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Energy Performance Analysis of Non-Domestic Buildings

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Abstract

The phenomena of more-diffused wealth and relatively cheaper energy have resulted in widespread increase in energy use. With sustainable buildings with low energy consumption becoming the norm these days, the architectural process requires some transformation which makes a worthwhile contribution which thereby reduces the energy consumption of buildings. This project examines why energy performance analysis is considered to be a part of post-occupancy evaluation and how it can mapped into the design process. The analysis was performed for non-domestic buildings which were designed by a Scottish firm via a case study approach. Within the context of green building design, UK and Scottish Legislation, Post Occupancy evaluation, an approach is laid to develop a framework for the methodology. The methodology which involves the knowledge obtained from literature review was then channelled into a process which describes the context of the buildings, to develop an ESP-r model and to perform an environmental analysis to obtain the necessary results. Within each case study a brief description about the building is given followed by the construction of a simple model in ESP-r and finally the results obtained from the environmental analysis and the simulation are tabulated. Moving on, the discussion is structured in such a way that it justifies the energy performance ratings which were awarded to each of the buildings. Post occupancy evaluation being a valuable process, suggestions are also given as to how the building's energy performance can be improved and a conclusion which stresses the importance of energy performance rating and the need for post-occupancy evaluation is also laid out.

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Chapter 1 - Introduction

In past centuries, the relative lack of resources to construct and maintain buildings meant energy-conservative and locally sourced materials were the norm. Since the industrial revolution, especially in the present century, the phenomena of more-diffused wealth and relatively cheaper energy have resulted in widespread increase in energy use. Such price reductions and energy efficient measures have resulted in bringing out buildings which are sustainable within the broad spectrum of social, economic and environmental issues and in this case social spectrum involves the quality of life for people, economic aspects include enhancing wealth and environmental aspects includes those factors which reduce the impact that buildings have on the planet. These aspects of sustainability is open-ended, people's aspirations and perceptions towards sustainability varies widely, and these factors need to be addressed when striving towards green design.

The first oil crisis in 1973 prompted governments to seek sources of energy with a view to reduce dependency on imported fuel. As years flew by, such measures became less urgent. When the second oil crisis sprung out in 1979, society had almost forgotten about the need to conserve energy and now it is predicted that the world will run out of oil in the coming years. Moreover global environmental crisis is impossible to ignore be it the destruction of ozone layer by CFC's, loss of habitat and diversity through pollution, desertification and deforestation, or the ever increasing high levels of CO2 emissions from building heating and other sources. Considering all these aspects to be improved by a wider margin, the focus is currently emphasized on the performance of buildings with key goals pertaining towards reduction of carbon emissions and reducing energy costs. Using sustainable materials and construction techniques which have less impact on the environment are brought to the forefront. To stress out this issue the European Union (EU) have set out their main goals towards reduction of energy consumption and eliminating waste and all these measures are part of the commitments on climate change made under the Kyoto Protocol.

With 40% of the energy consumed by buildings, the EU introduced certain legislations to ensure that energy consumption is reduced over the years and this led to the introduction of the Energy Performance of Buildings Directive (EPBD) which was first published in 2002. Through this scheme came out the practice of introducing the energy certification schemes for all buildings and this seemed to be a great opportunity to mobilise energy efficiency in EU buildings. Additionally UNEP's report *Building and Climate Change* (UNEP SBCI, 2009) states that the building sector accounts for 30% of global annual green house gas emissions and consumes up to 40% of all energy. Given the fact that the massive growth in new construction in economies is on, if nothing is done greenhouse gas emissions from buildings will be more than double in the next 20 years. With *The UK climate change bill (2007)* setting new challenges and targets such as reducing carbon emissions from buildings by 50% margin by the year 2020, delivering 15% of total energy from renewable sources, zero carbon homes and schools by 2016 , imperative green design therefore holds a key factor in reducing the emissions from buildings and it must the cornerstone of every national climate change strategy. In one way or the other EPBD has led to changes in Building regulations and towards Zero Carbon building design/Sustainable Building design. Alongside energy consumption buildings are known to impact ecosystems by means of emissions and these sort of regulations henceforth help to overcome these issues and thereby set tone to a new era of architectural design.

Sustainable buildings are meant to be resilient to any kind of climate change and moreover it must be adaptable, flexible and durable to increase its life-span. The 'cradle to cradle' approach refers to a building that is designed to be deconstructed and where materials are recyclable. Nevertheless, besides designing and constructing a building, architects and building services engineers never check whether a building's energy performance is as expected. This attitude is unacceptable within a zero-carbon context and without taking a step towards knowing the energy performance of the building, there is no solution towards improving the building standards. In order to solve this problem a solution came out which was known as 'Post Occupancy Evaluation' (POE) and POE has been put into practice ever since 1962.

With increasing demand for more energy efficient buildings, the construction industry is faced with the challenge to ensure that the energy performance predicted during the design stage is achieved once a building is in use. However of late, there are significant evidences which show that some buildings are not performing as expected. The practice of 'Post-Occupancy Evaluation (POE)' aims to address this issue by evaluating the performance of the building after it is built and occupied and thereby providing designers with feedback on actual in-use performance. This underlying hypothesis thereby emphasizes that the paradigm for sustainable buildings not only involves a new design process but it should also include a proper evaluation and feedback system which on the whole rejuvenates the architectural design process.

The aim of the project is to analyse the energy consumption usage in support of POE and to underpin the fact that POE is a key factor towards the construction of sustainable buildings. The objective of the project is to perform a Post-Occupancy analysis on current buildings via a case study analysis. This is achieved by engaging with a Scottish Architectural firm called Page\Park Architects and 4 of their award winning exemplar non-domestic buildings were chosen to undertake a energy performance analysis.

The methodology is quantitative, involving data analysis on the energy usage of buildings and comparing this with the benchmark values set out by CIBSE on a per unit floor area basis. A context was established by undertaking a literature review focussing on; green design parameters, UK and Scottish Building Legislation, Evaluation systems, context of POE keeping in mind the sustainability indicators, different POE methods and last but not the least a brief about the CIBSE TM46 benchmark. Alongside this modelling has been carried out in ESP-r to compare and contrast the various predictions proposed by the engineers in their respective design reports for each of the case study buildings.

Chapter 2 - Literature Review

The literature review was undertaken to adopt a methodology and also to set a context. The topics covered in the literature review relate to "green building design, UK and Scottish Building Legislation, the background on POE, today's approach to POE with respect to sustainability indicators and CIBSE good practice indicators including the TM46 benchmark standards. The green building design brings out the need for sustainability in buildings and describes the principles that can bring about this change in the design process and sets context for the UK and Scottish Legislation that are the key drivers for the design and construction of sustainable buildings and along with this, how this helps the built environment today. The POE section outlines the basic definition of what POE is and the importance of it in today's UK construction industry and how it is being suggested to be one of the key elements in improving sustainable building standards. A brief about the various techniques used in evaluation such as the DQM and KPI methods and about the benchmarks against which the energy performance comparison is drawn out are described. This review is thereby helpful in bringing out a common methodology which could be used to analyse the energy performance of buildings in future endeavours.

2.1 Green Building Design

Environmentally friendly, environmentally conscious, energy conscious, sustainable, greener, or simply green architecture- these are the underlying factors that need to be addressed when striving towards a green design. The *vitruvian* code says that there is no straight forward definition for green architecture. The relative use of renewable energy inputs to maximise energy conservation, usage of materials which are non-toxic are all part of the imperative green design. The urgent need to create a new 'sustainable society' was laid out in the book *A Blueprint for Survival* (Goldsmith, 1972). The author concluded that the expanding industrialized society was not sustainable on the grounds that it was damaging the planet's ecosystems and depleting resources. Buildings in some way or the other have an impact on the planets ecosystems by means of CO_2 emissions, energy losses etc and to overcome this new era of architectural design needs to take the forefront. Years later, in *Green Architecture Design for a Sustainable Future* (1991) Vale and Vale described 6 principles that were the basis for the design process

1. Conserving Energy- Building should be constructed so as to minimise the need for fossil fuels to run it.
2. Working with climate- Buildings should be designed to work with climate and natural energy resources

3. Minimising new resources- Building should be designed to minimise the use of new resources and, at the end of its useful life, to form the resources for other architecture
4. Respect for users- A green design/architecture recognises the importance of all people involved with it
5. Respect for site- A building will *'touch-this-earth-lightly'*
6. Holism- All the green principles need to be embodied in a holistic approach to the built environment. (Vale and Vale, 1991)

The importance of green design was clearly laid out in the book *A Green Vitruvius* which stated that in the past centuries the lack of resources to construct and maintain buildings meant energy-conservation measures and locally sourced materials were the norm and this has been a driving force towards bringing out a much efficient greener design. Moreover extensive review brought out the fact that till the nineteenth century only the wealthy could afford thermal baths or orangeries but ever since the industrial revolution and that too in this particular century, the phenomena of more widely-diffused wealth and relatively cheaper energy have triggered a great reduction in the proportional cost of energy and thereby has increased the affordability factor.

It is now impossible to ignore the global environmental crisis, be it the destruction of ozone layer by chlorofluorocarbons or the increasing levels of carbon dioxide by emissions from building heating and other inputs. These are the primary reasons as to why the European Union (EU), national governments and private citizens invoke higher standards of building design. With a view to reduce energy consumption and eliminating wastage the EU set out a legislation called the Energy Performance of Buildings Directive (EPBD). This legislation ensures that able support is laid towards improving energy efficiency and to meet the commitments on climate change made under the Kyoto protocol. Moreover it is under this legislation the introduction of Energy certification schemes for buildings was brought to the forefront. To underpin this scenario the Carbon Trust quoted saying that,

> "Wherever possible, simplicity should be the aim of the design whilst still delivering the performance you require" (Carbon Trust)

The carbon trust thus gives an insight towards planning, building and managing cost-effective low carbon buildings that really work to save carbon emissions and money.

From the vitruvian practice one can clearly say that Green design has other advantages too. The ongoing financial savings which energy efficient design can achieve can be of real importance in daily life, winter heating costs can consume a significant portion of family income, and the extra floor area afforded by a simply constructed sunspace is welcome in many crowded households for spatial as well as economic reasons. The other reason for architects to promote green design is to improve the architectural quality through improved daylight savings, natural ventilation and so on.

Cities of the developed world produce waste and pollution, which contribute to climate change experienced by inhabitants and this has happened before especially in the UK during the industrial revolution which took place in the nineteenth century. In *The Sources of Modern Architecture and Design* (Pevsner, 1968) the author described the evolution of the city from the old era which was described by Ebenezer Howard in his book *Garden Cities of Tomorrow* (1899). Pevsner applauded the contribution of architects towards designing a successful habitat for future. In 1998 as a mark of the urban decline in UK cities the UK government invited Richard Rogers to establish the Urban Task Force to provide an insight into a new vision for the future, and also he emphasized the increasing demand for housing in England (Rogers, 1998).

Richard Rogers had the vision to develop a compact city model similar to older medieval cities. The key factor of this design was to have well designed and managed public spaces and a good mix of basic amenities to facilitate human interaction. In his book *Cities for a small country* (Rogers, 2000) Glasgow is highlighted as a good example of a compact city that was part of the regeneration process. Glasgow had been transformed in the 1980's with the refurbishment of traditional tenements mixed with new buildings. This transformation attracted more people towards city living and a new 'city of culture' was born along with shopping being the prime reputation, Rogers argues. Nowadays Glasgow's reputation has expanded to more than shopping to hosting the Commonwealth games and moreover it has become the first UK city to win a grant from IBM to develop itself as a 'Smart City' where the city can become a much better place to live, work and play.

Figure 1- 'Homes for the Future' Glasgow, Architects: Ushida Findlay, Elder & Cannon, Rick Mather, City of Architecture 1999 (Source: Rogers, 2000)

An update on the Urban task force findings in 2005, provided a mixed verdict on UK's current landscape. There was a definitive increase in people living in city centres but on the contrary new issues have emerged and environmental degradation holds top priority. The report thereby concludes that sustainable design opportunities have been missed in few occasions and thus buildings are units in cities that contribute to waste, energy use and pollution. UNEP's report *Buildings and Climate Change* (UNEP SBCI, 2009) states that the building sector accounts for 30% of global annual green house gas emissions and consumes up to 40% of all energy. Given the fact that the massive growth in new construction in economies is on, if nothing is done greenhouse gas emissions from buildings will be more than double in the next 20 years (UNEP SBCI, 2009). Therefore imperative green design holds a key factor in reducing the emissions from buildings and it must the cornerstone of every national climate change strategy.

2.2 UK and Scottish Legislation

The UK now has a huge opportunity to optimise the energy use of both domestic and business customers, reducing bills through implementation of new equipment, materials etc and at the same time to deliver a more sustainable society. The Carbon Plan which was framed in December 2011 quoted that "Energy efficiency is of critical importance in our long-term energy policy". Edward Davey, Secretary of State for Energy and Climate Change in his foreword quoted that

> "Energy Efficiency belongs at the heart of a low-carbon economy. By reducing energy use and cutting down on waste, we can reduce energy bills, make our energy system more sustainable and drive down greenhouse gas emissions." (Edward Davey, 2009)

From his point of view it is clear that to reduce energy bills more energy efficient buildings should be constructed and not only that it must be made clear that once the building is constructed engineers should make sure that the building is performing as the benchmarks set out by the Government and the other organisations.

The UK Climate Change Bill (2007) set certain challenging targets for carbon reductions across the UK with a commitment to a 50% cut in carbon emissions from the built environment by 2020. Moreover under the EU commitment the UK was destined to deliver 15% of total energy from renewable sources. To achieve this, the zero carbon new building programme is acting as an active driver towards the target. As per the UK government, all new homes should be zero carbon by 2016, all new schools zero carbon by 2016, public sector buildings by 2018 and potentially all new buildings by 2019. With respect to this strategy, *The Code for Sustainable Homes (CSH)* was introduced in 2006. The main aim of this code is to assess the water usage, materials, pollution, energy and CO_2 emissions and to provide an overall rating to the building with respect to the net zero carbon emissions over a year. The calculation of a zero carbon home was given as

> "all energy consumed in the building, the contribution of energy from on-site renewable/low carbon installations, and off-site renewable contributions that are directly supplied to the dwellings by private wire arrangements*"* (UK Green Building Council, 2008)

This definition was recently clarified in July 2010 by the UK housing minister and he reinforced the Government's support for the policy. He was keen in forming a community energy fund through which solutions for off-site generation of renewable energy could be delivered and this same standard was later made applicable to non-domestic and retro-fit buildings.

The Chartered Institute of Builders (CIOB) stressed the importance of whole life calculations of energy Used in building, maintaining and ultimately in the removal of the building (CIOB, 2008). The cradle to grave approach for calculating energy used includes the energy used in manufacturing and transporting the materials. The ultimate message over here is to design buildings that are flexible and adaptable and this in-turn will significantly prolong the life-span of a building. As a matter of fact George Baird in his book *Sustainable Buildings in Practice- What the users think* said that if buildings work well, they will enhance our lives, our communities and our culture. (Baird *et al.,* 2010). Moreover George Baird stressed out the fact that to bring out the environmentally sustainable design into practice, engineers and architects have to outline the design and in addition to this *Building Evaluation* techniques have to be implemented so that one can get feedback from the end user and this in-turn would help the architects to set out improvements that can be dwelled in the buildings which are underperforming.

In August 2007, the Scottish Government appointed a panel of experts to give recommendations as to how performance of buildings could be improved. The outcome was *A Low Carbon Building Standards Strategy for Scotland*, widely known as *The Sullivan Report* (Sullivan, 2007). Of the 56 recommendations which were laid out in the report, most of them are within the remit of the Scottish Building Standards agency. The main aim of the report was to deliver a step change in the legislation, design and construction practice. Looking into the future, this can be an aspiring step to move to a total life of zero carbon buildings by 2030.

The Climate Change (Scotland) Act 2009 passed by the Scottish Parliament in 2009 set out an ambitious target of reducing greenhouse gas emissions by 80% by 2050. As a driving to achieve this target the

Scottish Government formulate a framework which was known as *Scotland's Climate Change Adaptation Framework* (Scottish Government, 2009) is an overarching framework which provides a focus and will drive to foster innovative ways to adapt to climate change across all sectors of the economy.

Legislation and poilices are the pillars and drivers for sustainable buildings. However the level of 'greenness' of a building depends on the ecological approach of the architect and the design team and the need to address the needs and expectations of the end-user more closely are ways of rethinking construction principles towards integration of quality and life-span. Thus one can say that today's ecological movement in architecture can be defined as designing with nature and this is the cornerstone for many of today's sustainable buildings.

2.3 Rethinking Construction

Sir John Egan in his report of the Construction Task Force to the Deputy Prime Minister, John Prescott issued a strong challenge to the construction industry to commit itself to change, so that, by working together a modern industry could be created which from the forefront would be ready to face the new millennium. (Sir John Egan, n.d).

The UK construction industry is at an excellent position due to its capability to deliver the most difficult and innovative projects but apart from that, the industry when looked upon as a whole is under-achieving due to low profitability and low capital investment. To change this scenario the task force identified five key drivers of change which were needed for the industry:

1. Committed Leadership
2. A Focus on the customer
3. Integrated processes and teams
4. Quality driven Agenda
5. Commitment to people

By keeping these factors in mind the task force stressed out the fact that defects in projects should be reduced by 20% per year. (Rethinking Construction, n.d) To be more precise the major cause for defects is client interaction. The work of an architect not only finishes after the design of a house or a building, but on the contrary once the occupants start using the building he/she must take the responsibility of talking to them about the comfort levels in the building, whether there is some sort of refurbishment needed and so on. It is during this point the evaluation system comes to the forefront. The building evaluation system is mainly carried to reduce client dissatisfaction and under-achievement can also be due to the growing dissatisfaction among the clients due to the poor standards and quality of buildings.

The British Property Federations in 1997 conducted a survey on major UK clients as to what they feel about the construction industry and this is what they told:

- More than a third of clients are dissatisfied with contractors' performance in keeping to the price quoted and delivering the final product of required quality.
- More than a third of clients are dissatisfied with consultants' performance in providing a speedy and reliable service when needed.

A recent survey by the Design Build Foundation revealed that the clients expect greater value from the buildings through the improvement of quality of construction, materials used and so on and moreover they feel that this could be addressed by integrating the design process with construction.

Jencks (1997) described architecture from 1950 onwards as traditional, late modern, new modern and post-modern. Jencks was one of the first person to describe the new style of architecture which sprung up in 1970 as 'Post-Modernism'.

> "It was a style of architecture that reacted to the public disillusionment with late Modernism as a result of housing failures and the fragmentation of cities." (Jencks, 1997)

To justify this, CABE and other organisations released a toolkit named as *Rethinking Construction* and in that book they outlined the need to integrate the design process and construction process. Moreover insights from clients were also part of the integration as per CABE,

> "Instead of dealing with parties sequentially, *integrate* the processes and the team around the service/project from the start-at conception. Get them to work together - pull together - with a common vision/goal. And once together - encourage them to try and stay together - to learn and develop so that they become a team, building on each other's strengths" (CABE, 2000)

Apart from this integrated approach, the key element over here is the design of buildings with respect to climate change. Vale and Vale stressed out the need for aesthetic approach in architecture but at the same time they concluded that the designer in the team holds the far reaching responsibility of designing any element of the built environment with an ecological approach. (Vale and Vale, 1991)

Before setting out to design a building the designer should know the importance of a low carbon building in today's scenario. The significant advantage of a low carbon building is that it uses less energy and emits less carbon than the industry benchmarks and at the same it provides a comfortable and productive space. Proper assessment methodologies should be adopted to assess whether the building is a low carbon one or not. Many such methods have evolved over the years such as,

- Part L of the Building Regulations- As per this benchmark, it is quintessential to calculate the building's CO_2 emission rate (BER) in $kgCO_2/m^2$/year. This calculation is based on the energy used for heating, ventilation, cooling and lighting systems.
- Based on the BER, the energy performance certificate (EPC) is calculated and buildings are rated from A-G.

Based on these calculations can actually bring out the predicted performance of a notional building but beyond this point lies the evaluation part, where the actual building has to be evaluated with that of the predictions made.

To bring out the importance of evaluation systems in building design and construction, RIBA brought out a framework called as *The Outline Plan of Work* (RIBA, 2007). This framework was devised to structure the design and construction processes. Many clients and architects use this as a management tool. The design and construction sequence from appraisal to post practical completion is broken down into a series of stages that can be arranged to suit different procurement methodologies. As per the framework the outcomes from the design and construction phases are as follows

1. Pre-design, feasibility and outline brief
2. Concept Design, design intent
3. Schematic design, design development, co-ordination, project brief
4. Detail design, tender and construction information
5. Post-Occupancy Evaluation

From RIBA's point of view, the concept of Post Occupancy Evaluation is part of the design and construction process. The evaluation part is extremely useful, both as a method of formally reviewing the energy and carbon performance of the building, and to gauge whether employees and occupants are satisfied with the building. (Carbon Trust, n.d) In *How Designers Think* (1997) Lawson describes the concept of analysis, synthesis and evaluation as a system that flows throughout the design phases. To bring out sustainable buildings, certain transformations are required in the design process. Kwok (2007) aimed at setting out strategies in his book *The Green Studio Handbook*. He emphasized the fact that sustainable design strategies are forms of giving and influencing the building design concept and along with that he laid out the need for architects to understand the various typologies which hold key during designing such as ecology, building physics and materials, in order to be able to design creatively from the outset of a project. This integrated design attempts to connect buildings and communities with ultimate aim of having minimal environmental impact along with a healthy lifestyle. The main strategies are grouped into topics,

- Envelope
- Lighting
- Heating
- Cooling
- Energy Production
- Water and waste

Post Occupancy evaluation tries to analyse all these factors through means of occupant interaction, comparison with energy benchmarks and provides these inputs to designers for any improvements required and using these data the designers, in future make additional changes whilst designing buildings which sustainable, low carbon type and energy efficient. This holistic approach towards designing is what architects and planners are expected to think and Bokalders (2010) in his book *The Whole Building Handbook* considered this holistic approach as a way of creating a sustainable society through ecological design. Birkland (2002) provides a view of ecological design as an ethic and paradigm for the 21st century. All professionals including architects, can be agents of change provided there existed a belief that sustainable design is intrinsic to the whole transformation process.

