
Hours of operation	= 24 hours x 7 days x 52 weeks = 8760 hours

Annual energy consumption for small server rooms (kW.h/year) = (number of rooms x rated power demand (kW) x ratio of rated to operational power demand x hours of operation) x 1.7

= (1 x 7.2 x 0.067 x 8760) x 1.7
= 7183 kW-h/year *estimated*

Tenant annual energy use per m^2 = Tenant annual energy use/ tenant area
= 22.2 kW.h/m^2

Tenant annual energy use per FTE = (tenant annual energy use/ tenant area) x tenant occupancy load factor)
= 133 kW.h/FTE

Minimum POU:

Input data:

Number of server rooms	= 1
Rated power demand of servers	= 1.2 kW [3 x 0.4 server]
Ratio of rated to operational demand	= 67%
Hours of operation	= 24 hours x 7 days x 52 weeks = 8760 hours

Annual energy consumption for small server rooms (kW.h/year) = (number of rooms x rated power demand (kW) x ratio of rated to operational power demand x hours of operation)

= (1 x 1.2 x 0.067 x 8760)
= 704 kW.h/year *estimated*

Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 22.2 kW.h/m^2/year**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 133 kW.h/FTE/year**
<u>Design [NCM]:</u>	
Total annual energy use [building]	= 24 655 kW.h/year [aggregated from compliance report]
Building area	= 1452m^2
Tenant area	= 726m^2
Tenant Use based on compliance report	= [(24 655/1452) x 726] **= 12 327 kW.h/year** *estimated*
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 22.2 kW.h/m^2**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 133 kW.h/FTE**
<u>Design: Cooling</u>	
Total annual energy use [building]	= 7 918 kW.h/year [aggregated from compliance report]
Building area	= 1452m2
Tenant area	= 726m2
Tenant Use based on compliance report	= [(7 918/1452) x 726] **= 3 958 kW.h/year** *estimate*
Tenant annual energy use per m^2	= Tenant annual energy use/ tenant area **= 22.2 kW.h/m^2**
Tenant annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 133 kW.h/FTE**

6.2.10 Tenant 3's Energy Performance Range

Figure 6.14 shows the tenant anticipated tailored energy performance for small power to be 18.5 kW.h/m^2/year and 153.5 kW.h/FTE/ year with a design target or optimal performance of 15.4 kW.h/m^2/year and 123.2 kW.h/FTE/ year. However, the calculations predict that the tenanted space would expect to fall within the range of between 15.4 and 21 kW.h/m^2/year and 126 and 385 kW.h/FTE/ year. The new method illustrates it is useful to (i) have an energy performance target to work towards (ii) understand what the energy performance of specific tenure operating conditions to determine if the facilities are operating as expected and (iii) communicate an energy performance range as an informative and realistic data set. The 'Building Energy Impact Assessment' requires a level of detail information to be collated and understood, however, this could be simplified if it was compatible with the NCM suite of tools and building management software.

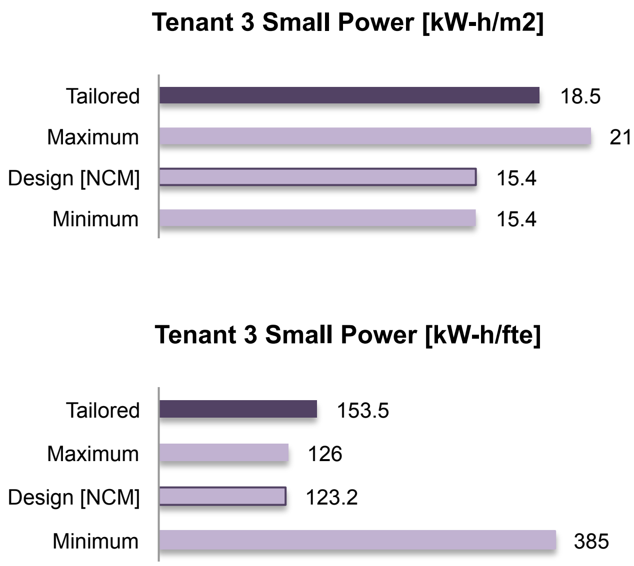


Figure 6.14 Tenant 3: Small Power Annual Estimates for Extreme [minimum and maximum], design [NCM] and Tailored POU.

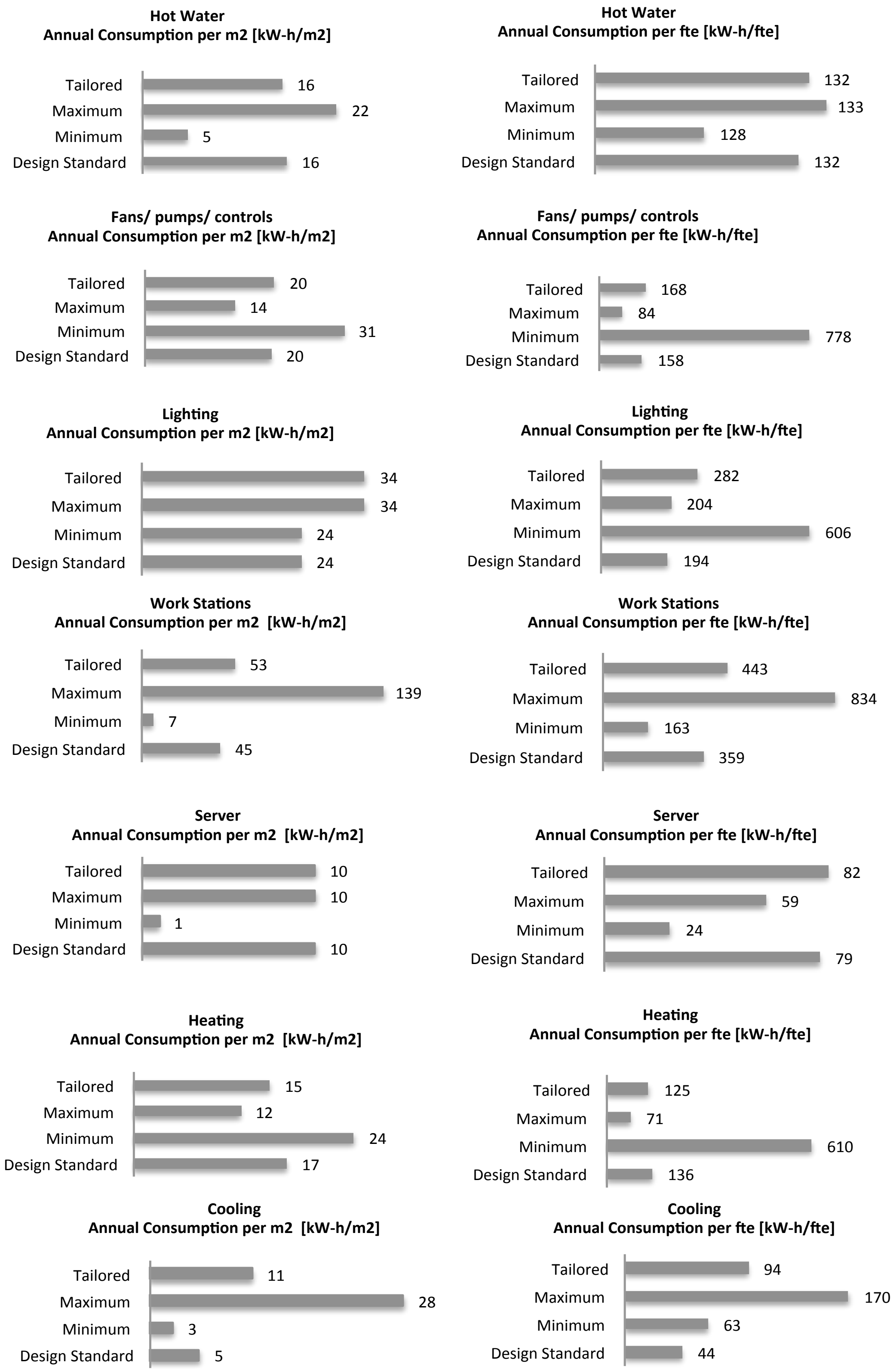


Figure 6.15 Tenant 3 Energy Performance Range for Each TM54 Building Activity Energy Load

Figure 6.15 shows the energy performance range for all the relevant building activities stated in [Template 3: Part 5]. The left column shows the annual energy consumption per unit of area and on the column on the right shows annual consumption per full time employee. Observing the benchmarks side by side has benefits; (i) the activities that are sensitive to changes in POU can be identified using kWh/FTE more successfully than using energy delivered by unit of area and (ii) tenants can identify if their POU vary from assumptions or find a POU that is a better representation. Illustrating variations in POU for the four different benchmarks, as a bar graph, is easier to interpret than the Building Energy Impact Assessment tabulated data. When the operational energy use is known it can be easily reference back. However, it would be easier for tenants to reference this style of energy reporting if the same metrics were used in the building management system and better still if the energy metering system was adapted and featured a more user friendly interface.

6.2.11 Energy Performance Range [Annual Electrical Energy Use]

The 'annual electric energy performance range' for tenant 3 is calculated in Box 5.6. The results of the 'Building Energy Impact Assessment' and expected tenure operating range can now be illustrated and recorded in the Tenant Energy Report and compared to the results of the monitored data in Chapter 5.

Box 5.6 Worked Example: Annual Energy Performance Range

Tenant Annual Energy Performance Range = Tenant annual energy performance minimum - Tenant annual energy performance maximum
= 80 057 - 203 448 kW-h/year

Tenant Annual Energy Performance Range [m^2] = Tenant annual energy performance minimum [m^2] - Tenant annual energy performance maximum [m^2]
= 110 - 280 kW-h/m^2 per year

FTE Performance Range = FTE energy performance minimum - FTE energy performance maximum
= 2757 - 1681 kW-h/FTE per year

6.2.12 Step 3: Report

The outputs from the 'Building Energy Impact Assessment' are to be reported to the tenant when a new building or tenure is handed over. Figure 6.16 illustrates the four predicted POU for all tenant 3 building activities and the cumulative effect on overall energy performance. The results can be compared to the building in use [discussed in the next section] and used to create the new style 'Tenant Energy Report', discussed in chapter 3 and illustrated in Figure 6.19. The calculations and building energy model can be updated to simulate the exact building operation; if any of the working practices differ they can be updated within their section or to record adjustments for a new tenant. Figure 6.16 shows the classic diagram used by CIBSE to illustrate energy use of different building activities. This representation of energy performance makes it is difficult to read individual energy use values, however, gives a good illustration of cumulative effect of the loads. The TM54 representation is clearer [Figure 6.17] showing the actual energy use against TM54 estimate, yet, it still does not explain perceived operational limits or promote an optimal or a targeted performance.

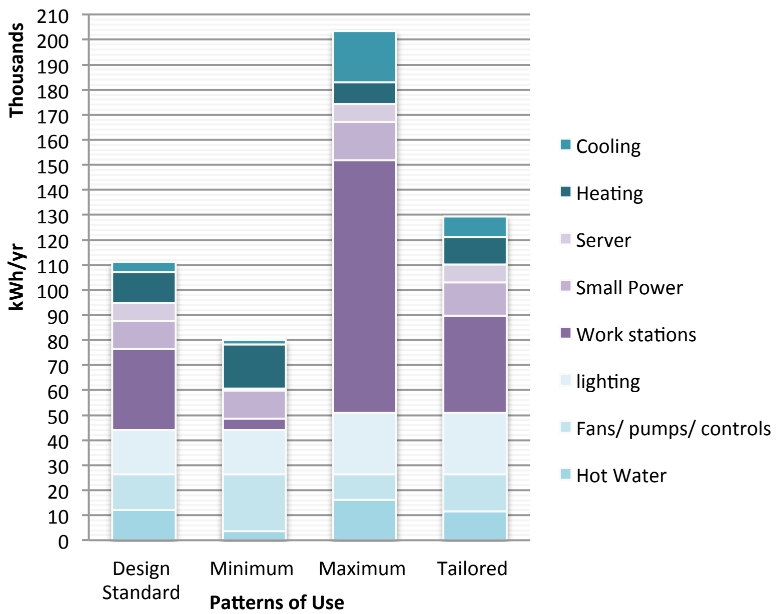


Figure 6.16 Benchmarking Study: The impact of POU occupancy capacity benchmarks on annual energy consumption for tenant 3 [kW.h/year]

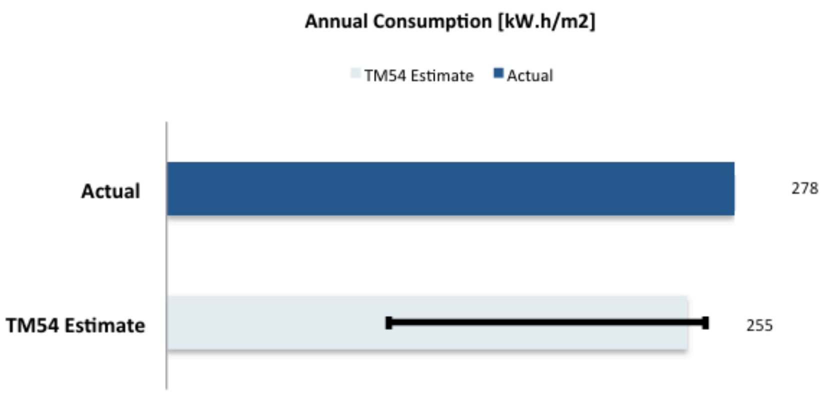


Figure 6.17 Illustration of 'TM54 Best Practice' demonstration of Tenant 3 Annual Consumption

Figure 6.18 illustrates the new method of demonstrating energy performance in comparison to existing CIBSE and TM54 methods. The new method provides clarity of the perceived operational limits, performance aspiration at design stage and an expected tailored POU for comparison to the operational data. An illustration showing the clarity of information provided to the tenant and how this is incorporated into the Tenant Energy Report, detailed in Chapter 3 [Section 3.2.15] is shown in Figure 6.19, for Tenant 3. The ratings show an aspiration for a B rating for both the energy deliver by unit of area and by FTE.

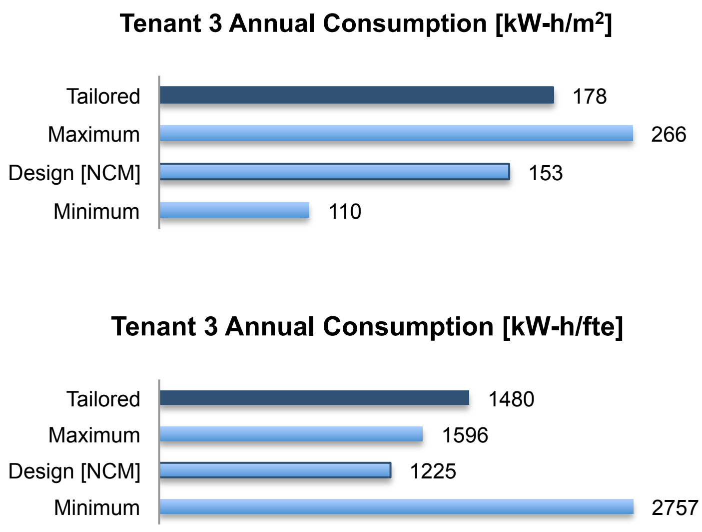


Figure 6.18 Annual consumption estimates for extreme and optimum POU.

Tenant Energy Report

HM Government

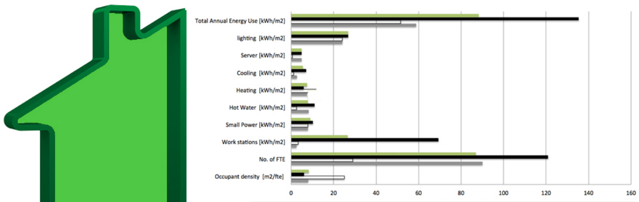
Tenant energy efficiency evaluation

Tenant 3
1st floor
Notional Building
Confidential Street
Anytown
A1 2BC

This report indicates the impact of the minimum and maximum patterns of use on annual energy consumption for (a) each fte and (b) the tenants let area. This also tells you the proposed Asset Rating based on the optimum design standard. The Operational Rating, Asset Rating, Minimum and Maximum patterns of use can be compared for each of the buildings activities, so that the tenant can check the performance of each activity as a means to lowering their consumption and lowering their carbon emissions. Details of the calculations are appended to this report.

Tenant Energy Performance Asset Rating [kWh/m²]

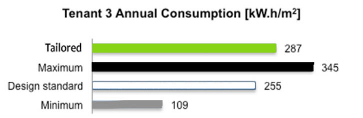
This tells you the predicted asset rating of the tenant area [design standard]. This also tells you the impact of extreme patterns of use on energy consumption, which categorized the tenants predicted energy performance range outlined in the predicted scenarios. The operational rating [actual] can be compared to the asset rating [design standard].



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/m2]	Small Power [kWh/m2]	Hot Water [kWh/m2]	Heating [kWh/m2]	Cooling [kWh/m2]	Server [kWh/m2]	lighting [kWh/m2]	Total Annual Energy Use [kWh/m2]
Actual	8.3	87	26.6	8.95	7.9	7.5	5.57	4.88	26.8	88.2
Maximum	6	121	69.4	10.3	11	5.9	7	4.88	26.9	135.38
Minimum	25	29	3.24	7.9	2.55	12.1	1.23	0.48	24.1	51.6
Design standard	8	90	2.48	7.92	8.19	8.47	2.68	4.95	24.1	58.79

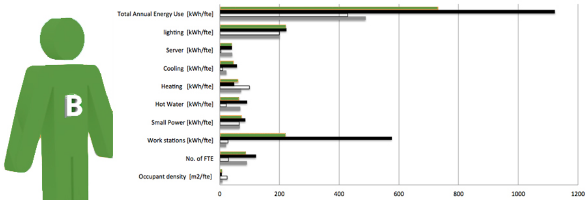
Annual Consumption

This tells you how efficiently energy has been used in the tenanted area in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed.



Tenant Energy Performance Asset Rating [kWh/fte]

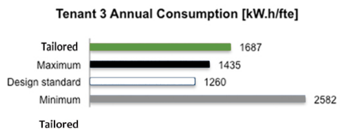
This tells you the predicted asset rating of each FTE [design standard]. This also tells you the impact of extreme patterns of use on energy consumption, which categorized the tenants predicted energy performance range outlined in the predicted scenarios. The operational rating [actual] can be compared to the asset rating [design standard].



	Occupant density [m2/fte]	No. of FTE	Work stations [kWh/fte]	Small Power [kWh/fte]	Hot Water [kWh/fte]	Heating [kWh/fte]	Cooling [kWh/fte]	Server [kWh/fte]	lighting [kWh/fte]	Total Annual Energy Use [kWh/fte]
Actual	8.3	87	220.7	74.2	65.6	62.3	46.2	40.5	222	731.5
Maximum	6	121	576	85.5	91.3	48.9	58	40.5	223	1123.2
Minimum	25	29	26.8	65.57	21.2	100	10.2	3.98	200	427.75
Design standard	8	90	20.58	65.7	67.9	70.3	22.2	41	200	487.68

Annual Consumption

This tells you how efficiently energy has been used by each FTE in comparison to how the building was designed to operate. Changes to the building fabric or HVAC system will require the tenant areas to be reassessed.



Technical Information

This tells you the scenarios used to calculate the different patterns of use. Details of the calculations are appended to this report.

Scenario 1 Minimum patterns of use	**Scenario 2** Design Standard	**Scenario 3** Maximum patterns of use	**Actual** Actual patterns of use
Low occupancy Occupant density: 25m2/FTE FTE'S: 29	Designed occupancy Occupant density: 8m2/FTE FTE'S: 90	Maximum occupancy Occupant density: 6m2/FTE FTE'S: 121	Actual occupancy Occupant density: 8.3m2/FTE FTE'S: 87
Minimum hours [0900 to 1700] No weekend hours	Minimum hours [0900 to 1700] No weekend hours	Maximum hours [0600 to 1800] No weekend hours	Actual hours [0600 to 1800] No weekend hours
Low IT use [good energy star rating of 4.0].	Moderate IT use [CIBSE Guide A].	High IT use [average energy star rating].	High IT use [average energy star rating].

Administrative information

This is a Tenant Energy Report as defined in SI2007:991 as amended.

Assessment Software:
Property Reference: 891123776612
Assessor Name: John Smith
Assessor Number: ABC12345
Accreditation Scheme: ABC Accreditation Ltd
Employer/Trading Name: EnergyWatch Ltd
Employer/Trading Address: Alpha House, New Way, Birmingham, B2 1AA
Issue Date: 12 May 2007
Nominated Date: 01 Apr 2007
Valid Until: 31 Mar 2008
Related Party Disclosure:
Recommendations for improving the energy efficiency of the building are contained in Report Reference Number 1234-1234-1234-1234

Figure 6.19 Tenant Energy Report illustrated for Tenant 3

TEMPLATE 5: TENANT ENERGY REPORTING METHOD [TERM]

PART 1: DATA QUALITY	
Source of Data [survey, bills,BMS.monitoring]	Monitoring
reporting method [TM22, BMS, EPC, DEC]	Not applied

PART 2: ACTUAL TOTAL ELECTRIC ENERGY USE	Tailored	Minimum	Maximum	Actual	Results +/-
Electrical energy use total per occupant [kWh/fte]	1502	2750	1596	2288	786
Electrical energy use total per m2 [kWh/m^2]	181	110	266	273	12

PART 3: NON-ELECTRIC ENERGY USE	Design	Minimum	Maximum	Actual	Results +/-
Non-electric energy use total [kWh/m2]					
space heating					
hot water					
Non-electric energy use total [kWh/fte]					
space heating					
hot water					

Part 4: ON-SITE GENERATION	Design	Minimum	Maximum	Actual	Results +/-
On-site Generation [kWh/m2]					
electrical energy					
non-electric (solar water etc)					
On-site Generation [kWh/fte]					
electrical energy					
non-electric (solar water etc)					

PART 5: SUB-METERED ENERGY USE	Design	Minimum	Maximum	Actual	Results +/-
Electrical energy use total [kWh/m2]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					
Electrical energy use total [kWh/fte]					
space heating					
hot water					
refrigeration & heat rejection (cooling)					
fans, pumps & controls					
lighting					
workstations					
server rooms					
small power					

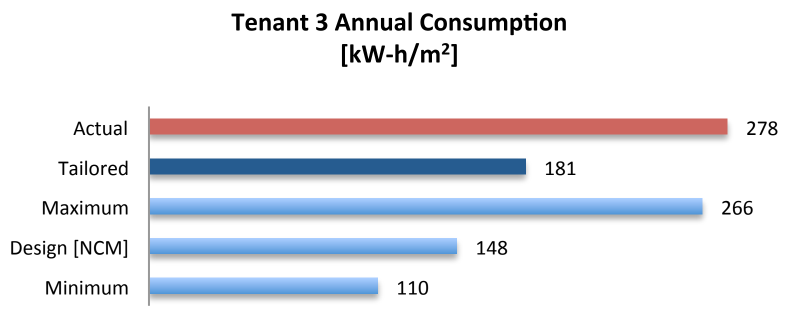
Figure 6.20 Tenant Energy Reporting Method Template 5: Tenant 3

6.2.13 Step 4: Evaluate

Box 5.7 shows the calculations required to convert the monitored data from kW.h/year to kW.h/m^2 and kW.h/FTE for comparison the predicted data in the 'Building Energy Impact Assessment,' Template 3. The 'Tenant Energy Report' results are compared in the 'Tenant Energy Reporting Method,' Template 5: Part 2, Figure 6.20. The results can now be used to produce the Tenant Energy Certificate and rate the tenants actual performance.

Box 5.7 Tenant 3:	
Annual Operational Energy Use	= 1,661,088 kW.h/year *estimate*
Tenant 3 Area	= 726m^2
Tenant 3 Actual Occupancy Load Factor	= 8.3m^2/FTE
Tenant 3 [Monday] energy use per m^2	= Tenant annual energy use/ tenant area
	= 1,661,088/ 726
	= 2288 kW.h/m^2
Tenant 3 Annual energy use per FTE occupancy load factor)	= (tenant annual energy use/ tenant area) x tenant **= 278 kW.h/FTE**

Figure 6.21 illustrates the potential of the new method to compare the predicted POU against the 'actual' operational monitored data. The monitored data was taken in the months of January and February so the annual results shown are a projection over the course of the year. The results indicate that the actual energy use (i) delivered per unit of area to exceed the tailored and maximum POU and (ii) delivered per FTE to fall within range, however, it does not illustrate why. This highlights the importance of sub-metering all building activities and carrying out the POU calculation for each. What the new method does do is provide context by which the tenant can start to assess and improve their performance.



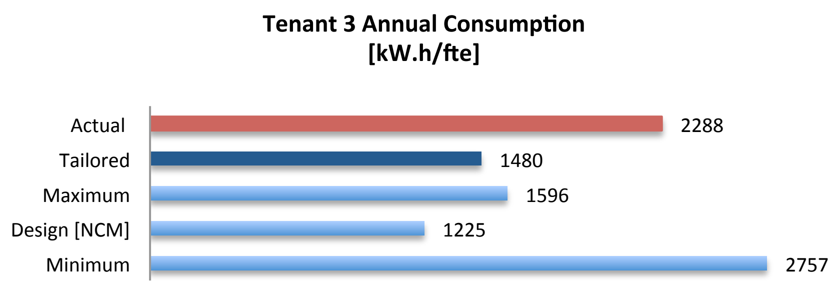


Figure 6.21 Tenant 3 Predicted Annual Energy Use and Actual Operational Use

The results show Tenant 3 can target reducing their energy use initially from 278 kW.h/m^2 to 266 kW.h/m^2 and from 2288 kW.h/FTE to 1596 kW.h/FTE, with the biggest reduction in energy delivered per FTE. The information detailed in new method documentation supports the tenant in achieving this target. If the calculations were only demonstrated for energy delivered per m^2 the gap between predicted and actual performance is not as great and may not instigate the tenant to take action due to the fact they have a high number of staff, however, the results regarding the energy delivered per FTE are more concerning and result in low rating in the Tenant Energy Certificate, shown in Figure 6.22, which if publicly reported may provide incentive for the tenant to take action and become more efficient. The 'Tenant Energy Certificate' shows performance over the past three years to target annual performance improvements.

Tenant Energy Certificate

HM Government

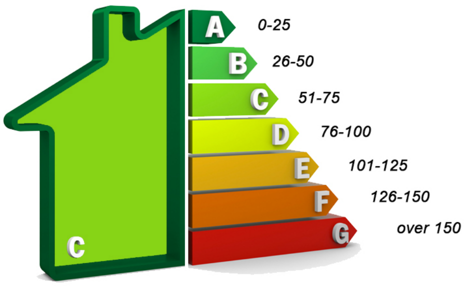
Tenant energy efficiency evaluation

Tenant 3
1st floor
Notional Building
Confidential Street
Anytown
A1 2BC

This certificate indicates the annual energy use of (a) each occupant, where performance is rated in terms of energy use per full time employee and (b) the tenants let area, where performance is rated in terms of energy use per square unit of floor area. The Operational Rating is based on meter readings of all the energy used by the tenant. It is compared to a benchmark that represents performance indicative of all offices of this type. Details of the Asset Rating calculations and predictions are summarised in the Tenant Energy Report.

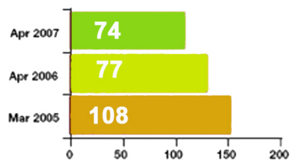
Tenant Energy Performance Operational Rating [kWh/m²]

This tells you how efficiently energy has been used per m2 of tenant floor area. The numbers do not represent actual units of energy consumed; they represent comparitive energy efficiency. 100 would be typical for this kind of building.



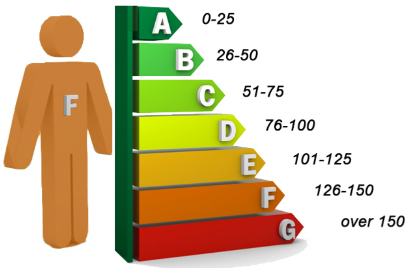
Previous Operational Ratings

This tells you how efficiently energy has been used in the tenanted area over the last three accounting periods.



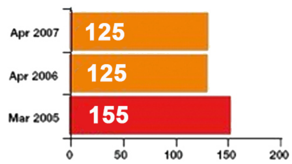
Tenant Energy Performance Operational Rating [kWh/fte]

This tells you how efficiently energy has been used per full time employee. The numbers do not represent actual units of energy consumed; they represent comparitive energy efficiency. 100 would be typical for this kind of building.