Given that green buildings are an important step on the path to a more sustainable society Hyde (2007) attempted at setting out a systematic approach towards the design delivery process in *The Environmental Brief, Pathways for Green Design.* The author argues that clients, designers and contractors are more interested in sustainable building design and the sustainable design encapsulates the economic, environmental and social issues throughout the design process. The Environmental briefing system involves the following

1. Aspirations- sustainable principles, outline brief
2. Divergence- establishing environmental objectives

3. Parameters- site and climate, environmental criteria, legislation and whole life costing
4. Environmental Strategies- passive/active systems design, material specification
5. Applications- design testing
6. Outcome- project brief

2.4 Post Occupancy Evaluation- Background

"Post Occupancy Evaluation (POE) is an umbrella term that includes a review of the process of planning, delivering and completing a project, as well as a review of the technical and functional performance of the building during occupation. This includes user views and experience" (Scottish Funding Council, 2007)

Post-Occupancy evaluation is not a new idea and was part of the RIBA outline plan of work as early as 1962. This framework serves as a guide of suggested work stages for the process of managing and designing a building projects. Formal feedback was, however not part of the design process and stage M was remove in 1972 but was later reintroduced in 2003 as feedback review i.e Part L (L3 review of project performance in use). Bill Bordass and Adrian Leaman set up Building Use Studies (BUS) in 1981 and are considered as the pioneers of POE. They have collected data from over 450 buildings around the world and have paved way to underpin government policy and the development of EPC ratings. The Post Occupancy Review of Buildings and their Engineering (PROBE) are a series of case studies on 'real buildings' which were carried out from 1997 to 2002 by the Building Services Journal and this programme was funded by the UK government. The PROBE approach taken was in depth, involved review of design and included technical survey, energy survey with respect to CIBSE TM22 analysis and additionally an occupant survey was also done. All these criteria of the PROBE studies are considered as a valuable source of insight into generic issues in the building design and construction process.

Bordass (2001) in *Assessing Building Performance in Use* reviewed the various PROBE reports and he came out with a valid point saying that, the emphasis is laid on improving the efficiency and production of the UK construction industry and that the performance of buildings is not revisited in the PROBE reports. The underlying point here is that feedback very often uncovers the successes that were overlooked and common re-occurring problems need to be addressed to move towards the triple bottom line of sustainability in the design process.

"Factors for success include making sure essential features are in place; seeking simplicity, usability, manageability and responsiveness; identifying and managing downside risks; a culture of feedback" (Bordass, 2001)

George Baird also quoted the importance of Building Evaluation in *Sustainable Buildings in Practice- What the users think* and stressed out the need to advance the practice of environmentally sustainable building design.

"Building Evaluation is well established as a concept. Most of the techniques described have reached the current level of sophistication through a process of development and refinement over the last two decades. The main opportunity for further innovation in their application. Through evaluation, people get commercial, organisational, operational, and design intelligent and make confident, successful decisions about buidings and operations within buildings. Few, if any, other tools offer such potential for radical improvement in the way we manage, design, and use individual buidlings." (Baird *et al.*, 1996: xxi)

During the 1990's world conferences evoked interest in all round performance of buildings and sustainability. During the Earth Summit in Rio de Janeiro in 1992, a framework was put in place and documents emerged from the gathering nations and served as blueprints for future sustainable development. One such highly influential document was *Agenda 21* and it set out a global agenda which was sanctioned by the international community. This was later developed as *Local Agenda 21* for use by local communities and defined social, economic and environmental targets by means of sustainability indicators. As a common matter of fact, sustainable development has three facets, environmental, economic and social and the most widely used description is,

"Development that meets the needs of the present without compromising the ability of future generations to meet their needs" (Bruntland, 1987)

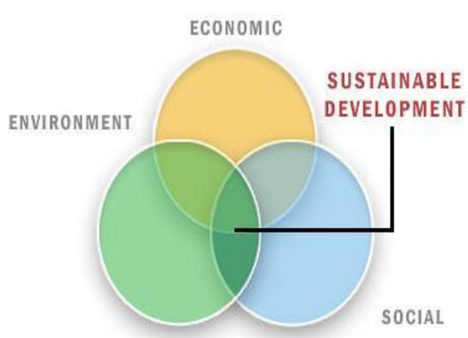


Figure 2- Facets of Sustainable Development

To support this statement and definition of POE, CABE's report shows that well-designed buildings are a significant factor in the recruitment of staff and students in higher education and to be more effective building evaluation system must happen throughout the lifecycle of the building and feedback seems to be an intrinsic part of good briefing and design of buildings. POE on the whole serves the following purposes:

Short term benefits

- Identification of and finding solutions to problems in buildings
- Response to user needs
- Improve space utilisation based on feedback from use
- Understanding of implications of change whether it is budget cuts or working context
- Informed decision making (Guide to Post Occupancy Evaluation, 2006)

Medium term benefits

- Built-in capacity of building adaptation to organisational change and growth
- Finding new uses for buildings
- Accountability for building performance by designers (Guide to Post Occupancy Evaluation, 2006)

Long term benefits

- Long-term improvements in building performance
- Improvement in design quality
- Strategic review (Guide to Post Occupancy Evaluation, 2006)

The best benefits from POE comes when the information is made available to as wide an audience as possible, beyond the institution/office whose building is evaluated, to the whole further educational/industrial sector and construction industry. Information from POEs can provide not only insights on a problem, but it also provides data to set out benchmarks with which other projects can be compared.

There is a range of POE techniques in use today and the Usable building trust (UBT) assembled a portfolio which shows a comparison of various POE methods such as Design Quality Indicators (DQI), Key Performance Indicators (KPI) and other methods. Design Quality Indicators for example gather the user's views on function, build quality and impact (Usable Buildings Trust, 2002)

2.5 Post Occupancy Evaluation - Context

The Building Research Establishment Environmental Assessment Method (BREEAM) is a sustainability evaluation used for all public buildings. This voluntary scheme aims to quantify and reduce the environmental impact of buildings by rewarding clients with a industry recognised environmental label. The BREEAM methodology is used in different sectors such as education, custodial, commercial, healthcare, industrial and so on. There are certain standard groupings under which the buildings are assessed

1. Management
2. Energy
3. Transport
4. Health & Well-being
5. Water
6. Materials
7. Operational Waste
8. Land use
9. Ecology
10. Pollution

Credits are awarded under each category and an equal environmental weighting is applied to calculate the overall rating and thereby buildings are rated as pass, good, very good, excellent or outstanding. One basic criticism of BREEAM from outside experts is that it is related to the installation of technology that could result in sustainable benefits, but it does not measure the performance in use. In a way to rethink the BREEAM approach BRE have launched BREEAM IN-USE methodology which is intended for building managers to self assess the performance of their building and in addition to this certification can be provided when audited by a third party. (BRE, 2010)

'The Movement for Innovation' was formed in 1998 to implement the recommendations that were laid out in the UK government's Task Force's report *Rethinking Construction* (Strategic Forum for Construction, 1998). This movement set out key environmental performance indicators (m4i) which are a set of 6 indicators for measuring environmental sustainability and they are listed below

1. Operational Energy
2. Embodied Energy

3. Water
4. Waste
5. Biodiversity
6. Transport

M4i does not however, deal with the broader social and economic issues of sustainability such as occupant satisfaction or impact on the community.

2.6 Framework for a Post Occupancy Evaluation and the various Post Occupancy Techniques

POE is relevant only if there's a particular approach which ideally considers all elements necessary to bring out a good and proper evaluation and this efficient approach depends on what will be reviewed, the level of detail that is needed and when the evaluation is to be carried out. The focus of POE is considered in three broad areas: *Process, Functional Performance and Technical Performanec* and the different aspects under each area was outlined clearly in *Guide to Post Occupancy Evaluation.*

Process Evaluation

The first aspect under this is the delivery of the project from the inspection stage to the handover stage, this approach looks at how the project was delivered and how the decisions were arrived at. The next is the operational management, where questions are asked to the estates team as to how well they manage the buildings.

Brief	The way in which the team developed the brief on which the design was based including financial management aspects.
Procurement	The way in which the team selection, contractual and technical processes were undertaken including time and value aspects.
Design	The way in which the team developed and refined the design including space planning, engineering and financial management aspects.
Construction	The way in which the construction phase until handover was managed, including financial and change management processes.
Commissioning Process	The way in which the final commissioning of the building was managed, including final adjustments and the provision of documentation.
Occupation	The way in which the handover process was managed including the rectification of last-minute snags and the removal/relocation process.

Table 1- The areas covered in a Process Evaluation

Functional Performance

This aspect addresses the fact that how well the building supports the institutions organisational goals and aspirations and additionally it addresses the fact as to how well the user needs are supported.

Strategic Value	Achievement of original business objectives
Aesthetics and Image	Harmonious, neutral, iconic, powerful, bland
Space	Size, relationships, adaptability
Comfort	Environmental aspects: Lighting, temperature, ventilation, noise and user control
Amenity	Services and equipment: completeness, capacity, positioning
Serviceability	Cleaning, routine maintenance, security, essential changes
Operational Cost	Energy Cost, water and waste, leases, cleaning, insurances
Life-Cycle Cost	Initial construction cost, cost of operating, maintenances and repairs, replacement costs, alterations, demoliton
Operational Management	Booking and space allocation systems, user support systems, help desks manuals, training

Table 2- The areas covered in a Functional Performance Evaluation

Technical Performance

This aspect involves measuring how the physical systems perform, for example lighting, energy use, ventilation and acoustics.

Physical Systems	Lighting, heating, ventilation, acoustics
Environmental systems	Energy Consumption, water consumption, CO_2 output
Adaptability	Ability to accommodate change
Durability	Robustness, need for routine extensive maintenance, incidence of "down time" for unplanned technical reasons

Table 3- The areas covered in a Technical Performance Review

As earlier explained, since CIBSE TM22 analysis and other such processes are widely regarded as a valuable source of insight into generic issues of building design and construction processes, it was quite important to keep in mind that the designs do not miss their targets. The Usable Buildings Trust has assembled a portfolio of POE techniques, it shows a comparison of various DQI, KPI and POE methods that are commonly used on projects today.

The Design Quality Method (DQM) is widely used today to assess new college and university buildings and moreover all projects funded by the Scottish Funding Council use this assessment method. The ultimate motive of carrying out a POE is to demonstrate the expenditure of public funding and to keep improving the briefing process of future projects and this strategy aims to ensure best practice and value for money.

UBT Feedback Portfolio: Techniques

This page: Sector [Where used in life cycle] [Development, Publication and Practical Details] →

Showing: Sustainability [All] [Facilitated_discussions] [Packages_of_techniques] [Process_improvement] [Questionnaires_and_interviews]

	Defence	Education		Health	Offices		Leisure	Housing	Other
	Defence	Higher education	Schools	Health	Public sector	Private sector	Sports	Housing	Other
AMA Workware Toolkit					Y	Y			
ASTM Standards									Generic
BCO POE Method									
BRE Design Quality Method	To some extent	To some extent	Y	Y	Y		To some extent		
BRE Toolkit									
BREEAM	Possible	Y	Y	Partial	Y	Y	Y		
BUS Occupant Survey	Partial	Y	Y	Partial	Y	Y	N	Y	Possible
CIBSE TM22 energy survey	N	Y	Y	Y	Y	Y			
CIC DQIs	Partial	Y	Y		Y	Y			
DEEP	Y								
DQI for Schools			Y						
Healthcare Design Quality		Y						Possibly ...	
HEDQF POE Forum		Y	Tested	Tested					
Learning from Experience	Y	Y	Y	Y	Y	Y	Y		
MARU Evaluation Studies				Y					
NEAT				Y					
Overall Liking Score					Y	Y			
POE 1st year Occupancy									
POE Getting Started									
Probe	N	Y	Y	Partial	Y	Y	Partial		
School Assessment			Y						
School Works			Y						
Soft Landings		Y							
UoD Healthcare POE Method				Y					

Figure 3- USB POE portfolio- different POE techniques

To be more innovative, embedding of Post-Occupancy Evaluation throughout the project lifecycle is through the implementation of *The Soft Landings Framework* (Way, 2009) by the UBT/BSRIA in 2009. The main intention of the framework is to unite all disciplines and stakeholders beyond hand over stage, various levels of POE techniques such as a 3-6 month walk round and questionnaire, a 1 year subjective and objective measurement, to a full 3 year aftercare service. The overall philosophy of this approach is to engender a collaborative approach between client, design team, and users, in a spirit of openness and non blame culture. (Way, 2009)

From the above discussion about the need for sustainable building design, integration of processes, building evaluation techniques and so on, it is clear that in today's scenario POE is far from routine but on the contrary it is emerging, alongside the growth of the sustainable agenda. Clients, designers and governments are becoming more interested in building performance and some require POE to be included as part of the contract document. In this way, post occupancy evaluation closes the loop in the sustainable design process and the lessons learned can inform future briefs and design.

Chapter 3 - Methodology

This chapter describes the work undertaken in evolving a methodology for a Post Occupancy evaluation. In approaching this project, knowledge gained from literature review needed to be channelled into a process to build an effective methodology for evaluating a building. One such aim was to blend aspects of sustainability such as evaluation of CO_2 emissions to the existing POE methodologies and then bring about a modelling approach to interpret the data given by the designers. Finally a data analysis to study the actual performance of the building was necessary to show the true facets of the building and to prove that POE is an effective tool for sustainable architecture.

3.1 Context

To start with, 4 non-domestic award winning buildings designed by Page\Park Architects were chosen as case studies for this project. Following the selection of the buildings, it is quintessential to understand the context behind the building design and construction. This understanding of the context of the building paves way for engineers to list out the pro's and con's of the building, in terms of materials used for construction, type of lighting systems, energy saving measures introduced and the different mechanical and electrical services installed within the building. Information on daily building use and environmental systems is amassed at this stage.

3.2 Modelling

ESP-r is an open source building simulation program developed for the simulation of thermal, visual and acoustic performance of buildings and the energy use associated with environmental control systems. The program allows the user to accurately simulate a buildings performance within a given set of climate data. For this project ESP-r was used to build a model i.e. one section for all the 4 non-domestic buildings.

ESP-r being a research tool, undergoes constant upgrading, tweaking and expansion of its abilities from the wide number of users throughout the academic world. So at times, it is necessary to use a stable version of ESP-r to model and get the accurate results. Furthermore to effectively build a simulations model, certain assumptions and factors had to be considered to make the model less vulnerable and to get accurate results.

Overview of Approach

The main aim of the modelling aspect in this project is to cross check the energy consumption predictions proposed by the designers and M&E engineers in their respective design reports for each of the 4 buildings. For all buildings the designers have used a 3D simulation software called as IES and corresponding outputs related to temperature and humidity levels inside the building were also obtained from IES. For this project, sections of each building were modelled (based on certain assumptions) using the architectural plans and sections and simulations were run in ESP-r to obtain the temperature results for a period of 12 months. For a model to be drawn and simulated in ESP-r, certain assumptions were made in order to make the model properly "bounded" and additionally to accurately reflect the U-values of the walls and the other surfaces.

To assist in developing the ESP-r model and determining what kind of simulations would need to be run, it was quintessential to identify the variables which could possibly have an effect upon the model simulation. The factors that could possibly influence the internal temperature and humidity levels of the building were,

- Casual gains from Occupancy
- Casual gains from equipment
- Casual gains from lighting
- Materials used for construction of external walls
- U-values of each surface
- Building orientation - depending on the type of building and site location

Heating and lighting strategies from their respective mechanical and electrical services has not been considered as an important factor for this modelling due to the time scale and complexity involved in them. Moreover similar kind of results as predicted by the designers have been obtained by considering the above mentioned factors.

Of the above listed factors occupancy and construction materials hold the first priority. Based on the CIBSE description of the buildings, certain occupancy assumptions were made to simulate the model, all such occupancy gains are listed in the case study section of the report. Since the buildings are all located in Scotland and owing to the climatic condition of the place, simulations were performed for the summer and winter months and the corresponding temperature and Relative Humidity outputs were obtained and cross checked with those outputs proposed by the designers in their respective design reports.

3.3 Environmental Analysis

The environmental analysis was performed to check the accuracy of the energy efficiency ratings for each building and the appropriateness of the awards which were given to each of the buildings. This involved comparing actual utilities data for each building with existing benchmarks in an Excel spreadsheet. The comparisons were drawn out between the performance of the building with the benchmark data from the Chartered Institute of Building Services Engineers (CIBSE) Guide L and TM46: 2008. These benchmarks allows to monitor the energy performance of the buildings and additionally provides an opportunity to compare the energy consumption in terms kWh/m^2 of the building.

By this approach, instantaneous observation and subsequent abnormalities in the energy use can be easily isolated through graphical outputs. Based on the data given, analysis was done on the following building parameters: heating, electricity and CO_2 emissions. This analysis was performed since it was considered to be the key area of performance and moreover it was one of the areas which could be analysed within the time frame of the project.

CIBSE TM46 is a benchmark which was convened at end of July 2007 and this was adopted by the CIBSE benchmarking group to form the basis of the statutory operational rating and procedures to implement the Energy performance regulations. There are currently 29 benchmark categories, and each category contains certain number of buildings. For each of these buildings benchmark values are expressed in terms of delivered energy used per unit of floor area (kWh/m^2), for both electrical and fossil fuel energy use. For operational rating purposes, these values are converted to carbon dioxide emissions per unit area ($kgCO_2/m^2$) for both electrical and fossil fuel energy use. Details of the categories and the subsequent benchmark values are given in appendix B.

To calculate the carbon dioxide emissions from the electrical and fossil thermal usage certain conversion factors were used and these are listed below

CO_2 Equivalents	$kgCO_2/kWh$
Biomass	0.025
Electricity	0.422
Coal	0.291
Natural Gas	0.194
Waste Heat	0.018

Biogas	0.025
LPG	0.234
Oil	0.265
Coal	0.291

Table 4- CO_2 Conversion Factors (CIBSE Guide L)

Based on these conversion factors the necessary emission values were calculated and suitable comparison were drawn out for all buildings. The graphical outputs obtained from the environmental analysis are outlined in the results section under each case study.

Chapter 4 - Case Study A: Loch Lomond and Trossachs National Park, Authority Headquarters

Loch Lomond and the Trossachs National Park Authority Headquarters is a leisure facility developed to provide a healthy, enjoyable, low-energy and sustainable working atmosphere. With the construction of a two-storey structure frame building with state of the art sustainable practice, the building was awarded a BREEAM 'Excellent' certificate in 2005 (Appendix---) From then on it has been a huge task for the building engineers and architects to maintain this same standard and to provide the same comfort level for all occupants.

Figure 4- Loch Lomond and Trossachs National Park Headquarters (Source: nationalparks.gov.co.uk)

4.1 Background & Context

The building is a two storey office building with an area of approximately 2200m^2. It is situated on the edge of a Scottish town close to a railway station and accommodates around 130+ staff and outside agencies. Accommodation within the building is used by community groups at times and the building has been in use ever since April 2008.

Low Carbon Design

The building had a low carbon brief at the design/development stage and achieved a BREEAM excellent, the industry benchmark for sustainable design. The low energy design is achieved by the building by

- having U-values 20% better than regulations
- improved air tightness,

- use of natural ventilation
- maximising daylight
- thermal modelling

The design efficiencies to reduce energy use include PIR (presence detection), lighting controls and BMS (Building Management System) and along with that a biomass boiler is used for heating and hot water. Many of the materials chosen have low embodied energy- stone, slate, sheep's wool insulation and timber, including green timber for the structural frame. The building consists of several rooms such as reception, meeting rooms, kitchens, fitness area, changing area and so on and the maximum temperature in all these rooms are around 22°C +/- 1°C

Lighting System

The building has been designed to bring in daylight and this can be quoted as an important contribution to sustainability since the amount of energy used for artificial lighting is reduced by a considerable margin. The Park Authority HQ allows majority of internal spaces to benefit from sufficient quality and uniformity of daylight so that they can be used with reduced artificial lighting from April to September. The artificial lighting system of the Park Authority included the installation of intelligent controls to dim down/ switch off lights when sufficient daylight enters a space. Fluorescent fittings with high frequency ballasts were fitted to reduce flicker and increase efficacy. Within the floor spaces high frequency fluorescent luminaries are suspended to ensure high lighting efficiency and to provide a brighter appearance to the environment.

Ventilation

As earlier mentioned, the building incorporates a natural ventilation system wherever possible and the designers have used the simplest and common way to provide this by keeping open windows. Additionally certain acoustic measure were taken in order to prevent noise intrusion into the building through the open windows and one such way was the provision of a facade furthest from the road. Although in areas like toilets, changing rooms and kitchens mechanical ventilation has been installed and along with that AHU are installed which recover the heat from these areas through thermal wheels and recuperators.

Mechanical Services

The water and energy resources locally available easily satisfied the requirements of the Park Authority HQ and henceforth a biomass boiler was installed. A lifecycle cost analysis was performed at the design to identify the cost of wood pellets needed for the biomass boiler and this showed that wind turbines and biomass were the cost effective methods which could eventually offset the CO_2 emissions. Moreover since the authority was involved in the trimming of forests, running cost of wood pellets was also reduced and this created a healthy income for the Park Authority. Since the biomass boiler is sized to supply base load (2/3 full load) a gas boiler has been installed to provide back-up with means of using it to 'top-up' the heating system when the demand is more than expected. The heating system used in the building is a Low temperature hot water (LTHW) system and the source of heat to power this heating system is the biomass boiler.

4.2 Modelling

4.2.1 Approach and Assumptions

ESP-r as a software has its very own complications but on the other hand it is one tool which can predict the energy performance of a building. With the time scale available it was feasible to model only one section (reception) using the software. The available details for this were plans and elevation diagrams of the building which are detailed in appendix A. Since the building has been constructed using low carbon techniques it was necessary to bring about the same kind of model in ESP-r, but since the original building has been constructed with advanced low carbon materials and due to the lack of details pertaining to these materials used the model thus developed is not architecturally accurate i.e. materials used for the walls and floors are different, the reception in reality will look different in size and structure. However the materials have been chosen in a way to maintain the same U-values as mentioned by the architects and the results obtained from the simulation are more or less close to the prediction.

The initial factor to be considered to model a building in ESP-r is the simplified box approach which is a representative version of the real-life situation but still with sufficient level of detail to produce usable results. The design report pertaining to the building quoted that the internal temperature throughout the building was the same and that for this building a natural ventilation system had been installed. To develop a plant system such as a natural ventilation or a mechanical service system such as a boiler sufficient information related to the different components used is necessary and with no details regarding these were available and the complexity of developing a plant system in ESP-r, this aspect was not considered but it was felt that reasonable results have still been able to be obtained.

4.2.2 Materials and Construction

As earlier explained in the background and context section, a low carbon design approach has been incorporated whilst designing the building. The composition of the wall for this building is shown below

Construction type

Element : Wall - Insulated timber framed wall

Timber framed wall

Internal surface emissivity : High External surface emissivity : High

Construction	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^2K/W)	Vapour Resistivity (MNs/gm)	Vapour Resistance (MNs/g)
Outside surface resistance	-	-	0.040	-	-
Limestone	250.0	2.000	0.125	60.00	15.00
Vented cavity	50.0	-	0.179	-	0.00
Breather membrane (BS5250)	-	-	-	-	0.50
Ply sheathing	19.0	0.143	0.133	450.00	8.55
Thermafleece insulation	100.0	0.038	2.600	5.00	0.50
Thermafleece insulation	50.0	0.038	1.300	5.00	0.25
Polythene,1000 gauge (0.25mm) (BS5250)	-	-	-	-	500.00
Gyproc Wallboard	12.5	-	0.070	-	0.75
Inside surface resistance	-	-	0.130	-	-

U-value - 0.24W/m²K

Figure 5- Composition of external wall

ESP-r does not have the materials listed above and therefore modelling the exact wall composition was not possible, however as earlier mentioned the U-values have been maintained as a constant factor when materials were chosen for this model. Since the thickness of the external walls are around 250mm materials were chosen according to the maximum thickness of the walls. With the same intent materials were chosen for the internal walls, base floor and ceiling. As per the design report the recommended U-values for the walls is 0.25 W/m^2K, for the floor it is 0.35 W/m^2K and for the door the recommended value is 2.0 W/m^2K. The list of materials used for this model is shown below

Internal Wall (U-value is 0.27W/m2K) is used for Wall 1, Wall 3 an Wall 4								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	paviour	1	100	0.96	2000	840	0.93	0.7
2	Glasswool	211	60	0.04	250	840		
3	Plasterboard (Uk code)	112	100	0.21	900	1000	0.91	0.7

External Wall (U-value- 0.25W/m2K) is used for Wall-2								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Lt Brown Brick	6	100	0.96	2000	650	0.9	0.7
2	Glasswool	211	75	0.04	250	840	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Breeze block	2	100	0.44	1500	650	0.9	0.65

Ceiling (U-value is 0.32 W/m2K) is used for the surface Top-5								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Glasswool	211	100	0.04	250	840	0.9	0.3
2	Ceiling Material	150	10	0.03	290	2000	0.9	0.6

Figure 6- Composition of Materials as chosen from ESP-r for Loch Lomond Reception area

Floor (U-value is 0.4 W/m2K) is used for the Base surface								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Wilton	221	6	0.06	186	1360	0.9	0.6
2	Chipboard	67	19	0.15	800	2093	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Heavy Mix Concrete	32	140	1.4	2100	653	0	0
5	Steel	42	4	50	7800	502	0.12	0.2

Door (U-value is 2.2 W/2K								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Oak	69	25	0.19	700	2390	0.9	0.65

Figure 7- Composition of Materials as chosen from ESP-r for Loch Lomond Reception area

4.2.3 Geometry

As earlier mentioned a rectangular model of the reception area was created owing to the simplicity of the dimensions given in the building plan. The figure below shows the geometry of the reception

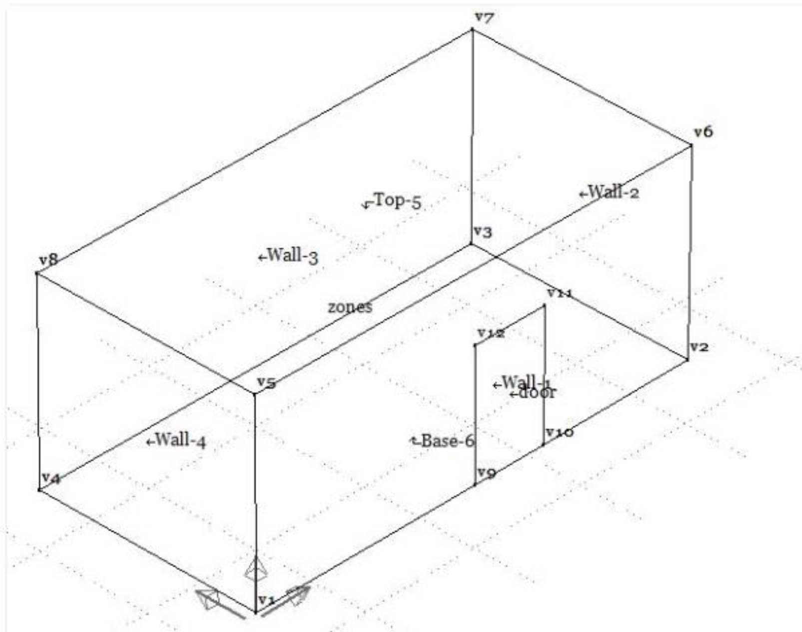


Figure 8- Reception area of the Park Authority HQ

The dimensions for this reception area was taken from the section plans and elevation diagrams provided by Page\Park Architects and are detailed in appendix A. As previously mentioned the building has a natural ventilation system installed but due to the constraints and the complexity involved in it, the definition of the ventilation was not possible within the time scale available for the project.

4.2.4 Internal Gains

The main internal gains to be defined for the model are those of occupancy and lighting gains. The occupancy gains were roughly based on an assumption that the reception area would have around 5 people working throughout the day. Furthermore an operational schedule had to be defined before assigning the sensible and latent gains for the occupants, the occupancy schedule for the Park Authority HQ were based on reasonable assumptions as with those of an office building with likely openings on weekends as well and thus the occupancy schedule was defined as follows

Day	**Time (i.e. 9am - 5pm)**
Monday	7am - 5pm
Tuesday	7am - 5pm
Wednesday	7am - 5pm

Thursday	7am - 5pm
Friday	7am - 5pm
Saturday	10am - 4pm
Sunday	10am - 4pm

Table 5- Average Occupancy Periods

Within the software the average gain of an individual is 100W sensible and 50W latent. For this building based on this operational schedule the occupancy for 5 people was defined as follows

- Sensible gain - 315.05W (63.01W/person)
- Latent Gain - 271.405W (54.281W/person)

Additionally lighting gains had to defined but since the building has daylighting techniques only 50% gain from the lighting sources was defined. Within the software the average gain for a light bulb is 100W sensible and 0W latent. For this building since fluorescent lights are installed, the lighting gain was defined as 40W sensible and 0W latent and this assumption was based on the fact that dimmers were installed to turn off the artificial as and when needed.

4.2.5 Simulation

With the ESP-r model now defined it was possible to begin simulations for the reception model of the Park Authority HQ to verify how the results differed from those mentioned by the designers. Since the model is not accurate and based on the underlying assumptions it is a known fact that there would be a significant variation in the internal temperature and RH values. Simulations were run for two climate presets,

- Summer: 01 June 2012 to 01 August 2012
- Winter: 09 January 2012 to 09 February 2012

From ESP-r the results are obtained as graphs which thereby clearly show the temperature and RH distribution inside the reception area for the defined seasonal information. The results thus obtained are shown in the results section of this case study.

4.3 Environmental Analysis

As per the CIBSE TM46 benchmark the Loch Lomond and Trossachs National Park Authority HQ falls under the category of a general office building which has an operational schedule of weekday openings and early evenings and the services included in the building are heating, lighting, cooling, employee appliances, standard IT and basic tea room. As earlier explained in the methodology part, the monthly energy consumption data in kWh was converted to the energy consumption for per m^2 of floor area. This metered energy consumption data was then converted to equivalent amounts of CO_2 emission in terms of $kgCO_2/m^2$ and for this calculation the following conversion factors were used

Fuel Used	Conversion Factor ($kgCO_2/kWh$)
Biomass	0.039
Gas	0.234
Electricity	0.422

Table 6- CO_2 conversion factors for electricity, biomass and gas

In this case, data analysis was done for the year 2009 for which the data was collected from the BMS installed in the building. Since the building has both the biomass boiler and the gas boiler installed, two different fuel sources are used i.e. biomass and gas. To calculate the CO_2 emission from the biomass boiler, the energy consumption value (kWh/m^2) of the biomass boiler is multiplied by the corresponding conversion factor for biomass which is 0.039 $kgCO_2/kWh$. The energy consumption values and the corresponding CO_2 emission values for the year 2009 are given below

Month	Biomass Boiler In-use consumption (kWh)	Biomass Boiler In-use consumption per m2 of floor area (kWh/m2)	CO2 emission from Biomass Boiler (kgCO2/m2)
April	0.00	0.00	0.00
May	0.00	0.00	0.00
June	0.00	0.00	0.00
July	2320.68	1.04	0.04
August	9862.87	4.43	0.17
September	11023.21	4.95	0.19
October	11603.38	5.21	0.20
November	34810.13	15.62	0.61
December	27848.10	12.50	0.49
January	31329.11	14.06	0.55
February	31329.11	14.06	0.55
March	6962.03	3.12	0.12

Figure 9- Monthly energy consumption from the biomass boiler and the corresponding CO_2 emission values for the year 2009

To calculate the CO_2 emission from the gas boiler, the energy consumption value (kWh/m^2) of the gas boiler is multiplied by the corresponding conversion factor for gas which is 0.234 $kgCO_2/kWh$.

Month	Gas Boiler In-Use Consumption (kWh)	Gas Boiler In-Use Consumption per m2 of floor area (kWh/m2)	CO2 emission from Gas boiler (kgCO2/m2)
April	0	0	0
May	0	0.00	0.00
June	0	0.00	0.00
July	0	0.00	0.00
August	0	0.00	0.00
September	0	0.00	0.00
October	0	0.00	0.00
November	0	0.00	0.00
December	8264	3.71	0.87
January	8662	3.89	0.91
February	7150	3.21	0.75
March	4226	1.90	0.44

Figure 10- Monthly energy consumption from the gas boiler and the corresponding CO_2 emission values for the year 2009

Month	Electricity Consumption (kWh)	Electricity Consumption per m2 of floor area (kWh/m2)
April	0	0.00
May	0	0.00
June	0	0.00
July	0	0.00
August	11080	4.97
September	12544	5.63
October	11754	5.28
November	18775	8.43
December	14398	6.46
January	13967	6.27
February	15613	7.01
March	7509	3.37

Figure 11- Monthly electricity consumption for the year 2009

To calculate the CO_2 emission from the electrical sources, the energy consumption value (kWh/m^2) of from electricity consumption is multiplied by the corresponding conversion factor for electricity which is 0.422 $kgCO_2/kWh$.

Month	Electricity Consumption per m2 of floor area (kWh/m2)	CO2 emission from Electrical Source (kgCO2/m2)
April	0.00	0.00
May	0.00	0.00
June	0.00	0.00
July	0.00	0.00
August	4.97	2.10
September	5.63	2.38
October	5.28	2.23
November	8.43	3.56
December	6.46	2.73
January	6.27	2.65
February	7.01	2.96
March	3.37	1.42

Figure 12- CO_2 emission from electricity for the year 2009

The calculated energy consumption values were then compared with the CIBSE benchmark values prescribed for this sort of building which are detailed below

Building Type	Electricity Typical benchmark (kWh/m^2)	Fossil-Thermal typical Benchmark (kWh/m^2)
General Office	95	120

Table 7- CIBSE TM46 energy consumption benchmark for an office building

Building Type	Electricity Typical benchmarl ($kgCO_2/m^2$)	Fossil-Thermal typical Benchmark ($kgCO_2/m^2$)
General Office	52.3	22.8

Table 8- CIBSE TM46 CO_2 emission benchmark for an office building

4.4 Results

The results obtained from the simulation of the model in ESP-r and the energy comparisons drawn with the CIBSE benchmark values are enclosed in this section

Modelling

Summer

The internal temperature output for the summer months simulation is shown below. This output is obtained for 5 occupants with a sensible gain of 315W and a latent gain of 54W.

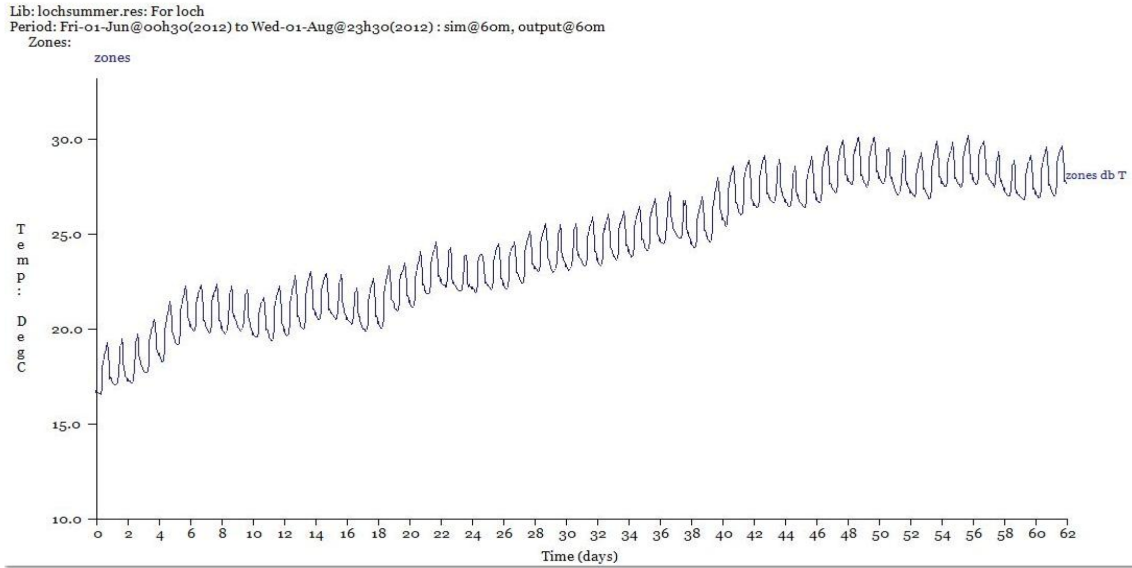


Figure 13- Temperature output from ESP-r for the summer month simulation

The relative humidity output for the summer month simulation is shown below. This simulation has been carried for an occupancy level of 5 people with a sensible gain of 315W and a latent gain of 54W.

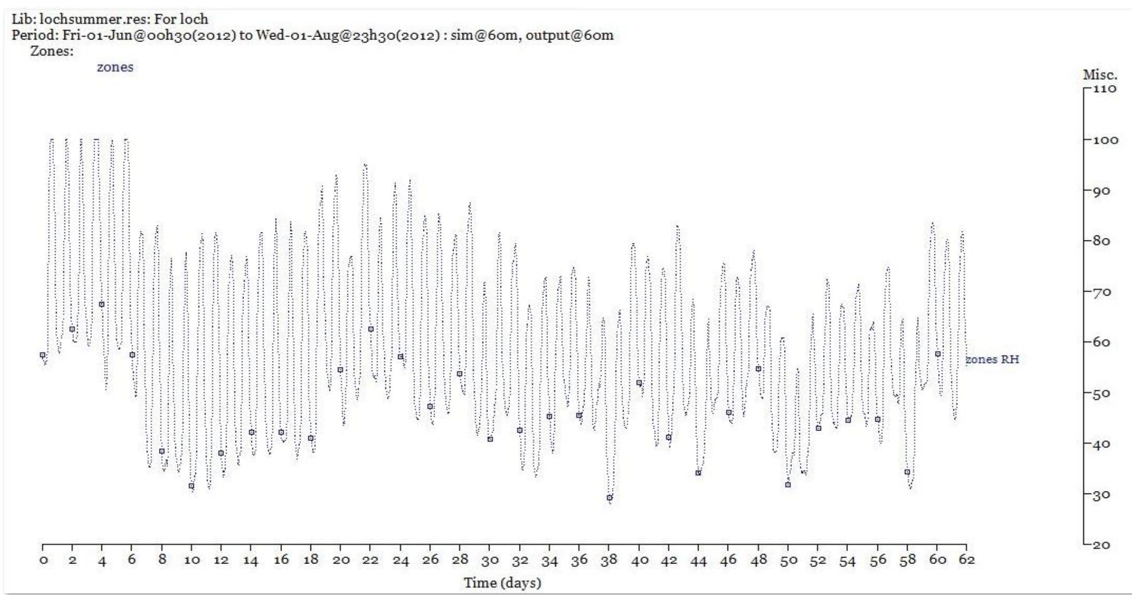


Figure 14- RH output from ESP-r for the summer month simulation

Winter

The internal temperature output for the winter months simulation is shown below. This output is obtained for 5 occupants with a sensible gain of 315W and a latent gain of 54W.

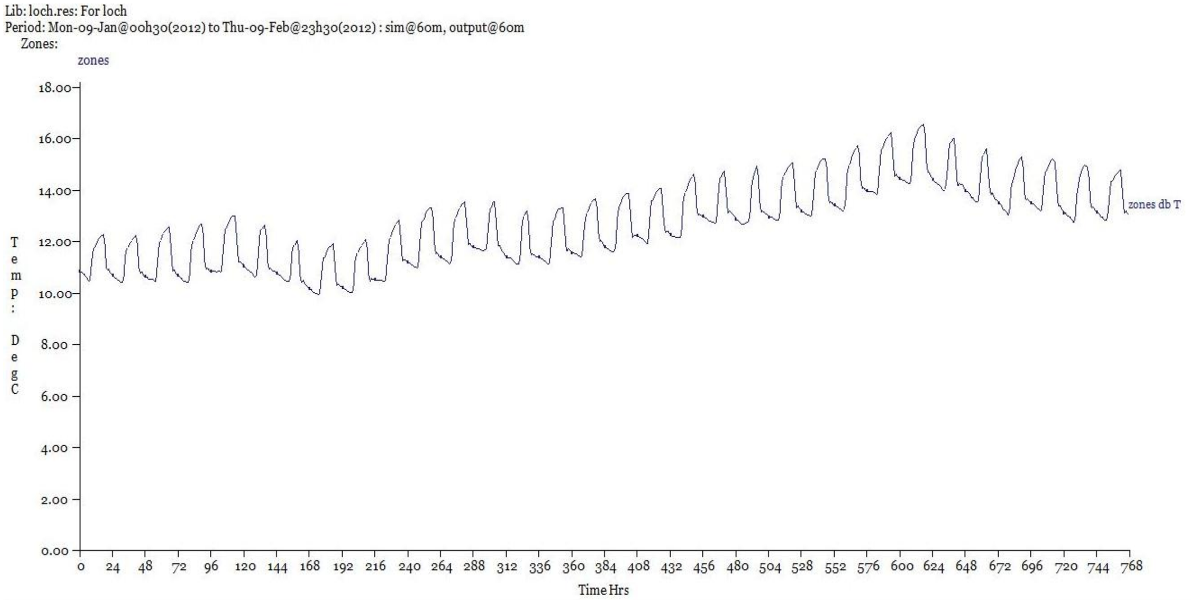


Figure 15- Temperature output from ESP-r for the winter month simulation

The relative humidity output for the winter month simulation is shown below. This simulation has been carried for an occupancy level of 5 people with a sensible gain of 315W and a latent gain of 54W.

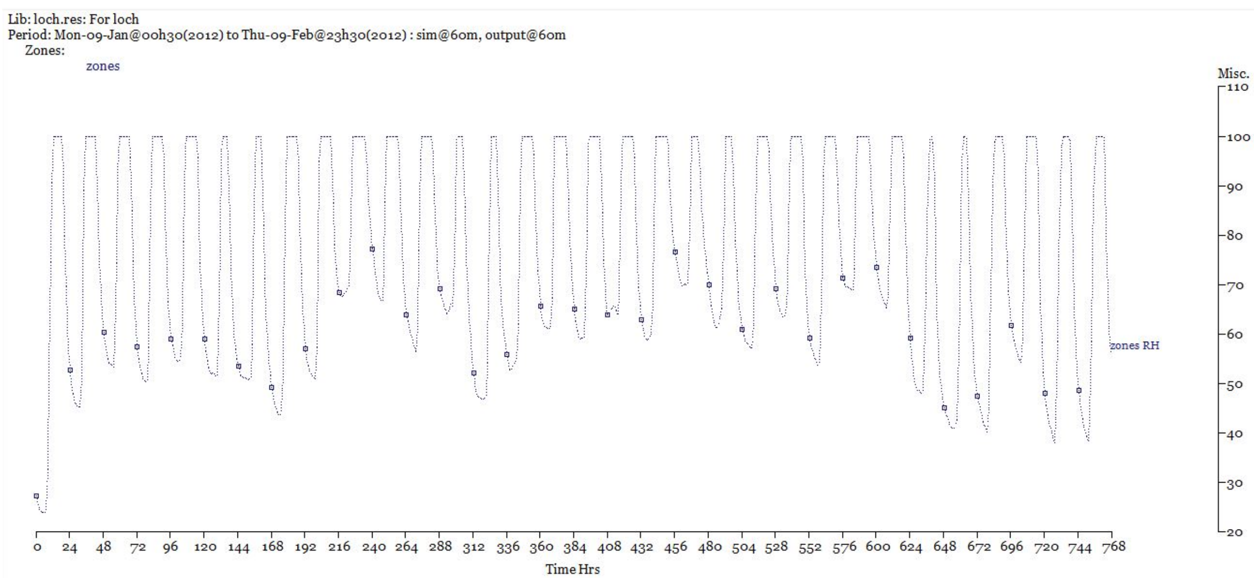


Figure 16- RH output from ESP-r for winter month simulation

Energy Consumption Comparison

The graphical outputs obtained for the electricity and gas consumptions comparison with the CIBSE TM46 benchmark and the corresponding CO_2 emission comparisons with the benchmark are given in this section of the report

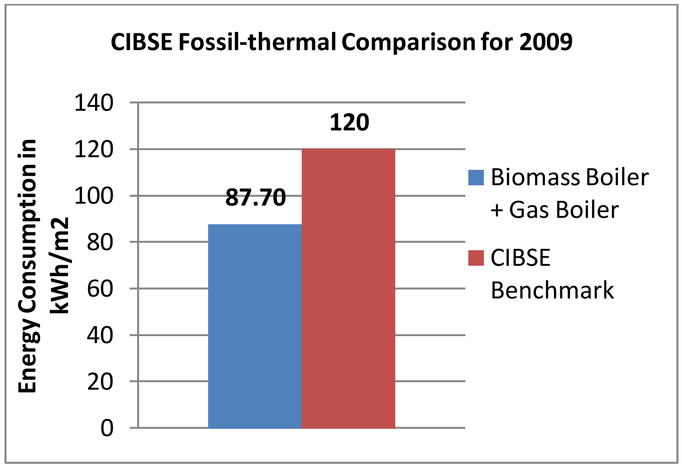


Figure 17- Fossil Thermal Consumption comparison with CIBSE benchmark for 2009

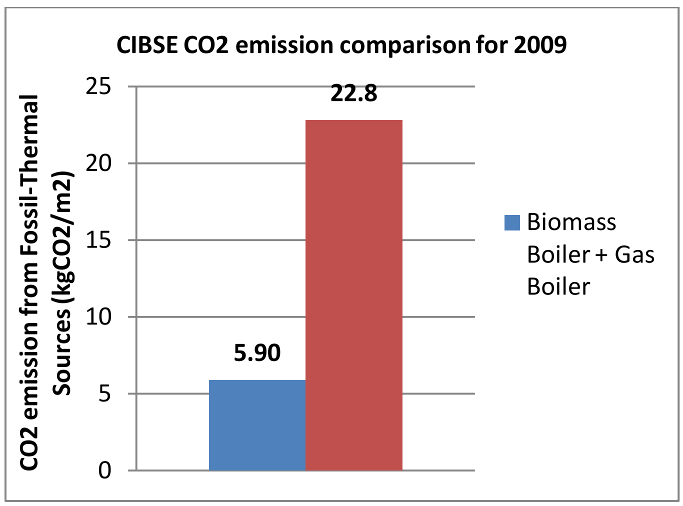


Figure 18- CO_2 emission comparison with CIBSE benchmark for 2009 (Fossil-Thermal)