Previous Operational Ratings

This tells you how efficiently energy has been used in the tenanted area over the last three accounting periods.



Technical information

This tells you technical information about how energy is used by the current tenant. Consumption data is based on actual readings.

Main Heating Fuel: Electricity
Building environment: Air Conditioned
Total Tenant Floor area: 726m2
Occupant density: 8m2 per fte
Asset Rating: 50

	Heating	Electrical
Annual Energy Use (kWh/m²/year)	126	129
Typical Energy Use (kWh/m²/year)	120	95
Energy from renewables	0%	20%

Figure 6.22 Tenant Energy Certificate Tenant 3

6.3 Review of the Proposed New Method in Application

The approach to the visual dissemination and the processing of complex data to the building users is integral to understanding and improving building performance. Existing energy performance evaluation methodologies will not inspire the tenants to reduce their consumption if they find it difficult to understand the impacts of their own regimes. Therefore careful consideration is required as to how this information can be easily conveyed and therefore useful.

The new method proposals are a pragmatic approach improving on best practice, aimed at illustrating each building activities performance, rating and interactions with one another. Figure 6.16 and 6.17 are both useful characterisations of predicted building activity energy loads depicting the cumulative, low and high-end performance but do not convey how energy use will change under different or extreme POU. The new 'Tenant Energy Report' is a useful method to illustrate likely tenant or building energy performance for differing POU. This also helps tenants understand what the major energy intensive loads and therefore cost intensive, which could be used to take steps to reduce overheads if possible and provides a much more detailed analysis by defining the energy consumption in kWh per year for each activity.

Building managers and energy assessors can assess operational performance in the 'Tenant Energy Certificate' in conjunction with the assumptions as noted in the 'Building Energy Impact Assessment' and 'Tenant Energy Report.' The illustrations provide the basis to show the interconnectedness of loads and potentially highlight problem areas to target. Facility managers and energy assessors can refer to the 'Tenant Energy Report' and POU scenarios to understand if increases in loads could be due to extended hours of operation and increased equipment, and monitor the appropriate loads.

6.4 Chapter Summary

It is difficult to quantify the exact breaking point of a building, as there are so many variables to consider, however, the application of the new method has demonstrated what could happen practically under the POU that the building would expect to accommodate. This chapter has proven the hypothesis, '*that a new method could be developed that articulates the impact of POU at design and operational stage that would be useful to the building users that defines an BEP range through occupant load factor benchmarks, occupancy capacity and variations in hours of operation [accounting for swing shift allowance]',* to be correct. The next chapter compares the tailored tenants POU to the actual monitored data to validate the results.

Chapter 7: Analysis of the Proposed New Method

Review of the Proposed New Method against Evaluation Criteria

7.0 Chapter Introduction

This chapter validates the results of the test application against the 'real life' case study results and appraises this as a method of both generating and testing the hypotheses; then evaluates the extent to which the hypothesis is correct. The 'real life' case study Patterns of Use [POU] scenarios are calculated using TM54 and a building energy model [ESP-r]. This allows the accuracy of the POU results to be verified against the monitored data in Chapter 5 and the predicted design POU to be compared to the National Calculation Method [NCM] model results in Chapter 4. The accuracy of the results and integrity of method are also reviewed.

7.1 Validate the Predicted Patterns of Use against the Operational Data

The design 'occupancy load factor' of each tenant's office was modeled in a BEM [ESP-r] to show the annual regulated energy demand of each tenure, which was then to compared to the overall building energy performance detailed in the Section 6 Compliance Report [Appendix C] to ensure the model results were reasonably accurate. Table 7.1 confirms the building energy model [ESP-r], selected to predict the results of the impacts of variations in POU on the building energy loads [based on the design occupancy load factor], are recorded with a 5.7% error, which is a reasonable variation for a building energy model.

Table 7.1 The percentage error between the compliance report calculations and the DSM calculations for the buildings annual regulated loads.

	Annual Energy Use [MWh]		
Regulated Loads	**Compliance report**	**ESP-r Aggregated**	**Percentage Error***
Heating	24	24,654	2.7%
Cooling	8	7,916	1.1%
Fans/ Pumps/ Controls	53	[23,948 + 28,672]	1.7%
Lights	35	35,178	0.5%
Total	**120**	**126,818**	**5.7%**

*Percentage error = [accepted value - experimental value] / accepted value x 100%

The largest variation between the NCM model and ESP-r was the heating load calculation, however, 2.7% is still reasonable. The hot water load has been included in the fans, pumps and controls calculations as it was not singularly recorded in the Section 6 Compliance Report and the calculations fell short by the value of the hot water energy use. The air change rates were adjusted to replicate the response of the heating and cooling shown in Table 7.1. The regulated and unregulated loads are then calculated for the three tenancies using the design occupancy load factor and TM54 methodology. This shows how the building was designed to perform so that the minimum and maximum POU can be related back to this optimum performance benchmark or datum. The calculations for the unregulated energy use, such as the server, plug loads and increased IT equipment cannot be verified, as this was not considered in the compliance report.

To ascertain if the collective calculations from TM54 and ESP-r are a reasonable representation of maximum and minimum POU, ESP-r and TM54 are used to calculate the impact of the tailored POU of the three tenants. The results are compared initially to building meter readings and to the monitored data; however, comparing the annual tailored energy performance results with the annual metered data readings was inconclusive as shown in Table 7.2.

Table 7.2 Annual Energy Use for Each Tenant taken from the meter readings

Metered data	Tenant 1	Tenant 2	Tenant 3
01.02.2012	268223	285453	591530
01.02.2013	29663	129166	332947
Annual Consumption	Inconclusive	Inconclusive	Inconclusive

The electric energy meter for Tenant 3 was not fully functional during the monitoring period and therefore there was an absence of results for reference. In addition, when the meters were recorded to check the data the following year all the meters appeared to be reset and therefore an annual reading for Tenant 1 and 2, was not available. While the annual readings were not present, useful data could be quickly extracted to show (i) overall weekend energy use from 6pm Friday night to 9.30am Monday morning (ii) a daily energy use figure between 9.30am and 6pm together with (iii) an overnight reading between 6pm and 9.30am, as shown in Table 7.3.

Table 7.3 Average January Energy Use taken from the meter readings

Metered data	Tenant 1	Tenant 2	Tenant 3
Average Weekend Reading [Friday 18:00 – 09:30 Monday]	620	117	-
Average Daily Readings [09:30 - 18:00]	98	70	-
Average Nightly Readings [18:00 – 09:30]	143	46	-
24 Hour Reading [09:00 – 09:30	241	116	650*
Average daily hourly Readings [09:30 - 18:00]	11.5	8.2	-
Average Nightly hourly Readings [18:00 – 09:30]	9.2	2.9	-

* From readings taken in 2013

The meter for Tenant 3 was not working in 2012; therefore it was not possible to get any depth of data. The recorded data was used to verify the data taken from the data logger was accurate over a 24-hour period. Recording metered data overnight, during working hours and over the weekend is a good way of understanding, high level, the operational characteristics and resulting energy performance of a tenure or building. The overnight readings highlight that Tenant 1 nightly energy use is high compared to Tenant 2, therefore this could be highlighted to the Tenant and investigated. It also highlights, high level, that there is a weekend energy load to be reviewed to understand if any savings could be made.

Initially the electric energy meter readings were taken randomly at 9.30 am and 4.30 pm, as a means of checking the monitored data, however, overall this drew attention to a simple and inexpensive method to illustrate how much energy a building or part thereof is using '*out of operation hours*' and could be used as a simple tool to reduce office energy consumption if *smart* meters were altered to record consumption in this way.

To test the accuracy of the building energy model and TM54 to predict the impacts of variations in POU on energy performance the calculations in Appendix D were compared to the actual monitored data taken from the data loggers. As all the tenants weekend energy use was pretty inconsistent and hard to model accurately the calculations are based on the total average weekday energy loads and hence, the sum of the average nightly and daily load determined by the tailored hours of operation. The tailored calculations were then compared to the monitored data. T2's results were very accurate [Table 7.4]. This can be attributed to the fact that this tenant has the most habitual POU and they have low occupancy numbers and minimal equipment so averaging the calculations gives quite a realistic data set both in speculation and as a result of streamlining the monitored data for comparison.

Table 7.4 Comparison between tailored calculations and actual for each Tenant

Metered data [Jan]	Tailored [kW.h]	Actual [kW.h]	**Percentage Error***
Tenant 1	3,731	4,320	13.6
Tenant 2	2,198	2,150	2
Tenant 3	11,927	14,479	17.6

*Percentage error = [accepted value - experimental value] / accepted value x 100%

However, when a tenant's POU are more erratic and difficult to determine due to inconsistency of definitive hours of operation, user preferences and out of hours operation, then as expected, the accuracy of the calculations is less robust. As illustrated in Table 7.4, the percentage error ranges from 2-18%. This shows that the tailored estimates in places are conservative and in reality, the monitored energy use is still considerably higher. However, a 20% increase is more accurate and acceptable than a 300% increase, shown in Chapter 2. This increase could be due to the air source heat pump using more energy than shown in the ESP-r model to heat and cool the building, however, this is speculation and the heat pump would need to be monitored to ascertain if this is correct. Also, the approximate energy use of the servers may be light but without accurate monitoring of individual building energy loads, it is impossible to determine what calculations are inaccurate.

7.2 Validate the Accuracy of the Results and Integrity of the Method

The accuracy of the results is compared with other studies in the field and assessment methods to justify the approach used and address rival explanations. The energy performance calculations were compared to the compliance model and to the case study results to validate the accuracy of the results. Repeating the sample over the same winter period for the following year checked the balance and robustness of the data. The results of the new method were validated through comparison of the field study data set to a restricted case [Tenant 2], giving confidence that the predicted results were accurate. The outcome of the building energy model and TM54 tailored calculations checked against the monitored data, proves that the results of the projected POU for Tenant 3 are representative of what the building and tenure energy performance range would be *if* the occupants POU were fairly consistent over the study period. As Tenant 2's POU were rigorous and consistent in operation this allowed the retrospective tailored calculations to be accurately represented in TM54 and the ESP-r with results within ±2% substantiating the hypothesis that a new method could be developed to capture and report POU at the design and operational stage, which improves on the current best available techniques.

The monitored data set was then compared to the electric energy meters over a 24-hour period time restriction to give confidence that the monitoring results were precise. The accuracy of ESP-r, as a tool to model energy performance, has been the subject of several validation studies in national and international projects within ±25% of daily values, which is reflected in this study.[126] The scenarios were compared using the traditional metric energy consumption per unit of area. This was then used to calculate the aggregated occupancy load factor to determine the energy consumption per person [FTE]. As the occupancy load factor benchmarks are based on industry standards this also gives confidence that the predicted energy performance range of the tenure is accurate.

The new method of evaluating tenant energy performance through considering POU through occupancy load factor benchmarks and hours of operation is valid as it allows tenants to evaluate the effect of the POU on energy performance with a greater degree of accuracy by framing the expected performance range of energy loads. The accuracy could be improved upon if the building utilised a Building Management System [BMS], which dynamically measured occupancy, hours of operation and energy use used the design data and occupancy load factor performance range as an operational target. A detailed building energy management system would also enable energy performance targets to be established for the different operational phases identified in the thesis to include; tenure hours of operation, building operating hours, twilight hours [base-loads] and swing shift periods to be evaluated in terms of energy loads and occupancy capacity to determine better management practices and energy utilisation.

The strength of the new method is dependent on a detailed sub-metering strategy, which would allow the tenants to compare the building activity design data with operational data. The barrier to the new method is the cost to the building owner to install this system, as it puts pressure on the building owner to make improvements to the building to ensure the building equipment is running efficiently and presently there is no incentive for building owners to install and maintain a detailed sub-metering system.

The use of the new methods metrics has also been validated as they have given valuable insight into the impact of occupancy and occupancy load factor on tenure and building energy performance. Both benchmarks are needed to establish the root cause of efficient or inefficient work patterns and hours of operation. In addition to using kW.h/m^2 and kW.h/FTE, a matrix was proposed to consider the effect of minimum and maximum POU in tandem with variations in hours of operation. A simplification of this method would be to introduce a metric, which would consider both the occupancy and hours of operation influence. This has been considered and proposed previously in a study looking at linking energy consumption to people,[127] whereby energy per area per occupied hours was proposed based on a tailored POU. This theoretically could be applied to the new method; however, the research presented in the thesis has shown that the building energy performance and tenant energy performance can vary significantly during different operational phases. The metric would, therefore, need to be refined to include all the differing operational phases [office hours, building hours, swing shift and twilight shift] for comparison and would require the BEM to evaluate cooling and heating over varying time-steps over an hourly period, at minute intervals. The new method simplifies this process by demonstrating what the overall likely energy use would be for a 24-hr period and including calculation allowances for base loads and twilight shift, which gives useful feedback to tenants without the need for dynamic energy monitoring and until such times that dynamic detailed tenant energy monitoring or building energy management system is commonly available.

7.3 Evaluation of the Hypothesis

This section discusses how the ‘real life’ case study and test application are appraised as a method of both generating and testing the hypotheses; then the extent to which the hypothesis is correct is evaluated. The case study and test application generated the hypothesis *'a new method capturing POU in BEP assessment provide useful insight (a) at the design stage and (b) the operational stage could be developed which could demonstrate variations in POU through benchmarking minimum and maximum BEP defined by a tenants chosen area, number of full-time employees and hours of operation for a whole building or part thereof'* by generating valuable data demonstrating the extent of variation between tenures in a 'real life' scenario confirming that POU do in fact exist and that they have a substantial impact on energy performance.

Although there was elements of the data missing from the case study, which would have been beneficial to further validate the works, gaps in data are fairly typical of monitoring studies.[21] Therefore, as demonstrated in this chapter there is a need to be able to check back the data from a number of reference points to enable validation of the monitoring results whilst the building is in operation. The test application was successful due to the operational POU of Tenant 2, which allowed the monitored data to be compared to the new method calculations with relative ease. Validation of the results and the resultant performance range and existing BEP benchmarks were then used in the operation phase to confirm that the new method could set limits on all the tenant energy loads. This would identify whether the building defects or the tenant's patterns of use were to blame for increased energy consumption; and furthermore, to highlight measures that could be improved upon that would be in direct control of the building tenants. The focus of this thesis was to ascertain if a new method could be established to convey the impact of variations in POU at the design and operational stage and this has proven to be correct.

7.4 Chapter Summary

The thesis works are not intended as a review of the accuracy of TM54 or a building energy model to simulate energy efficiency; nevertheless, the results have demonstrated that the outcomes of the thesis works are accurate and reliable. The benefit of the new method is illustrating and comparing the impacts of variations in POU, and as such, although the numerical output shown is not 100% precise, the relative difference in the POU are valid as they show how occupancy load factors and hours of operation affect energy use, and therefore efficiency, and highlight how energy effective practices could be investigated. In addition, accurate comparison of the actual and tailored data relies on monitored data being as rigorous and as detailed in assessment as the calculations.

Chapter 8: Discussion of Results and Proposed General Applications

Outcomes from the Thesis and the New Method Application

8.0 Chapter Introduction

This chapter reviews the new method to establish if it could be incorporated into industry, the existing Building Energy Performance [BEP] methodologies, and compliance procedures, to provide useful insight at both the design and operational stages. Then determines if it is suitable to project BEP 'Patterns of Use' [POU] as 'new method to examine performance gaps in use.'

8.1 New Method Integration at the Design and Operational Stages

This section evaluates how the research documented in the previous chapters can be used to inform and improve the UK energy reporting method. The aim is to discuss how the research can be translated into practice by demonstrating the changes needed for implementation into the existing National Calculation Method [NCM] suite of tools and evaluating the barriers and benefits of changing the process. This section clearly defines the contributions to BEP through reviewing the proposed changes and integration of the new method and metric into the existing the national energy reporting methodology to include (i) NCM, Energy Performance Certificates and Energy Ratings (ii) a new style NCM Building Energy Model called TBEM (iii) alignment with CIBSE guidance TM54 and TM22, and (iv) building energy modeling techniques and quality assessment procedures.

8.1.1 Integration with NCM, Energy Performance Certificates and Energy Ratings

This thesis has demonstrated that the new method could be used to inform a new energy rating and certification model, which draws on EPC and DEC principles to align with existing NCM processes. The new method incorporates the old EPC and DEC methods by illustrating the standard NCM energy performance calculations against the new 'occupancy load factor' benchmarks and 'operational hour' scenarios. The calculations are based on energy delivered per m^2 and per FTE to establish best practice for (a) the entire building under single occupancy or (b) part of the building, subject to the sub-metering strategy, when the building is multi-tenanted and is illustrated in the existing NCM energy rating band system A-G. The main barriers to the successful implementation of TER and TEC are:

- Ensuring adequate technology is in place to monitor the energy performance building activities [sub-metering].
- The ability of a paper certificate to present enough data that is both comprehendible and useful to building mangers and users.
- Creating a NCM building energy model capable of predicting POU by tenure in tandem with the TM54 reporting method.

The next section discussed the possibility of a new building energy model to demonstrate the effect of POU on BEP.

8.1.2 New Method Integration with the NCM Building Energy Model

The official NCM software SBEM could be adapted to allow variations in POU to be calculated for an office building tenure. To enable the method of assessment proposed in this thesis, a new Tenant Building Energy Model [TBEM] could be created, as shown in Figure 8.1. SBEM works with monthly mean values however the databases include hourly rates for compatibility with approved dynamic simulation tools such as ESP-r. Therefore it is possible to amend SBEM to demonstrate energy performance at different scales and with the new proposed [kW.h/FTE] metric.

The output could give a TEP range based on the proposed occupancy load factor benchmarks and operating hour scenarios and an expected energy performance range for each building activity. The introduction of TBEM is only put forward as a new tool specification, as part of the thesis works, as a response to the requirements of the new Tenant Energy Regulations. The capacity of the software to enable all of the above changes has not been examined and would need to be further reviewed independent of this work. The next section discussed the new method integration with building management systems.

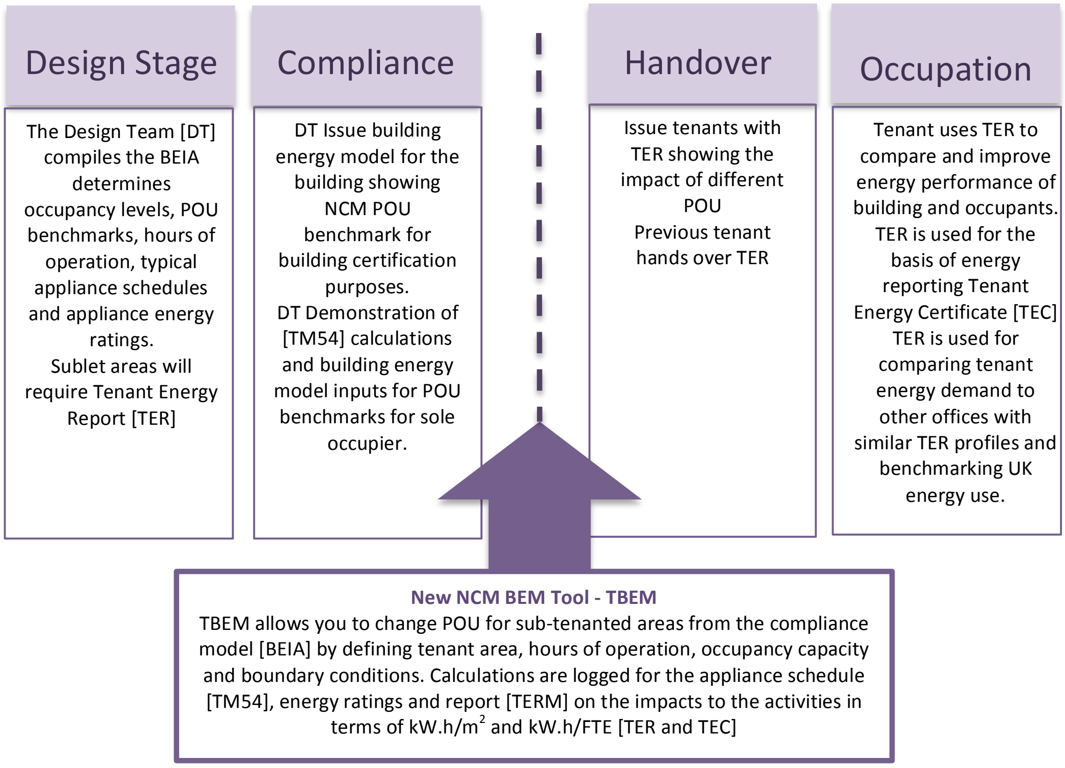


Figure 8.1 Proposed changes to the design process to introduce TBEM

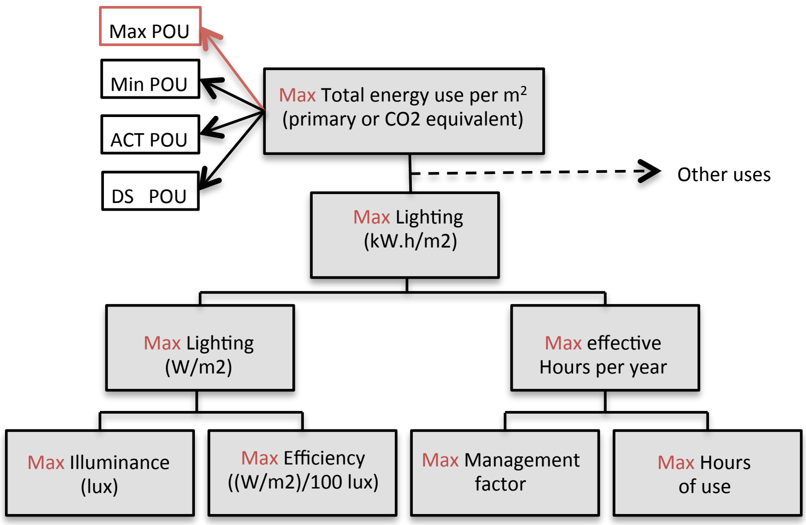
8.1.3 New Method Integration with Building Management Systems

The new method could compliment a building management systems [BMS] as they share a common purpose to control building activities, minimise operating cost and secure building systems against system failure. The new method POU benchmarks and scenarios could be used to better inform inefficiencies, however, a method of dynamically measuring building occupancy in tandem with BMS data would be required. This could be established through occupancy sensors and tracked through the BMS. The capacity of BMS systems to enable the monitoring of occupancy data has not been examined in the thesis works and would need to be reviewed independent of this work. The next section discusses the new method integration with CIBSE Technical Memorandum [TM] 22 and 54.

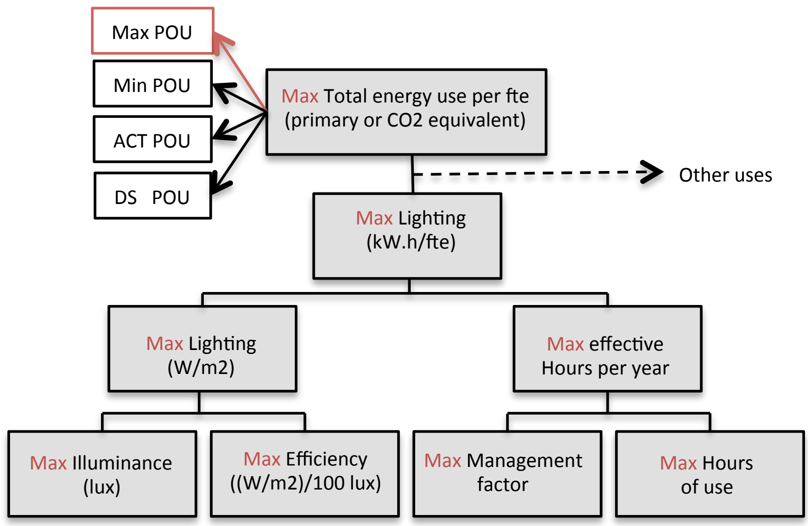
8.1.4 New Method Integration with TM22

The new method enhances the TM22 Energy Assessment and Reporting Method by offering occupancy load factor benchmarks not defined in current guidance. The

Box 8.1 Analysis of tenant energy consumption and service provision; each item can be considered as an occupancy benchmark for energy use per m² and per FTE



CIBSE TM22 Energy Tree diagram Assessment: Total Energy Use per m²



CIBSE TM22 Energy Tree diagram Assessment: Total Energy Use per FTE intention is that designers could use the redefined TM22 tool to carry out a sensitivity analysis of BEP under different POU at design stage and discuss the building's likely POU load profiles with the client and define a BEP range to set realistic performance targets. The new method delivers a detailed breakdown for all categories of electrical end use and has the potential to be a powerful tool of analysis, providing a common reference point for designers and operators. Using the occupancy benchmarks in TM22 would provide a useful aid for aligning expectations and a checking mechanism for a regulatory tool like TBEM.

The new method will automatically generate a graphical breakdown of annual energy use to compare POU to good practice guidance and metered data. Box 8.1 shows how the TM22 Energy Tree Diagram Assessment could be adapted to record and demonstrate the total energy use per m^2 and per FTE for all energy uses for each POU benchmark. The tree diagram allows for detailed representation of variations in POU to be logged for all aspects of the calculations if required by the building designer, client or end user.

8.1.5 New Method Integration with TM54

As highlighted in the EPC guidance a building can be single or multi-tenancy. TM54 endorses the use of a consistent floor area for comparison to BEP benchmarks set out in CIBSE Guide F, which is beneficial to sole tenants with a tailored POU but does not demonstrate how multi-tenancies variations in POU may affect energy use profiles. The new method could be integrated into TM54 calculations to represent tenant floor areas and tenant occupancy load, in design and in use. The calculation adjustments allow for tenant specific variations in POU to be accounted for in all the TM54 steps listed in Figure 8.2.

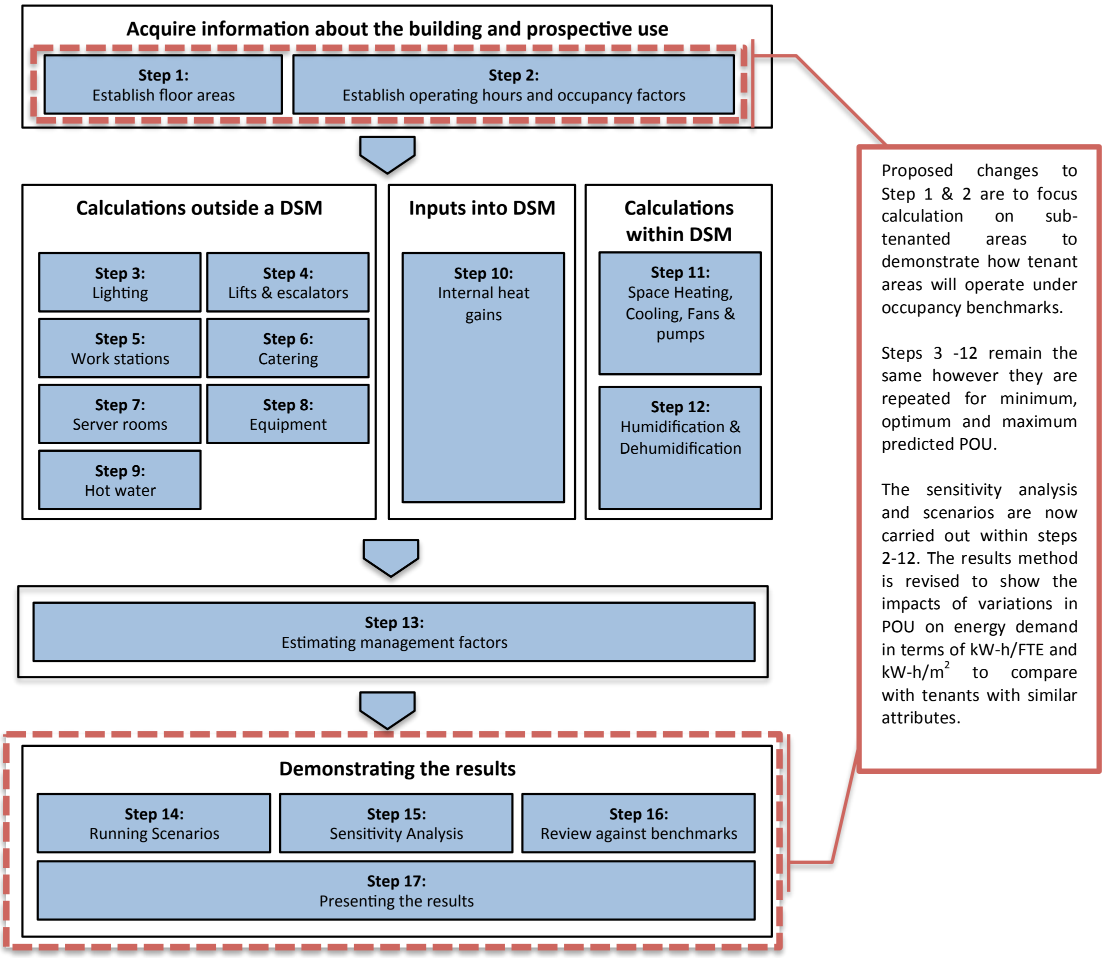


Figure 8.2 Methodology for evaluating tenant operational energy use at design stage: proposed changes to TM54 method. [12]

New analysis of occupancy load factor benchmarks and operating hours offers a detailed account of expected performance for evaluation. A detailed account of how this is developed and tested is detailed in Chapters 3 and 6. The next section discusses integrating the new method with energy auditing and reporting.