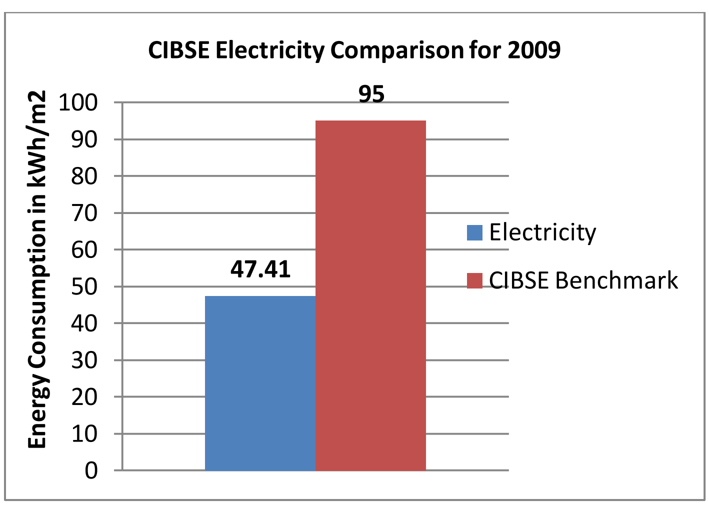


Figure 19- Electricity Consumption comparison with CIBSE benchmark for 2009

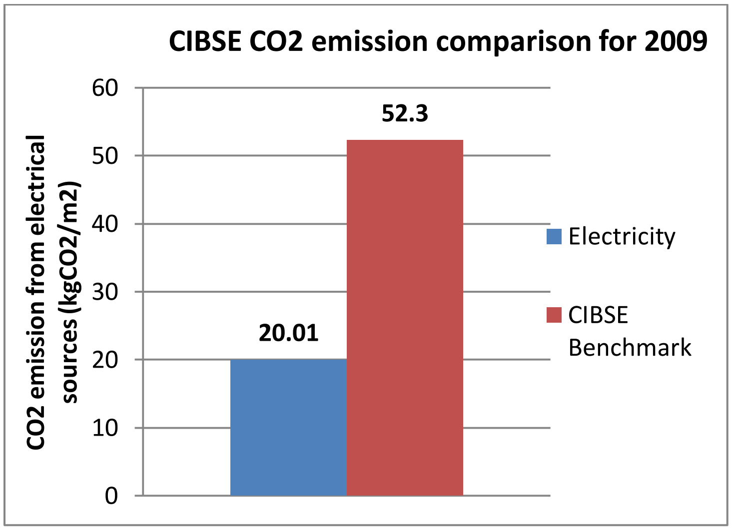


Figure 20- CO_2 emission comparison with CIBSE benchmark for 2009 (Electricity)

Chapter 5 - Case Study B: The Scottish War Blinded Facility, Linburn Centre

The Scottish War Blinded facility is an emblematic new building designed by Page\Park Architects for the Royal Blind commission to serve the needs of the blind and partially sighted. The building is located at Linburn and has a partially tranquil outlook over looking fields and some hills. The south facing aspect of the building allows the use of daylight to be fully exploited in the design.

Figure 21- Scottish War Blinded Facility in Linburn (Source: www.royalblind.org)

5.1 Background & Context

The facility has been designed for a total capacity of 35 users per day with a number of services ranging from workshop space, gym, art room and living room with a total building area of around 700m^2. The main structure of the building is made of a portalised steel frame which provides a curvy geometry, while the frames were constructed using steel frames and the walls are composed of timber frame cladding.

The services within the building are concealed with minimum fittings and general lighting is concealed on the tops of pods. The lighting systems have been developed with a view to combine low energy sources together with different styles and illumination, and thus assisting in ensuring user's comfort inside the building. Natural ventilation is utilised as much as possible except for areas like the toilets and the kitchen where mechanical ventilation systems are installed. The simple but effective ventilation systems are combined with the effective passive solutions and the combination thus minimises the need for heating and mechanical ventilation inside the building.

The heating to the building is provided through underfloor systems with energy being produced from ground source heat pumps. The GSHP system was considered on the basis of minimising the building running costs whilst also taking into the account the availability of energy supplies from local sources and additionally to ensure that enough energy is available in the coming years. The GSHP utilises electricity at a high level of efficiency and this was considered as a viable renewable energy source due to the increased contribution to the electricity grid in Scotland from wind farms and hydro generation installations.

In order to minimise energy requirements, the building has been highly insulated with careful amounts of glazing with a balanced need to control glare, solar gain and heat loss. The external walls are made up of series of vertical strips which are formed in alternating glazed and timber panels which span from the ground to the eaves. The building envelope uses highly insulated materials and are detailed to ensure that air permeability is low at $10m^3/hr/m^2$ at 50pa. These factors ensure that the heating requirements are low and additionally they make sure that the heat is not lost through poor construction.

Sustainable principles were very much put into practice during the design stage of the building and some of the key aspects were

- To orientate the building on the site to allow good views and good natural lighting into all rooms.
- Openable windows which are the main source of natural ventilation.
- Incorporation of high levels of insulation.
- Design of the building with high level of air tightness by using BRE robust details.
- Installation of passive systems such as ground source heat pump for heating and hot water services.

This sustainable aspect was considered to be rationale and henceforth the building was awarded an Energy Performance rating of B (appendix B) which brings out the fact that the building is carbon efficient.

5.2 Modelling

5.2.1 Overview and approach

ESP-r as a software has its own complications but on the other hand it is one tool which can predict the accurate energy performance of a building. With the time scale available for this project, an approach was laid to develop only one room from the entire building and space chosen in this case the space chosen was the art room. Since intricate detailing is required to model the roof of the building and due to the timescale involved it was not possible to model the roof. The available details for this were plans of the building (appendix A) and simple cross sections. Since the building has been constructed with low carbon techniques such as daylighting, high level glazing and so on it was necessary to bring out the same kind of model in ESP-r and the model when looked from a broader perspective would seem to be architecturally inaccurate i.e. materials used for the walls and floors are different. The materials used for the construction are very advanced and since these materials are not available in the ESP-r database it was decided to keep the U-values constant by choosing materials from the existing ESP-r database.

The initial method to be considered when modelling a building in ESP-r is the simplified box approach which is a representative version of the real life situation but still with sufficient level of detail to produce usable results. The design report quoted that the internal temperature throughout the building was the same and that for this building a natural ventilation system and a mechanical ventilation system (toilets, kitchen and changing room) had been installed. Similar to the previous case study the plant system and the ventilation system were neglected due to the complications involved and henceforth the results are not as accurate as the ones specified by the designers.

5.2.2 Materials and Composition

The nature of the construction process was to use materials which were highly efficient and at the same time not impede the comfort level of the occupants. The composition of the wall used by the designers is given below

Element Description	Element Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Vapour Resistivity (MNs/gm)	Vapour Resistance (MNs/g)
Outside surface resistance	-	-	0.130	-	-
T _G CLADDING	22.0	-	0.000	-	1.32
VERTICAL BATTEN CAVITY - VENTILATED	25.0	0.000	0.000	0.00	0.00
COUNTER BATTEN CAVITY	38.0	0.000	0.000	0.00	0.00
BREATHABLE MEMBRANE	0.5	-	0.006	-	0.20
PLYWOOD SHEATHING	18.0	0.140	0.129	520.00	9.36
KINGSPAN THERMAWALL TW55 15.0% Timber Frame (120mm)	120.0	0.022	5.455	-	100.00
TIMBER STUD CAVITY; U/V. 15.0% Timber Frame (130mm)	130.0	-	0.644	-	0.00
POLYTHENE VAPOUR CONTROL LAYER	0.5	-	0.001	-	500.00
PLASTERBOARD	12.5	0.190	0.066	50.00	0.63
Inside surface resistance	-	-	0.130	-	-

Figure 22- Composition of the timber framed wall used by the designers (Source: Page\Park)

ES-P-r does not have the materials listed above and therefore modelling the exact wall composition was not possible, however as earlier mentioned the U-values have been maintained as a constant factor and materials of similar quality were defined for the walls, floor and ceiling. The U-values as proposed by the designers for the walls is 0.24 W/m^{2}K. The list of materials used for the ESP-r model is shown below

Internal Wall (U-value is 0.27W/m2K) is used for Wall 1, Wall 5, Wall 6								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	paviour	1	100	0.96	2000	840	0.93	0.7
2	Glasswool	211	60	0.04	250	840		
3	Plasterboard (Uk code)	112	100	0.21	900	1000	0.91	0.7
External Wall (U-value- 0.25W/m2K) is used for Wall 2, Wall 3, Wall 4								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Lt Brown Brick	6	100	0.96	2000	650	0.9	0.7
2	Glasswool	211	75	0.04	250	840	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Breeze block	2	100	0.44	1500	650	0.9	0.65
Ceiling (U-value is 0.32 W/m2K) is used for the surface Top-7								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Glasswool	211	100	0.04	250	840	0.9	0.3
2	Ceiling Material	150	10	0.03	290	2000	0.9	0.6

Figure 23- Composition of Materials as chosen from ESP-r for War blinded art room

Floor (U-value is 0.4 W/m2K) is used for the surface Base 8								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Wilton	221	6	0.06	186	1360	0.9	0.6
2	Chipboard	67	19	0.15	800	2093	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Heavy Mix Concrete	32	140	1.4	2100	653	0	0
5	Steel	42	4	50	7800	502	0.12	0.2
Window (U-value is 2.2 W/2K)								
Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Plate Glass	242	6	0.76	2710	837	0.83	0.05
2	Air Gap (R=0.170)	50	0	0	0	0	0	0
3	Plate Glass	242	6	0.76	2710	837	0.83	0.05

Figure 24- Composition of Materials as chosen from ESP-r for War blinded art room

5.2.3 Geometry

As earlier discussed in the approach to building a model, a rectangular model was created with the art room being specified as the zone to get more representative results. The figure below shows the geometry of the gallery

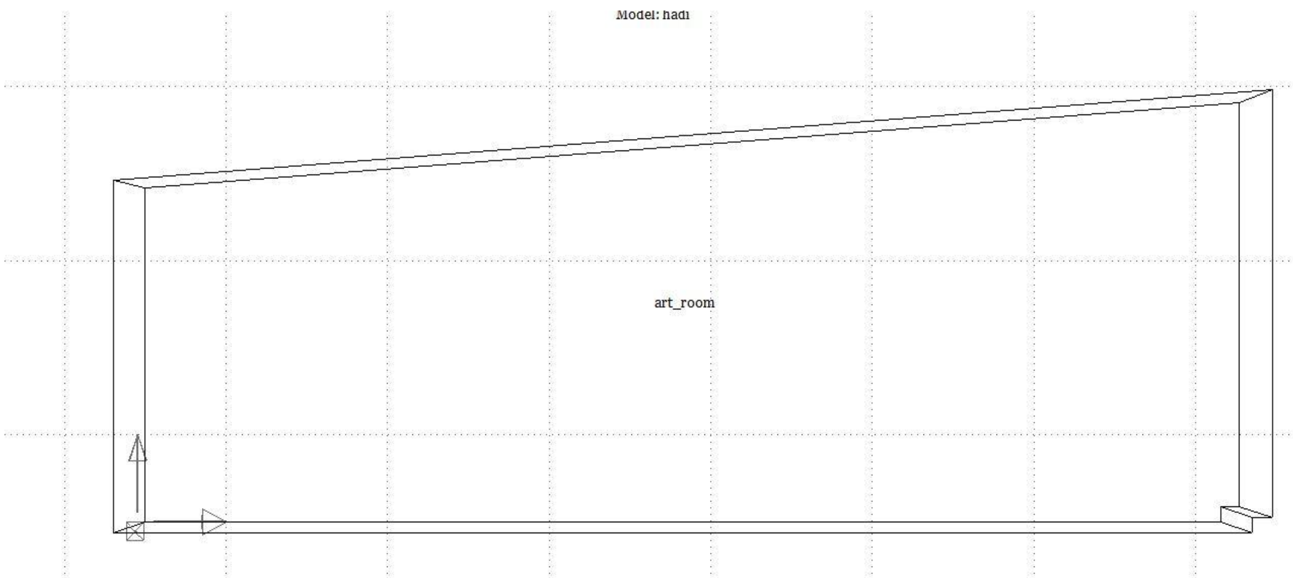


Figure 25- Front view of the art room

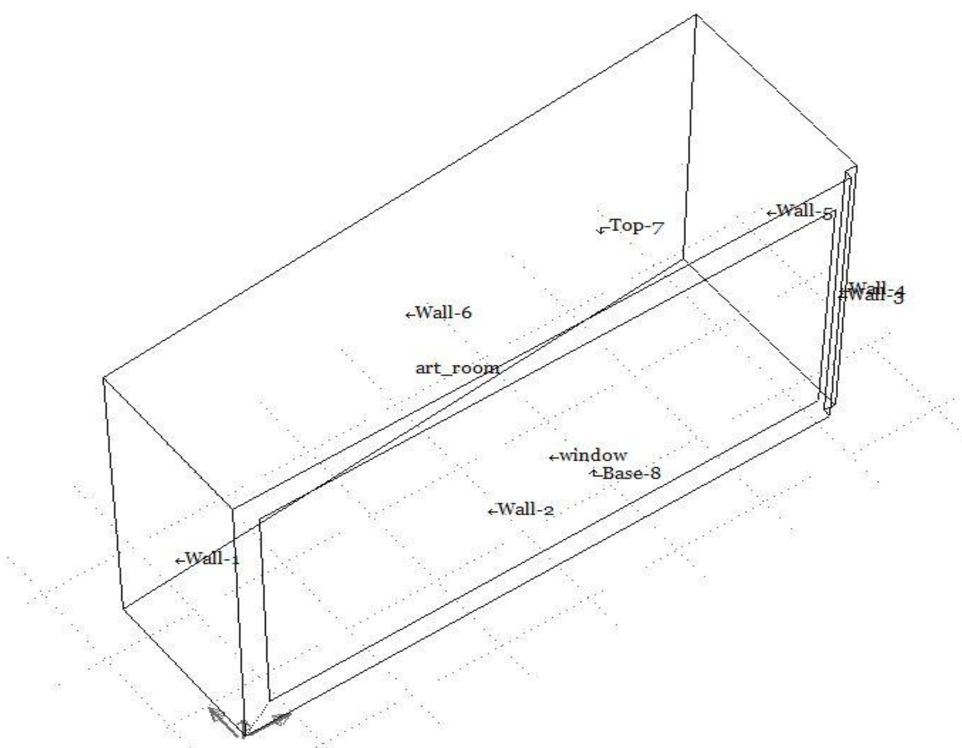


Figure 26- Art room model with glazing

The dimensions for this gallery was taken from the floor plans and section plans provided by Page\Park Architects, detailed in appendix A. As previously mentioned the building has a natural ventilation system installed but due to the constraints and the complexity involved in it, the definition of the ventilation was not possible within the time scale available for the project.

5.2.4 Internal Gains

The main internal gains to be defined for the model are those of occupancy and lighting gains. It has been mentioned in the design report that the total number of occupants per day is around 35 people and since the art room has been modelled in ESP-r, it has been assumed that around 5 people would occupy the room in a day. As per the CIBSE description this building has continuous occupancy but due to the fact that an art room would be occupied only lesser period of time, the occupancy periods were defined as follows

Day	**Time (i.e. 10am - 4pm)**
Monday	10am - 4pm
Tuesday	10am - 4pm
Wednesday	10am - 4pm
Thursday	10am - 4pm
Friday	10am - 4pm
Saturday	10am - 4pm
Sunday	10am - 4pm

Table 9- Average Occupancy periods

Within the software the average gain of an individual is 100W sensible and 50W latent. For this building based on this operational schedule the occupancy for 5 people was defined as follows

- Sensible gain - 315W (63W/person)
- Latent gain - 271.405W (54.281W/person)

Alongside this since fluorescent lighting sources are installed inside the building and since daylighting practices are installed it was assumed that around 50% gain would be achieved from the light sources. Within the software the average gain for a light bulb is 100W sensible and 0W latent, whereas the art room of the Scottish war blinded facility having an area of $60m^2$ the lighting gain was defined as 30W sensible (50% of floor area) and 0W latent and this assumption was based on the fact that more daylight is utilised within the building.

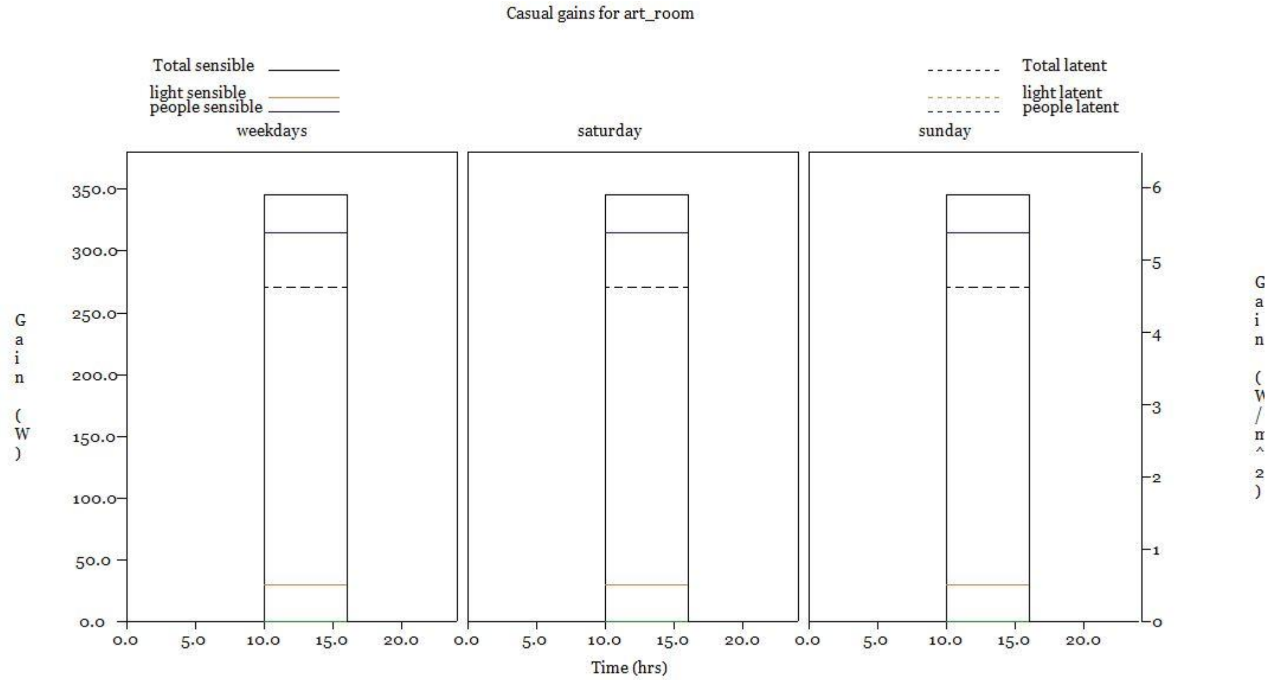


Figure 27- Casual gains for the art room

5.2.4 Simulation

With the ESP-r model now defined it was possible to begin simulations for the art room model of the Scottish War Blinded facility to see how the results differed from those obtained by the designers. Since the model is fairly simplified and based on certain underlying assumptions, it is a known fact that there would be a significant variation in the internal temperature values.

Simulations were run for two climate seasons,

- Summer: June 2012 to August 2012
- Winter: January 2012 - February 2012

From ESP-r the results are obtained as graphs which clearly show the temperature distribution over the defined seasonal information. The results thus obtained are shown in the results section of this case study.

5.3 Environmental Analysis

As per the CIBSE TM46 benchmark the Scottish War Blinded Facility falls under the category of a homeless unit which has full sleeping space, day time space and all domestic facilities. The services in this building are heating, cooling, lighting, laundry, appliances, food and hot water services.

As earlier explained in the methodology part, the monthly energy consumption data in kWh was converted to the energy consumption per m^2 of floor area. This metered energy consumption data was then converted to equivalent amounts of CO_2 emission in terms of$kgCO_2/m_2$ and to calculate this the following conversion factors were used

Fuel Used	Conversion Factor (kgCO2/kWh)
Electricity	0.422

Table 10- CO_2 conversion factor for electricity

In this case, data analysis was done for the year 2009 for which the data was collected from the BMS installed. Since GSHP is the heating source, the heating efficiencies of the pump have to be taken into consideration while calculating the energy consumption. In this case the heating efficiency of the GSHP were as follows

- January - 70%
- February - 70%
- March - 80%
- April - 90%
- May to September- 100%
- October - 90%
- November - 80%
- December - 70%

The metered reading from the GSHP for every month was multiplied by the corresponding efficiency to get the actual energy consumption for every month starting from January to December. The energy consumption values and the corresponding CO_2 emission values for the year 2009 are given below.

Month	Electricity Consumption through GSHP (kWh)	Electricity consumption as per heating efficiencies of the GSHP (kWh)	Electricity consumption per m2 of floor area (kWh/m2)
January	13739.36	9617.55	13.21
February	12035.43	8424.80	11.57
March	11491.63	9193.30	12.63
April	9352.65	8417.38	11.56
May	7141.17	714.12	0.98
June	4204.61	420.46	0.58
July	2826.96	282.70	0.39
August	2826.96	282.70	0.39
September	4313.37	431.34	0.59
October	7394.94	6655.45	9.14
November	10730.29	8584.24	11.79
December	13920.63	9744.44	13.39

Figure 28- Electricity consumption for 2009

Since the building has a Ground Source Heat Pump (GSHP) system installed, electricity is the main fuel used to power the heat pump. To calculate the CO_2 emission from the GSHP system, the energy consumption value (kWh/m^2) of the GSHP system is multiplied by the corresponding conversion factor of the fuel which is 0.422 kgCO_2/kWh.

Month	Electricity consumption per m2 of floor area (kWh/m2)	CO2 emission in kgCO2/m2
January	13.21	5.58
February	11.57	4.88
March	12.63	5.33
April	11.56	4.88
May	0.98	0.41
June	0.58	0.24
July	0.39	0.16
August	0.39	0.16
September	0.59	0.25
October	9.14	3.86
November	11.79	4.98
December	13.39	5.65

Figure 29- CO_2 emission from electricity for the year 2009

The calculated energy consumption values were then compared with the corresponding CIBSE benchmark values as prescribed for this sort of building, the benchmark is given below

Building Type	Electricity Typical benchmark (kWh/m^2)	Fossil-Thermal typical Benchmark (kWh/m^2)
Homeless Unit	65	420

Table 11- CIBSE TM46 Energy Consumption benchmark for Long term residential building

Building Type	Electricity Typical benchmark ($kgCO_2/m^2$)	Fossil-Thermal typical Benchmark ($kgCO_2/m^2$)
Homeless Unit	35.8	79.8

Table 12- CIBSE TM46 CO_2 emission benchmark for Long term residential building

The results obtained from this comparison are in the form of graphical outputs and henceforth they are given in the results section.

5.4 Results

The results obtained from the simulation of the model in ESP-r and the CIBSE energy consumption comparison are enclosed in this section.

Modelling and Simulation

Summer

The internal temperature outputs for the summer month simulation is shown below. This output is obtained for an occupancy of 5 people with a sensible gain of 315W and a latent gain of 54W.

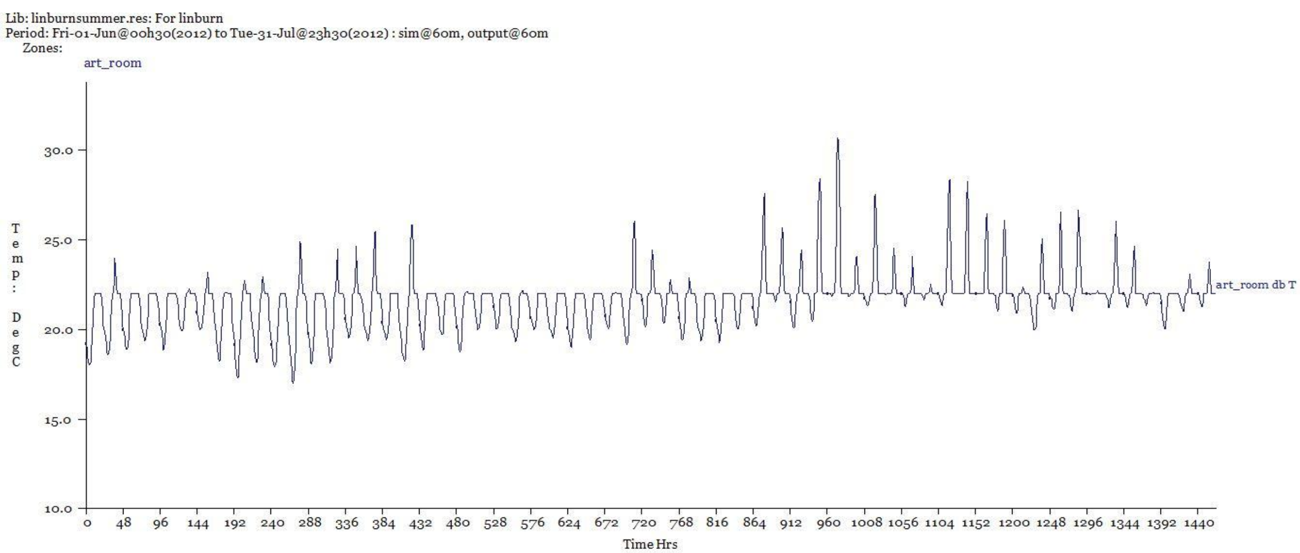


Figure 30- Art room temperature distribution for the summer month simulation

The relative humidity output for the summer month simulation is shown below. This simulation has been carried out for an occupancy level of 5 people with a sensible gain of 315W and a latent gain of 54W.

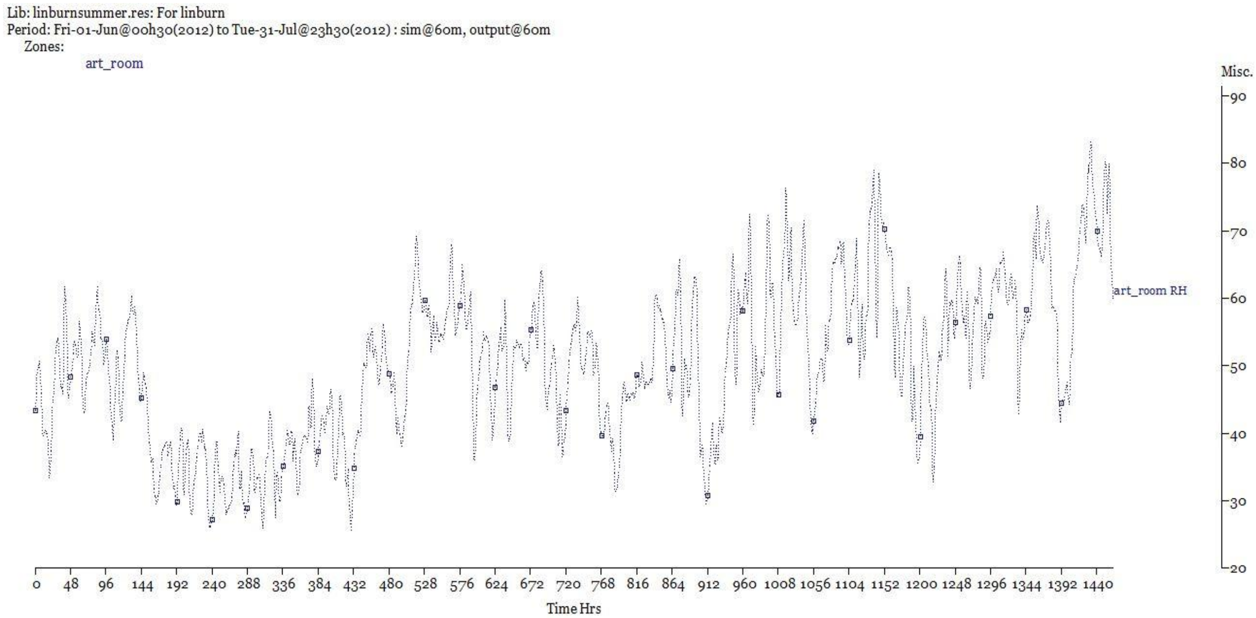


Figure 31- RH distribution of the art room for the summer month simulation

Winter

The internal temperature outputs for the winter months simulation is shown below and this simulation has been carried out for the same occupancy levels

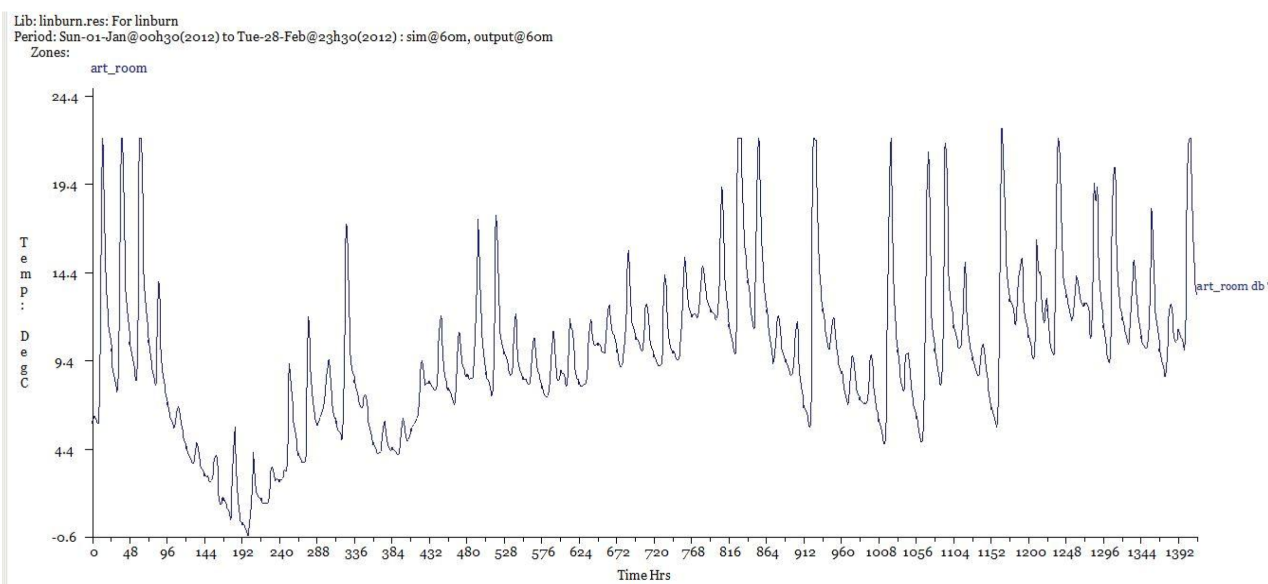


Figure 32- Temperature of the art room for the winter month simulation

The relative humidity (RH) output for the winter month simulation with an occupancy of 5 people is shown below

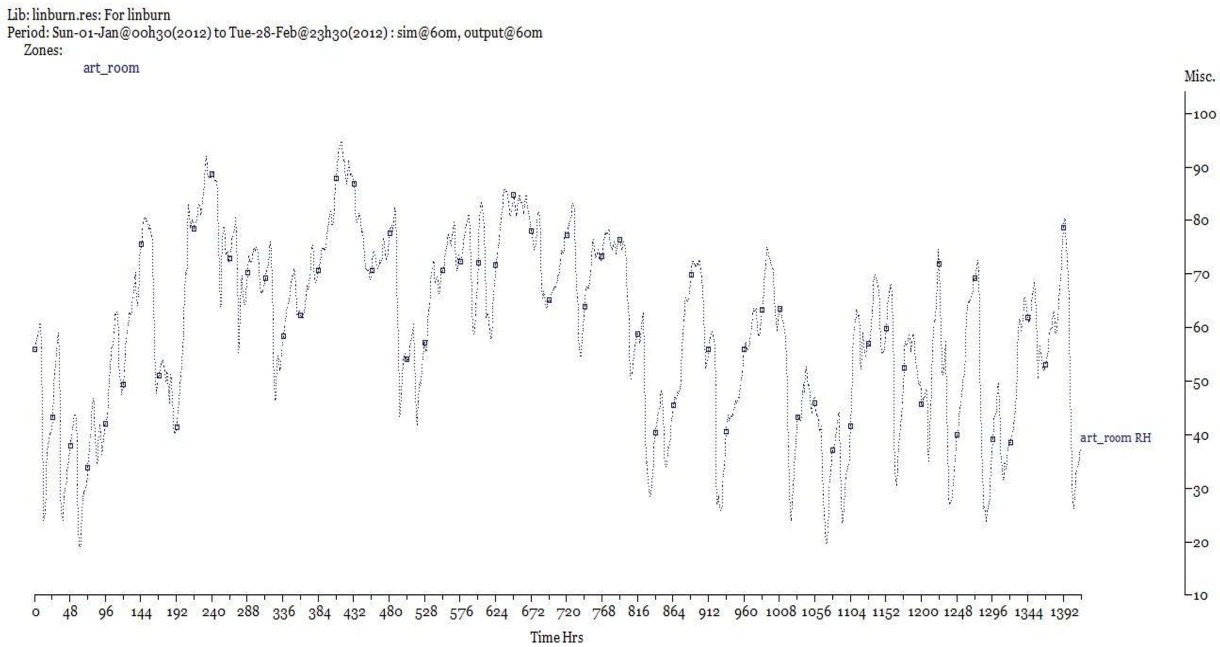


Figure 33- RH distribution of the art room for the winter month simulation

Energy Consumption Comparison

2009

The graphical outputs obtained for the electricity comparison with the CIBSE benchmark and the corresponding CO_2 emission comparisons with the benchmark are shown below

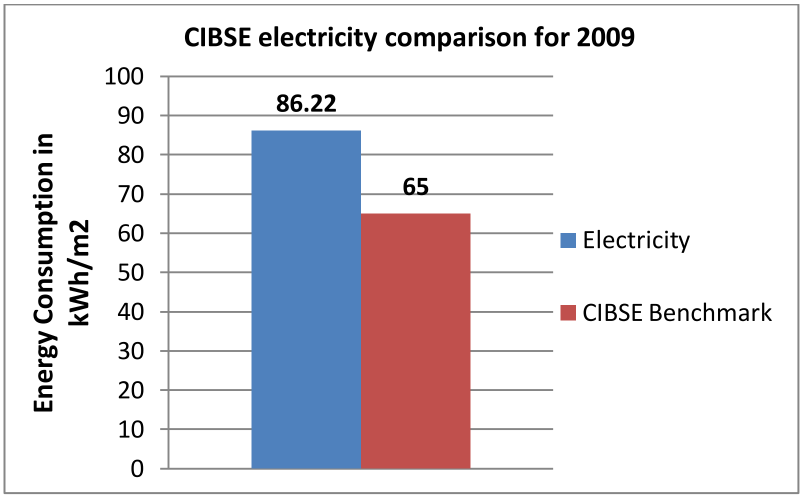


Figure 34- Electricity consumption comparison with CIBSE benchmark for 2009

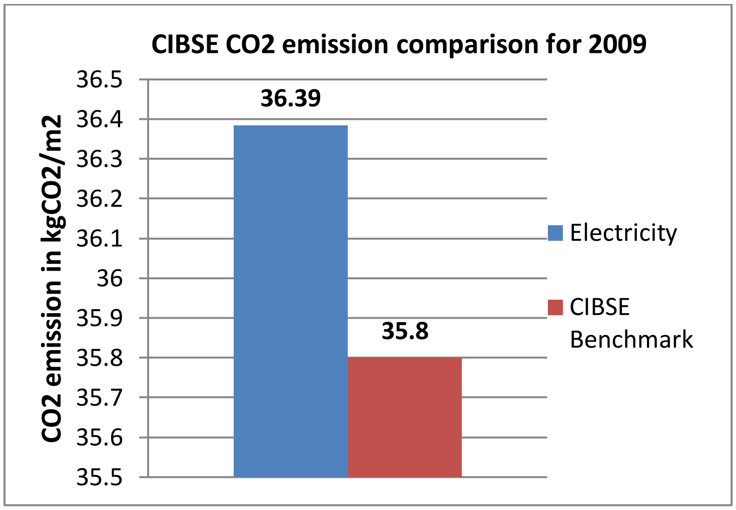


Figure 35- CO_2 emission comparison with CIBSE benchmark for 2009 (Electricity)

Chapter 6 - Case Study C: Scottish National Portrait Gallery

An art gallery is a room or series of rooms where works of art are exhibited.

The Scottish National Portrait Gallery is a remarkable building situated in Edinburgh and is held in great affection by many. Over the years there have been many presumptions to alter the historic fabric without good reason but off late, the main renovation issue was the replacement of old and inadequate plant and the installation of proper, modern sustainable services which could certainly propagate the building to improved and better energy efficient standards.

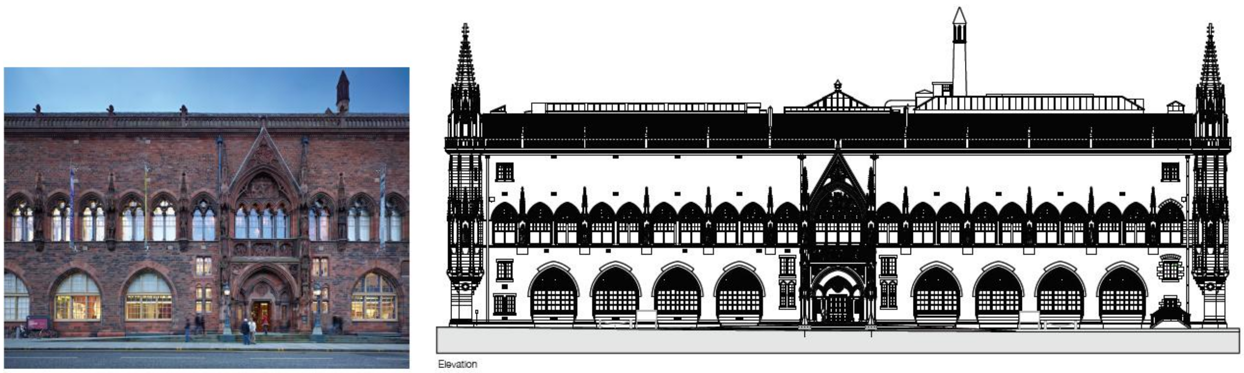


Figure 36- Scottish National Portrait Gallery- Front Elevation (Source: Carbon trust)

Page\Park architects were chosen to bring about this change and alongside they strove along the right path to meet the clients demands for affordable renovation and to bring about a sustainable building which sets new standards for how a museum and gallery design should be and also to allow the staff to undertake a planned process of change.

6.1 Background & Context

Description

The Scottish National Gallery is a two storey building with 9 galleries situated right at the heart of Edinburgh new town. The building being listed in Category A required certain refurbishments to improve its standard as an environmentally reliable and efficient building. The building has a overall area of 4513m^2 along with a gallery area of 2062m^2.

The first floor consists of two galleries on the east wing and one gallery on the west wing. Additionally a research area is located on the west side behind the gallery space and a storage space is located on the extreme right side of the west wing on the first floor. All lighting controls to the west wing are provided from the distribution board situated on the west side of the floor. Similarly the galleries on the east side are supplied with power from the distribution board on the east side of the floor. The aerial view of the first floor plan is shown below

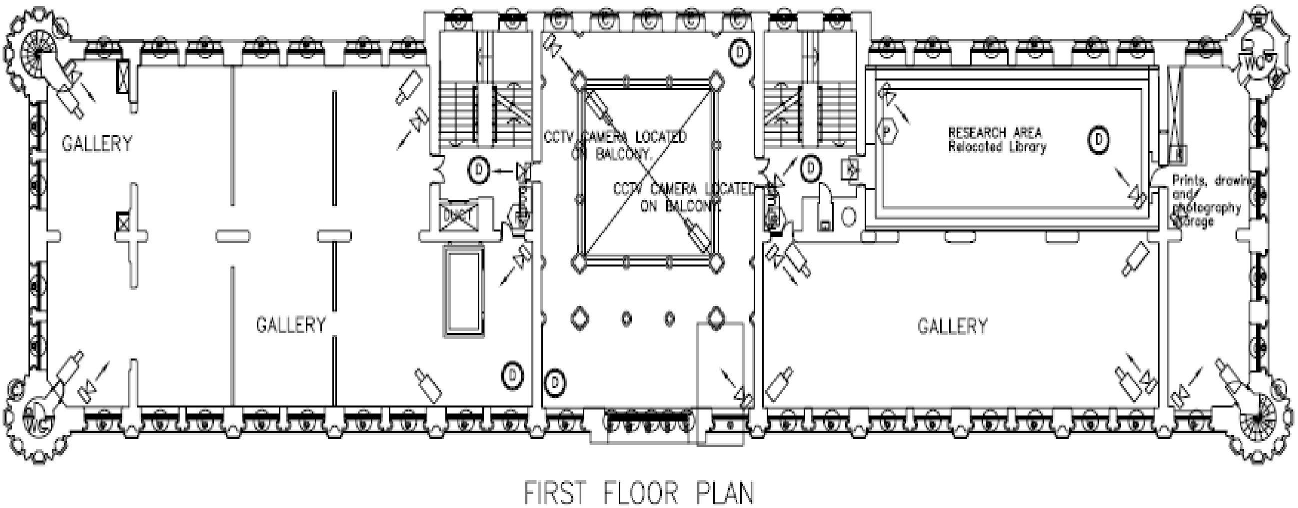


Figure 37- First Floor plan (Source: Page\Park Architects)

The second floor on the contrary has 9 galleries, i.e. 4 on the east side, 4 on the left side and 1 in the middle of the floor. The floor plan shown below gives a clear idea of how the galleries are spaced

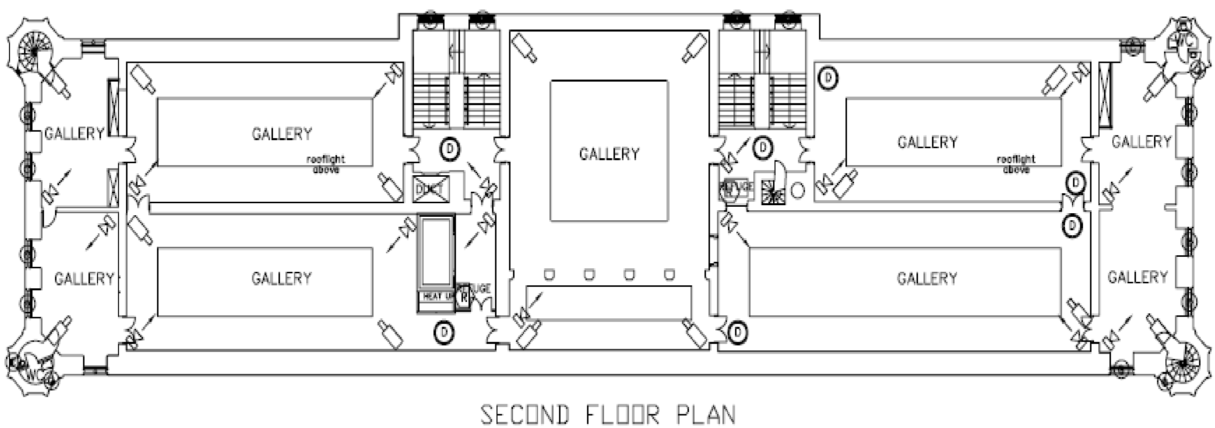


Figure 38- Second Floor Plan (Source: Page\Park Architects)

Mezzanine

The mezzanine floor consists of a wide range of office spaces along with storage spaces and other M&E services on the west end whereas a kitchen in located in the central part of the mezzanine floor. The east end of the mezzanine floor consists of an additional library space with disabled access. The diagram below shows this clearly

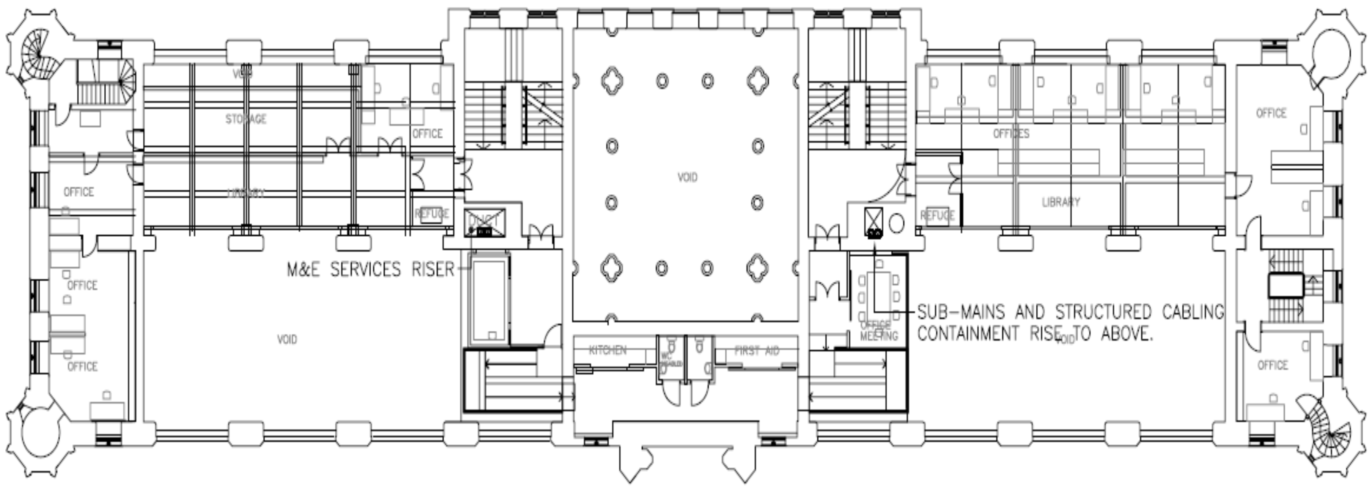


Figure 39- Mezzanine Floor Plan (Source: Page\Park Architects)

Design Intent

The passive design approach to improve the building's form and fabric, orientation resulted in reduce of overheating and minimal cooling requirements and the following refurbishments were undertaken in order to improve the energy efficiency of the building.