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[12] Image Source: Adapted from TM54: Evaluating operational energy performance of buildings at design stage.

8.1.6 Integration with Energy Auditing and Reporting

The process of auditing and reporting energy is not tethered to the buildings design process and as such there is a lack of best available techniques to successfully compare the building in use to how it was designed to function. Soft landings discusses the benefits of synthesising the process but the guidance does not set down principles by which this could be done. This thesis has systematically investigated a new method to engage both the designers and the building occupants to evaluate how a building or part thereof would perform under different POU to produce an energy performance range and target optimal use. Further articulation of POU benchmarks and energy used by a full time employee in direct relation to the tenure area opposed to the building has increased both the accuracy and the understanding of the tenant's individual impact.

The current method adopted by UK government to document and report on energy performance is through commissioning an accredited energy assessor to assess and compile an EPC [or DEC], which is printed or displayed and given to the building proprietor reporting as an articulated snapshot of probabilistic performance reported every five years for an EPC or annually for a DEC. As office building energy performance is in a state of flux over a 24hr period, a week or a season it would be better to have a live and dynamic reporting method and knowledge base of national building performance. Dynamic reporting has not been implemented due to the cost and resources needed to put this into action and of course who would vet and manage it? This raises speculation over how the research presented can be articulated to the end users in a way, which is useful and can help them improve their energy performance and lower costs.

The following is a proposal of how the information could be portrayed but this is only achievable if a national standard of a dynamic 'Tenant Energy Report', 'Tenant Energy Certificate' or EPC equivalent could be administrated.

Figure 8.3 Tenant Energy Dashboard integrating TER and TEC data.

As shown in Figure 8.3, benchmarking POU has the potential to give energy ratings to all building activities for the tenant, the building and per FTE and convey the percentage split, the annual performance of each activity and how changes in POU affect the *energy balance*. To unlock the true potential of the new method of assessment, the data could be made more accessible by conveying the results of the 'Tenant Energy Report' and 'Tenant Energy Certificate' as an app [Figure 8.3]. This would take the form of an interactive graphical presentation showing the building users what areas they have control over improving, what the possible impacts could be and who should pay, the tenant or the landlord. Forecasting changes to POU would be a powerful tool to evaluate the impact of improvement measures to ensure the best cost and energy savings are being made. This method of monitoring energy consumption within a set of predefined operational limits through a sensitivity analysis of how the building should perform allows the building to be measured and compared in real-time if the technology to measure occupancy and energy use is available. The results could be expressed for hourly, daily, monthly or annual comparisons if the app was synced with the buildings monitored activity data. The dashboard could show the results of the new method assessment to include:

- POU scenarios assumptions and calculations.
- POU Sensitivity analysis on each energy load [kW.h, kW.h/m^2 & kW.h/FTE].
- Asset Rating, Operational Rating and Previous Operational Rating per m^2.
- Asset Rating, Operational Rating and Previous Operational Rating per FTE.

The new method caveats are (i) the building energy model is based on a realistic equipment list and specification (ii) each building activity is sub metered (iii) existing NCM SBEM software is adapted to allow POU to be calculated (iv) POU is recorded, tested, reported and evaluated and (v) an expected energy performance range and band for each building activity and metric. This would provide criteria by which the building and tenure energy performance in use could be tested against. A hard copy or dynamic representation of the **'**Tenant Energy Report' would be handed over to the building users together with the new style 'Tenant Energy Certificate.' Daily, weekly and monthly live energy use reporting using the new method principles for each of the building activities would allow the building to be assessed immediately after building handover to address technical defects.

The accuracy of the energy reporting method is based on the ability to assess and record the new method using TM54 and a building energy model. As this is a new way of representing energy performance a new set of 'Modeling Quality Assessment Procedures' would need to be documented so that the calculations and assessment were repeatable and true to the original building design or could be adopted to meet a change in design or use. Documentation of the building energy modeling data should be a mandatory for compliance so that the model can be duplicated and the assumptions made in the model easily understood. Replication of the model is required for an energy audit trail to test the buildings energy performance for future improvements or renovations. Replication is also useful to understand how the building was designed to operate. Its important to understand how the energy consumption of the building was calculated and hence how the building limitations were established as it will be important to check both the operation of the building and the operation of the model, if the building does not perform as expected. It should therefore be mandatory that any assumptions made when inputting data into the building energy model should be documented and accessible to the building users and therefore be part of the building handbook. Currently there is a lot of data present in the model. This should be explained and defined so that a facility manager, energy modeler or energy auditor can understand it. This data should be understood without having to access the model. All aspects should be documented so that if the model were to be repeated, the same results would be given. If the modeling strategy and therefore the design strategy is easy to understand, it will also be easy to understand if there is a departure from how the building was intended to operate. For instance, if the building blinds have been replaced by the occupier this could cause an imbalance in the heating and cooling load and a departure from the original heating and cooling load calculations. If the specification of the solar shading (internal blinds) is documented and listed as a key design consideration with an impact assessment on the performance spectrum then this will be targeted as an energy performance measure of the building and controlled by the building users and facilities managers appropriately.

There is CIBSE and BSRIA guidance on building handbooks[128, 129] and what they should contain. This could be updated to include a section, which includes the 'Building Energy Impact Assessment' and 'Tenant Energy Reporting Method' criteria or at the very least includes the documentation to allow a post occupancy evaluation of energy performance. This handbook section would also ideally comprise of:

- Building performance limitations.
- HVAC limitations based on POU.
- Building energy model and building energy model *epilogue.*
- Specific building performance considerations.
- Best practice performance measures.
- Section 6 Compliance Report with accompanying energy calculations, building details and u-values.

The culmination of 'Building Energy Impact Assessment', 'Tenant Energy Reporting Method' and POU represented in 'Tenant Energy Report' and 'Tenant Energy Certificate' best practice measures and supporting documentation should be dynamically represented in a buildings management system to enable tenants to accurately monitor and evaluate energy efficiency daily. The next section discusses how the new method can examine performance gaps in use.

8.3 A New Method to Examine Performance Gaps in Use

Chapter 6 has given a simple demonstration of what can be expected by calculating the sensitivity of the building to variations in POU, at the extremes of the energy performance scale for Tenant 3 with the predicted maximum POU [Figure 6.21] nearly double the design POU [measured in energy delivered per m^2]. Thus, the new method gives insight and meaning as to why the energy performance gap of 240 UK offices exists [identified in Chapter 2]. In reality operational energy use is commonly double the predicted values, as the current calculations do not consider the effects of variations in POU and tenants maximising the performance of the building. One case study sample is not enough to prove the hypothesis that the existing reporting method creates the energy performance gap but it does illustrate the potential of the new method to make the energy prediction calculations more robust by disseminating valuable and varied design information to the end users. It would be beneficial to extend the study to analyse further office buildings in detail to prove and substantiate the hypothesis that the current NCM calculation method creates the misunderstanding of how buildings perform. The new method and metric is useful as it clearly demonstrates the impact of variations in POU and on (i) total energy use (ii) energy loads by building activity and by creating an energy performance range, which the tenant can assess their performance at handover and when the building is in operation as a means to determine inefficient operation or technical defects and thus, allows a more detailed method and analysis to assess gaps in building performance by building activity in use.

8.2 Chapter Summary

The advantages of being able to assess POU in use with your tenant neighbour and tenures with similar POU is that facilities managers and tenants can discuss specific responses to energy efficient or inefficient practices and make changes before carrying out expensive monitoring exercises. In addition to the issues raised over the current energy rating system noted by Pérez-Lombard et al, the new method is useful as it focuses energy audits on specific areas of energy consumption negating expensive holistic monitoring exercises and acts as an early warning sign if any if the activities are not performing as expected.

Chapter 9: Conclusions

Hypothesis, Further work, Conclusions, and Contribution

9.0 Chapter Introduction

This chapter concludes the thesis with a discussion on (i) the research strengths and weaknesses (ii) outcomes of the research study and (iii) restates the hypothesis, contributions to knowledge and potential opportunity for future work.

9.1 Research Strengths and Weaknesses

The aim of this thesis is to make a contribution to tenant energy performance evaluation at both the design and operational stage of a building's lifecycle. The thesis has given evidence of the problem that existing BEP methods assume that different building tenants will all use the building in exactly the same way whether the tenant (i) accommodates the gross floor area of the building or part thereof (ii) have a high or low number of staff and equipment per m^2 or (iii) have longer or shorter operating hours than the proposed standard POU. In reality, as demonstrated in the 'real-life' case study, different tenant groups vary in their patterns of use resulting in different operational and energy requirements. Variations in 'Patterns of Use' [POU], as defined in the thesis works, is determined by tenure net internal floor area, occupancy capacity, resultant occupancy load factor and hours of operation, which contribute to the intensity of use of all energy loads and overall performance. The research presented highlights gaps regarding (i) the impact of variations in patterns of use and its effect on building performance and (ii) whether the building or the tenant patterns of use are operating effectively.

In terms of scientific reliability, investigation into the relationship between occupancy capacity and energy performance of three independent tenants, in the 'real-life' case study was effective. The Better Building Partnership intimated in 2009, 'variations in energy consumptions due to POU and occupancy should be recognised' and 'building occupancy should be recorded and reviewed to reduce excessive consumption in periods of low occupancy.' This inspired a review of how a building performed in occupation and after hours. The case study results demonstrated low and high occupancy during 'standard' office hours, which were gained blind by assessing the variations in POU that exist between tenures. Further research of the NCM reporting methodology highlighted that low occupancy is not currently considered and therefore energy performance reporting for offices with low numbers of staff could give false reports of efficient work practices and HVAC equipment in comparison to highly occupied buildings. The outcome of the case study pre-empted the articulation of the building energy model and mathematical models to represent the impact of variations in POU on energy performance. The new method improves upon building performance evaluation best practice by demonstrating at design and operational stage how a tenure or building will operated under different POU by (i) framing what the expected energy performance will be through determining a set of minimum and maximum occupancy load factor benchmarks (ii) demonstrating hours of operation scenarios and (iii) measuring energy performance through energy delivered by unit of area [kW.h/m^2] relative to tenure occupancy load Factors and energy delivered per person [full time employee] relative to occupancy load Factors [kW.h/FTE], which allow the tenure operating conditions and energy loads to be assessed.

The new method introduces the 'Building Energy Impact Assessment' [BEIA] into the RIBA plan of work stages to implement key energy evaluation techniques and reporting measures throughout the design process. Ultimately to improve the building design, understand the building operating limits and pass on the predicted operational data onto the building users so that the building can be tested and evaluated in operation. The 'Building Energy Impact Assessment' records and documents expected building performance under different POU for the 'Tenant Energy Report' at the design stage for comparison to monitored operational data from either the 'Tenant Energy Reporting Method' or 'Tenant Energy Certificate.' The strength of the reporting method is being able to evaluate the impact of tenants POU measured in energy delivered per FTE and providing efficiency targets.

The key benefits of communicating and benchmarking POU creates a fair, universal, scalable and robust method of evaluating tenant energy performance together with the energy performance of our buildings, which can be integrated with the existing UK energy performance evaluation methods. Enabling tenants to run their buildings with better control and efficiency. Still, this will only be possible through smarter and live monitoring of POU and building activities. Detailed monitoring is significant. The future of POE will be data driven by more accurate monitoring exercise, which can be recorded and compared back to design data. New regulation is demanding that building tenants meet specific energy performance targets, which necessitates a new method of energy monitoring and reporting. The new method allows tenants to understand how much energy a single occupant is using albeit an aggregated value. As technology advances it will be possible through sensor networks to evaluate an individual's personal energy use, working patterns and levels of comfort to personally inform them of their individual energy or environmental impacts. The new method takes energy performance evaluation one-step close to achieving this goal.

Capturing the case study results over a short period and the resultant small data sample could bring the validity of the research into question, as the results may only apply to the case study office building. However, the importance of the research was to highlight that achieving energy performance predictions in newly occupied building may not represent the true energy performance *unless* occupancy load factor benchmarks and the use of an occupant metric is interjected, as low occupancy levels in periods of standard hours of operation falsify results in a similar way to over occupancy, *which is* currently represented in the reporting framework. As such, the use of the desktop and case study data was sufficient to test the relevance of variations in POU and to generate a sensitivity analysis to define an energy performance range. The building energy model and TM54 results worked well and illustrated the benefits of the new methods to articulate building and tenure performance. As Lerum states 'the benefit of performing *what-if* scenarios and analysing their effect in building simulation programs lies in the comparison of alternative solutions.' Although the actual numerical output may be less reliable, the relative differences in a series of iterations are valid as criteria for selecting which solution will create the most energy savings.'[89] The test application used the best available techniques and mathematical models to demonstrate the new method, which was then cross-referenced to the real-life data, validating the results. As such, the new method is a valid tool to calculate tenure energy performance and the relative scenarios set by the POU benchmarks and specified operating conditions.

The new method is only effective if the design data and monitored data is recorded accurately, which is an intensive and costly process, with a joint financial responsibility between the design team, building owner and occupier. As such, the implementation of detailed monitoring relies on legislation, such as the Tenant Energy Regulation becoming more stringent year on year and the appointment of a governing body to enforce responsibility and validate correct reporting measures.

9.2 Outcomes of the Research Study

Due to the Tenant Energy Efficiency Regulations, there is an immediate need to articulate tenant energy consumption so that tenants can better predict, understand and compare their energy use patterns. The new method is useful to help tenants and landlords understand how their office building will work by conveying a probabilistic energy performance specification range and a sensitivity analysis based on probabilistic building occupant levels and hours of operation, in addition to the activities highlighted in TM54. Although it is not conceivable to model every potential pattern of tenant use, demonstrating the optimum designed standard with the expected maximum and minimum operations limitations is a good way of defining and then tested building performance evaluation in design and operation. The new method and its outputs are intended to provide useful feedback in design and in building operation, which can be integrated into existing building energy evaluation methodologies. The following measures are recommended in order for this method to become effective:

- Define current NCM standard energy performance calculations explicitly as *an optimum design standard* rather than a demonstration of *predicted energy performance*, and
- Demonstrate the impact of occupancy load factors and hours of operation on tenant energy use throughout the design concept, design and handover stage to communicate how a building performs under different POU.

The new method put forward in the thesis has shown to be useful and to address the current challenges in energy performance evaluation. The new method was successfully tested and applied to a multi-tenant office building. The use of the new method and associated templates to record and monitor energy performance both at a design and operational stage was demonstrated. Application of the new method to other buildings is achievable with the relevant metrics and occupancy load factors.

9.3 Restates the Hypothesis

A critical evaluation of the existing BEP assessment methods provides the following hypotheses: (a) the absence of POU benchmarks creates a barrier to understanding the impact of variations in tenants rentable area, number of full-time employees and hours of operation on building energy use, and (b) POU benchmarks are needed to meet energy reduction targets and new imminent energy performance legislation, as the current standard method of measurement does not demonstrate the impact of variations in POU on BEP. As such, the research question devised was:

‘Can a method capturing POU in BEP assessment provide useful insight (a) at the design stage and (b) at the operational stage?’ The resulting hypothesis was that a new method could be developed at design stage which could demonstrate variations in POU through benchmarking minimum and maximum BEP defined by a tenants chosen rentable area, number of full-time employees and hours of operation whether they were renting the whole building or part thereof. The resultant performance range and existing BEP benchmarks could then be used in the operation phase to set limits on all the tenant's energy loads; and furthermore, to highlight measures that could be improved upon that would be in direct control of the building tenants. The research described in thesis developed, tested and demonstrated the application of the new method and provides insights for further research in this field. Future works are described in the next section.

9.4 Further Work

The new method considers and compares buildings area [kW.h/m^2], energy use [kW.h] and occupancy load factor kW.h/FTE [in design] or [in use] together with patterns of operational use. This is transferable to other building types such as education, healthcare, and public buildings. Evaluating building traffic and 24-hour energy use profiles can determine efficient design proposals and management strategies to optimise building energy efficiency e.g. practical design measures to ensure the areas of use in the building during the swing and twilight phases of operation are located together to reduce the footprint and energy use of the beyond peak occupancy hours. Further monitoring and POU evaluation work would test the new method application to hospitals, libraries, schools and universities where the number of occupants fluctuates over a 24-hour period.

Future work could also explore fine-tuning the evaluation of extreme POU to indicate specific criteria for when a building would break. This could help inform design restrictions, behaviour patterns and efficient building operation to prevent over or under heating in highly insulated buildings. In addition, smart pervasive sensor networks could be explored to stream live accurate energy monitoring and comfort assessments, which are in direct control of the occupant & their immediate environment.

The introduction of the new method metrics makes it easier to understand the buildings loading requirements and the impacts of POU. KW.h/fte was chosen, as kW.h/fte per hour is too generic as the thesis works prove tenant energy consumption fluctuates greatly over a 24-hour period. However, this could be further investigated to provide further metrics such as kW.h/fte per ‘base-load hour’ and kW.h/fte per ‘hour of operation’ with more detailed monitoring data across a greater number of case study samples.

9.5 Contributions to knowledge

The contributions to knowledge are; the new method allows the tenant to (a) evaluate the impact of a tenure through detailing the aggregated energy use of a full-time employee; (b) evaluate the minimum and maximum POU scenarios to understand the impact of the tenant's POU on tenure and building energy performance; and (c) to understand if the building or the occupant's POU are inefficient, improving on best practice.

9.6 Concluding Statement

Energy performance experts suggest that ‘the more complex the procedure, the larger the inputs, the greater the possibility of errors’. Yet the research presented demonstrated accurate energy reporting and evaluation needs a realistic data set, which sets down how a building is projected to function, which factors in how the building is likely to operate under the influence of variation in POU. This necessitates an analysis of an extensive and detailed dataset from the outset of a building project. This thesis has exemplified and evaluated how this could be implemented and how the changes could be integrated into the NCM suite of tools. The research concludes that it is important to represent POU to fairly and accurately demonstrate energy performance and to understand who is to blame for poor performance, the tenants and their operational requirements or the building design and systems.

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Glossary of Terms:

Actual Occupancy Load

Operational internal heat or power load due to occupants, lights and equipment [Watts] used to calculate tailored heating and cooling requirements in building BEMs to compare the energy use of HVAC in operation.

Building Activity

For the purpose of the thesis building activity is given to the items that require a calculation to determine their energy load at design stage and have an energy use in operation grouped as follows: lighting, lifts and escalators, small power, catering, server rooms, hot water, space heating, cooling, fans, pumps and controls.

Building Baseload

The permanent minimum load that a power supply system is required to deliver to a building to maintain operation.

Building Energy Modeling

Building Energy Modeling (BEM), also called Building Energy Simulation, (or energy modeling in context), is the use of software to predict the energy use of a building.

Building Lifecycle

Building life cycle refers to the view of a building over the course of its entire life - in other words, viewing it not just as an operational building, but also taking into account the design, construction, operation, demolition and waste treatment.

Building Performance Evaluation

BSRIA (Building Services Research and Information Association) defines Building Performance Evaluation as: ‘a form of Post-Occupancy Evaluation (POE) which can be used at any point in a building's life to assess energy performance, occupant comfort and make comparisons with design targets.’

Building Energy Management System

A building energy management system (BEMS) is a sophisticated method to monitor and control the building's energy needs. BEMS technology can be applied in both residential and commercial buildings. The teaser image illustrates several of the different functions a BEMS can monitor and control.

Building Management System

A building management system (BMS) or a building automation system is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems.

Building Tenant Group

A person, or group of people, which rents or owns a [office space in a] building.

Building Users

A person, or group of people, which use a [office] building.

Carbon Buzz

Carbon Buzz is an RIBA CIBSE platform for benchmarking and tracking energy use in projects from design to operation. It is intended to encourage users to go beyond compliance of mandatory Building Regulations calculations and refine estimates to account for additional energy loads in-use. The platform allows users to compare design energy use with actual energy use side by side to help users close the design and operational energy performance gap in buildings.

Display Energy Certificate

Since 9 July 2015 public buildings in the UK over 250m2 must display a Display Energy Certificate (DEC) prominently at all times. The aim of the Energy Performance of Buildings Directive is for the public to receive energy information about a building they are visiting.

Department of Energy and Climate Change

The Department of Energy and Climate Change (DECC) is a British government department created on 3 October 2008, to take over some of the functions related to energy of the Department for Business, Enterprise and Regulatory Reform, and those relating to climate change of the Department for Environment, Food and Rural Affairs.

Energy Benchmark

A standard or point of reference against which energy performance may be compared.

Energy Consumption
Energy consumption is the amount of energy or power used.

Energy Performance Gap
The performance gap is a term commonly used to denote the disparity that is found between the energy use predicted in the design stage of buildings and the energy use of those buildings in operation.

Energy Efficiency
Efficient energy use, sometimes simply called energy efficiency, is the goal to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature.

Energy Load
The predicted and operational energy use of building activities, singular or plural.

Energy Load Parameters
A numerical measurable factor forming one of a set that defines the energy load calculations system and sets the conditions of their operation.

Energy Performance of Buildings Directive
The Energy Performance of Buildings Directive (EPBD) is an EU initiative aimed at reducing the amount of energy consumed by buildings in an attempt to reduce carbon emissions.

Energy Performance Certificates
Energy Performance Certificates (EPC) is a list of statistics about the energy efficiency of a building. They also have recommendations on where you could make improvements. EPCs carry ratings on energy use and carbon dioxide emissions.

Energy Monitoring
Energy monitoring is the act of collecting real-time or interval energy data, so it can be managed efficiently. Energy monitoring can be done in real-time when data is sent to energy management software that can be accessed from outside of the building.

Full-time Employee

For the purpose of the calculations carried out in this thesis a full-time employee is defined as someone who works 40 hours every week, for 120 days every year.

Green Tenancy Agreement

A 'Green Lease' is a lease of a commercial or public building, which incorporates an agreement between a landlord and a tenant as to how a building is to be occupied, operated and managed in a sustainable way and reflects the parties desire to improve and be accountable for energy efficiency at a building.

Gross Internal Floor Area

Gross Internal Floor Area (GIFA) is the area of a building measured to the internal face of the perimeter walls at each floor level.

Metric

A system or standard of measurement.

National Calculation Method

The National Calculation Method (NCM) is defined by the Department for Communities and Local Government (DCLG). It describes the procedure, for buildings other than dwellings, for demonstrating compliance with the carbon emission requirements of regulation 17C of the Building Regulations and for calculating 'operational ratings' and 'asset ratings' in the production of Energy Performance Certificates (EPC's) in relation to the Energy Performance of Buildings Directive (EPBD).

NCM Standard Occupancy

The NCM Activity Database provides 'standard occupancy,' temperature set-points, outdoor air rates, and heat gain profiles based on standard occupancy for each type of space in the buildings, so that buildings with the same mix of activities differ only in terms of their geometry, construction, building services and weather location. This makes it possible for the Section 6 compliance checks and EPCs to compare buildings by their intrinsic potential performance, regardless of how they are used in practice. The NCM 'Standard Occupancy' of an office is $9m^2$ per person. [71]

Net Lettable Area

The Net Lettable Area (NLA) is the actual square-unit of a building that may be leased or rented to tenants, the area upon, which the lease or rental payments are computed. It usually excludes common areas, elevator shafts, stairways, and space devoted to cooling, heating, or other equipment.

Occupancy
The action or fact of occupying a place or building.

Occupancy Capacity
The calculation of the appropriate number of occupants in a building or each space for normal circumstances, calculated for building regulation purposes and the client's requirements. The occupancy capacity can be estimated by assigning a floor area per occupant [called the occupancy load factor (m^2/person)]. The occupancy capacity of a room or space can then be obtained by dividing the area in square meters by the relevant occupancy load factor. [69]

Occupant Density
A designation of square metres per person in the NCM BEM software SBEM used to determine the Occupant Load Average. 'Occupant density' can be designated either 'standard occupancy' or 'tailored occupancy.'

Occupancy Factors
Defined as variations in occupancy capacity, building hours of operation, IT and personal equipment, plug loads, server demand and the impact of these patterns of use on energy loads.

Occupancy Load Factor
A designation of area per person (m^2/person) based upon fire safety regulation. It is used to determine a maximum 'occupancy capacity' by dividing the occupancy load factor by the overall square footage of a habitable area. The recommended occupancy limit for an office building is based on an 'occupancy load factor' of 6.0.

Occupant Load Average
Average predicted internal heat or power load due to occupants, lights and equipment [Watts] used to calculate heating and cooling requirements in BEMs.

Occupancy Load Factor Benchmark
Tenant Energy Performance is evaluated through the proposed new method six Occupancy Load Factor benchmarks [Maximum, Minimum, Design, NCM, Tailored and Actual] either defined as demonstrated in the thesis by industry standards or by

stating what the tenants expected occupancy load factor would be for each of the proposed benchmarks.

Hours of Operation

Hours of operation are the hours during the day in which business is commonly conducted. Typical business hours vary widely by country. By observing common informal standards for business hours, workers may communicate with each other more easily and find a convenient divide between work life and home life.

Post Occupancy Evaluation

Post-Occupancy Evaluation (POE) is the process of obtaining feedback on a building's performance in use. The value of POE is being increasingly recognised, and it is becoming mandatory on many public projects.

Simplified Building Energy Model

The NCM calculations can be performed using approved simulation software (Approved Dynamic Simulation Models (DSMs)) or by using the Simplified Building Energy Model (SBEM), a 'simplified' compliance tool developed by BRE, which has a user interface called iSBEM.

Tailored Occupancy

The occupancy capacity used to predict energy performance for building regulation and certification purposes reflects the occupancy capacity in use.

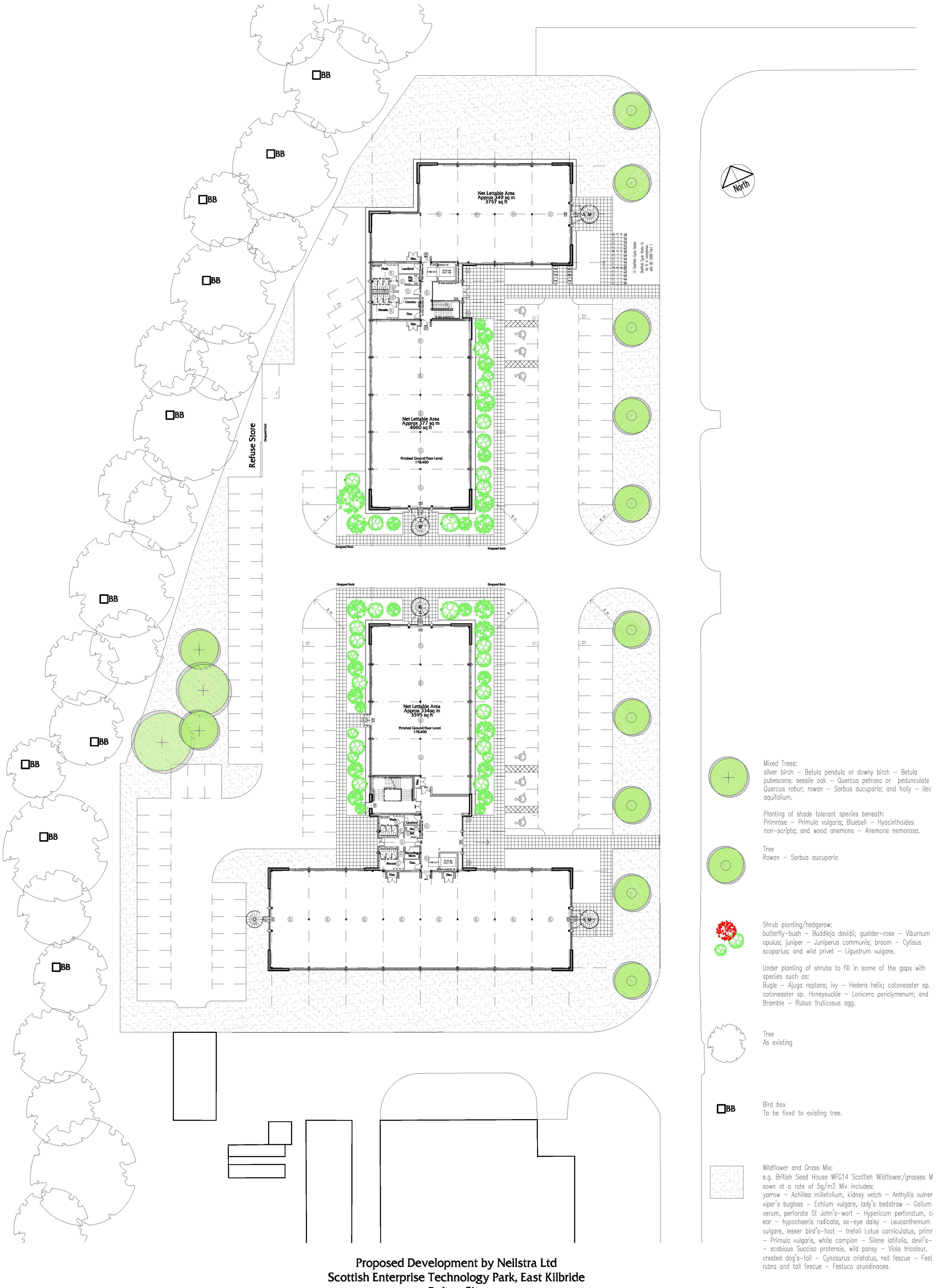
Usage Pattern

The energy use demonstrated by monitoring and recording energy consumption over a set period of time.