Exposing Brickwork- The old building was designed in such a way to expose the internal brickwork but this approach exposed the building's thermal mass.

Top lit galleries- The upper floor galleries have been configured to be provided with natural light, new double glazed and low E rooflights have been installed to reduce the need for artificial lighting.

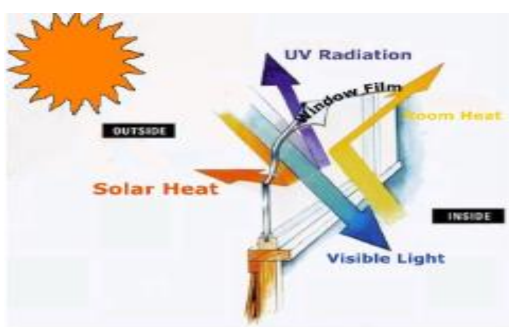


Figure 40- Artificial lighting technique (Source: Environmental presentation by Harley Haddow Engineers)

Windows and Double Glazing- Wherever possible windows have been opened up to use natural light and reduce the need for artificial lighting and additionally secondary double-glazing has been introduced throughout the building.

Insulation- The whole of the original roof finish was removed and a new insulated asphalt roof has been introduced and additional insulation has been introduced within the roof space itself.

Space Efficiency- Small amount of mezzanine space at ground floor was added and thereby 40% of more gallery hanging space was created within the building. This access to the other floors of the building through the mezzanine floor was evolved without the need to extend the building, saving resources and energy output.

Through this design the buildings temperature level and humidity levels were reduced to around 23°C and 65% respectively. The design team thereby achieved the following conditions in terms of people comfort, gallery requirements as follows

- People comfort : 18°C - 23°C
- Humidity : 40% - 65% RH
- Rates of change - 3% RH change in 1 hour & 15% RH change in 24 hours

The graph represents the seasonal temperature variation along with the corresponding humidity levels

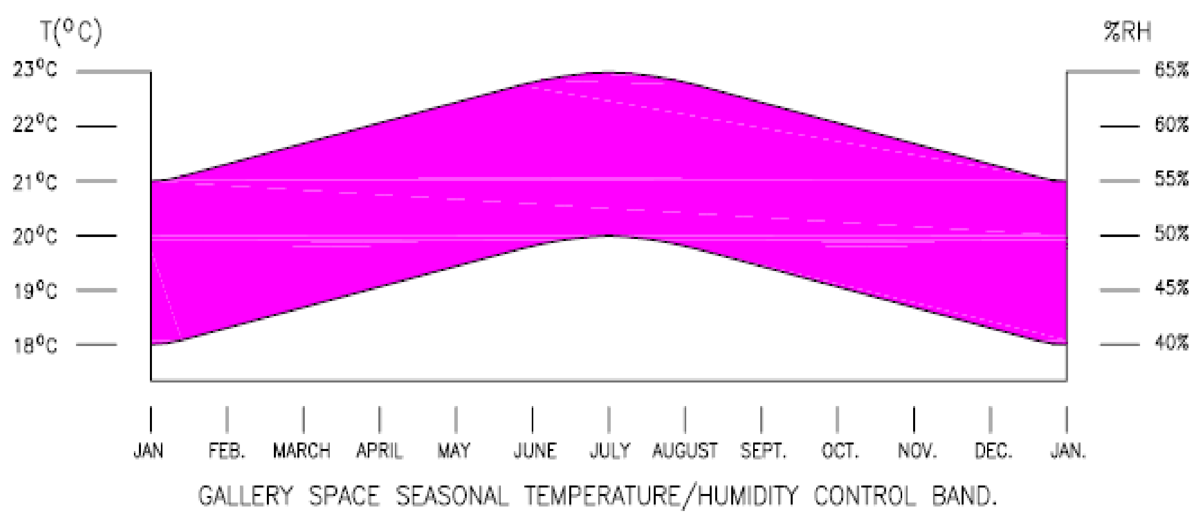


Figure 41- Design Aspect- Temperature and Humidity levels

The main purpose of controlling the humidity and temperature levels is to prevent the collection from degradation and also to maximise the benefit that can be gained from the thermal mass of the building and this is a key aspect of reducing energy consumption. Thus the main aim of the design team was to reduce the carbon footprint of the building and to improve the environmental zoning on both the floors.

Mechanical & Electrical Services

The building is served with high efficiency gas fired condensing boiler plant installation with zoned heating to all areas of the building and additionally it serves the various AHU units serving the ventilated spaces. The boiler is controlled to operate according to the demand of the building through the plant optimisation feature. This feature reduces the temperature of the heating water and results in increased efficiency gains from the boiler plant. This design of the M&E services have ensured that the heat loss is minimised throughout the building and thereby improving the comfort level of the people visiting the gallery.

A chiller has been installed to provide chilled water via DX based refrigeration air cooled plant. The AHU systems which serve the 'non-gallery' areas are fitted with a thermal wheel to allow to heat to be removed back to the space being ventilated. All lighting is provided by high efficiency linear fluorescent fittings and the galleries are fiited with LED lighting tracks and daylighting. 95% of the gallery lighting has dimmers allowing control and lowering of light levels to suit the ambient light levels provided by the daylighting and this installation has reduced the energy consumption by 79.9% since 2008.

Sustainability Aspect

Although the envelope of the building had generally been well maintained the interior of the building had become worn in its finishes, especially in the un-used museum spaces. The aim of the architects and designers was to deliver a high quality product that could sustain the wear and tear of a gallery environment and thereby reduce the maintenance and lifecycle costs. Wherever possible the existing materials were retained and to a large extent removal of accretions from the finishes was the first priority. Carpets were removed to reveal the original timber parquet floors which were made good, sanded and sealed. Such kind of measures thereby reduced the operating cost and on a larger scale the design used standard component sizes and prefabrication to reduce wastage on site and if waste were collected, they were segregated for recycling.

Moving on from the context of the building, the report will now focus on the modelling which was undertaken and the furthermore the simulated results and results obtained from the environmental analysis are also shown.

6.2 Modelling

6.2.1 Approach and Assumptions

ESP-r as a software has its very own complications but despite this, it is one tool which can predict the accurate energy performance of the building when proper modelling is carried out. Hence, an approach was laid to develop only one gallery space from the entire and the gallery space chosen in this case was the gallery situated in the west end on the 2nd floor. The available details for this were plans and section diagrams of the building (appendix A). Since this is a refurbishment project, the construction details were absent, especially those pertaining to the composition of the external walls, insulation material used, maximum U-values permitted and those concerned with the minimisation of internal temperature. The lack of all these details meant that the model created would not be architecturally accurate i.e. the choice of materials were based on an assumption that the recommended U-value for a building would be around 0.24 W/m^2K.

The initial method to be considered when modelling a building in ESP-r is the simplified box approach which is a representative version of the real-life situation but still with sufficient level of detail to produce usable results. The design report pertaining to the building quoted that the internal temperature throughout the building was the same and that a MVHR system was installed in the gallery. Similar to the previous case study the modelling of MVHR system was neglected due to the complexity and the timescale involved.

6.2.2 Materials and Construction

The nature of the refurbishment process was to make sure that the existing materials were not to be changed wherever possible and importance was laid to insulate the roof and to provide indoor comfort for people visiting the place and to the staff. Since no detail pertaining to the U-values of the walls, doors, roofs and floors were given, general materials were implied to the walls (both external and internal) and this assumption was made to ensure that the results obtained were similar to the designers proposals. However since the materials were chosen based on assumptions as in the previous case, it was felt that reasonable results have still been able to be obtained.

The details of the materials chosen for the ESP-r model is shown below

Internal Wall (U-value is 0.27W/m2K) is used for Wall 3 and Wall 4

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	paviour brick	1	100	0.96	2000	840	0.93	0.7
2	Glasswool	211	60	0.04	250	840		
3	Plasterboard (Uk code)	112	100	0.21	900	1000	0.91	0.7

External Wall (U-value- 0.25W/m2K) is used for Wall-1, Wall-2

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Lt Brown Brick	6	100	0.96	2000	650	0.9	0.7
2	Glasswool	211	75	0.04	250	840	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Breeze block	2	100	0.44	1500	650	0.9	0.65

Ceiling (U-value is 0.32 W/m2K) is used for the surface Top-5

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Glasswool	211	100	0.04	250	840	0.9	0.3
2	Ceiling Material	150	10	0.03	290	2000	0.9	0.6

Figure 42- Composition of Materials as chosen from ESP-r for SNPG gallery space

Floor (U-value is 0.4 W/m2K) is used for the surface Base-6

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Wilton	221	6	0.06	186	1360	0.9	0.6
2	Chipboard	67	19	0.15	800	2093	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Heavy Mix Concrete	32	140	1.4	2100	653	0	0
5	Steel	42	4	50	7800	502	0.12	0.2

Door (U-value is 2.2 W/2K)

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Oak	69	25	0.19	700	2390	0.9	0.65

Figure 43- Composition of Materials as chosen from ESP-r for SNPG gallery space

6.2.3 Geometry

As earlier discussed in the approach to building the model, a rectangular model was created with one zone created for the gallery. The figure below shows the geometry of the gallery

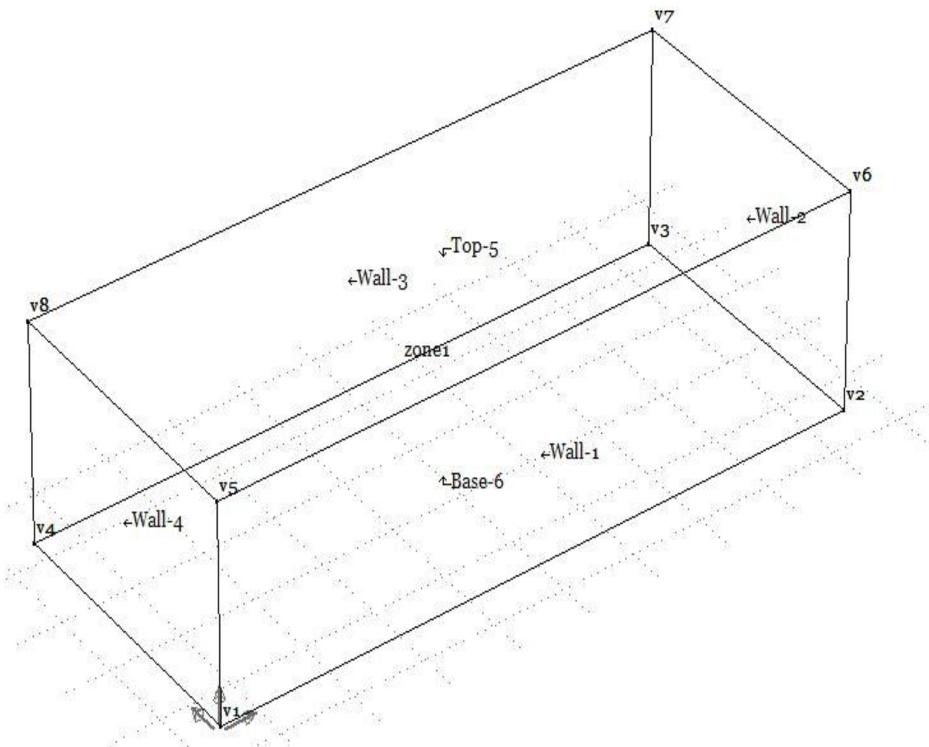


Figure 44- Gallery space without the door

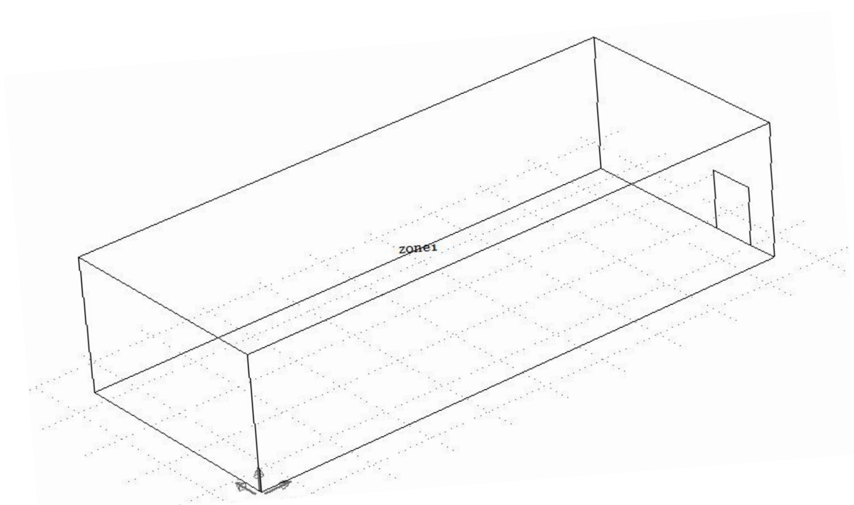


Figure 45- Gallery space with the door

The dimensions for this gallery was taken from the floor plans and section plans provided by Page\Park Architects, detailed in appendix A. This simple model was created since the building has a mezzanine floor above this, which has plant systems incorporated into it. Owing to the necessity for this project detailed modelling of a plant system was out of scope and henceforth the simulations were further done using this model.

6.2.4 Internal gains

The main internal gains to be defined for the model are those of occupancy and lighting. The Scottish National Portrait Gallery being a public place, the occupancy calculation was based on a judgemnet depending on the number of visitors visiting the gallery. As per statistics by Herald Scotland, the gallery had attracted around 327,980 visitors during the year 2012. Based on this information it was found that around 6430 people would be visiting the place in a week and this number was further brought down to around 918 people/day visiting the galleries. Since only one gallery was modelled, the occupancy was assumed to be around 10 people/gallery. As per the CIBSE description, the occupancy schedule for an art gallery is similar to that of an office but more likely weekends should also be considered. Based on this the occupancy schedule for the winter months of January, February, March and for the summer months of June, July and August were

Day	**Time (i.e. 9am - 5pm)**
Monday	9am - 5pm
Tuesday	9am - 5pm
Wednesday	9am - 5pm
Thursday	9am - 5pm
Friday	9am - 5pm
Saturday	9am - 5pm
Sunday	9am - 5pm

Table 13- Average Occupancy Schedule

Within the software the average gain of an individual is 100W sensible and 50W latent. For this building based on the occupancy schedule the internal gains for 10 people who are considered to be standing as defined as follows

- Sensible heat - 283.5W
- Latent Heat - 244.26W

Since during the refurbishment process, daylighting practices were introduced through the installation of roof lights and dimmers, it was assumed that around 50% gain would be achieved from the light sources. Within the software the average gain for a light bulb is 100W sensible and 0W latent. For the Scottish National Portrait gallery the lighting gain was defined as 70W sensible and 0W latent for all and this 50% gain is due to the assumption that dimmers would come into place when there is sufficient daylight. The figure below shows the lighting gain and the operational schedule for this model

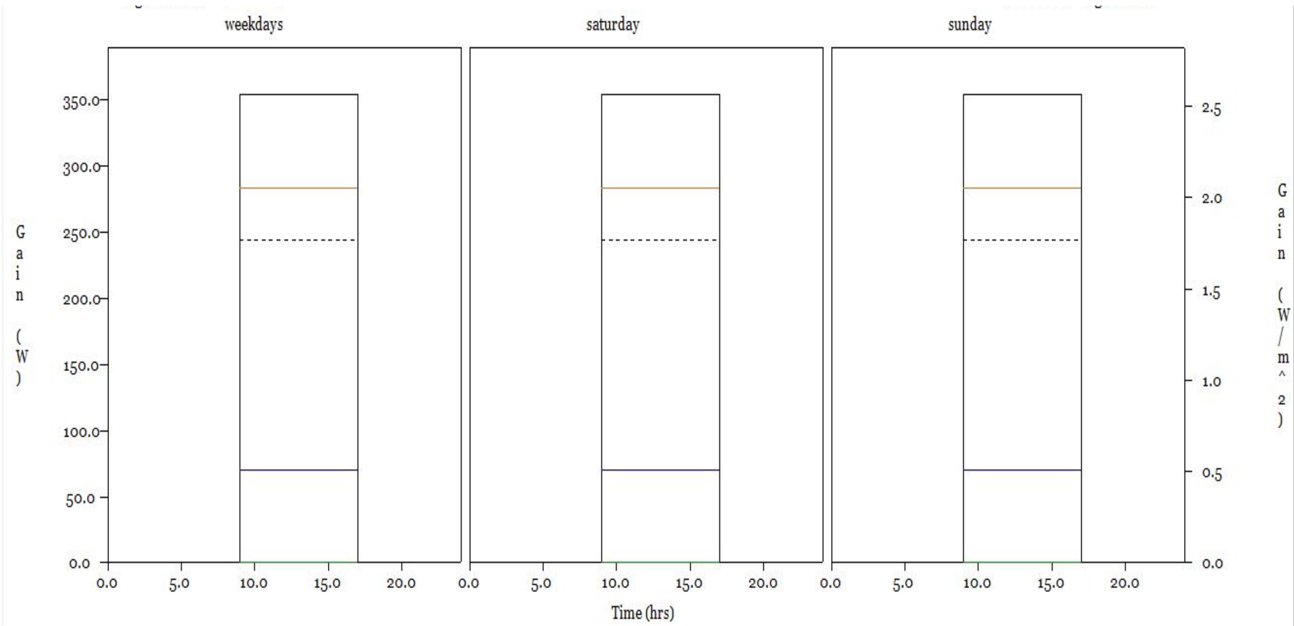


Figure 46- Internal Gains from light sources

6.2.5 Simulation

With the ESP-r model now defined it was possible to begin simulations for the gallery model of the Scottish National Portrait Gallery to see how the results differed from those obtained by the designers. Since the model is not accurate and based on the underlying assumptions it is a known fact that there would be a significant variation in the internal temperature values.

Simulations were run for two climate seasons,

- Summer: June 2012 to August 2012
- Winter: January 2012 - February 2012

From ESP-r the results can be obtained as graphs which clearly show the temperature distribution over the defined seasonal information. The results thus obtained are shown in the results section of this case study.

6.3 Environmental Analysis

As per the CIBSE TM46 benchmark the Scottish National Portrait Gallery falls under the category of a cultural activity building which has a operational schedule of daytime, similar to office hours but more likely to be opened on weekends and the services included in the building are heating, lighting, cooling and humidity control.

As earlier explained in the methodology part, the monthly energy consumption data in kWh was converted to the energy consumption for per m^2 of floor area. This metered energy consumption data was then converted to equivalent amounts of CO_2 emission in terms of $kgCO_2/m^2$ and for this calculation the following conversion factors were used

Fuel Used	Conversion Factor ($kgCO_2/kWh$)
Electricity	0.422
Gas	0.194

Table 14- CO_2 conversion factors for electricity and gas

In this case, data analysis was done for the years 2008 and 2012 for which the data was collected from the Building Management System installed. To calculate the CO_2 emission from the electricity sources, the energy consumption value (kWh/m^2) is multiplied by the corresponding conversion factor for electricity which is 0.422 $kgCO_2/kWh$.

The energy consumption values and the corresponding CO_2 emission values for the year 2008 and 2012 are given below

Month	Electricity (kWh)	Electricity (kWh/m2)	CO2 Emission (kg CO2/m2)
Nov	46204	10.24	4.32
Dec	56256	12.47	5.26
Jan	57320	12.70	5.36
Feb	51260	11.36	4.79
Mar	52360	11.60	4.90
Apr	53110	11.77	4.97
May	53110	11.77	4.97
Jun	52140	11.55	4.88
Jul	47380	10.50	4.43
Aug	52540	11.64	4.91
Sep	46890	10.39	4.38
Oct	47650	10.56	4.46
Total	**616220**	**136.54**	**57.62**

Figure 47- Monthly Electricity Consumption and the corresponding CO_2 emission for 2012

To calculate the CO_2 emission from the gas boiler, the energy consumption value (kWh/m^2) of the gas boiler is multiplied by the corresponding conversion factor for gas which is 0.194 $kgCO_2/kWh$.

Month	Gas (kWh)	Gas (kWh/m2)	CO2 Emission (kg CO2/m2)
Nov	67055	16.22	3.15
Dec	111735	27.03	5.24
Jan	107102	25.91	5.03
Feb	115413	27.92	5.42
Mar	38949	9.42	1.83
Apr	69940	16.92	3.28
May	62536	15.13	2.94
Jun	49768	12.04	2.34
Jul	40686	9.84	1.91
Aug	36675	8.87	1.72
Sep	42343	10.25	1.99
Oct	63272	15.31	2.97
Total	**805474**	**194.89**	**37.81**

Figure 48- Monthly Gas Consumption and corresponding CO_2 emission for 2012

To calculate the CO_2 emission from the electricity sources, the energy consumption value (kWh/m^2) is multiplied by the corresponding conversion factor for electricity which is 0.422 $kgCO_2/kWh$.

Month	Electricity (kWh)	Electricity (kWh/m2)	CO2 Emission (kg CO2/m2)
Nov	58970	14.27	6.02
Dec	55410	13.41	5.66
Jan	64200	15.53	6.56
Feb	72900	17.64	7.44
Mar	66810	16.17	6.82
Apr	69327	16.77	7.08
May	59054	14.29	6.03
Jun	59742	14.45	6.10
Jul	53670	12.99	5.48
Aug	61687	14.93	6.30
Sep	47130	11.40	4.81
Oct	60070	14.53	6.13
Total	**728970**	**176.38**	**74.43**

Figure 49- Monthly Electricity Consumption and the corresponding CO_2 emission for 2008

To calculate the CO_2 emission from the gas boiler, the energy consumption value (kWh/m^2) of the gas boiler is multiplied by the corresponding conversion factor for gas which is 0.194 $kgCO_2/kWh$.