Variations in Patterns of Use

Referred to in the thesis as: Variations in a tenant's occupied floor space, the number of full-time employees, patterns of operation, hours of use and intensity of equipment use. All of which affects overall energy use and deviates from the 'standard occupancy' and 'Occupant Load Average' used in National Calculation Method [NCM] and approved Building Energy Models [BEM].

Appendix A: Architect's Drawings



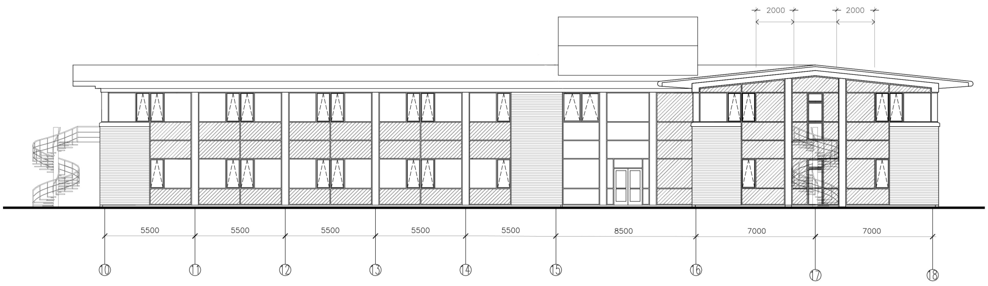
Proposed Development by Neilstra Ltd
Scottish Enterprise Technology Park, East Kilbride
Dalton Site

Site Layout As Proposed

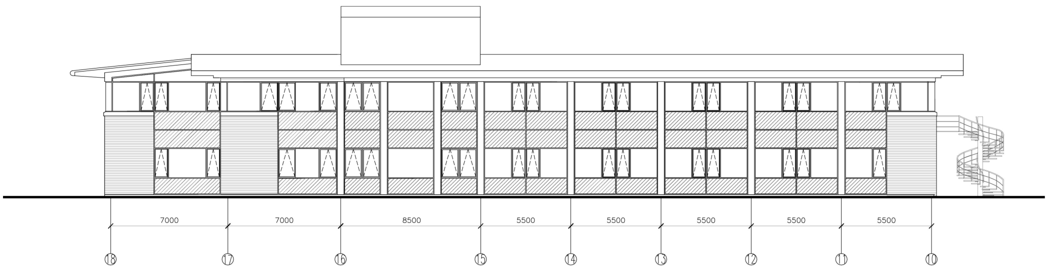
[redacted]

December 2006
Drawing No 4963/201A

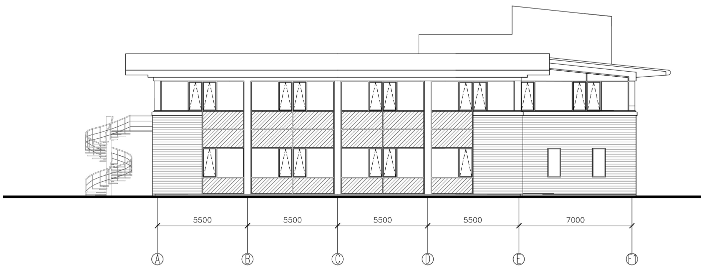
Scale A3 1:500



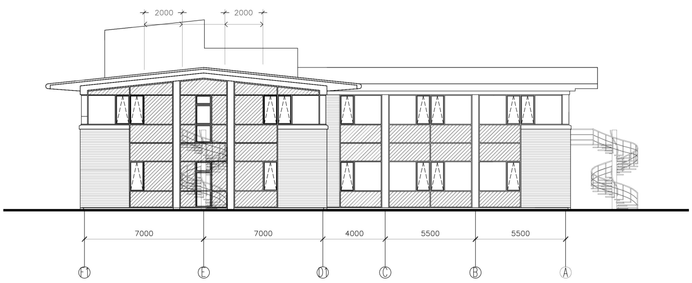
South East Elevation



North West Elevation

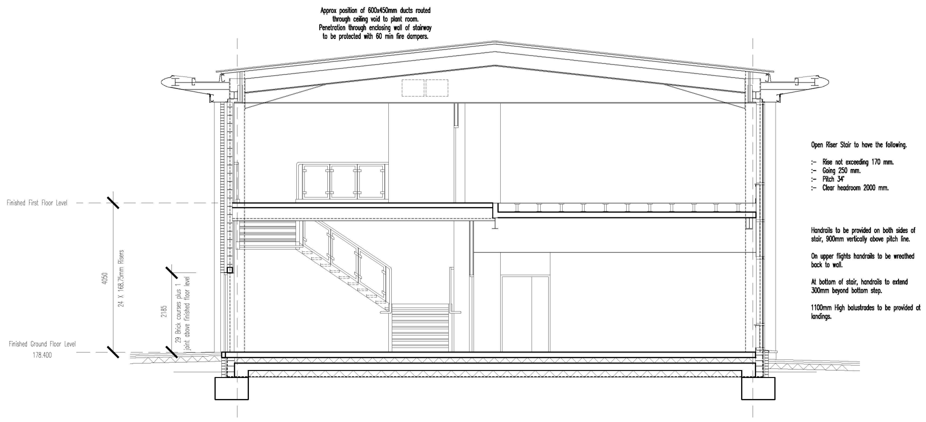


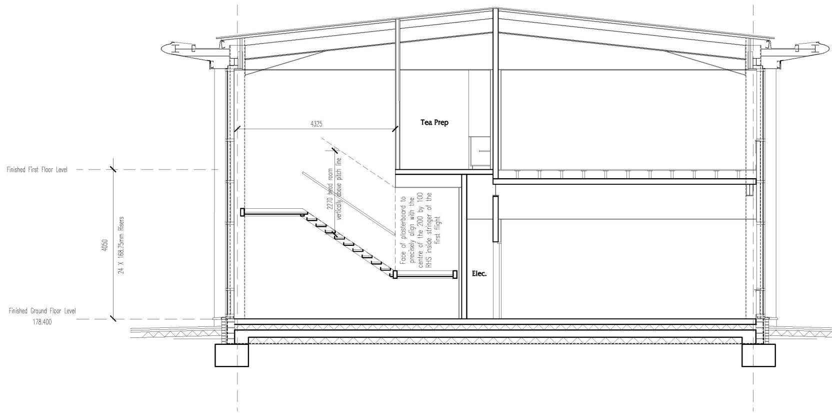
North East Elevation



South West Elevation

Proposed Development for Neilstra Ltd
Scottish Enterprise Technology Park, East Kilbride
Dalton Site





Cross Sections Through Stair
T-Building

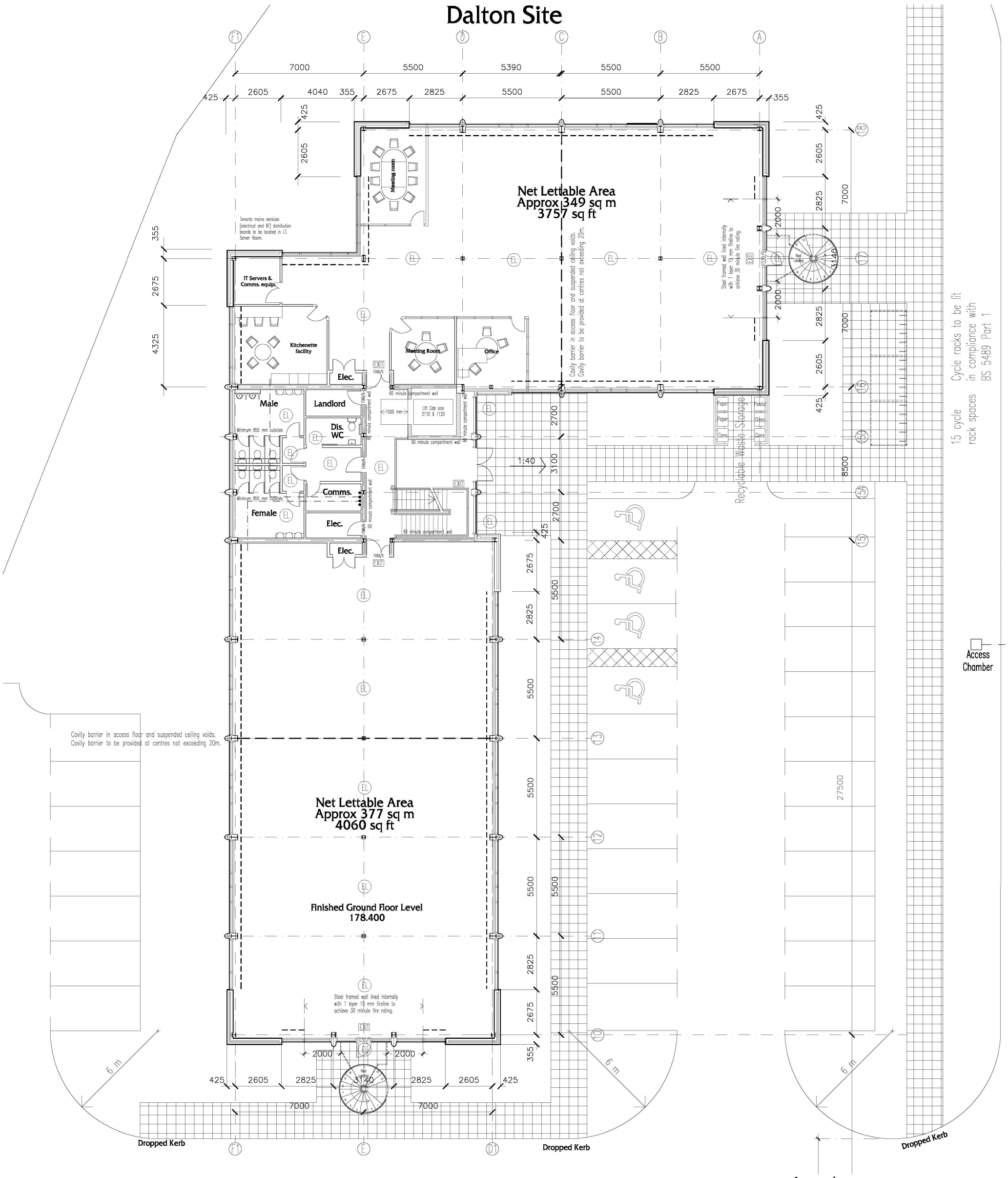
February 2008
Drawing No 4963/21C

Rev. A:	Stairs Revised.	20.02.08
Rev. B:	Walls Repositioned	21.02.08
Rev. C:	Dimensions Revised	27.02.08

[redacted]

Scale A1 1:50

Proposed Development by Neilstra Ltd
Scottish Enterprise Technology Park, East Kilbride
Dalton Site



March 2007
Drawing No 4963/9 T

Rev. A:	Stair revised. Gradient added at entrance.	30.07.07
Rev. B:	Stair revised. Furniture added.	31.07.07
Rev. C:	Internal layout revised. Steel columns added.	08.08.07
Rev. D:	Additional emergency lighting and legend added.	22.08.07
Rev. E:	External stairs revised.	24.08.07
Rev. F:	External stairs revised.	30.08.07
Rev. G:	Fibre optic cable altered	12.09.07
Rev. H:	Furniture layout revised.	25.09.07
Rev. I:	External stairs revised.	16.10.07
Rev. J:	I.T. Server Room added.	30.10.07
Rev. K:	Foul drainage added.	14.11.07
Rev. L:	Drainage to Dis. WC added.	07.12.07
Rev. M:	Note relating to gas fired boiler deleted. Recyclable Waste Storage added.	10.01.08
Rev. N:	Glare Control Blinds Added	04.02.08
Rev. P:	Central Core revised	18.03.08
Rev. Q:	BRE Offices added.	09.07.08
Rev. R:	BRE Offices revised layout.	31.07.08
Rev. S:	Cavity barriers shown.	19.11.08
Rev. T:	Glare control blinds revised.	27.02.09

[redacted]

Legend

EXIT — Illuminated Exit Sign

EL — Emergency Light

Hatching indicates 60 minute fire resistant compartment wall.

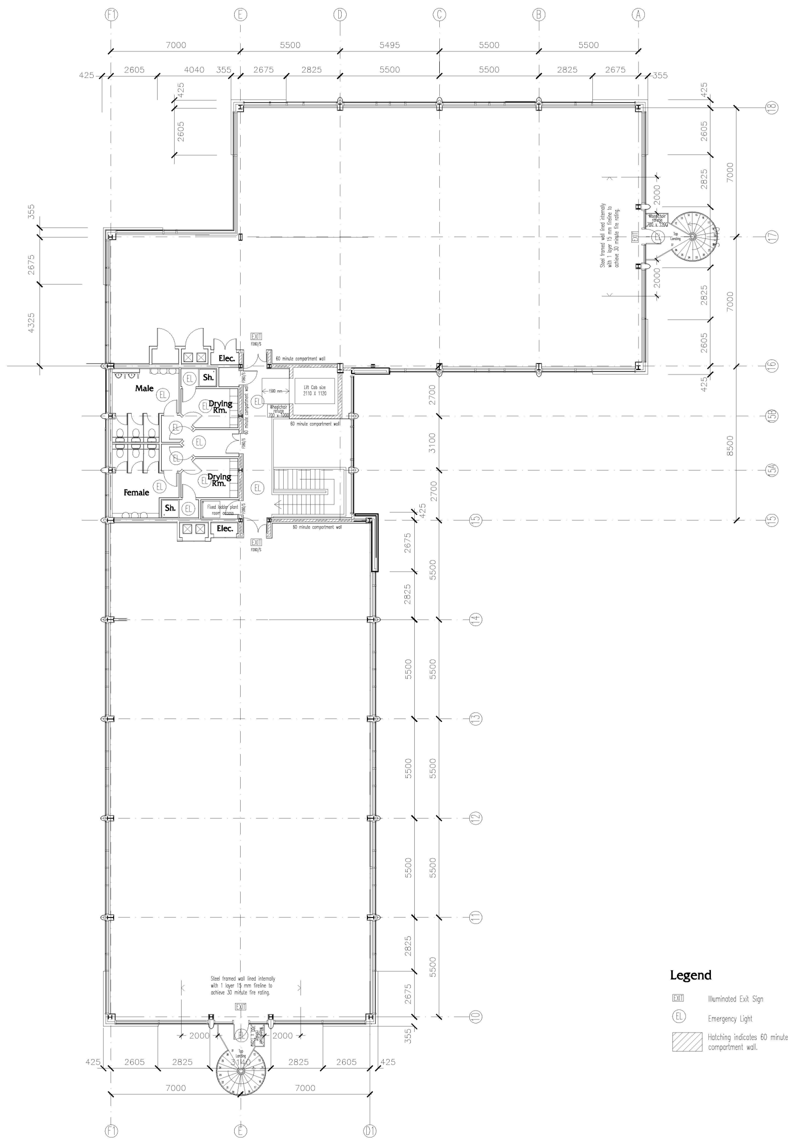
- - - - - - Glare Control Blinds to be installed by tenants on north, east, south and west elevations indicated by dotted lines

Please use figured dimensions only.

Do not scale from this drawing.

Scale A1 1:100

Proposed Development by Neilstra Ltd
Scottish Enterprise Technology Park, East Kilbride
Dalton Site



Legend

Illuminated Exit Sign

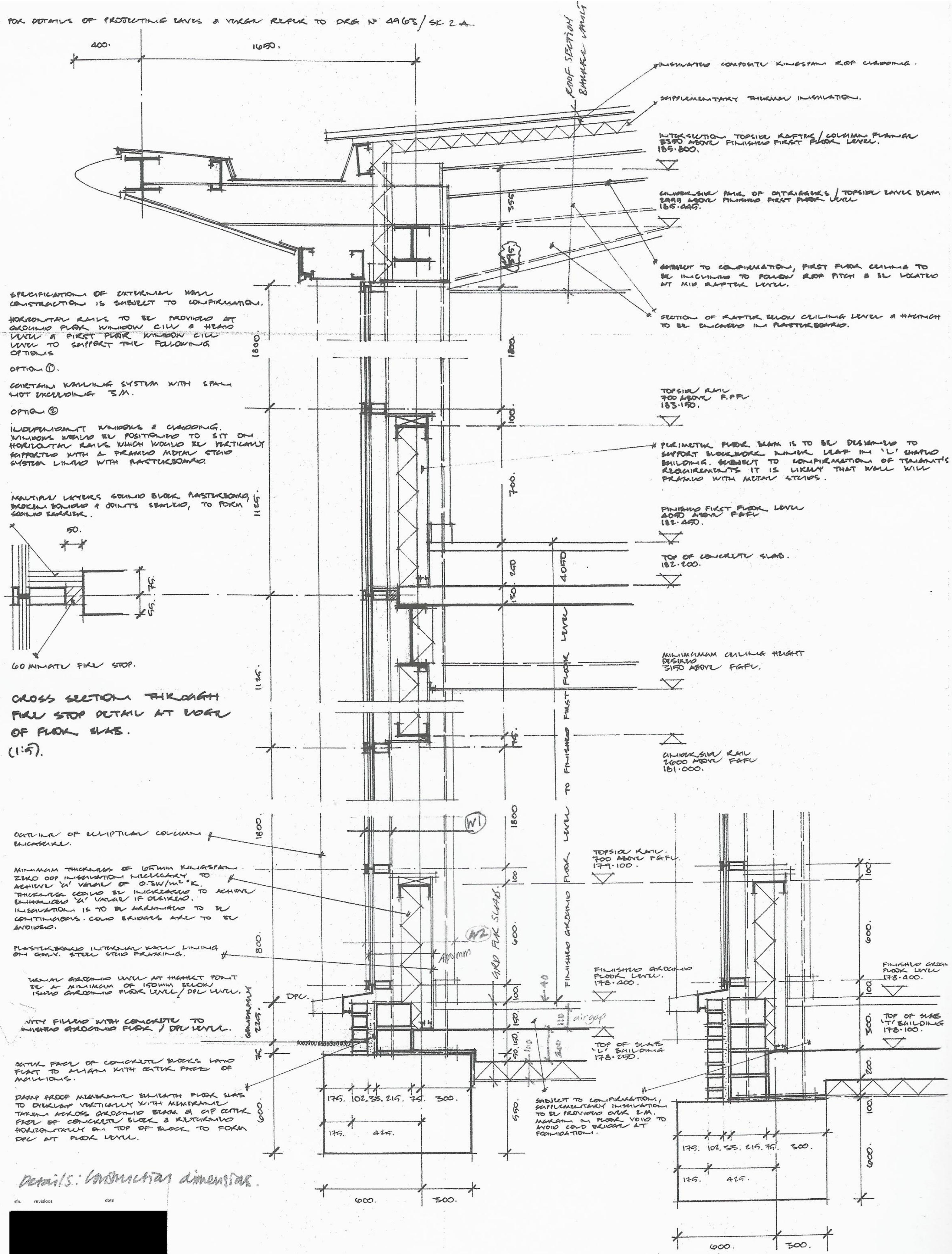
Emergency Light

Hatching indicates 60 minute fire resistant compartment wall.

[redacted]

April 2010
Drawing No 4963-10-003

Scale A1 1:100



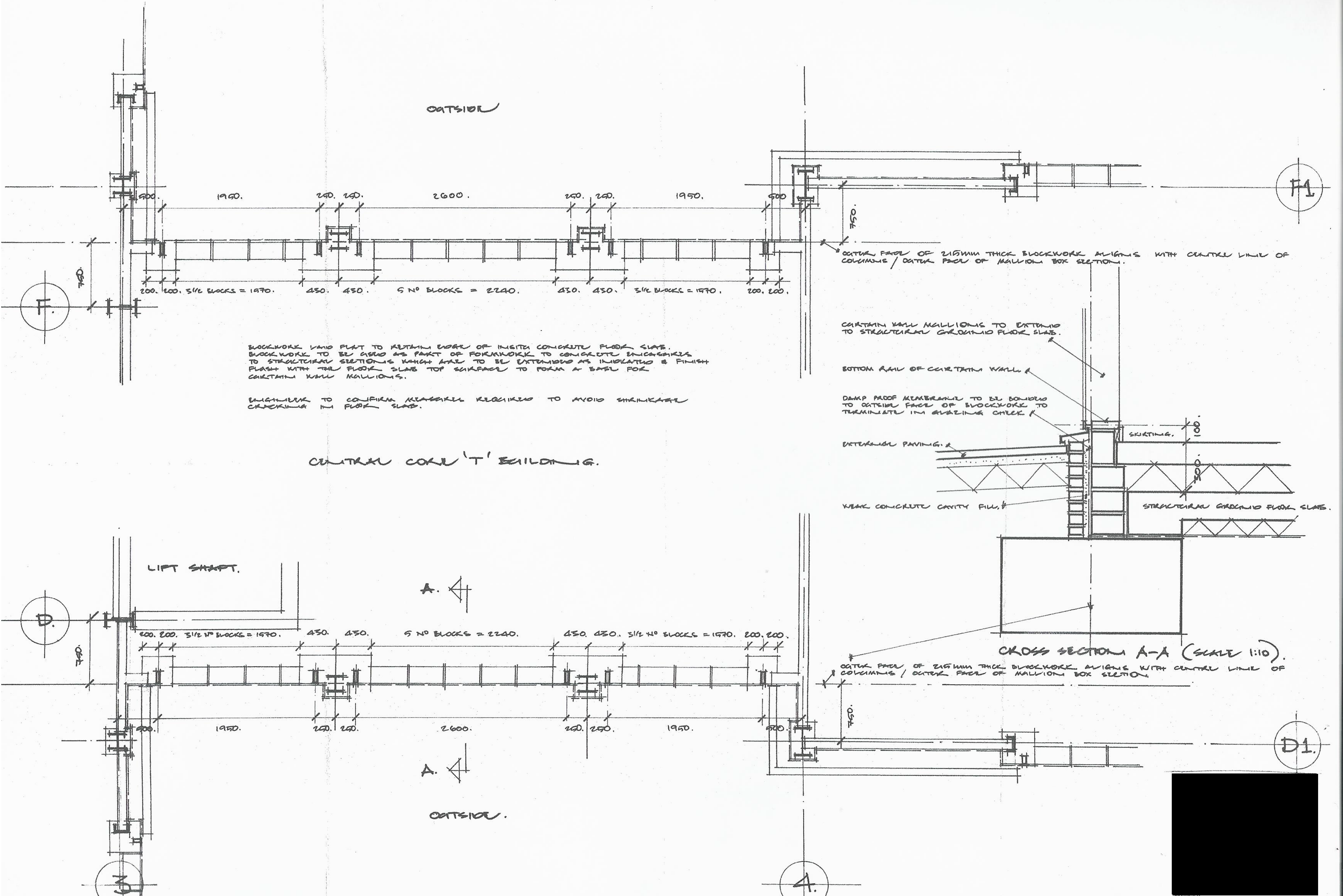
stx. revisions date

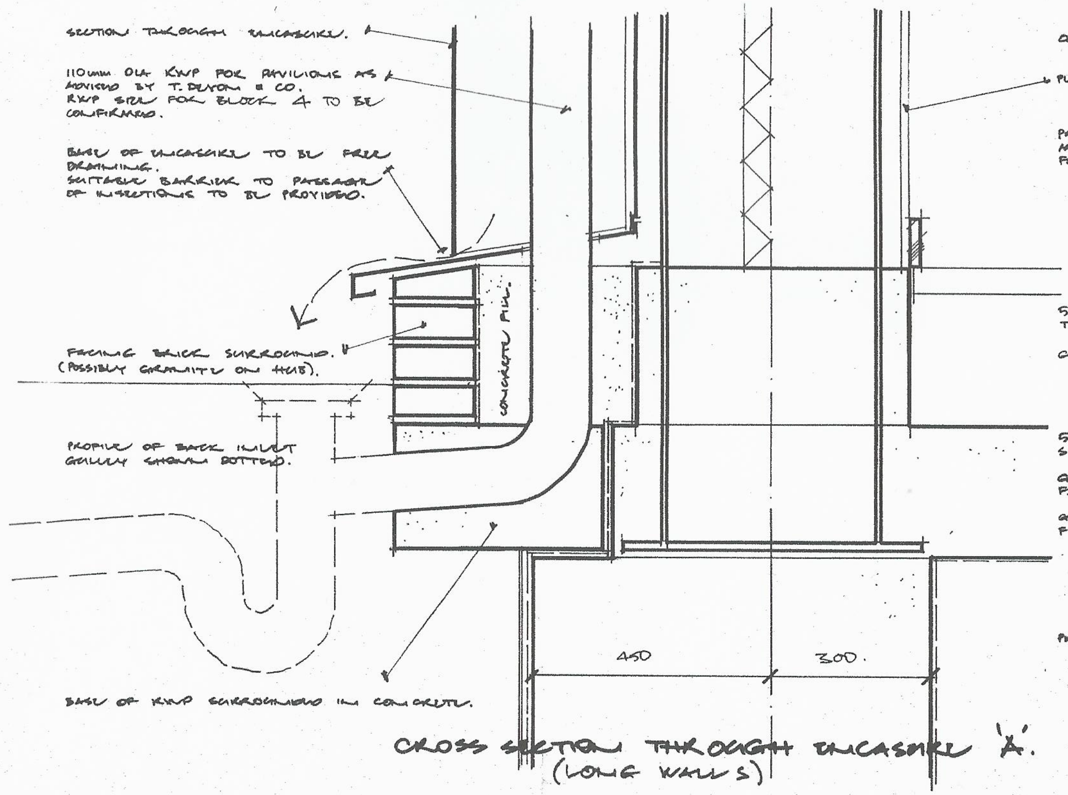
[redacted]

CROSS SECTION THROUGH EXTERNAL WALL 'L' SHAPED BUILDING (1:10).

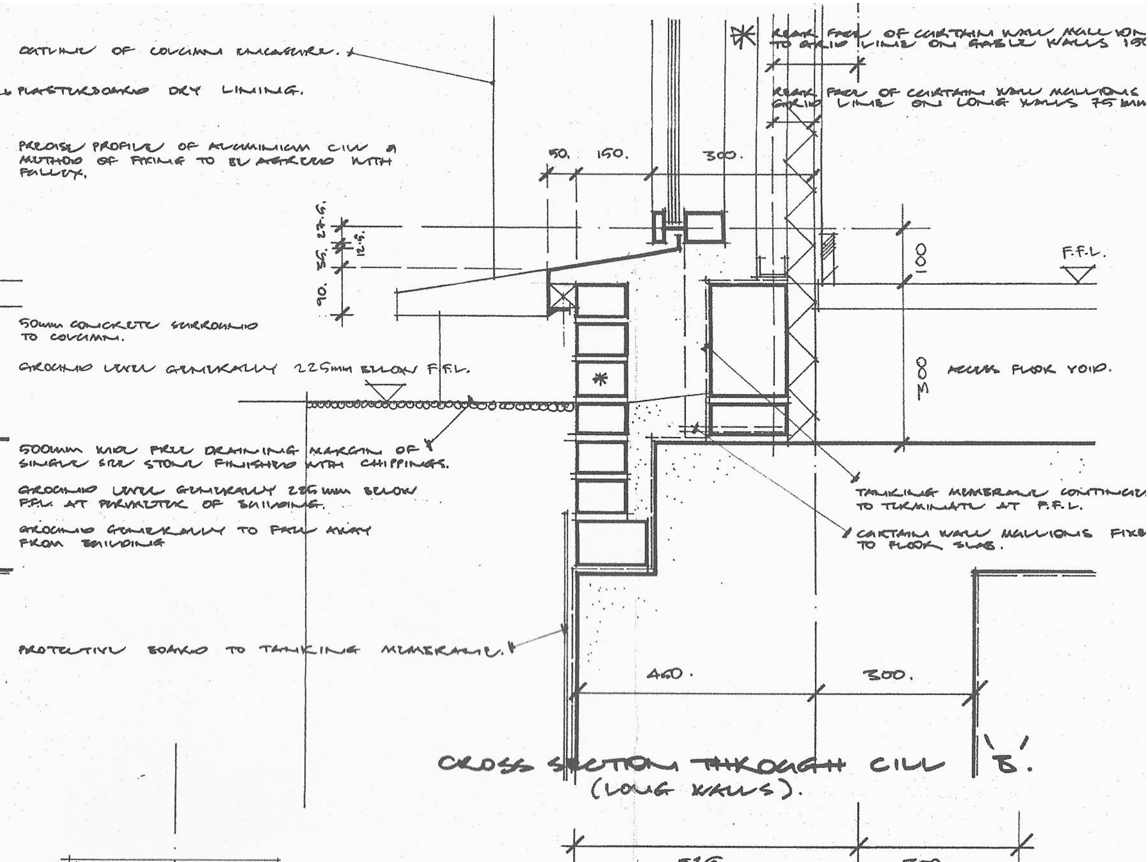
CROSS SECTION THROUGH BASE OF EXTERNAL WALL 'T' SHAPED BUILDING (1:10).

REV A. DIMENSION 395 REVISED 7.9.07.
REV B. ACCESS FLOOR PROVIDED IN 'L' BUILDING 5.11.07.
REV C GROUND LEVEL & CAVITY FILL REVISED 8.11.07.


OUTSIDE
1950.
250. 250.
2600.
250. 250.
1950.
500
750.
200. 200. 5½ BLOCKS = 1970.
430. 430.
5 Nº BLOCKS = 2240.
430. 430.
5½ BLOCKS = 1970.
200. 200.
F.
F1
OUTER FACE OF 215MM THICK BLOCKWORK ALIGNS WITH CENTRE LINE OF COLUMNS / OUTER FACE OF MULLION BOX SECTION.
BLOCKWORK LAID FLAT TO RETAIN EDGE OF INSITU CONCRETE FLOOR SLAB. BLOCKWORK TO BE USED AS PART OF FORMWORK TO CONCRETE ENGINEERS TO STRUCTURAL SECTIONS WHICH ARE TO BE EXTENDED AS INDICATED & FINISH FLUSH WITH THE FLOOR SLAB TOP SURFACE TO FORM A BASE FOR CURTAIN WALL MULLIONS.
ENGINEER TO CONFIRM MEASURES REQUIRED TO AVOID SHRINKAGE CRACKING IN FLOOR SLAB.
CENTRAL CORE 'T' BUILDING.
CURTAIN WALL MULLIONS TO EXTEND TO STRUCTURAL GROUND FLOOR SLAB.
BOTTOM RAIL OF CURTAIN WALL
DAMP PROOF MEMBRANE TO BE BONDED TO OUTSIDE FACE OF BLOCKWORK TO TERMINATE IN GLAZING CHECK
SKIRTING.
100
EXTERNAL PAVING.
300
WEAK CONCRETE CAVITY FILL
STRUCTURAL GROUND FLOOR SLAB.
LIFT SHAFT.
A.
D.
200. 200. 5½ Nº BLOCKS = 1970.
430. 430.
5 Nº BLOCKS = 2240.
430. 430. 5½ Nº BLOCKS = 1970.
200. 200.
CROSS SECTION A-A (SCALE 1:10).
OUTER FACE OF 215MM THICK BLOCKWORK ALIGNS WITH CENTRE LINE OF COLUMNS / OUTER FACE OF MULLION BOX SECTION.
1950.
250. 250.
2600.
250. 250.
1950.
500
750.
D1.
A.
OUTSIDE.
3.
4.
[redacted]

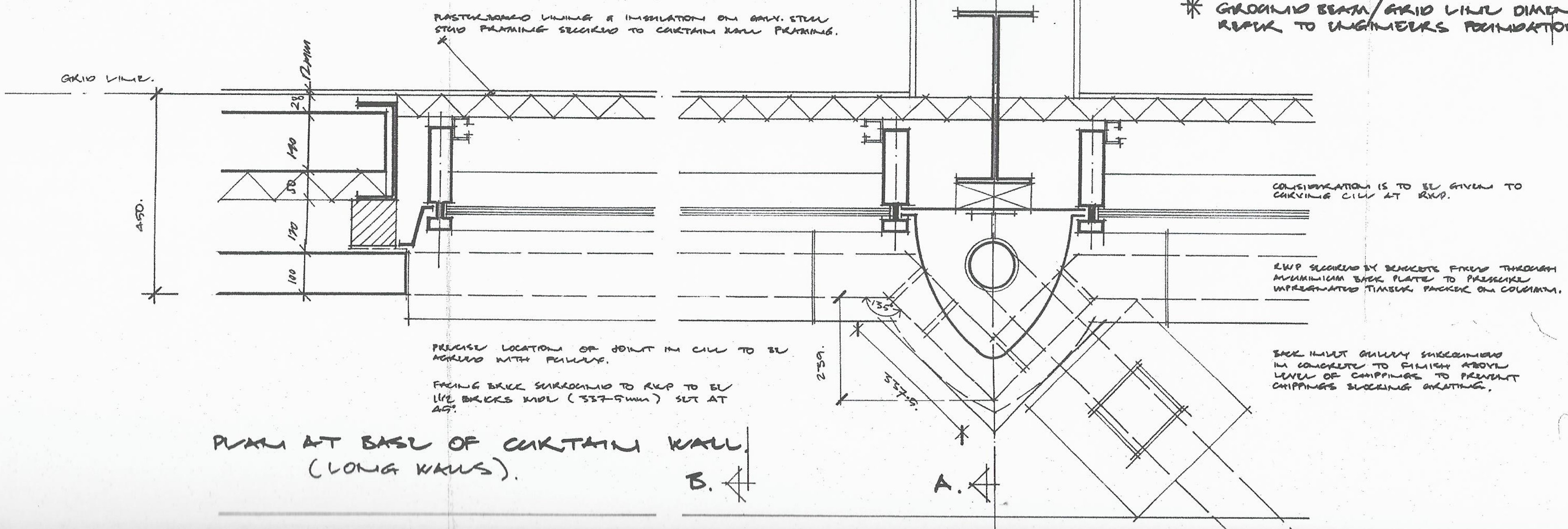


CROSS SECTION THROUGH ENCASEMENT 'A'. (LONG WALLS)



CROSS SECTION THROUGH CILL 'B'. (LONG WALLS).

* GROUND BEAM/GRID LINE DIMENSIONS GABLE WALLS REFER TO ENGINEERS FOUNDATION LAYOUT 06073-02



PLAN AT BASE OF CURTAIN WALL (LONG WALLS).

REV. A. REFERENCE TO GRANITE PLINTH AT BASE OF MULLION PANELS DELETED. 24.10.06

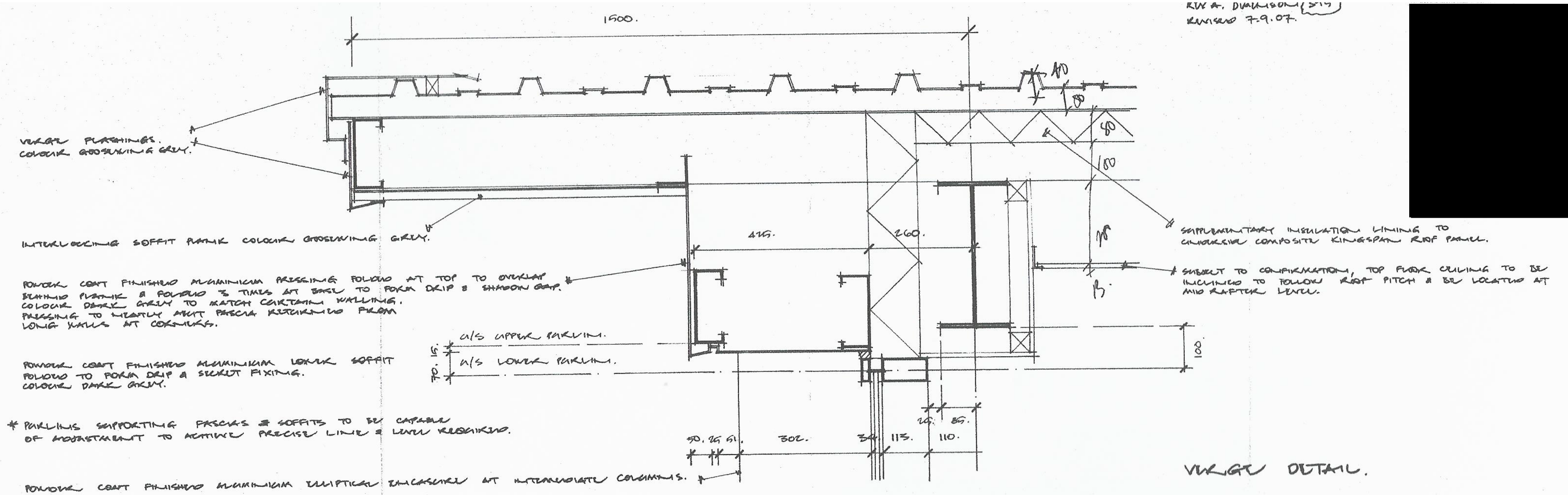
sfx. revisions date

PROJECT

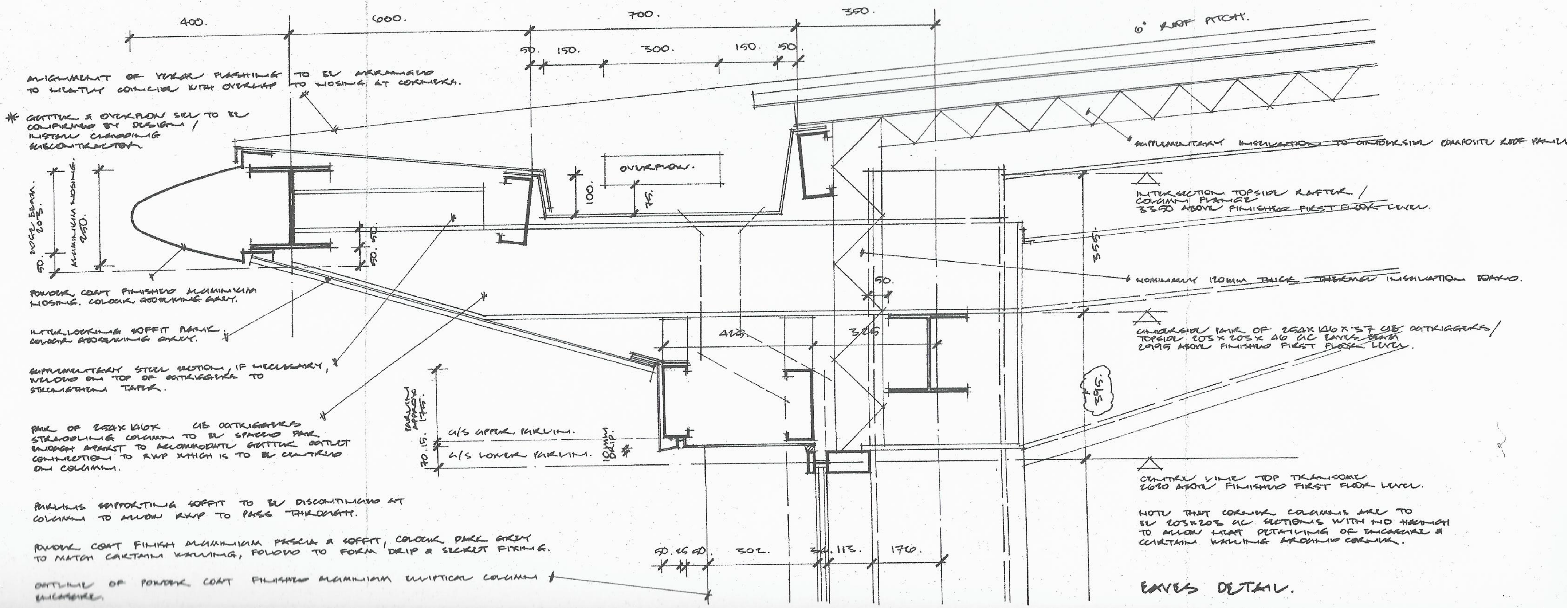
[redacted]

REV A. DIMENSION (3-4)
REVISED 7.9.07.

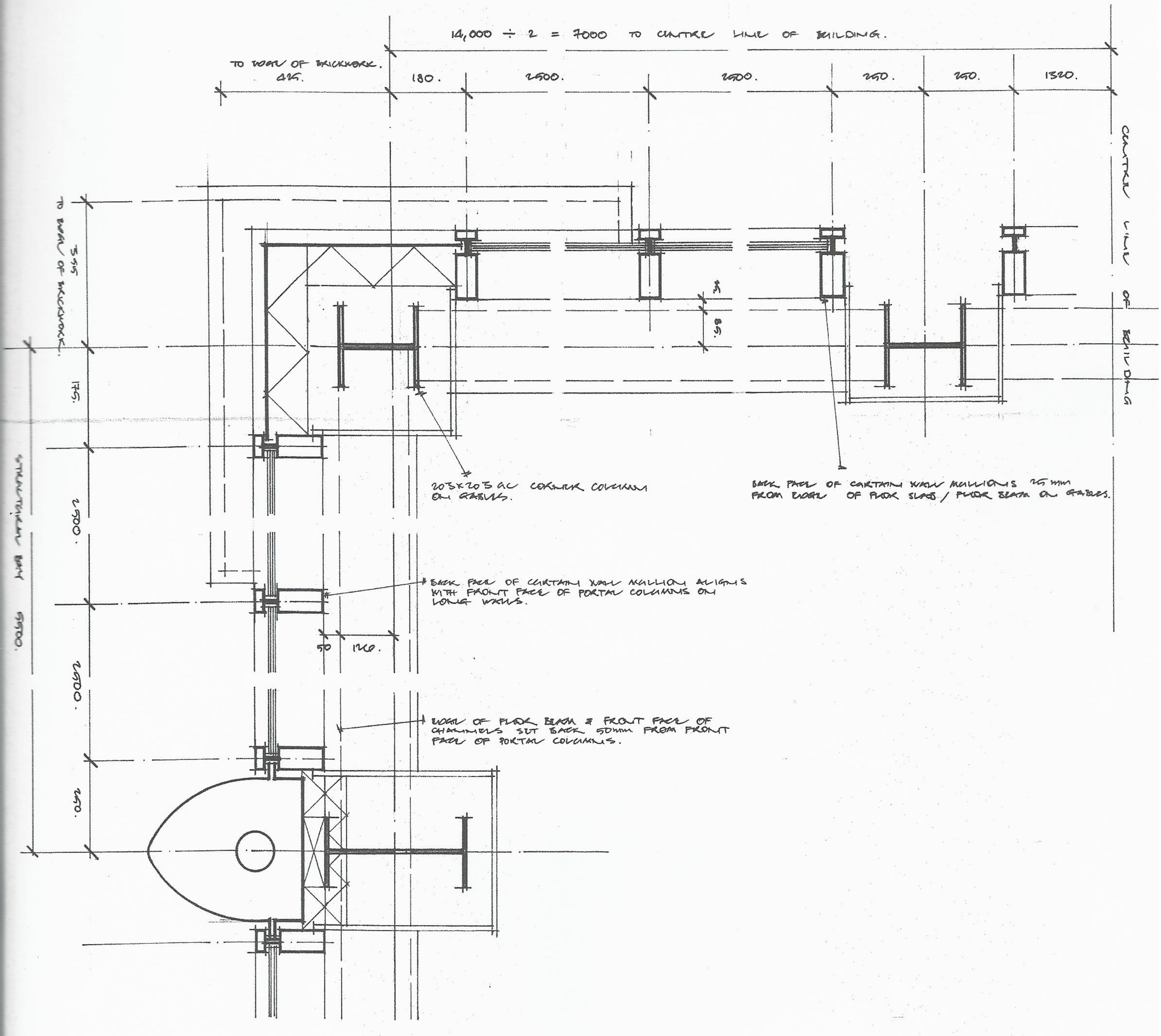
[redacted]



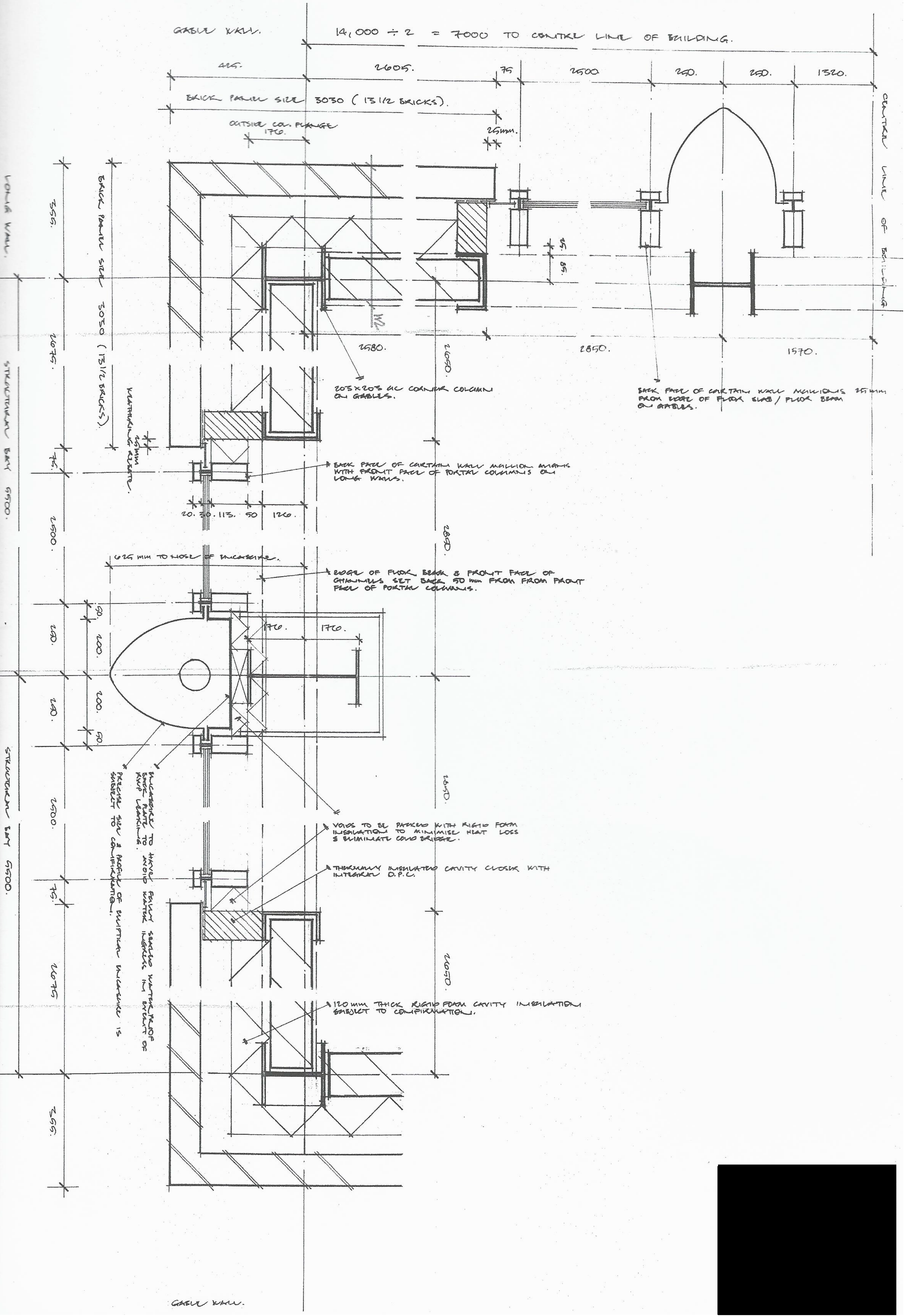
VERGE DETAIL.



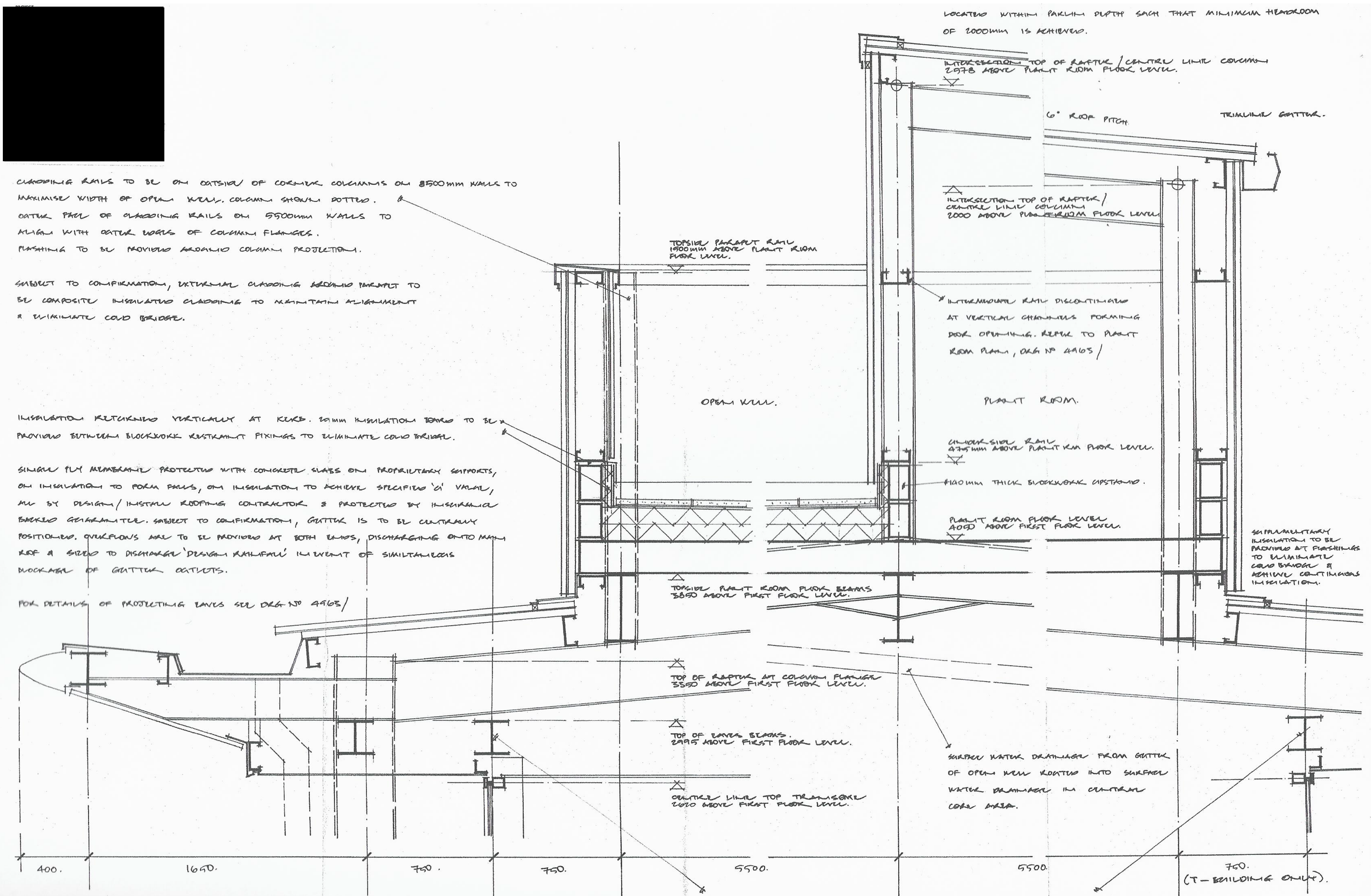
EAVES DETAIL.


14,000 ÷ 2 = 7000 TO CENTRE LINE OF BUILDING.
TO FACE OF BRICKWORK.
215.
180.
2500.
2500.
250.
250.
1320.
CENTRE LINE OF BUILDING
355
TO FACE OF BRICKWORK.
175.
2500.
2500.
250.
5500.
STRUCTURAL BAY
34
85.
50
120.
203x203 UC CORNER COLUMN ON GABLES.
BACK FACE OF CURTAIN WALL MULLIONS 25mm FROM EDGE OF FLOOR SLAB / FLOOR BEAM ON GABLES.
BACK FACE OF CURTAIN WALL MULLION ALIGNS WITH FRONT FACE OF PORTAL COLUMNS ON LONG WALLS.
EDGE OF FLOOR BEAM & FRONT FACE OF CHANNELS SET BACK 50mm FROM FRONT FACE OF PORTAL COLUMNS.