Month	Gas (kWh)	Gas (kWh/m2)	CO2 Emission (kg CO2/m2)
Nov	123041	29.77	5.78
Dec	153956	37.25	7.23
Jan	167014	40.41	7.84
Feb	171097	41.40	8.03
Mar	162913	39.42	7.65
Apr	128790	31.16	6.05
May	58152	14.07	2.73
Jun	41259	9.98	1.94
Jul	35288	8.54	1.66
Aug	34524	8.35	1.62
Sep	25674	6.21	1.21
Oct	102030	24.69	4.79
Total	**1203738**	**291.25**	**56.50**

Figure 50- Monthly Gas Consumption and corresponding CO_2 emission for 2008

The calculated energy consumption values were then compared with the CIBSE benchmark values prescribed for this sort of building, the benchmark is given below

BuildingType	ElectricityTypical benchmark (kWh/m^2)	Fossil-Thermal typical Benchmark (kWh/m^2)
Art Gallery	70	200

Table 15- CIBSE TM46 Energy Consumption benchmark for Art Gallery

BuildingType	ElectricityTypical benchmark ($kgCO_2/m^2$)	Fossil-Thermal typical Benchmark ($kgCO_2/m^2$)
Art Gallery	38.5	38.0

Table 16- CIBSE TM46 CO_2 emissions benchmark for Art Gallery

The results obtained from this comparison are in the form of graphical outputs and henceforth they are given in the results section.

6.4 Results

The results obtained from the simulation of the model in ESP-r and the CIBSE energy consumption comparison are enclosed in this section.

Modelling and Simulation

Summer

The internal temperature output for the summer month is shown below. In this case the simulation was carried out for a occupancy level of 5 people in the room.

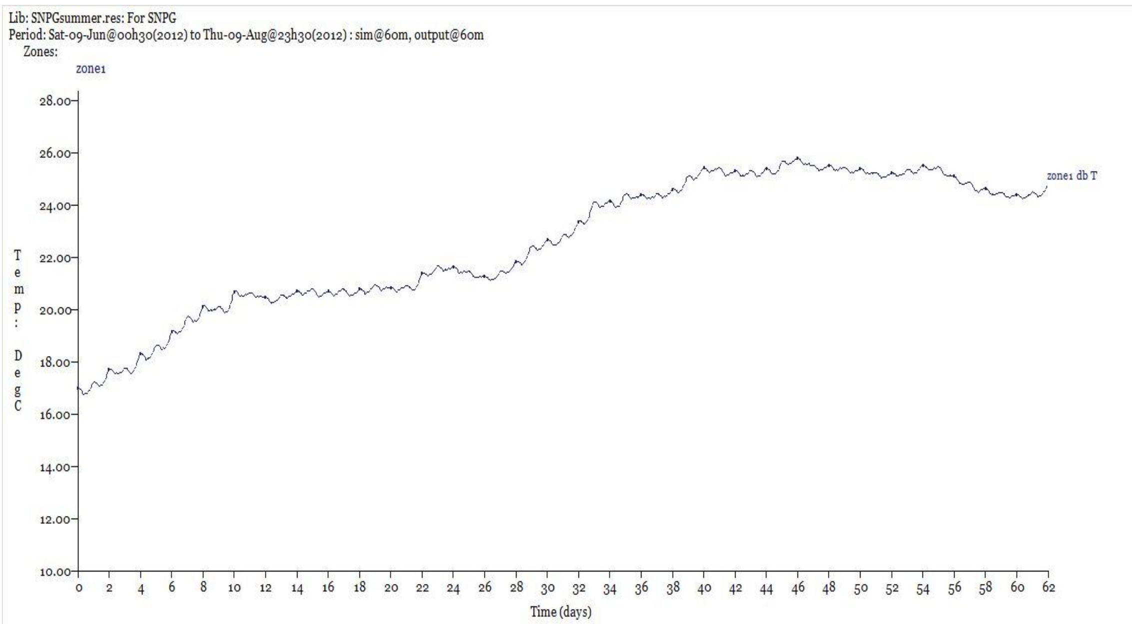


Figure 51- Internal temperature of the gallery zone for summer months

Winter

The internal temperature output for the winter month simulation is shown below. The simulation has been carried out for an occupancy level of 5 people in the room.

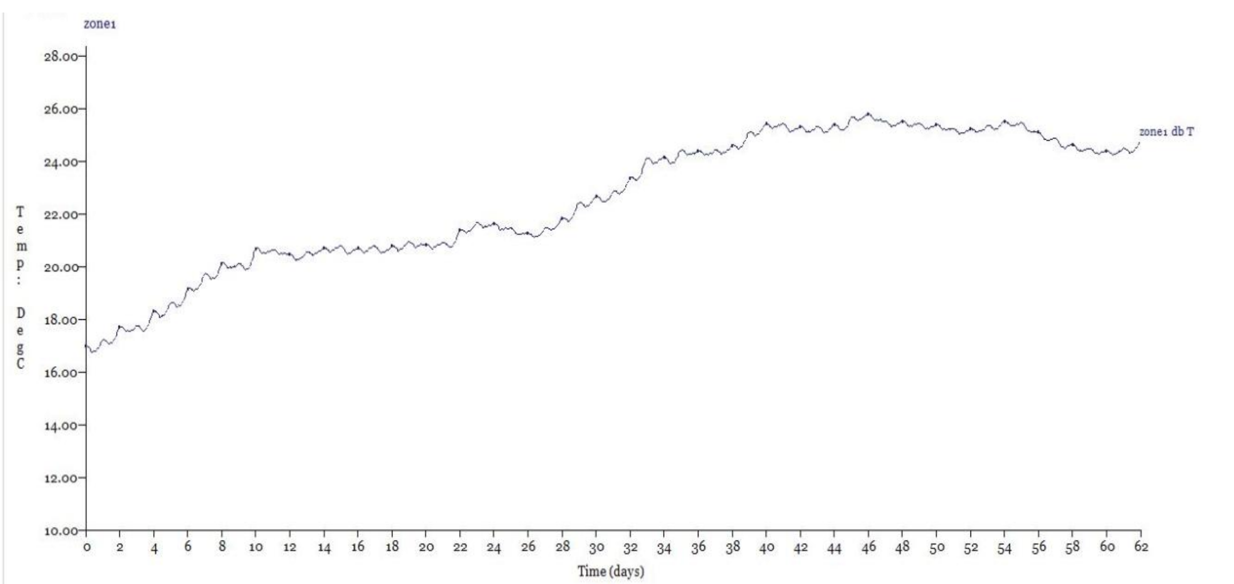


Figure 52- Internal temperature of the gallery zone for winter months

Energy Consumption Comparison

2008

The graphical outputs obtained for the electricity and gas consumptions comparison with the CIBSE TM46 benchmark and the corresponding CO_2 emission comparisons with the benchmark are given in this section of the report

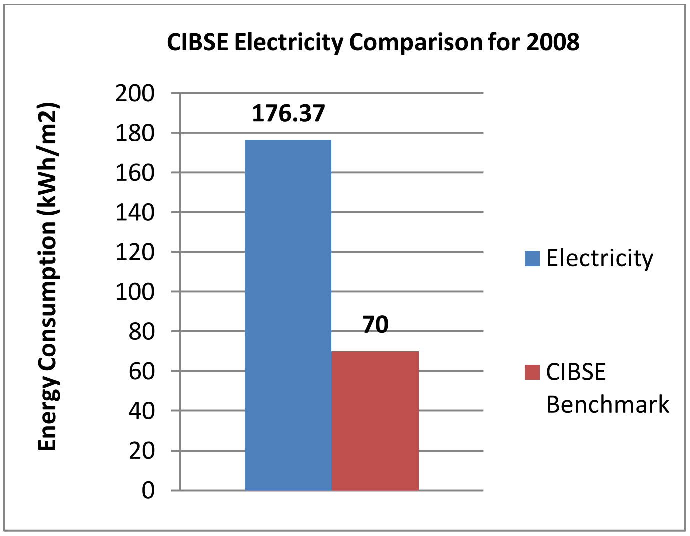


Figure 53- Electricity consumption comparison with CIBSE benchmark for 2008

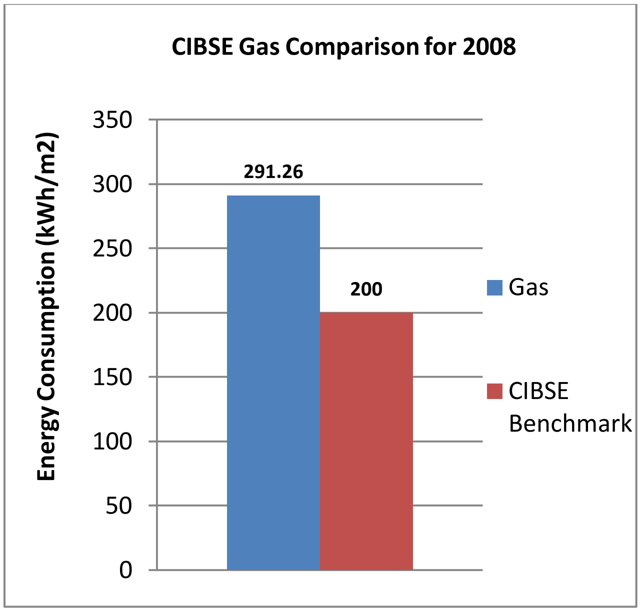


Figure 54- Gas consumption comparison with CIBSE benchmark for 2008

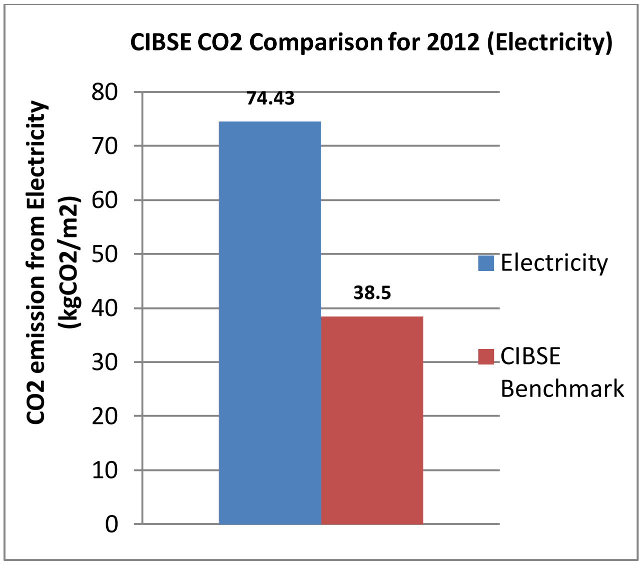


Figure 55- CO_2 emission comparison with CIBSE benchmark for 2008 (Electricity)

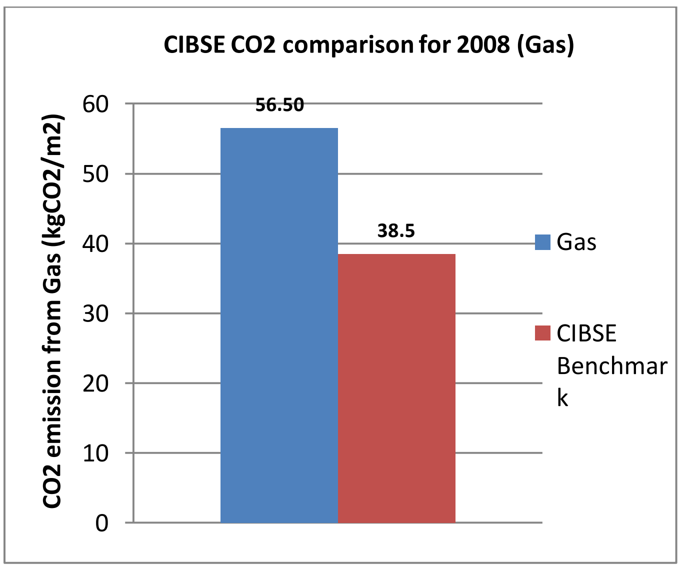


Figure 56- CO_2 emission comparison with CIBSE benchmark for 2008 (Gas)

2012

The graphical outputs obtained for the electricity and gas consumptions comparison with the CIBSE TM46 benchmark and the corresponding CO_2 emission comparisons with the benchmark are given in this section of the report

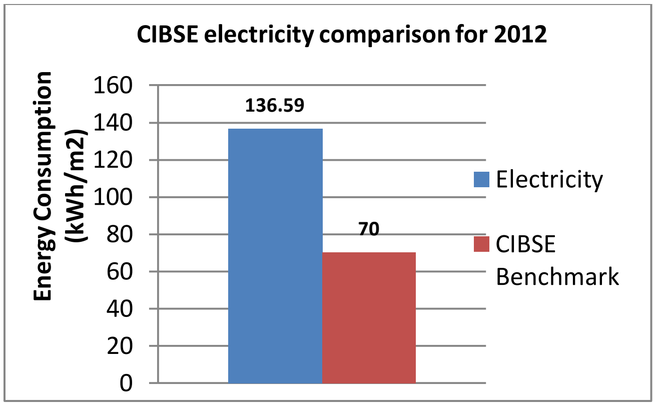


Figure 57- Electricity consumption comparison with CIBSE benchmark for 2012

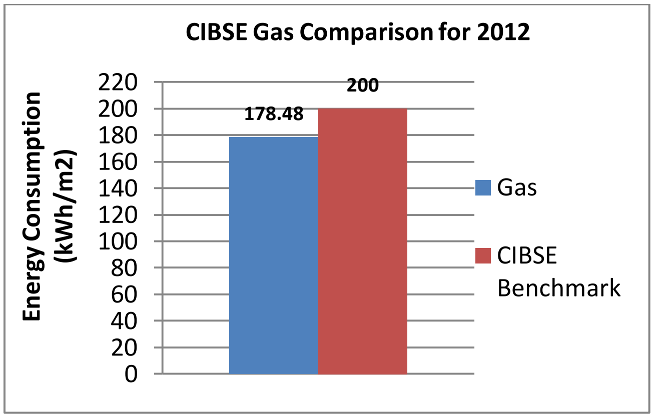


Figure 58- Gas consumption comparison with CIBSE benchmark for 2012

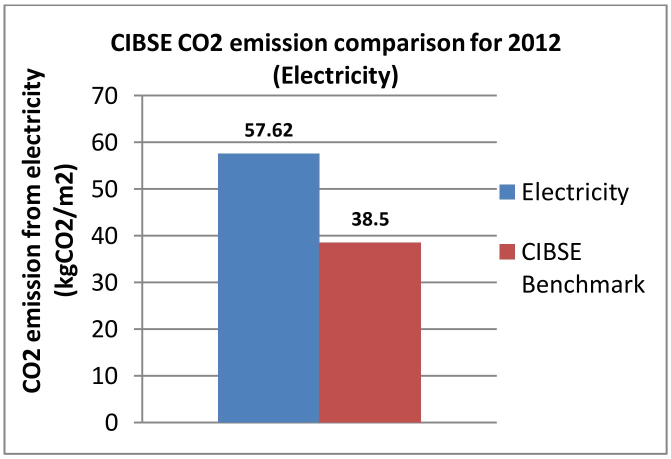


Figure 59- CO_2 emission comparison with CIBSE benchmark for 2012 (Electricity)

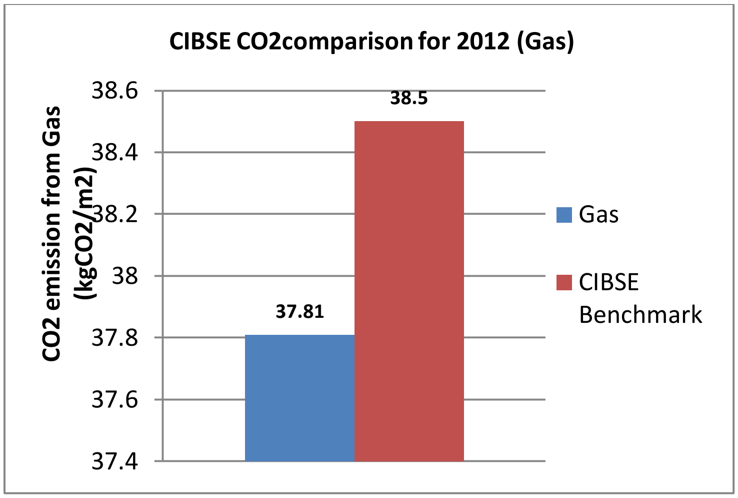


Figure 60- CO_2 emission comparison with CIBSE benchmark for 2012 (Gas)

Chapter 7 - Collegelands Office, High Street

Collegelands is one of Scotland's largest regeneration projects situated on high street. The office building consists of large array of vibrant office space along with a multi-storey car park.

Figure 61- Collgelands office building(extreme right)

7.1 Background & Context

The collegelands office building has been awarded an Energy performance rating of B for its viability against carbon emissions. The building consists of 6 storeys of open plan office space (ground + 5 floors along with a basement car park for 54 cars and roof top plant area. The materials used for the construction of the building have a significant value which are detailed below

- External wall - Insulated to achieve U-value of 0.3 W/m^2k
- Ground Floor - Insulated to achieve U values of 0.25 W/m^2k
- Roof - Insulated to achieve U value of 0.25 W/m^2k
- Glazing - U values of 2.2 W/m2k

With the use of low carbon materials, the room temperature existing within the general office is around 22°C with a occupancy gain of 90W/person (sensible) and a lighting gain of 12 W/m^2.

The main open plan office areas are served by a variant refrigerant volume (VRV) air conditioning system which provides continuous heating and cooling. The system has been to be part of the heat recovery system thereby improving the overall efficiency of the system. The stairwells and toilet areas are heated by electric panel heaters. Fresh air is provided to the building through an AHU installed at the roof. The main fuel used to power all these plant systems is grid supplied electricity.

With regards to the lighting system, the office areas are illuminated via high frequency 1200 x 150 recessed, direct/indirect luminaries in a ceiling raft arrangement. This illumination is variable between 300lux to 500lux depending on the type of jobs inside the office and occupants can increase or lower the level whenever needed. Additionally lighting control system is provided which has a rooftop which tracks the sun and this system is daylight linked and dimmers are installed to switch off the artificial lights when sufficient natural light is available thereby maximising energy savings.

7.2 Modelling

7.2.1 Overview and Approach

ESP-r as a software has its own complications but on the other hand it is one tool which can predict the accurate energy performance of a building. Since this is an open plan office and owing to the the time scale available for this project, an approach was laid to develop only the 4th floor of the building. The available details for this were plans of the building (appendix A) and simple cross sections. Since the building has been constructed with low carbon techniques such as daylighting, high level glazing and so on it was necessary to bring out the same kind of model in ESP-r and the model when looked from a broader perspective would seem to be architecturally inaccurate i.e. materials used for the walls and floors are different. The materials used for the construction are very advanced and since these materials are not available in the ESP-r database , therefore it was decided to keep the U-values constant and alongside this materials were chosen from the existing ESP-r database.

The initial method to be considered when modelling a building in ESP-r is the simplified box approach which is a representative version of the real life situation but still with sufficient level of detail to produce usable results. The design report quoted that the internal temperature throughout the building was the same and that for this building AHU had been installed. Similar to the previous modelling of an AHU was neglected due to the complications involved and henceforth the results are not as accurate as the ones specified by the designers.

7.2.2 Materials and Construction

The design report did not have any details related to the materials but it had the recommeded U-values for the walls, floors and ceilings. This is given below

Element	$U_{a\text{-}Limit}$	$U_{a\text{-}Calc}$	$U_{i\text{-}Limit}$
Wall	0.3***	0.15	0.7
Floor	0.25	0.24	0.7
Roof	0.25	0.21	0.35
Windows**, roof windows, and rooflights	2.2	1.63	3.3
Personnel doors	2.2	0	3.3
Vehicle access & similar large doors	1.5	0	1.5

Figure 62- Recommended U-values

However since the materials were chosen based on assumptions as in the previous case, it was felt that reasonable results have still been able to be obtained. The list of materials chosen from ESP-r is given below

External Wall (U-value- 0.25W/m2K) is used for all walls i.e. wall 1 to wall17

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Lt Brown Brick	6	100	0.96	2000	650	0.9	0.7
2	Glasswool	211	75	0.04	250	840	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Breeze block	2	100	0.44	1500	650	0.9	0.65

Ceiling (U-value is 0.32 W/m2K) is used for the surface Top-19

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Glasswool	211	100	0.04	250	840	0.9	0.3
2	Ceiling Material	150	10	0.03	290	2000	0.9	0.6

Floor (U-value is 0.4 W/m2K) is used for the Base 18

Surface Layer	Description	Material	Thickness (mm)	Conductivity	Density	Specific Heat	IR emis	Solar Abs
1	Wilton	221	6	0.06	186	1360	0.9	0.6
2	Chipboard	67	19	0.15	800	2093	0	0
3	Air Gap (R=0.170)	0	50	0	0	0	0	0
4	Heavy Mix Concrete	32	140	1.4	2100	653	0	0
5	Steel	42	4	50	7800	502	0.12	0.2

Figure 63- Composition of Materials as chosen from ESP-r for Collegelands floor space

7.2.3 Geometry

As earlier discussed a simple 4th floor plan was developed in ESP-r and the geometry is shown below

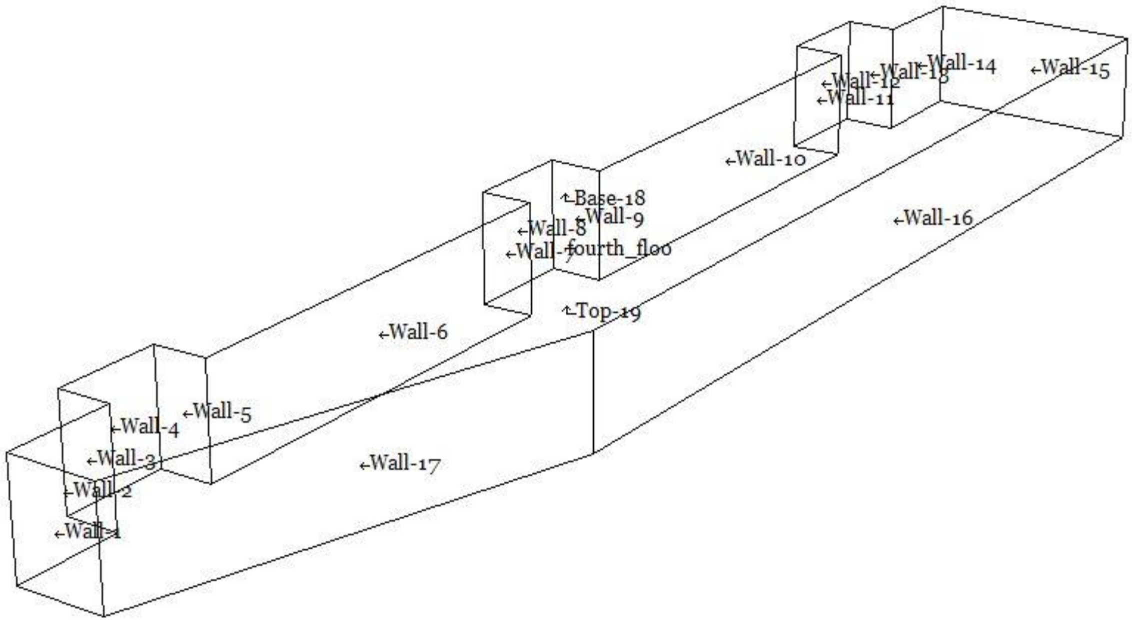


Figure 64- 4th floor model

7.2.4 Internal Gains

Since this is an open plan office, it was assumed that around 25 people would be working in the office. An office of this kind would be generally be open on weekdays and based on this the occupancy schedule was defined as follows

Day	Time
Monday	7am - 5 pm
Tuesday	7am - 5 pm
Wednesday	7am - 5 pm
Thursday	7am - 5 pm
Friday	7am - 5 pm

Table 17. Occupancy Schedule

Within the software the average gain for an individual is defined as 100W sensible and 50W latent. As per the design report the internal gains from the occupant was estimated as 90W/person (sensible) and 60W/person. Based on this for 25 people the internal gain was defined as

- Sensible gain - 2250W
- Latent gain - 1500W

Additionally the design report quoted that the lighting gain for this 4 storey building would be around 12 W/m^2. Since only one floor was modelled it was assumed that the lighting gain would be around 3 W/m2 and henceforth for the above floor which has an area of 2920m^2 the lighting gain was defined as 8760W.