[redacted]

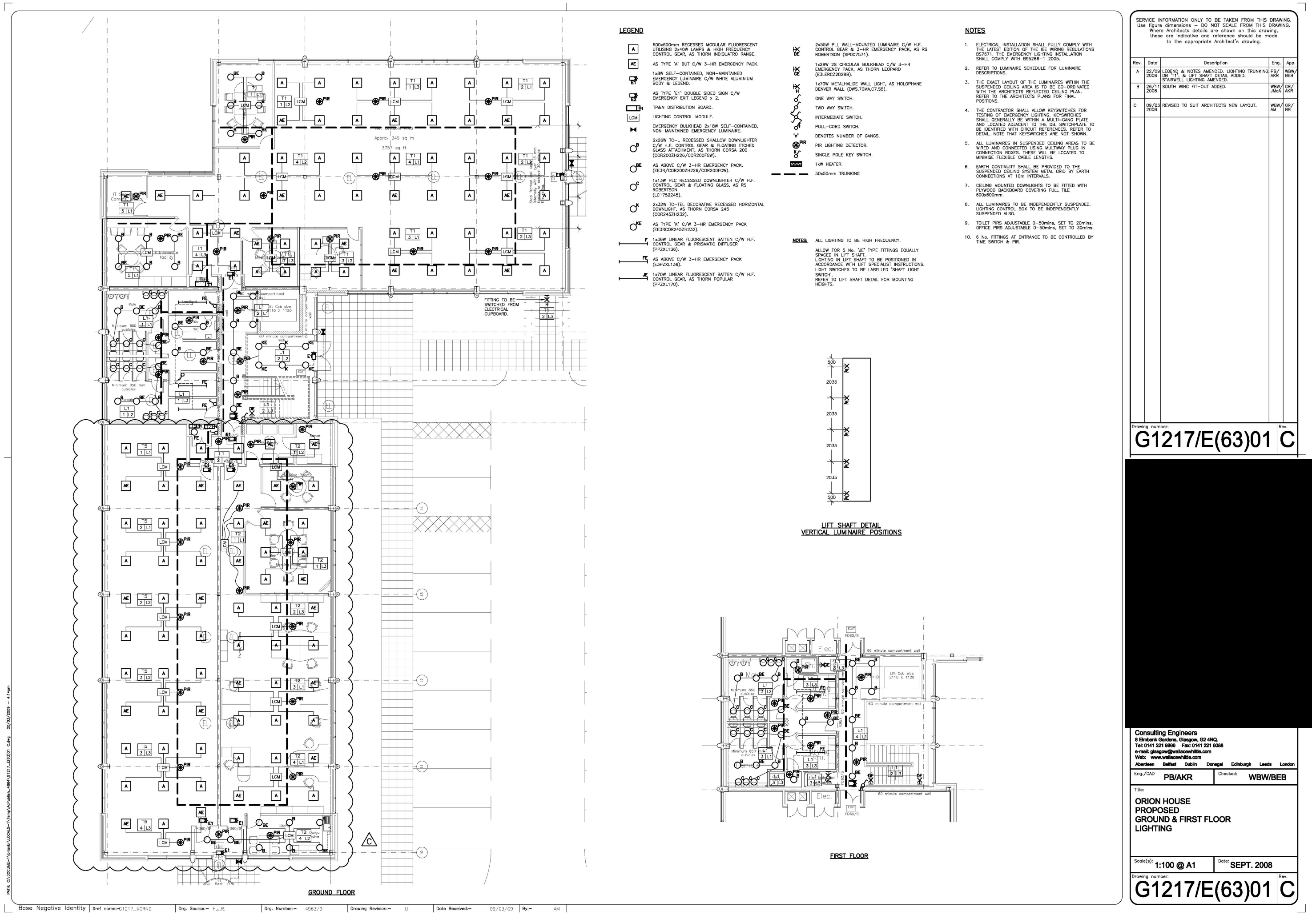

GABLE WALL.
14,000 ÷ 2 = 7000 TO CENTRE LINE OF BUILDING.
445.
2605.
75
2500
250.
250.
1320.
BRICK PANEL SIZE 3030 (13 1/2 BRICKS).
OUTSIDE COL. FLANGE
1760.
25mm.
CENTRE LINE OF BUILDING.
LONG WALL.
555.
BRICK PANEL SIZE 3030 (13 1/2 BRICKS).
2075.
75.
2500.
250.
250.
2500.
75.
2075.
555.
STRUCTURAL BAY 5500.
STRUCTURAL BAY 5500.
2580.
2650.
2850.
1570.
203x203 UC CORNER COLUMN ON GABLES.
BACK FACE OF CURTAIN WALL MULLIONS 25mm FROM EDGE OF FLOOR SLAB / FLOOR BEAM ON GABLES.
BACK FACE OF CURTAIN WALL MULLION ALIGNS WITH FRONT FACE OF PORTAL COLUMNS ON LONG WALLS.
20. 30. 113. 50 126.
2850.
625 mm TO NOSE OF BRICKWORK.
EDGE OF FLOOR BEAM & FRONT FACE OF CHANNELS SET BACK 50 mm FROM FROM FRONT FACE OF PORTAL COLUMNS.
50.
200.
200.
50.
1760.
1760.
BRICKWORK TO HAVE FULLY SEALED WATERPROOF BASE PLATE TO AVOID WATER INGRESS IN EVENT OF ROOF LEAKING.
PRECISE SIZE & PROFILE OF ELLIPTICAL BRICKWORK IS SUBJECT TO CONFIRMATION.
2850.
VOIDS TO BE PACKED WITH RIGID FOAM INSULATION TO MINIMISE HEAT LOSS & ELIMINATE COLD BRIDGE.
THERMALLY INSULATED CAVITY CLOSER WITH INTEGRAL D.P.C.
2650.
120 mm THICK RIGID FOAM CAVITY INSULATION SUBJECT TO CONFIRMATION.
GABLE WALL.
[redacted]

[redacted]

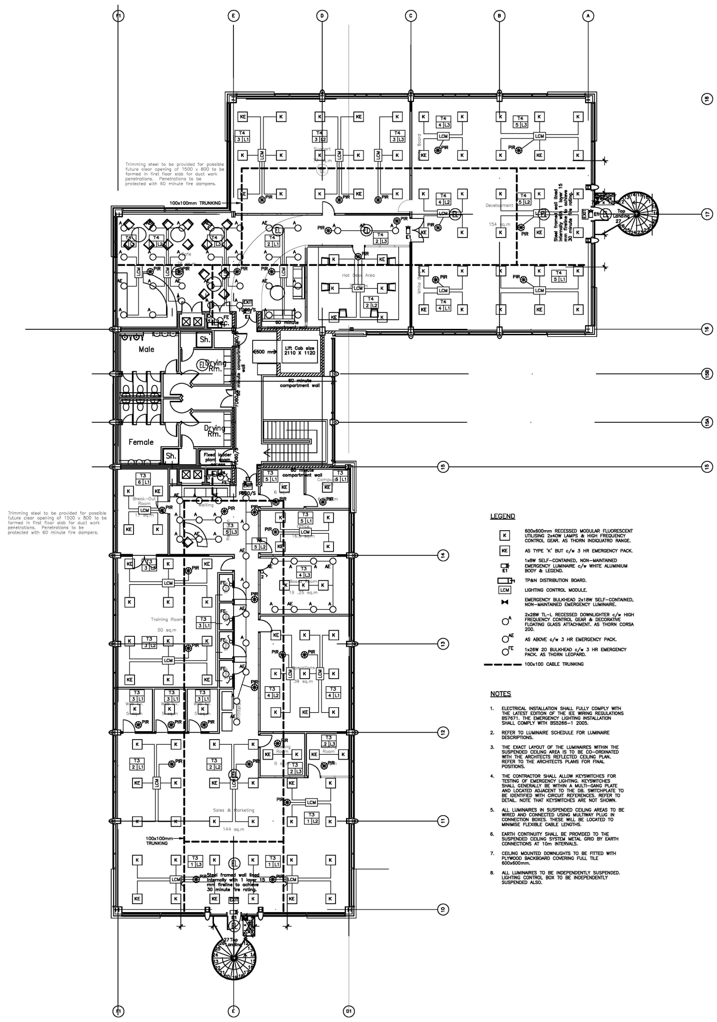


CROSS SECTION THROUGH PLANT ROOM & OPEN WELL

Appendix B: Engineer's Drawings



LEGEND
600x600mm RECESSED MODULAR FLUORESCENT UTILISING 2x40W LAMPS & HIGH FREQUENCY CONTROL GEAR, AS THORN INDIQUATRO RANGE.
AS TYPE 'A' BUT C/W 3-HR EMERGENCY PACK.
1x8W SELF-CONTAINED, NON-MAINTAINED EMERGENCY LUMINAIRE C/W WHITE ALUMINIUM BODY & LEGEND.
AS TYPE 'E1' DOUBLE SIDED SIGN C/W EMERGENCY EXIT LEGEND x 2.
TP&N DISTRIBUTION BOARD.
LIGHTING CONTROL MODULE.
EMERGENCY BULKHEAD 2x18W SELF-CONTAINED, NON-MAINTAINED EMERGENCY LUMINAIRE.
2x26W TC-L RECESSED SHALLOW DOWNLIGHTER C/W H.F. CONTROL GEAR & FLOATING ETCHED GLASS ATTACHMENT, AS THORN CORSA 200 (COR200ZH226/COR200FGW).
AS ABOVE C/W 3-HR EMERGENCY PACK. (EE3R/COR200ZH226/COR200FGW).
1x13W PLC RECESSED DOWNLIGHTER C/W H.F. CONTROL GEAR & FLOATING GLASS, AS RS ROBERTSON (LC1752245).
2x32W TC-TEL DECORATIVE RECESSED HORIZONTAL DOWNLIGHT, AS THORN CORSA 245 (COR245ZH232).
AS TYPE 'K' C/W 3-HR EMERGENCY PACK (EE3RCOR245ZH232).
1x36W LINEAR FLUORESCENT BATTEN C/W H.F. CONTROL GEAR & PRISMATIC DIFFUSER (PPZXL136).
AS ABOVE C/W 3-HR EMERGENCY PACK (E3PZXL136).
1x70W LINEAR FLUORESCENT BATTEN C/W H.F. CONTROL GEAR, AS THORN POPULAR (PPZXL170).
2x55W PLL WALL-MOUNTED LUMINAIRE C/W H.F. CONTROL GEAR & 3-HR EMERGENCY PACK, AS RS ROBERTSON (SP007571).
1x28W 2S CIRCULAR BULKHEAD C/W 3-HR EMERGENCY PACK, AS THORN LEOPARD (E3LERCZ2D28B).
1x70W METALHALIDE WALL LIGHT, AS HOLOPHANE DENVER WALL (DWS,70MA,C7,S5).
ONE WAY SWITCH.
TWO WAY SWITCH.
INTERMEDIATE SWITCH.
PULL-CORD SWITCH.
'n' DENOTES NUMBER OF GANGS.
PIR LIGHTING DETECTOR.
SINGLE POLE KEY SWITCH.
1kW HEATER.
50x50mm TRUNKING
NOTES: ALL LIGHTING TO BE HIGH FREQUENCY.
ALLOW FOR 5 No. 'JE' TYPE FITTINGS EQUALLY SPACED IN LIFT SHAFT.
LIGHTING IN LIFT SHAFT TO BE POSITIONED IN ACCORDANCE WITH LIFT SPECIALIST INSTRUCTIONS.
LIGHT SWITCHES TO BE LABELLED 'SHAFT LIGHT SWITCH'.
REFER TO LIFT SHAFT DETAIL FOR MOUNTING HEIGHTS.
NOTES
1. ELECTRICAL INSTALLATION SHALL FULLY COMPLY WITH THE LATEST EDITION OF THE IEE WIRING REGULATIONS BS7671. THE EMERGENCY LIGHTING INSTALLATION SHALL COMPLY WITH BS5266-1 2005.
2. REFER TO LUMINAIRE SCHEDULE FOR LUMINAIRE DESCRIPTIONS.
3. THE EXACT LAYOUT OF THE LUMINAIRES WITHIN THE SUSPENDED CEILING AREA IS TO BE CO-ORDINATED WITH THE ARCHITECTS REFLECTED CEILING PLAN. REFER TO THE ARCHITECTS PLANS FOR FINAL POSITIONS.
4. THE CONTRACTOR SHALL ALLOW KEYSWITCHES FOR TESTING OF EMERGENCY LIGHTING. KEYSWITCHES SHALL GENERALLY BE WITHIN A MULTI-GANG PLATE AND LOCATED ADJACENT TO THE DB. SWITCHPLATE TO BE IDENTIFIED WITH CIRCUIT REFERENCES. REFER TO DETAIL. NOTE THAT KEYSWITCHES ARE NOT SHOWN.
5. ALL LUMINAIRES IN SUSPENDED CEILING AREAS TO BE WIRED AND CONNECTED USING MULTIWAY PLUG IN CONNECTION BOXES. THESE WILL BE LOCATED TO MINIMISE FLEXIBLE CABLE LENGTHS.
6. EARTH CONTINUITY SHALL BE PROVIDED TO THE SUSPENDED CEILING SYSTEM METAL GRID BY EARTH CONNECTIONS AT 10m INTERVALS.
7. CEILING MOUNTED DOWNLIGHTS TO BE FITTED WITH PLYWOOD BACKBOARD COVERING FULL TILE 600x600mm.
8. ALL LUMINAIRES TO BE INDEPENDENTLY SUSPENDED. LIGHTING CONTROL BOX TO BE INDEPENDENTLY SUSPENDED ALSO.
9. TOILET PIRS ADJUSTABLE 0-50mins, SET TO 20mins. OFFICE PIRS ADJUSTABLE 0-50mins, SET TO 30mins.
10. 6 No. FITTINGS AT ENTRANCE TO BE CONTROLLED BY TIME SWITCH & PIR.
FITTING TO BE SWITCHED FROM ELECTRICAL CUPBOARD.
LIFT SHAFT DETAIL
VERTICAL LUMINAIRE POSITIONS
GROUND FLOOR
FIRST FLOOR
SERVICE INFORMATION ONLY TO BE TAKEN FROM THIS DRAWING. Use figure dimensions – DO NOT SCALE FROM THIS DRAWING. Where Architects details are shown on this drawing, these are indicative and reference should be made to the appropriate Architect's drawing.
Rev. | Date | Description | Eng. | App.
A | 22/09 2008 | LEGEND & NOTES AMENDED. LIGHTING TRUNKING, DB 'T1', & LIFT SHAFT DETAIL ADDED. STAIRWELL LIGHTING AMENDED. | PB/AKR | WBW/BEB
B | 26/11 2008 | SOUTH WING FIT-OUT ADDED. | WBW/JMcA | GR/AKR
C | 09/03 2008 | REVISED TO SUIT ARCHITECTS NEW LAYOUT. | WBW/AM | GR/BB
Drawing number: G1217/E(63)01 Rev. C
[redacted]
Consulting Engineers
8 Elmbank Gardens, Glasgow, G2 4NQ.
Tel: 0141 221 9866 Fax: 0141 221 6088
e-mail: glasgow@wallacewhittle.com
Web: www.wallacewhittle.com
Aberdeen Belfast Dublin Donegal Edinburgh Leeds London
Eng./CAD PB/AKR
Checked: WBW/BEB
Title: ORION HOUSE PROPOSED GROUND & FIRST FLOOR LIGHTING
Scale(s): 1:100 @ A1
Date: SEPT. 2008
Drawing number: G1217/E(63)01 Rev. C



LEGEND

K	600x600mm RECESSED MODULAR FLUORESCENT UTILISING 2x40W LAMPS & HIGH FREQUENCY CONTROL GEAR. AS THORN INDIQUATRO RANGE.
KE	AS TYPE 'K' BUT c/w 3 HR EMERGENCY PACK.
E1	1x8W SELF-CONTAINED, NON-MAINTAINED EMERGENCY LUMINAIRE c/w WHITE ALUMINIUM BODY & LEGEND.
	TP&N DISTRIBUTION BOARD.
LCM	LIGHTING CONTROL MODULE.
	EMERGENCY BULKHEAD 2x18W SELF-CONTAINED, NON-MAINTAINED EMERGENCY LUMINAIRE.
A	2x28W TL-L RECESSED DOWNLIGHTER c/w HIGH FREQUENCY CONTROL GEAR & DECORATIVE FLOATING GLASS ATTACHMENT. AS THORN CORSA 200.
AE	AS ABOVE c/w 3 HR EMERGENCY PACK.
FE	1x26W 20 BULKHEAD c/w 3 HR EMERGENCY PACK. AS THORN LEOPARD.
— — —	100x100 CABLE TRUNKING

NOTES

1. ELECTRICAL INSTALLATION SHALL FULLY COMPLY WITH THE LATEST EDITION OF THE IEE WIRING REGULATIONS BS7671. THE EMERGENCY LIGHTING INSTALLATION SHALL COMPLY WITH BS5266-1 2005.
2. REFER TO LUMINAIRE SCHEDULE FOR LUMINAIRE DESCRIPTIONS.
3. THE EXACT LAYOUT OF THE LUMINAIRES WITHIN THE SUSPENDED CEILING AREA IS TO BE CO-ORDINATED WITH THE ARCHITECTS REFLECTED CEILING PLAN. REFER TO THE ARCHITECTS PLANS FOR FINAL POSITIONS.
4. THE CONTRACTOR SHALL ALLOW KEYSWITCHES FOR TESTING OF EMERGENCY LIGHTING. KEYSWITCHES SHALL GENERALLY BE WITHIN A MULTI-GANG PLATE AND LOCATED ADJACENT TO THE DB. SWITCHPLATE TO BE IDENTIFIED WITH CIRCUIT REFERENCES. REFER TO DETAIL. NOTE THAT KEYSWITCHES ARE NOT SHOWN.
5. ALL LUMINAIRES IN SUSPENDED CEILING AREAS TO BE WIRED AND CONNECTED USING MULTIWAY PLUG IN CONNECTION BOXES. THESE WILL BE LOCATED TO MINIMISE FLEXIBLE CABLE LENGTHS.
6. EARTH CONTINUITY SHALL BE PROVIDED TO THE SUSPENDED CEILING SYSTEM METAL GRID BY EARTH CONNECTIONS AT 10m INTERVALS.
7. CEILING MOUNTED DOWNLIGHTS TO BE FITTED WITH PLYWOOD BACKBOARD COVERING FULL TILE 600x600mm.
8. ALL LUMINAIRES TO BE INDEPENDENTLY SUSPENDED. LIGHTING CONTROL BOX TO BE INDEPENDENTLY SUSPENDED ALSO.

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SERVICE INFORMATION ONLY TO BE TAKEN FROM THIS DRAWING.

Use figure dimensions DO NOT SCALE FROM THIS DRAWING.

Where Architects details are shown on this drawing, these are indicative and reference should be made to the appropriate Architect's drawing.

Rev.	Date	Description	Eng.	App.

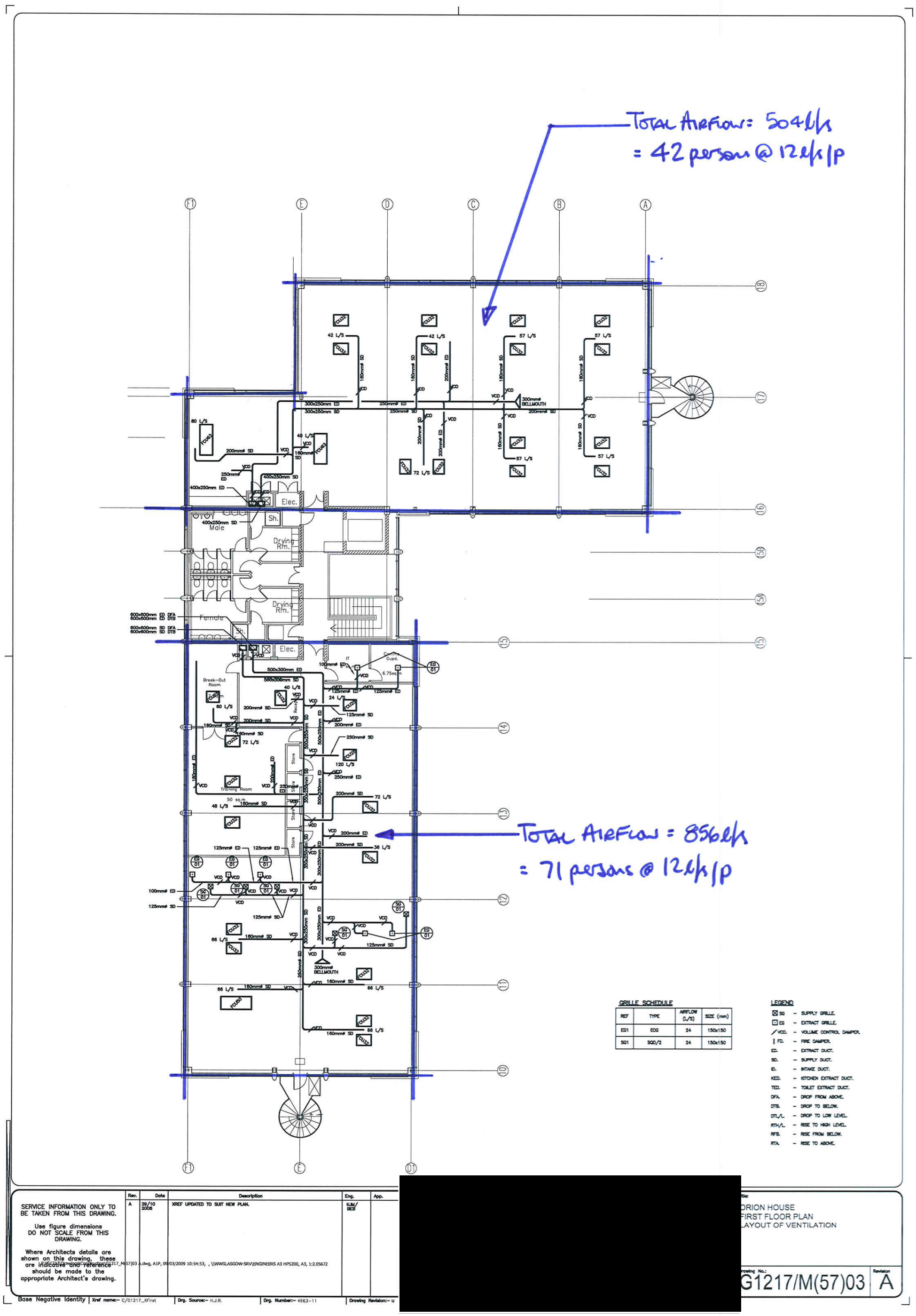
[redacted]

Title: FIRST FLOOR PLAN LIGHTING LAYOUT

Drawing No.: G1217/E(63)02

Revision

Base Negative Identity | Xref name:- G1217_XFirst | Drg. Source:- H.J.R. | Drg. Number:- 4963-11H | Drawing Revision:- –



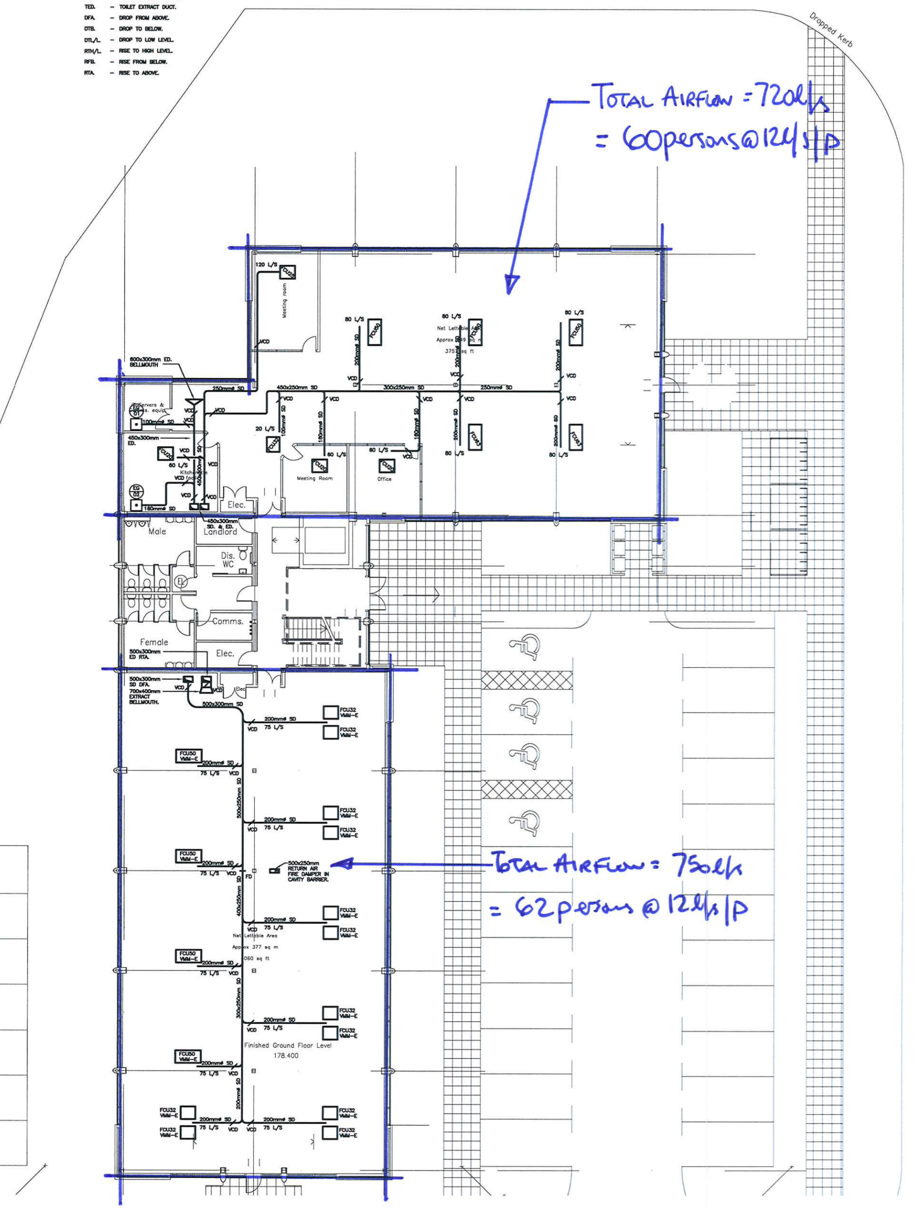
Total Airflow: 504 l/s
= 42 person @ 12 l/s/p
Total Airflow = 856 l/s
= 71 persons @ 12 l/s/p
GRILLE SCHEDULE
REF | TYPE | AIRFLOW (L/S) | SIZE (mm)
EG1 | ECG | 24 | 150x150
SG1 | SQD/2 | 24 | 150x150
LEGEND
SG - SUPPLY GRILLE.
EG - EXTRACT GRILLE.
VCD. - VOLUME CONTROL DAMPER.
FD. - FIRE DAMPER.
ED. - EXTRACT DUCT.
SD. - SUPPLY DUCT.
ID. - INTAKE DUCT.
KED. - KITCHEN EXTRACT DUCT.
TED. - TOILET EXTRACT DUCT.
DFA. - DROP FROM ABOVE.
DTB. - DROP TO BELOW.
DTL/L. - DROP TO LOW LEVEL.
RTH/L. - RISE TO HIGH LEVEL.
RFB. - RISE FROM BELOW.
RTA. - RISE TO ABOVE.
SERVICE INFORMATION ONLY TO BE TAKEN FROM THIS DRAWING.
Use figure dimensions DO NOT SCALE FROM THIS DRAWING.
Where Architects details are shown on this drawing, these are indicative and reference should be made to the appropriate Architect's drawing.
Rev. | Date | Description | Eng. | App.
A | 29/10 2008 | XREF UPDATED TO SUIT NEW PLAN. | KJM/ BEB |
[redacted]
Title: ORION HOUSE
FIRST FLOOR PLAN
LAYOUT OF VENTILATION
Drawing No.: G1217/M(57)03
Revision: A
Base Negative Identity
Xref name:- C/G1217_XFirst
Drg. Source:- H.J.R.
Drg. Number:- 4963-11

EXTRACT GRILLE SCHEDULE

REF	TYPE	AIRFLOW (L/S)	SIZE (mm)
EG1	ESG	24	150x150
EG2	ESG	60	200x200

LEGEND

- SG – SUPPLY GRILLE.
- EG – EXTRACT GRILLE.
- VCD. – VOLUME CONTROL DAMPER.
- FD. – FIRE DAMPER.
- ED. – EXTRACT DUCT.
- SD. – SUPPLY DUCT.
- ID. – INTAKE DUCT.
- KED. – KITCHEN EXTRACT DUCT.
- TED. – TOILET EXTRACT DUCT.
- DFA. – DROP FROM ABOVE.
- DTB. – DROP TO BELOW.
- DTL/L. – DROP TO LOW LEVEL.
- RTH/L. – RISE TO HIGH LEVEL.
- RFB. – RISE FROM BELOW.
- RTA. – RISE TO ABOVE.



SERVICE INFORMATION ONLY TO BE TAKEN FROM THIS DRAWING. Use figure dimensions DO NOT SCALE FROM THIS DRAWING. Where Architects details are shown on this drawing, these are indicative and reference should be made to the appropriate Architect's drawing.	Rev.	Date	Description	Eng.	App.
	A	26/11/2008	VENTILATION ADDED TO SOUTH WING.	KJM/ JMcA	KM/ AKR

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Base Negative Identity | Xref name:– G1217_XGRND | Drg. Source:– H.J.R. | Drg. Number:– 4963-9R | Drawing Revision:– R

[redacted]

Title:
ORION HOUSE
GROUND FLOOR PLAN
LAYOUT OF VENTILATION

Drawing No.: G1217/M(57)02 | Revision: A

Appendix C: Section 6 Compliance Report

Orion House

Scottish Enterprise Technology Park, East Kilbride

Building Regulations Energy Performance Section 6 (IES) Compliance Check

May 2008

[redacted]

CONTENTS

1.0 Executive Summary

This report presents a summary of the building energy performance in respect of the mandatory requirement for compliance with the Building Regulations Energy Performance.

To demonstrate compliance with the Building Regulations an energy efficiency strategy has been developed and analysed through the use of dynamic thermal simulation.

The strategy adopted for the design of this project has been to:

- Minimise the use of energy
- Supply energy efficiently and effectively
- To incorporate sustainable energy technologies wherever feasible

Results achieved are as follows:

Notional Building Emission Rate	59.1857 kg.CO_2/m^2
Target Emission Rate	42.6137 kg.CO_2/m^2
Building Emissions Rate	26.7325 kg.CO_2/m^2

Table 1: Summary of Carbon Emissions for the proposed development.

The proposed design specification of the "actual building" has been proven to comply with the requirements of section 6 (2007) of the Scottish Building Regulations.

The calculated Building Emissions Rate (BER) for the **VRF multi split air conditioning system** exceeds the Target Emissions Rate (TER) by **37.27%.**

The percentage reduction due to the LZC equipment for the **VRF multi split air conditioning system** is **19.26 %** which is greater than the required 15% therefore this system will meet the SPP6 requirements.

2.0 Introduction

[redacted]d' energy performance analysis for the proposed Orion House to assess compliance with the local Building Regulations requirement for energy performance.

To realistically model the likely energy performance and hence determine detailed heating and ventilation load profiles, a comprehensive Dynamic Thermal Simulation (DTS) has been performed. This has entailed the development of a detailed 3D computerised model[1] containing a number of defined zone types (i.e. classrooms, offices, circulation areas etc) each with their own operating profiles and characteristics.

The model has been run for an operational year in order to determine estimated annual carbon dioxide (CO_2) emissions with respect to demonstrating compliance with the Building Regulations.

IES software[2] has been utilised for this process as it is regarded as the industry leader in this field and is accredited for use using the National Calculation Method (NCM) via the Building Research Establishment (BRE).[3]

1 Based upon latest architectural drawings and building fabric specification (U-values).
2 www.iesve.com
3 www.ncm.bre.co.uk

3.0 Building Regulations – Energy Performance Requirements

UK national Building Regulations require energy performance of buildings to be assessed to demonstrate compliance with mandatory levels of energy performance. The assessment is based upon CO_2 emissions for the "Actual[4]" building compared to target emissions from a "Notional[5] " building of a similar nature.

Specific Regulations apply within Scotland, England, Wales and Ireland. This project falls under the jurisdiction of the Scottish Building Regulations.

The intention of the regulations is to ensure that effective measures for the conservation of fuel and power are incorporated in buildings. In addition to energy conservation provisions for the building fabric and the building services it contains, a carbon dioxide emissions standard obliges a designer to consider new buildings in a holistic way. In view of this, localised or building-integrated low and zero carbon technologies (LZCT's) (e.g. photovoltaics, active solar water heating, biomass, combined heat and power, and heat pumps) can be used as a contribution towards meeting this standard.

The latest requirements are intended to achieve a significant and demanding emissions reduction when compared against previous standards, however, nothing prevents a building from being designed and constructed to be even more energy efficient and make greater use of LZCT's. Where this occurs, both the monetary and environmental savings will be improved.

A key role of the planning system is to support a move towards low and zero carbon development through the use of energy efficient, micro-generating and decentralised renewable energy systems. Scottish Planning Policy (SPP) 6 and Planning Advice Note (PAN) 84 provide guidance on implementing targets in Scotland. SPP6 states that:

"all future applications proposing development with a total cumulative floorspace of 500 square metres or more should incorporate on-site zero and low carbon equipment contributing at least an extra 15% reduction in CO_2 emissions beyond the 2007 building regulations carbon dioxide emissions standard"

[4] The **actual** building is the building as designed but subject to standard patterns of occupancy and plant operation.

[5] The **notional** building is a version of the building that conforms to standards similar to those applying to the previous building regulations standards. The notional building is subject to the same geometry (with the exception of glazing and door area), orientation, occupancy and plant operation patterns as the actual building. It is also exposed to the same weather conditions.

To demonstrate compliance with the Scottish Building Regulations there are a number of compliance criteria that are necessary to be met:

1. The calculated CO_2 emission rate for the ‘Actual Building’, the Building Emission Rate (BER) must not be greater than the target rate (the Target Emission Rate, TER[6]) – determined by application of an improvement factor[7] and a LZC benchmark[8] to the CO_2 emission rate of the ‘Notional Building’ ($C_{notional}$) built to comply with previous building regulations standards. The TER is obtained from the following formula:

    - TER= $C_{notional}$ x (1- improvement factor) x (1-LZC benchmark)

Building services strategy for the actual building	**Improvement factor**	**LZC benchmark**
Heated and naturally ventilated	0.15	0.10
Heated and mechanically ventilated[9]	0.20	0.10
Air conditioned	0.20	0.10

Table 2: Improvement factors and LZC benchmarks

For example, the TER for an air conditioned building would be
TER = $C_{notional}$ *x (1 - 0.20) x (1 - 0.10) = 0.72 x* $C_{notional}$
(an improvement of 28 % over the previous building regulations standards)

2. The performance of the building fabric (U-Values) and services (SFP’s, COP’s, seasonal efficiencies etc.) must meet the current minimum standards specified in Section 6 (2007) of the Scottish Building Regulations.

3. Means must be provided to limit solar gains in summer.

4. The quality of construction must be ensured and confirmed with mandatory pressure testing of buildings

5. Information must be provided to enable building users to operate buildings in an energy efficient manner.

[6] Target Carbon Dioxide Emission Rate (TER) is the minimum energy performance required for new buildings.

[7] Improvement factor is the improvement in energy efficiency appropriate to the classes of building services in the proposed building.

[8] LZC benchmark is the benchmark provision for low and zero carbon technologies, which can make substantial and cost-effective contributions to achieving TER's. However LZC technologies are not mandatory but are included in the calculation to encourage designers to consider these technologies before construction starts.

[9] Mechanical ventilation means systems intended to run continuously during occupied hours. This excludes intermittent toilet extract fans.

With regards to submission to Building Control, two energy performance calculations for the ‘Actual’ building are required to demonstrate compliance:

1. Design calculations presented in a report to Building Control.

2. Following completion of construction, a final calculation to confirm that the building complies ‘as built’.

In summary, an energy efficient building will deliver major benefits in terms of both reduced environmental impact and lower operating cost. In order to demonstrate compliance with the regulations it is necessary to assess the building energy performance in addition to meeting key minimum standards.

Energy Performance must surpass a similar ‘notional’ building built to comply with previous building standards, by circa 23% to 28% on a $CO_2/m^2/yr$ basis depending upon services strategy (i.e. natural ventilation, mechanical ventilation or air conditioning).

The target is to incorporate sufficient low and zero carbon equipment to reduce the building’s carbon emissions by 15% more than the level set by the current building standard.

The building fabric and the energy efficient design and specification of HVAC plant, air distribution and lighting systems will prove fundamental to achieving this objective.

4.0 Energy Performance Compliance Analysis

4.1 Dynamic Thermal Simulation

Dynamic thermal simulation is a very detailed form of building energy and environmental modelling. Amongst other benefits it allows the comparison of different Plant/HVAC options in order to optimise building thermal and carbon performance.

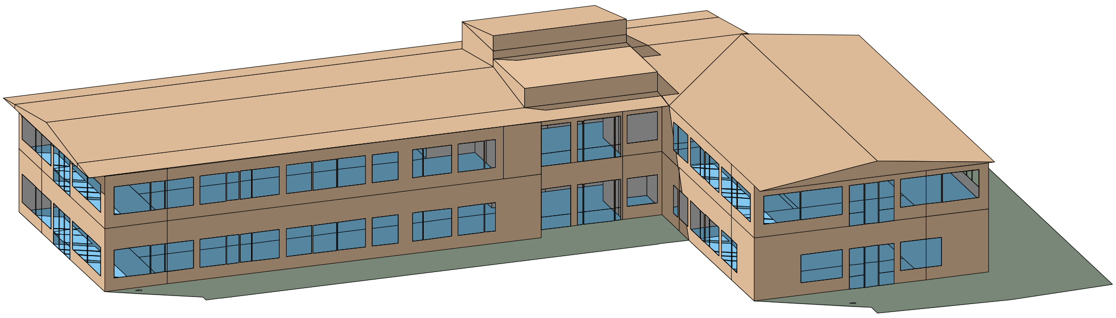

Figure 1: IES 3D Geometry representation of the proposed building

Dynamic thermal simulation is able to base its performance calculations upon incremental time steps as low as 10 minutes. This allowed realistic variations in fabric thermal storage (thermal mass effects), weather conditions, occupancy, internal and solar gains etc. to be taken into account and their implications upon building/plant operation modelled effectively.

- With increasing levels of insulation, air tightness and internal gains of buildings, the room heat balance has become delicate and dynamic.
- Peak space cooling loads usually occur during the occupied period and therefore it is necessary to take account of both solar and internal gains.
- Radiant gains will only become a load upon the system by heating the building fabric. Fabric thermal storage means that the gain is attenuated and shifted in time making it essential to use a calculation method that can take into account the thermal response of the building.
- Space temperatures during periods of occupancy are the result of complex interactions between gains, building fabric and occupant behaviour which require the complexity of a dynamic thermal model in order to replicate effectively.

In summary, dynamic thermal simulation uses location specific detailed weather data, zone specific operational profiles (occupancy, DHW demand, lighting, ventilation etc.) and HVAC plant performance data to effectively model and predict the energy performance of a building. This comprehensive approach is considered current best practice for assessment building energy performance assessment of associated carbon emissions.

To date the analysis performed has enabled a detailed comparison to be made between the ‘Notional’ and ‘Actual’ buildings and a clear comparison to be made between their associated carbon emissions[10].

[10] Note: During this process it has been necessary to ensure that both the building fabric and the proposed services meet minimum performance standards (Criterion 1&2). The remaining three criteria are not considered during this preliminary assessment.

5.0 Applied Design/Modelling Parameters

5.1 Building Geometry

The 3D geometry and building construction materials were designed based upon the architectural plans and elevations. The details are specified in the appendices of this report.

The 3D geometry has been subdivided into a series of generic zone types which were assigned operational templates and compared against default National Calculation Methodology (NCM) operational templates.

The building was then identified room by room and assigned National Calculation Methodology (NCM) activity templates based on the operational requirements of the room. i.e. the open plan offices in the building were assigned the open plan office activity template. Activity templates used are stated below:

- Open Plan Offices
- Toilets
- Changing Facilities
- Meeting Rooms
- Tea Preperation
- Storage
- Offices
- Circulation

For compliance the simulation then applies an NCM template based on the room activity to each room in the notional building and applies a fixed set of space operational characteristics to the actual building including:

- Occupancy densities
- Ventilation rates
- Small power loads
- Domestic hot water consumption

A detailed breakdown of the operational characteristics used in the simulation is listed in Appendix B.

NB: *Although the ‘Notional’ and ‘Actual’ calculations use standard NCM casual gains and activity data they do closely match that expected in the ‘Real*[11] *’ office building. Separate to the energy analysis, a further detailed thermal analysis will require to be performed on the ‘real’ office building to establish its true behaviour.*

[11] The **real** building is the building as designed, and with the occupancy and plant operation conditions expected to apply in reality, rather than the standard conditions stipulated in the current building regulations compliance.

5.2 HVAC System Overview

All areas except the plant rooms, toilets and stores were heated using a VRF multi split air conditioning system with heat recovery. The toilets were heated using electric heaters.

The domestic hot water was supplied by electric immersion heaters.

Mechanical ventilation with heat recovery from the exhaust air stream has been provided for all areas.

5.3 Weather Data

Dynamic thermal simulation provides the ability to utilise detailed site specific climatic information. Hourly climatic data is the most frequently sampled source of climatic data available and represents the most powerful determinant for simulation of building performance.

Weather years sourced from hourly recorded measurements arranged in sequence, form a useful basis for the prediction and comparison of annual energy consumption. Our analysis utilises the industry standard CIBSE Test Reference Year (TRY) data set as dictated by the NCM methodology.

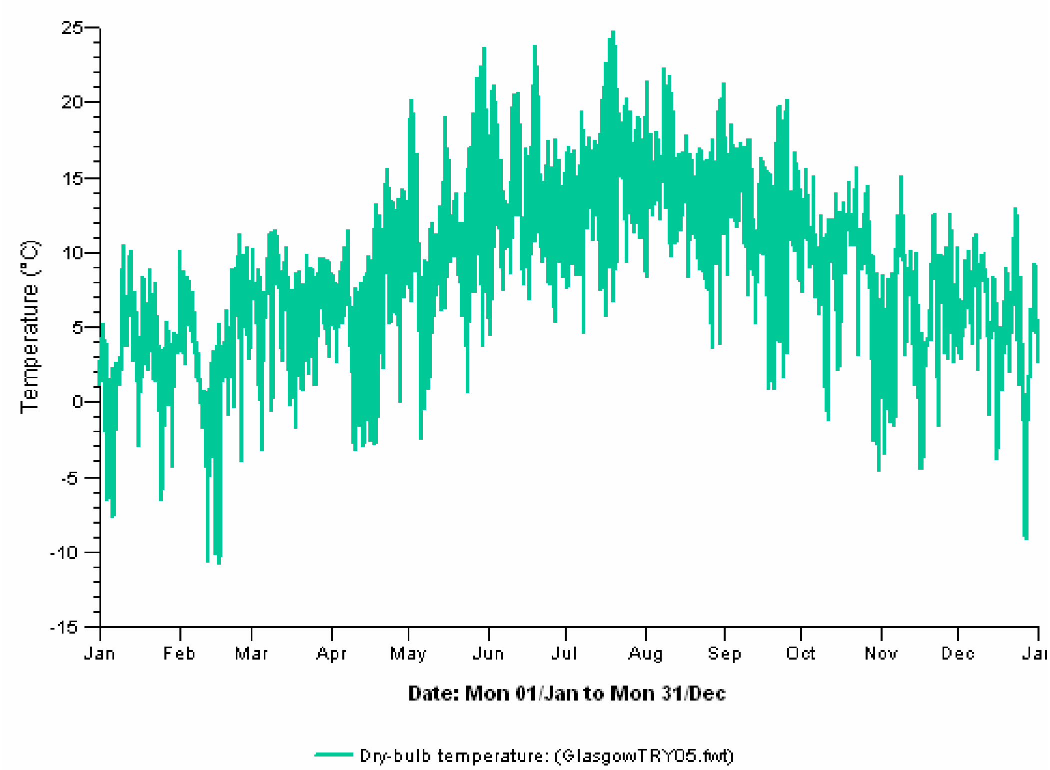

Figure 2: Glasgow CIBSE TRY2005 Weather Data - External Dry Bulb Temperature

5.4 Fuel Emission Factors

For the purpose of the current building regulation compliance it is the annual operational carbon emissions figure that is of most importance. These are determined on the basis of the applied system performance characteristics and the fuels they utilise.

From the default NCM emission factors shown below, it is clear that the emission factor associated with Natural Gas (0.194kgCO_2/kWh) falls far below that for grid supplied electricity (0.422kgCO_2/kWh). Therefore, any efficiency measures taken to save electricity will save more than double the amount of CO_2 (on an equal kWh basis) in comparison to the associated reduced gas consumption. However, it will be necessary to limit both electricity and gas consumption in order to significantly benefit overall building performance.

Carbon dioxide emission factors

Fuel	Carbon dioxide emission factor (kg$C0_2$/kWh)
Natural gas	0.194
LPG	0.234
Biogas	0.025
Oil	0.265
Coal	0.291
Anthracite	0.314
Smokeless fuel (incl. coke)	0.392
Dual fuel appliances (mineral + wood)	0.187
Biomass [3]	0.025
Grid supplied electricity	0.422
Grid displaced electricity [1]	0.568
Waste heat [2]	0.018

Notes:

1. Grid displaced electricity comprises all electricity generated by *building* integrated power generation systems (photovoltaic (PV), combined heat and power (CHP) etc). The associated CO_2 emissions are deduced from the total CO_2 emissions for the *building* before determining the actual *building* emission rate. Any fuel used by the *building* integrated power generation system (e.g. to power the CHP engine) must be industrial processes and power stations.
2. Includes waste heat from industrial processes and power stations rate more than 10MWe and with a power efficiency greater than 35%.
3. For biomass-fired systems rated at greater than 100kW output but where there is an alternative appliance to provide standby, the CO_2 emission factor should be based on the fuel of the lead boiler.
4. For systems rated at less than 100kW output where the same appliance is capable of burning both bio-fuel and fossil fuel, the CO_2 emission factor for dual fuel should be used, except where the building is in a smoke control area, when the smokeless fuel figure should be used.
5. If thermal energy is supplied from a district or community heating or cooing system, emission factors will have to be determined based on the particular details of the scheme, but should take account of the annual average performance of the whole system (i.e. the distribution circuits, and all the heat generating plant, including any CHP, and any waste heat recovery or heat dumping).

Table 3: Default NCM Fuel Carbon Emission Factors

6.0 Results Analysis

6.1 Building Emission Rate (BER) and Target Emission Rate (TER)

As stated earlier, in order to demonstrate compliance with the carbon emissions aspect of the current building standards, it is necessary that the Building Emissions rate (BER) for the natural building is less than the Target Emission Rate (TER) for the notional building.

In general terms, the improvements required when compared to a 'Notional Building' built to comply with the previous building standards requirements are:

- **Heated and Naturally Ventilated (23.5%)**
- **Heated & Mechanically Ventilated (28%)**
- **Air Conditioned (28%)**

The simulation is analysed over one year for the 'Actual' and 'Notional' buildings using:

- Detailed location specific weather data
- Operational/occupational profiles
- Internal gains incl. occupant densities, lighting loads[12] and small power
- Auxiliary ventilation and infiltration rates

The above information is fixed by NCM and cannot be changed with the exception of lighting loads and infiltration rates[13]. This is to allow a comparison between the 2 buildings under the same conditions.

N.B.:

(1) ***The Notional building has the identical geometry and operating profiles to that of the Actual building, however, it applies standard glazing percentages, fabric U-values and utilises default HVAC efficiencies.***

(2) ***An electrical power factor correction for the actual building has been assumed at a rating between 0.9 and 0.95 based on efficient luminaires.***

[12] NB: Lighting loads (m^2) have been reduced to values stated in Appendix B of this report due to the combination of the proposed lighting scheme and an effective daylighting control strategy.

6.2 Calculated Monthly Energy Usage Profiles and Final Emission Figures

Prior to the determination of operational carbon emissions it is necessary to assess total annual energy consumptions in order to highlight areas where efficiency measures can be applied.

This report illustrates the predicted energy consumption and carbon dioxide emissions for the Proposed Orion House using a VRF multi split air conditioning system and with electric heaters servicing the toilets.

Figure 3 shown below illustrates the monthly energy usage for the 'Notional' building used as the comparator in the analysis. This is the building as designed to comply with the previous building standard requirements prior to the 2007 review.

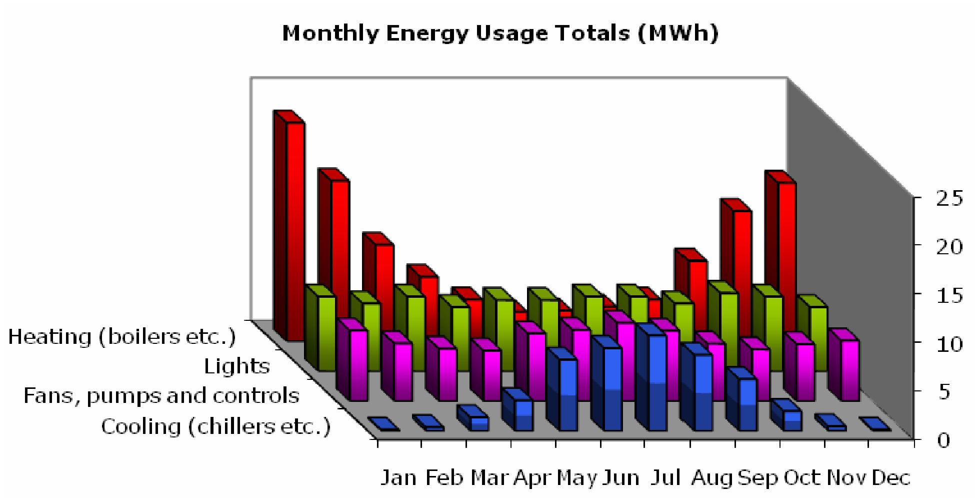

Figure 3: <u>Notional Building</u> Monthly <u>Energy</u> Usage Profile (MWh)

Figure 4 shown below illustrates the monthly carbon emission for the 'Notional' building.

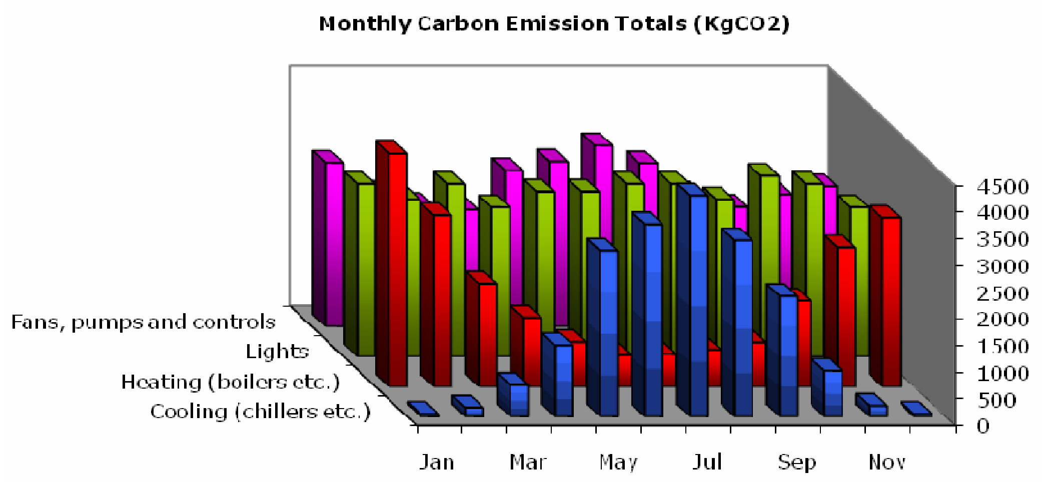

Figure 4: **<u>Notional Building</u> Monthly <u>Carbon</u> Emission Profiles (kgCO2)**

Figure 5 shown below illustrates the monthly energy usage for the 'Actual' building. This is the building as designed to comply with the current building standard requirements excluding power to client's equipment:

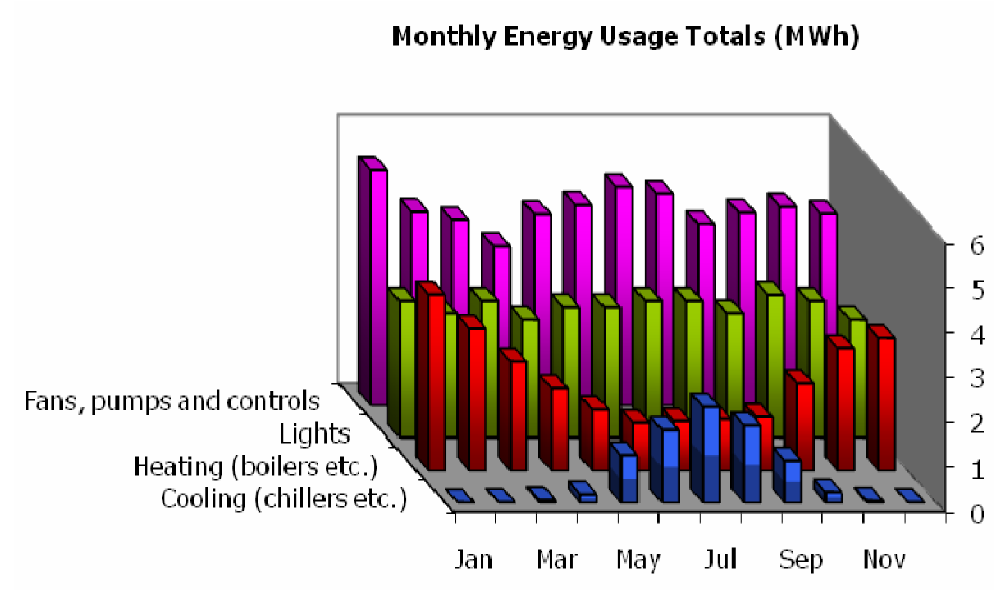

Figure 5:– <u>Actual Building</u> Monthly <u>Energy</u> Usage (MWh)

Figure 6 shown below illustrates the monthly carbon emission for the 'Actual building excluding power to client's equipment.'

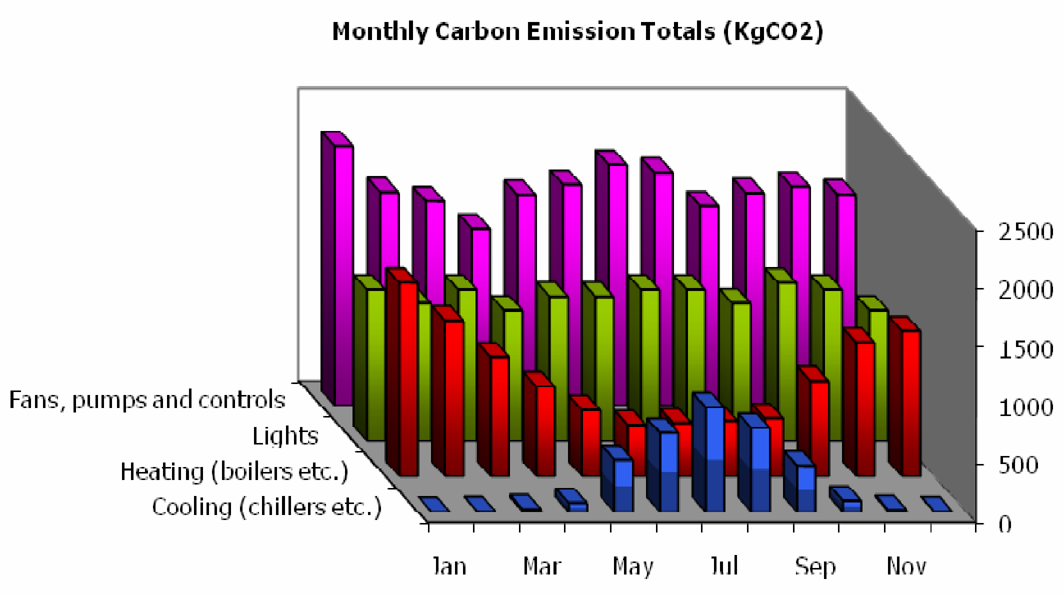

Figure 6: **<u>Actual Building</u> Monthly <u>Carbon</u> Emission Profiles (kgCO2)**

Figure 7 shown below illustrates the annual energy usage breakdown for the 'Notional' building and the 'Actual' building using a VRF multi split air conditioning system with heat recovery.

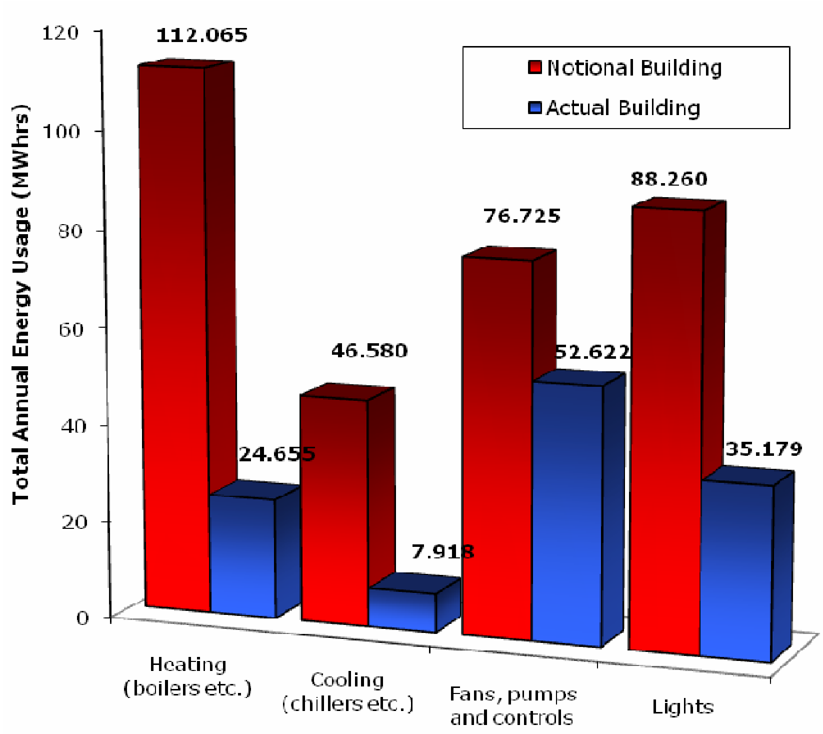

Figure 7: Annual <u>Energy Usage</u> Breakdown – Notional vs. Actual Building Performance

Figure 8 shown below illustrates the annual carbon emission breakdown for the 'Actual' and 'Notional' building.

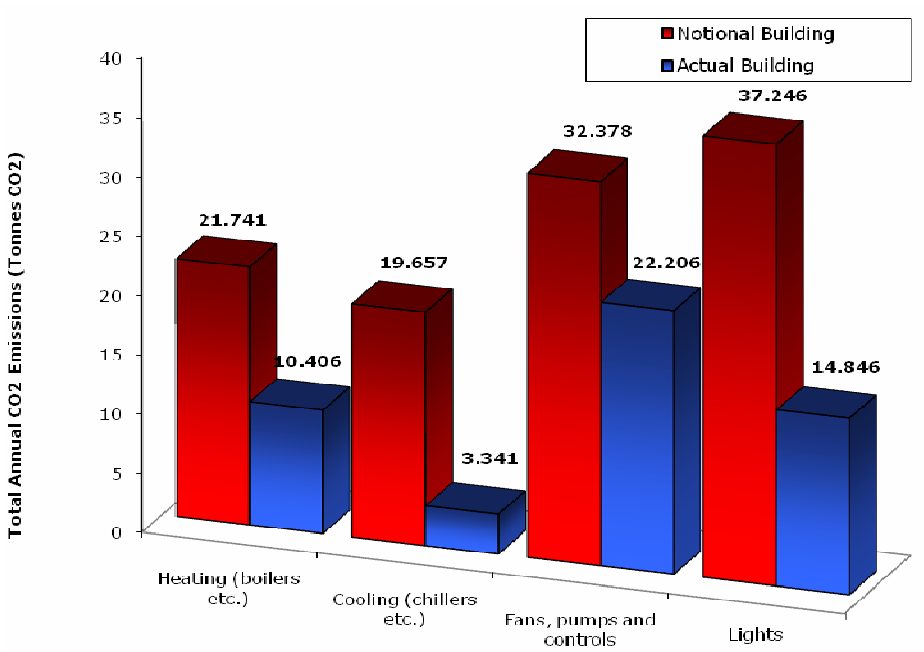

Figure 8: Annual <u>Carbon Emissions</u> Breakdown – Notional vs. Actual Building Performance

Figure 9 shown below illustrates the annual total carbon emission for the ‘Actual’ and ‘Notional’ building.

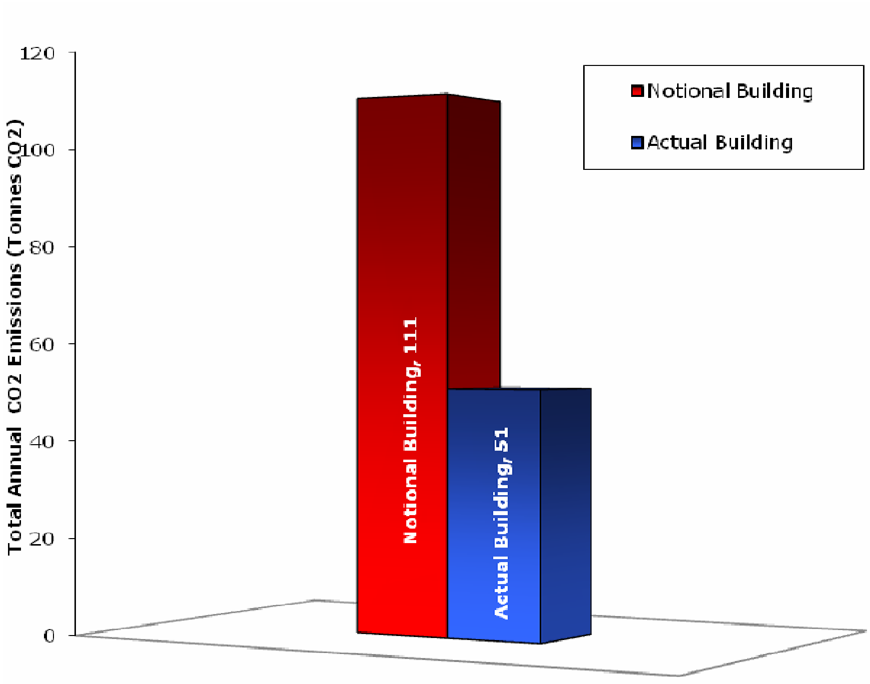

Figure 9: <u>Annual Total Carbon Emissions Summary</u> – Notional vs. Actual Building Performance

Figure 10 shown below illustrates the total annual CO2 emissions as calculated by IES.

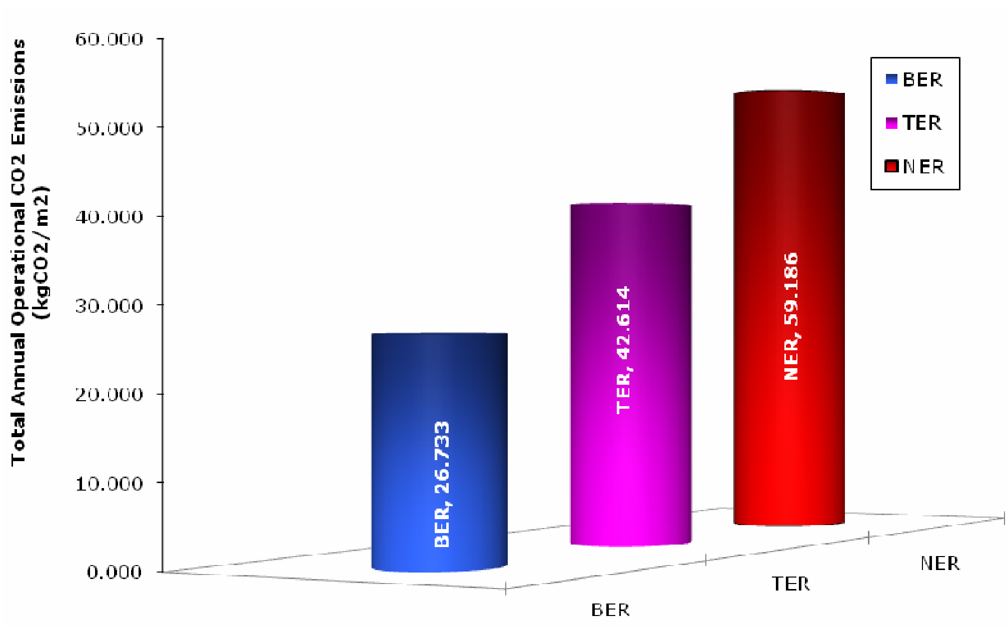

Figure 10: <u>Total Annual CO2 Emissions</u> as Calculated by IES- Notional vs. Base Case Actual Building

6.3 SPP6/PAN84 Calculation

To satisfy requirements of SPP6 and Pan 84 in ensuring that 15% carbon emissions savings are from Low and Zero Carbon Technologies a calculation was performed comparing the VRF multi split air conditioning system against a gas boiler system to the minimum standards of the building regulations. A summary is shown in Table 4.

Calculation Step (PAN 84)		VRF air conditioining / Gas Boiler System
1	**2007 Building Regulations CO2 emission standard**	**42.6137 kg/CO2/m^2**
2	**Actual emissions rate using LZC Equipment**	**26.7325 kg/CO2/m^2**
3	**Percentage Reduction**	**37.27%**
4	**Actual Reduction Rate Without LZC Equipment**	**34.9409 kg/CO2/m^2**
5	**Percentage Reduction Due to LZC Equipment**	**19.26%**

Table 4: PAN 84 calculation summary for air conditioning/Gas Boiler System

The calculation indicates that the PAN 84 requirements are satisfied as the percentage reduction of carbon dioxide emissions due to the VRF multi split air conditioning system are 19.26%. This is in excess of the required 15% hence compliance is achieved.

6.4 Summary of Results

Utilising a VRF multi split air conditioning system with heat recovery provides a considerable energy saving in the building. Using high efficiency units with high CoP and EER's to serve all areas except the toilets and changing areas provides considerable energy savings. This heating and cooling strategy combined with energy efficient glazing, energy efficient plant, low energy luminaires and a lighting control strategy with localised switching provides a highly energy efficient building.

The corresponding carbon dioxide emissions from the actual and notional building indicates the main carbon contributors are from the lighting, fans, pumps and controls with the heating and cooling contributing the rest of the building emissions. As all the systems use electricity as a fuel source, which has a higher carbon dioxide emission than natural gas for every kW of energy, a higher percentage of carbon dioxide is produced per kW consumed.

The system analysed, satisfied PAN 84 and SPP6 requirements for ensuring that 15% emissions were produced solely from low and Zero Carbon Technologies. The VRF with heat recovery had a 19.2% reduction in carbon emissions.

7.0 Conclusions & Recommendations

7.1 Building Regulations Compliance

The findings presented in this report illustrate how the proposed development will satisfy the requirements of Section 6 of the Scottish building regulations. The report concludes that the proposed Heating, Cooling and Ventilation system(s) and energy efficient design strategy(s) will reduce energy and corresponding carbon emissions in the proposed development.

7.2 Section 6

Summaries of the emissions and percentage reductions for the VRF multi split air conditioning system with VRF are tabulated in Table 5. Findings indicate that the Buildings Emissions Rate (BER) is Lower than the Target Emissions Rate (TER).

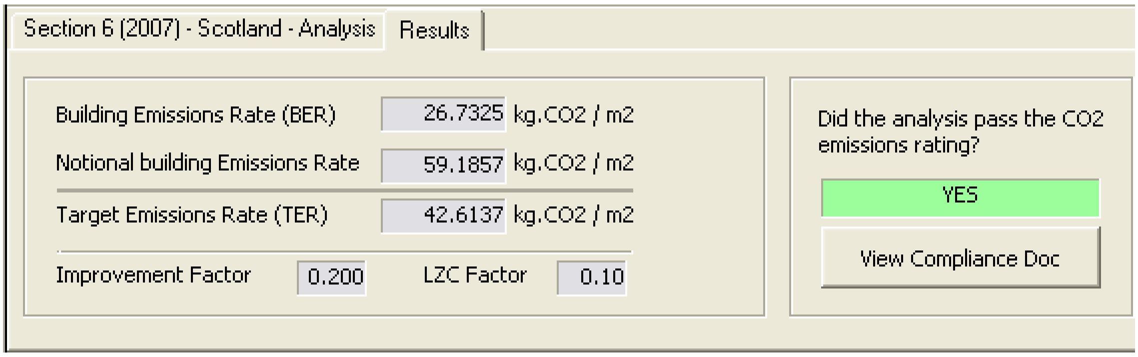

Table 5: Carbon dioxide emissions rating table illustrating compliance result.

The calculated Building Emissions Rate (BER) for the combined Biomass/Gas boiler configuration driving the underfloor heating system is **54.83%** lower than the Notional Building Emissions Rate (NER) and exceeds the Target Emissions Rate (TER) by **37.27%.**

The proposed design specification of the "actual building" has been proven to comply with the requirements of section 6 (2007) of the Scottish Building Regulations.

7.3 Pan 84

Summaries of requirements for PAN 84 are presented in Table 6 for the combined Gas/Biomass Boiler. The table illustrates compliance with PAN 84 guidelines for ensuring a minimum of 15% contribution on carbon emissions is from low and zero carbon technologies.

Calculation Step (PAN 84)		VRF air conditioining / Gas Boiler System
1	2007 Building Regulations CO2 emission standard	42.6137 kg/CO2/m^2
2	Actual emissions rate using LZC Equipment	26.7325 kg/CO2/m^2
3	Percentage Reduction	37.27%
4	Actual Reduction Rate Without LZC Equipment	34.9409 kg/CO2/m^2
5	Percentage Reduction Due to LZC Equipment	19.26%

Table 6: PAN 84 compliance information for an air conditioning/Gas boiler system

The percentage reduction due to the LZC equipment for the **VRF multi split air conditioning system with heat recovery/Gas boiler system** is **19.26%** which is greater than the required 15% therefore this system will meet the SPP6 requirements.

7.4 Comments on Systems

Utilising a VRF multi split air conditioning system with heat recovery provides a considerable energy saving in the building. Using high efficiency units with high CoP and EER's to serve all areas except the toilets and changing areas provides considerable energy savings. This heating and cooling strategy combined with energy efficient glazing, energy efficient plant, low energy luminaires and a lighting control strategy with localised switching provides a highly energy efficient building.

The corresponding carbon dioxide emissions from the actual and notional building indicates the main carbon contributors are from the lighting, fans, pumps and controls with the heating and cooling contributing the rest of the building emissions. As all the systems use electricity as a fuel source, which has a higher carbon dioxide emission than natural gas for every kW of energy, a higher percentage of carbon dioxide is produced per kW consumed.

Utilising an energy efficient lighting strategy with an average output of 11 W/m^2, with PIR sensors in the open office areas contributes significantly to reducing the energy consumption of the building.

Fans, pumps and control systems contribute significantly to the energy usage of the building due to the highly complex nature of the heating and cooling system. Utilising high energy efficiency fans, pumps and controls in the building minimises energy consumption in the building.

If artificial lighting, the controls, pumps and fans were powered by photovoltaics or any other additional low and zero carbon technology the carbon emissions of the building could be reduced even further. In addition, utilisation of solar water heating could also reduce the carbon emissions

Appendix D: Chapter 7 Tailored and Monitored Data Calculations: Section 7.1: Table 7.4.

Tenant 1: Tailored Patterns of Use Calculations

Exercise 2A: Tenant 1
Occupancy capacity: 19m2/person **Occupied Area:** 349m2
FTE'S: 18 **Operational Details: Thermally significant energy loads**

Occupancy Schedule [Week days]

Building Operational Hours		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	08:00	0	0	0
08:00	09:00	1	75	55
09:00	13:00	18	1350	990
13:00	14:00	9	675	495
14:00	17:30	18	1350	990
17:30	18:30	5	375	275
18:30	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Operational Hours		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	08:00	0	0	0
08:00	18:30	5392	0.3	0.7
18:30	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Operational Hours		Appliance load [$W.m^{-2}$]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:30	10*	0.4	0.6
18:30	00:00	0	0	0

Assumptions:
Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 20m2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Operational Hours		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
08:00	18:30	0.12	-
18:30	00:00	-	0.25

Assumptions:
Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 18 people @ 12 l/s = 216 l/s assumed for hours of operation [216 x 0.001 = 0.216].

Set points [Week days]

Building Operational Hours		Capacity [kW]	Heating Set point [^oC]	Cooling Set point [^oC]
00:00	07:00	50	10	0
08:00	18:30	50	18	26
18:30	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Calculating energy use for regulated and unregulated small power [New Methodology] To include; office equipment, other equipment [including catering equipment and task lighting], server rooms and server cooling.

Hot water

Input data:

Daily hot water consumption per person	= 8 l/person
Number of occupants	= 18
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 37 440 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 37 440 x 1 = 37 440 kg
Supply temperature of domestic hot water	= 65^{o}C
Return temperature of domestic hot water	= 10^{o}C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water (Cρ)	= 4.187 kJ/kg.K

Annual energy consumption (kW.h/year) = mass of water (kg) x ΔT (K) x Cρ (kJ/kg.K) /3600
= 37 440 x 55 x 4.187 / 3600
= 2394 kW.h/year

Fans pumps and controls

Total annual energy use [building]	= 52 622 kW.h/year
Building area	= 1452m2
Tenant area	= 349m2
Tenant Use based on compliance report	= [(52 622/1452) x 349]

= 12 648 kW.h/year *estimated*

Workstation energy consumption [Tenant 1]:

Input data:

Number of workstations	= 18
Workstation equipment	= 0.6 desktop + 1.4 screen + 0.6 laptop dock [laptop] + 1.6 phone
Average power demand	= 65 W/desktop + 30 W/ screen + 45 W/dock + 5 W/phone + 15 W/misc* = 39 + 42 + 27 + 8 + 15 = 131W
Swing Shift power demand	= 131W /2 = 65.5W
Sleep mode power demand	= 20 W/desktop + 0 W/ screen + 15 W/dock + 0 W/phone = 39
Hours of operation	
[Occupied hours]	= 5 days x 8 hours x 52 weeks = 2080 hours
[Swing shift hours 0800-0900]	= 5 days x 1 hours x 52 weeks = 260 hours
[Swing shift hours 1700-1830]	= 5 days x 1.5 hours x 52 weeks = 390 hours
	= 2080 + 260 + 390 = 2730 hours
Total hours per year	= 8760 hours

*Occasional desktop printer, chargers, desk fans, speakers etc.

Annual energy consumption for tenant 1 workstations [kW.h/year]= number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {18 x [(131 x 2080) + (65.5 x 260) + (65.5 x 390) + (39 x (8760-2730))]} /1000

= {18 x [272 480 + 17 030 + 25 545 + 235 170]}/ 1000
= 9904 kW.h/year

Communal small power consumption [Tenant 1]

Input data:

Typical equipment installed (a)	= 1 photocopier + 2 printers + 1 fridge
Average power demand	= 460 W/photocopier + 460 W/ printer + 200 W/ fridge = 1380W
Sleep mode power demand	= 17 W/photocopier + 17 W/ printer + 20 W/ fridge = 71W
Hours of operation	
[Occupied hours]	= *7 days x 8 hours x 52 weeks = 2912 hours
[Swing shift hours 0800-0900]	= *7 days x 1 hours x 52 weeks = 364 hours
[Swing shift hours 1700-1830]	= *7 days x 1.5 hours x 52 weeks = 546 hours
	= 2912 + 364 + 546 = 3822 hours
Total hours per year	= 8760 hours

*NB: Dubious about 7 hour allocation in TM54

Annual energy consumption for tenant 1 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(1380 x 2912) + (71 x 364) + (71 x 546) + (71 x (8760 – 3822))]/1000
= [4 018 560 + 25 844 + 38 766 + 350 598] /1000
= 4414 kW.h/year

Other equipment installed	*= 1 franking machine [120W] + 1 shredder [500W] + 1 heater [3000W] + 1 projector [460W] + 1 Internet hub [10W] + 1 conference call station [5W] + 1 conference mic [20W] + 1 microwave [800W] + 1 coffee machine [670W] + 1 kettle [3000W] + 1 television [210W] + task light [100W] + 1 toaster [1500W] + 1 dishwasher [1200W] + 1 water cooler/ heater [870W] + 1 smart meter [0.25W]*
Average power demand	= 12 465W *estimated*
Sleep mode power demand	= 20W *estimated*
Hours of operation	= 5 days x 0.65 hours x 52 weeks = 169 hours *estimated*
Total hours per year	= 8760 hours

**20% increase allowed for due to the 20% increase in occupied hours.*

Annual energy consumption for tenant 1 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(12 465 x 169) + (20 x (8760 – 169))]/1000
= [2 106 585 + 171 820] /1000
= 2278 kW.h/year *estimated*

Small server room without local cooling [Tenant 1]

Input data:

Number of server rooms	= 1
Rated power demand of servers	= 1.6 kW [double server]
Ratio of rated to operational demand	= 67%
Hours of operation	= 24 hours x 7 days x 52 weeks = 8760 hours

Annual energy consumption for small server rooms (kW.h/year) = number of rooms x rated power demand (kW0 x ratio of rated to operational power demand x hours of operation

= (1 x 1.6 x 0.067 x 8760)
= 939 kW.h/year

DSM Results

Heating and Cooling : 10312 kW-h/year *estimated*

Total Tailored Annual Energy Demand [Tenant 3]

Input data:

Days of operation Tenant	= 5 days x 52 weeks = 260 days
Area	= 349m2
Tenant occupancy capacity	= 19m2/ fte

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 2394 + 10 254 [12 648 – 2394] + 9904 + 4414 + 2278 + 939 + 10 312

= 40 495 kW-h/year ***estimated***

Tenant annual energy use per m2 = Tenant annual energy use/ tenant area
= 116 kW.h/m2

Tennant annual energy use per fte = (tenant annual energy use/ tenant area) x tenant occupancy capacity)
= 2204 kW.h/fte

Tenant 2: Tailored Patterns of Use Calculations

Exercise 2B: Tenant 2
Occupancy capacity: 19m2/person **Occupied Area:** 188.5m2
FTE'S: 10 **Operational Details: Thermally significant energy loads**

Occupancy Schedule [Week days]

Building Operational Hours		Occupancy [W]	Sensible heat* [W]	Latent heat* [W]
00:00	08:00	0	0	0
08:00	09:00	1	75	55
09:00	10:00	5	375	275
10:00	13:00	10	750	550
13:00	14:00	5	375	275
14:00	17:00	10	750	550
17:00	18:30	5	375	275
18:30	00:00	0	0	0

Assumptions:
**Standard values of heat gain from CIBSE A: 75W sensible & 55W latent per occupant and 0.6 Radiant heat and 0.4 convective heat.*

Lighting [Week days]

Building Operational Hours		Lighting load [W]	Radiant heat [W]	Convective heat [W]
00:00	08:00	0	0	0
08:00	18:30	5816	0.3	0.7
18:30	00:00	0	0	0

Assumptions:
Lighting calculated from the lighting specification and mechanical and electrical layout drawings.

Small Power [Week days]

Building Operational Hours		Appliance load [$W.m^{-2}$]	Radiant heat	Convective heat
00:00	08:00	0	0	0
08:00	18:30	17.5*	0.4	0.6
18:30	00:00	0	0	0

Assumptions:
Small power includes standard allocation of computers and office equipment, electric motors, electric appliances and other domestic equipment. This does not include special functions, IT servers or an assumption for tenant plug loads.
*Equipment heat gains based on 10m2/ person derived from Table 6.1 Benchmark values for internal heat gains for offices, CIBSE Guide A.

Air Flows [Week days]

Building Operational Hours		Infiltration Rate [m^3/s]	Ventilation Rate [ac/h]
00:00	09:00	-	0.25
08:00	18:30	0.12	-
18:30	00:00	-	0.25

Assumptions: Basic infiltration rate of 0.25 ac/h assumed from compliance document. Ventilation rates as per engineers drawings: 10 people @ 12 l/s = 120 l/s assumed for hours of operation [120 x 0.001 = 0.12].

Set points [Week days]

Building Operational Hours		Capacity [kW]	Heating Set point [^oC]	Cooling Set point [^oC]
00:00	07:00	50	10	0
07:00	08:00	50	18	26
09:00	17:00	50	20	24
17:00	18:30	50	18	26
18:30	00:00	50	10	0

Assumptions: There is a minimum temperature of 10^{o}C for frost protection of the heating system [pipes and ASHP].

Calculating energy use for regulated and unregulated small power [New Methodology] To include; office equipment, other equipment [including catering equipment and task lighting], server rooms and server cooling.

Hot water

Input data:

Daily hot water consumption per person	= 8 l/person
Number of occupants	= 10
Number of occupied days per year	= 260 (5 days a week, 52 weeks per year)
Volume of water consumed per year	= 20 800 litres
Water density at ambient temperature	= 1 kg/ litre
Mass of water consumed per year	= 20 800 x 1 = 20 800 kg
Supply temperature of domestic hot water	= 65^{o}C
Return temperature of domestic hot water	= 10^{o}C
Temperature difference (ΔT)	= 55 K
Specific heat capacity of water ($C\rho$)	= 4.187 kJ/kg.K

Annual energy consumption (kW.h/year) = mass of water (kg) x ΔT (K) x $C\rho$ (kJ/kg.K) /3600
= 20 800 x 55 x 4.187 / 3600
= 1330.5 kW.h/year

Fans pumps and controls

Total annual energy use [building]	= 52 622 kW.h/year
Building area	= 1452m2
Tenant area	= 188.5m2
Tenant Use based on compliance report	= [(52 622/1452) x 188.5]

= 6 831 kW.h/year *estimated*

Workstation energy consumption [Tenant 2]:

Input data:

Number of workstations	= 11
Workstation equipment	= 1 desktop + 1 screen + 1 laptop dock [laptop] + 1 phone +
Average power demand	= 65 W/desktop + 30 W/ screen + 45 W/dock + 5 W/phone + [no miscellaneous provision]*= 145W
Swing Shift power demand	= 145W /2 = 72.5W
Sleep mode power demand	= 20 W/desktop + 0 W/ screen + 15 W/dock + 0 W/phone = 35W
Hours of operation	
[Occupied hours]	= 5 days x 8 hours x 52 weeks = 2080 hours
[Swing shift hours 0800-0900]	= 5 days x 1 hours x 52 weeks = 260 hours
[Swing shift hours 1700-1830]	= 5 days x 1.5 hours x 52 weeks = 390 hours
	= 2080 + 260 + 390 = 2730 hours
Total hours per year	= 8760 hours

*Occasional desktop printer, chargers, desk fans, speakers etc.

Annual energy consumption for tenant 2 workstations [kW.h/year]= number of workstations x {[average power demand during operation x hours of operation] + [sleep mode power demand x (8760-hours of operation)]}/ 1000

= {11 x [(145 x 2080) + (72.5 x 260) + (72.5 x 390) + (35 x (8760-2730))]} /1000
= {11 x [301 600 + 18 850 + 28 275 + 211 050]}/ 1000
= 6157 kW.h/year

Communal small power consumption [Tenant 2]

Input data:

Typical equipment installed (a)	= 1 photocopier + 2 printers + 1 counter fridge
Average power demand	= 250 W/photocopier + 85 W/ printer + 65 W/ fridge = 485W
Swing shift power demand	= 485W/2 = 242.5W
Sleep mode power demand	= 40 W/photocopier + 10 W/ printer + 10 W/ fridge = 70W
Hours of operation	
[Occupied hours]	= *7 days x 8 hours x 52 weeks = 2912 hours
[Swing shift hours 0800-0900]	= *7 days x 1 hours x 52 weeks = 364 hours
[Swing shift hours 1700-1830]	= *7 days x 1.5 hours x 52 weeks = 546 hours
	= 2912 + 364 + 546 = 3822 hours
Total hours per year	= 8760 hours

*NB: Dubious about 7 hour allocation in TM54

Annual energy consumption for tenant 2 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(485x 2912) + (242.5 x 365) + (242.5 x 546) + (70 x (8760 – 3822))]/1000
= [1 412 320 + 88 513 + 132 405 + 345 660] /1000
= 1978 kW.h/year

Other equipment installed	*= 1 paper punch [150W] + 1 shredder [150W] + 1 heater [3000W] + 1 projector [200W] + 1 Internet hub [10W] + 1 conference call station [10W] + 1 conference mic [20W] + 1 microwave [700W] + 1 coffee machine [670W] + 1 kettle [3000W] + 1 television [190W]*
Average power demand	= 8100W *estimated*
Sleep mode power demand	= 20W *estimated*
Hours of operation	= 5 days x 0.6* hours x 52 weeks = 156 hours *estimated*
Total hours per year	= 8760 hours

**20% increase allowed for due to the 20% increase in occupied hours.*

Annual energy consumption for tenant 2 communal small power [kW.h/year] = [(power demand during operation x hours of operation) + (out of hours power demand x (8760 – hours of operation)]/1000

= [(8100x 156) + (20 x (8760 – 156))]/1000
= [1 263 600 + 172 080] /1000
= 1436 kW.h/year *estimated*

Small server room without local cooling [Tenant 2]

Input data:

Number of server rooms	= 1
Rated power demand of servers	= 0.4 kW
Ratio of rated to operational demand	= 67%
Hours of operation	= 24 hours x 7 days x 52 weeks = 8760 hours

Annual energy consumption for small server rooms (kW.h/year) = number of rooms x rated power demand (kW0 x ratio of rated to operational power demand x hours of operation

= (1 x 0.4 x 0.067 x 8760)
= 234 kW.h/year

Assumptions: Calculations derived from appliance schedule from walk through and server calculations estimated using energy star online calculator accessed at: http://www.eu-energystar.org/en/database/

DSM Results

Heating + Cooling: 7223 kW-h/year *estimated*

Total Tailored Annual Energy Demand [Tenant 3]

Input data:

Days of operation Tenant Area	= 5 days x 52 weeks = 260 days
Tenant occupancy capacity	= 188.5m2
	= 19m2/ fte

Total predicted annual energy consumption (kW.h/year) is equal to the sum of the regulated loads [Hot water + fans, pumps, control + lights + heating + cooling] and the unregulated loads [communal small power + servers + small power for work stations].

= 1331 + 5500 [6831 – 1331] + 6157 + 1978 + 1436 + 234 + 7223

= 23 859 kW-h/year *estimated*

Tenant annual energy use per m2 = Tenant annual energy use/ tenant area
= 126 kW.h/m2

Tennant annual energy use per fte = (tenant annual energy use/ tenant area) x tenant occupancy capacity)
= 2394 kW.h/fte

Monitored Data Calculations

Average Daily January Energy Use [Monitored Data]

	Tenant 1	Tenant 2	Tenant 3
Timescale	0800–1830 [10.5hrs]	0830 –1830 [10hrs]	0600 –1830 [12.5 hrs]
Metered Data [amps]	5093	3064	23696
Metered Data [kW]*	1222	735	5687
Daily Usage [kWh]	116	73.5	454.9
January Daily Average Usage [kWh]	2,320	1,470	9,099

* where $P_{(kW)} = I_{(A)} \times V_{(V)} / 1000$

Average Nightly January Energy Use [Monitored Data]

	Tenant 1	Tenant 2	Tenant 3
Timescale	13.5 hrs	14 hrs	11.5 hrs
Metered Data [amps]	5,665	1,414	12,929
Metered Data [kW]*	1359	339	3102
Nightly Usage [kWh]	100	34	269
January Nightly Average Usage [kWh]	2,000	680	5,380

* where $P_{(kW)} = I_{(A)} \times V_{(V)} / 1000$