Equipments are part of offices and for this open plan the designers estimated that the casual gains from the different equipments would be around 25W/m^2. For the 4th floor an occupancy gain of 6.25W/m^2 was assumed and henceforth the casual gain from the equipment was defined as 18250W.

7.2.5 Simulation

With the ESP-r model now defined it was possible to begin simulations for the gallery model of the Scottish National Portrait Gallery to see how the results differed from those obtained by the designers. Since the model is not accurate and based on the underlying assumptions it is a known fact that there would be a significant variation in the internal temperature values.

Simulations were run for two climate seasons,

- Summer: June 2012 to August 2012
- Winter: January 2012 - February 2012

From ESP-r the results can be obtained as graphs which clearly show the temperature distribution over the defined seasonal information. The results thus obtained are shown in the results section of this case study.

7.3 Environmental Analysis

As per the CIBSE TM46 benchmark the Loch Lomond and Trossachs National Park Authority HQ falls under the category of a general office building which has an operational schedule of weekday openings and early evenings and the services included in the building are heating, lighting, cooling, employee appliances, standard IT and basic tea room.

As earlier explained in the methodology part, the monthly energy consumption data in kWh was converted to the energy consumption for per m^2 of floor area. This metered energy consumption data was then converted to equivalent amounts of CO_2 emission in terms of $kgCO_2/m^2$ and for this calculation the following conversion factors were used

Fuel Used	Conversion Factor (kgCO2/kWh)
Electricity	0.422

Table 18- CO_2 conversion factors for electricity and gas

In this case data analysis was done for the year 2012 (for the actual building and the notional building) for which the data was collected from the BMS installed. The energy consumption values and the corresponding CO_2 emission values for the year 2012 are given below

	Heating Consumption					Electrical Consumption			
Month	Boilers Space conditioning Energy (kWh)	Boilers DWH Energy (kWh)	Chillers Energy (kWh)	Aux + DWH/Solar Pumps Energy (kWh)	Heat Rejected Fans/Pumps Energy (kWh)	Lights Electricity (kWh)	Equipments Electricity (kWh)	Total Electicity consumption (kWh)	Total Electricity consumption per floor area (kWh/m2)
Jan	153953.4	8216.6	0	5265.6	0	0	45465.6	212901.2	20.97
Feb	120532.6	7469.6	0.8	4786.9	0.3	0.3	41224.6	174014.5	17.14
Mar	75643.1	8216.6	40.4	5265.6	18.6	18.6	45251.3	134417	13.24
Apr	47536.8	7096.1	628.2	4547.5	289	289	39044	98852.6	9.74
May	16916.4	7843.1	7033.1	5026.2	3235.2	3235.2	43133.8	79952.6	7.88
Jun	2885.5	7843.1	12441.6	5026.2	5723.1	5723.1	43130.3	71326.7	7.03
Jul	2499.7	8216.6	16331.8	5265.6	7512.6	7512.6	45185.4	77499.1	7.63
Aug	4827.7	8216.6	12896.6	5265.6	5932.5	5932.5	45204.6	76411.1	7.53
Sep	13204.2	7469.6	6694.2	4786.9	3079.3	3079.3	41118.7	73273.6	7.22
Oct	46991.2	8590.1	763.4	5504.9	351.2	351.2	47379.9	109229.5	10.76
Nov	90152.6	8216.6	1.5	5265.6	0.7	0.7	45417.9	149054.2	14.68
Dec	109653.6	7096.1	0	4547.5	0	0	39295.4	160592.6	15.82

Figure 65- Monthly electricity consumption from different sources installed in the building (Notional Building)

To calculate the CO_2 emission from the electricity sources, the energy consumption value (kWh/m^2) is multiplied by the corresponding conversion factor for electricity which is 0.422 $kgCO_2/kWh$.

Month	Total Electricity consumption per floor area (kWh/m2)	CO2 emission (kgCO2/m2)
Jan	20.97	8.85
Feb	17.14	7.23
Mar	13.24	5.59
Apr	9.74	4.11
May	7.88	3.32
Jun	7.03	2.97
Jul	7.63	3.22
Aug	7.53	3.18
Sep	7.22	3.05
Oct	10.76	4.54
Nov	14.68	6.20
Dec	15.82	6.68

Figure 66- Monthly electricity consumption and the corresponding CO_2 emission for 2012 (Notional building)

	Heating Consumption					Electrical Consumption			
Month	Boilers Space conditioning Energy (kWh)	Boilers DWH Energy (kWh)	Chillers Energy (kWh)	Aux + DWH/Solar Pumps Energy (kWh)	Heat Rejected Fans/Pumps Energy (kWh)	Lights Electricity (kWh)	Equipments Electricity (kWh)	Total Electicity consumption (kWh)	Total Electricity consumption per floor area (kWh/m2)
Jan	42808.2	1225.9	0	6369.6	0	29817.2	38947.1	119168	11.74
Feb	34397.1	1114.5	1.2	5790.5	0.8	27021.3	35376.9	103700.7	10.22
Mar	22246.1	1225.9	4.8	6369.6	3.3	29630.7	38947	98420.8	9.70
Apr	15240.2	1058.8	44.2	5501	30.9	25535.5	34160.4	81509.2	8.03
May	6471	1170.2	1405.1	6080	983.5	28197.3	37405.7	79745.8	7.86
Jun	1592.9	1170.2	2534.7	6080	1774.3	28189.9	37243.2	75036.6	7.39
Jul	1308.4	1225.9	4155.8	6369.6	2909.1	29535.1	38947	78632.7	7.75
Aug	1898.4	1225.9	3265.9	6369.6	2286.2	29563.8	38947	78984.4	7.78
Sep	4888.9	1114.5	1241.1	5790.5	868.7	26903.6	35701.8	74771.7	7.37
Oct	15668	1281.7	99.1	6659.1	69.4	31053.7	40488.4	95180.6	9.38
Nov	27115.7	1225.9	0.4	6369.6	0.3	29786.4	38784.6	103282.3	10.17
Dec	31483.7	1058.8	0	5501	0	25765.9	34322.9	98132.3	9.67

Figure 67- Monthly electricity consumption from different sources installed in the building (Actual Building)

To calculate the CO_2 emission from the electricity sources, the energy consumption value (kWh/m^2) is multiplied by the corresponding conversion factor for electricity which is 0.422 $kgCO_2/kWh$.

Month	Total Electricity consumption per floor area (kWh/m2)	CO2 emission (kgCO2/m2)
Jan	11.74	4.95
Feb	10.22	4.31
Mar	9.70	4.09
Apr	8.03	3.39
May	7.86	3.32
Jun	7.39	3.12
Jul	7.75	3.27
Aug	7.78	3.28
Sep	7.37	3.11
Oct	9.38	3.96
Nov	10.17	4.29
Dec	9.67	4.08

Figure 68- Monthly electricity consumption and the corresponding CO_2 emission for 2012 (Actual building)

The calculated energy consumption values were then compared with the CIBSE benchmark values prescribed for this sort of building which are detailed below

Building Type	Electricity Typical Benchmark (kWh/m^2)	Fossil-Thermal typical Benchmark (kWh/m^2)
General Office	95	120

Table 19- CIBSE TM46 energy consumption benchmark for an office building

Building Type	Electricity Typical Benchmark (kWh/m^2)	Fossil-Thermal typical Benchmark (kWh/m^2)
General Office	52.3	22.8

Table 20- CIBSE TM46 CO_2 emission benchmark for an office building

The results obtained from this comparison are in the form of graphical outputs and henceforth they are given in the results section.

7.4 Results

The results obtained from the simulation of the model in ESP-r and the CIBSE energy consumption comparison are enclosed in this section.

Modelling and Simulation

Summer

The internal temperature output obtained for the summer months is shown below. This output was obtained for an occupancy of 25 people.

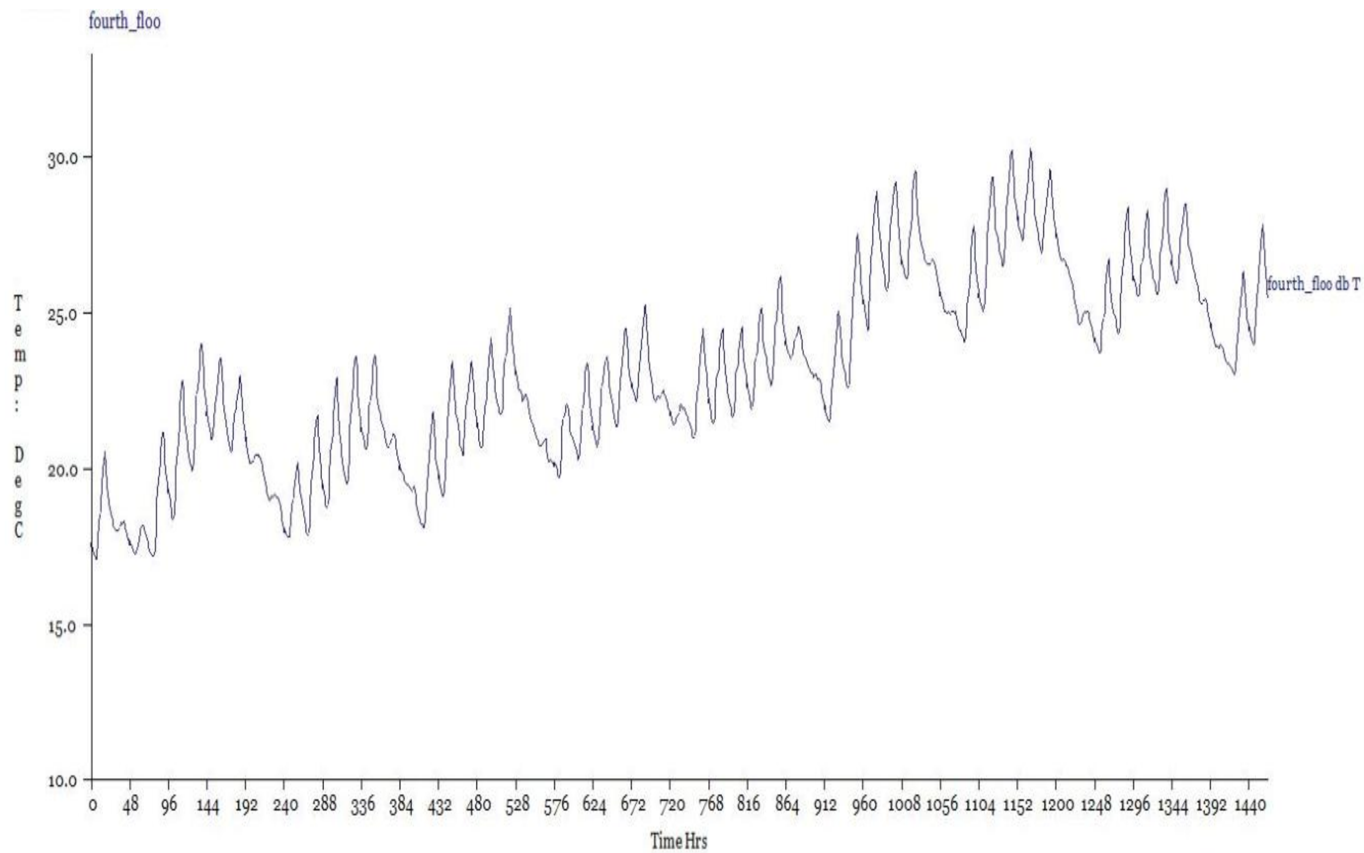


Figure 69- Internal temperature of the 4th floor for summer month simulation

The relative humidity output for the summer month simulation is shown below. This simulation has been carried out for an occupancy level of 25 people with a sensible gain of 2250W and a latent gain of 1500W.

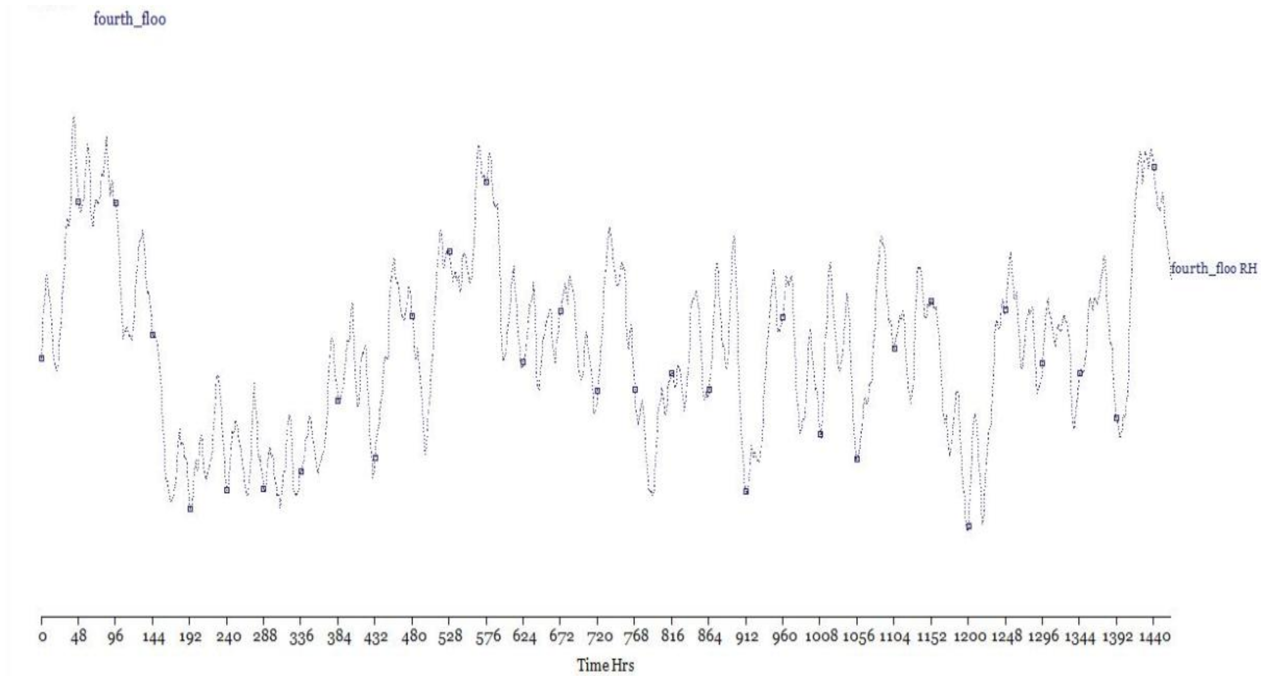


Figure 70- Relative Humidity for the summer month simulation

Winter

The internal temperature output obtained for the summer months is shown below. This output was obtained for an occupancy of 25 people.

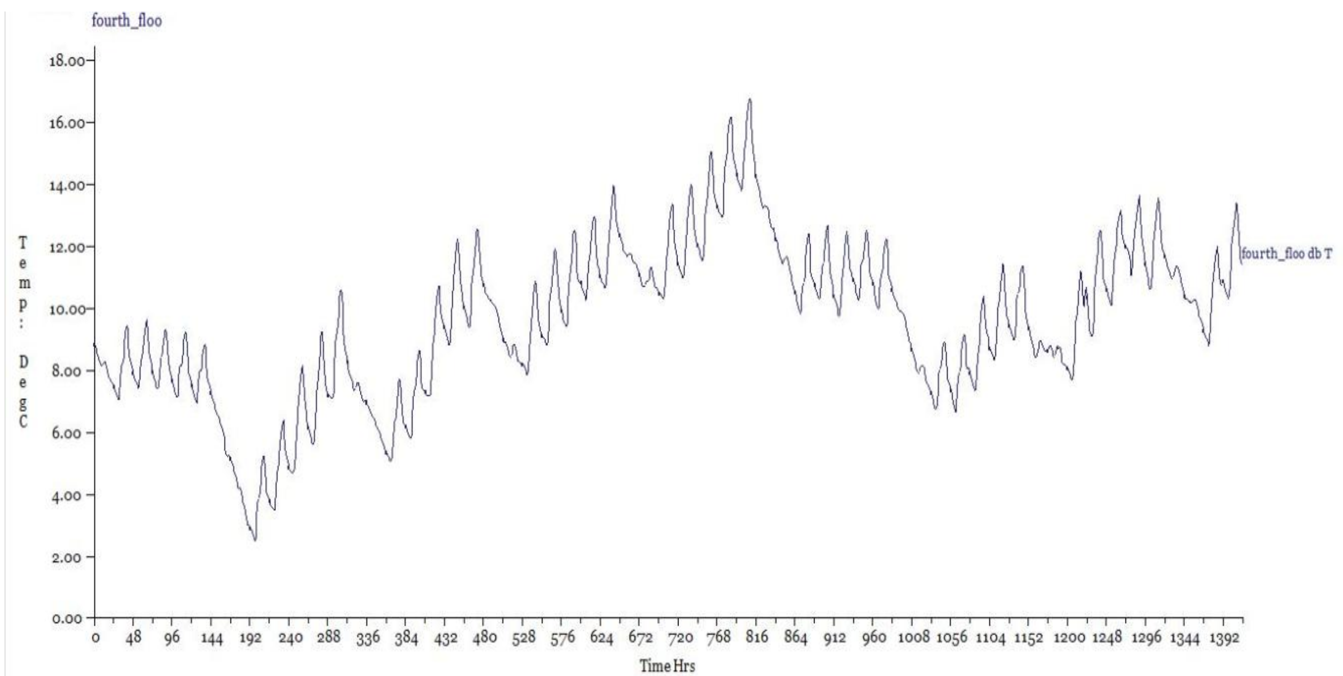


Figure 71- Internal temperature for winter month simulation

The relative humidity output for the winter month simulation is shown below. This simulation has been carried out for an occupancy level of 25 people with a sensible gain of 2250W and a latent gain of 1500W.

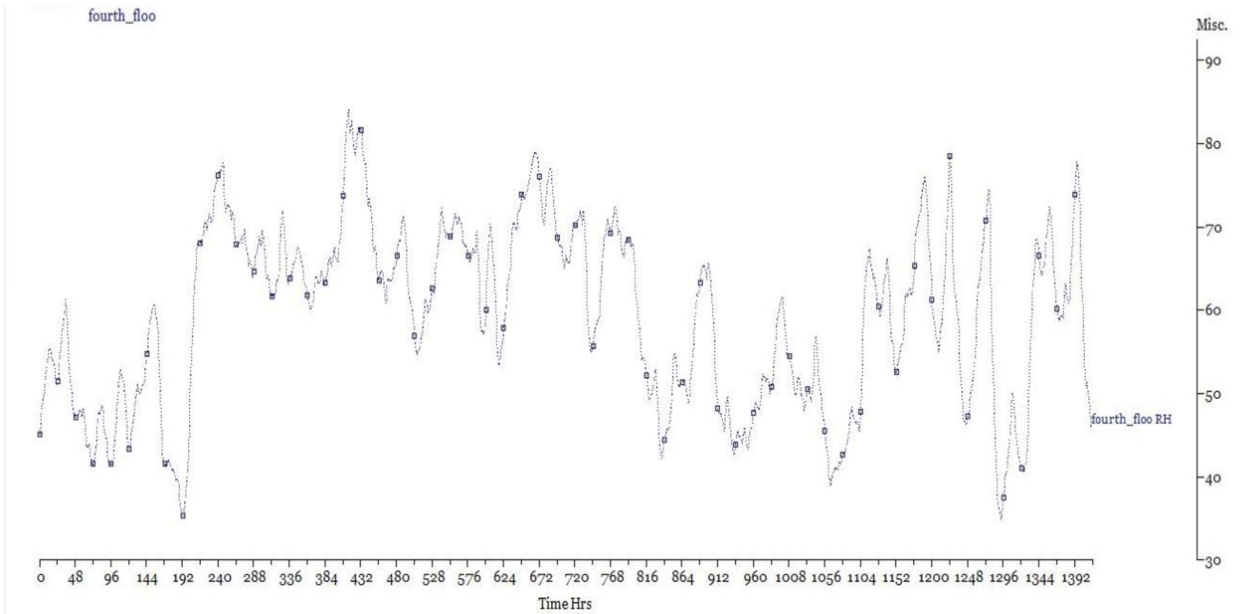


Figure 72- Relative Humidity levels for winter month simulation

Energy Consumption Comparison

The graphical outputs obtained for the electricity and gas consumptions comparison with the CIBSE TM46 benchmark and the corresponding CO_2 emission comparisons with the benchmark are given in this section of the report.

Actual Building

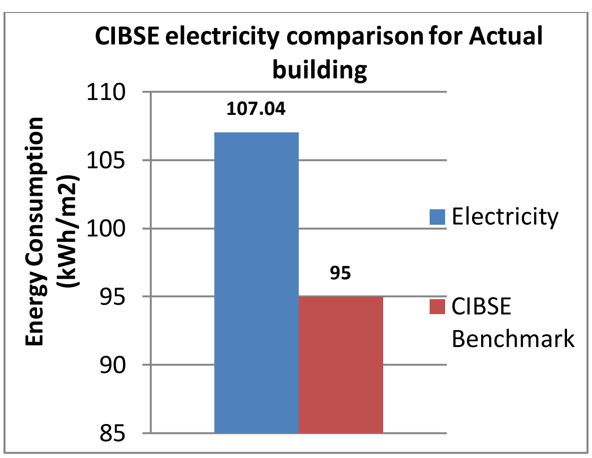


Figure 73- Electricity comparison with CIBSE benchmark for 2012 (Actual Building)

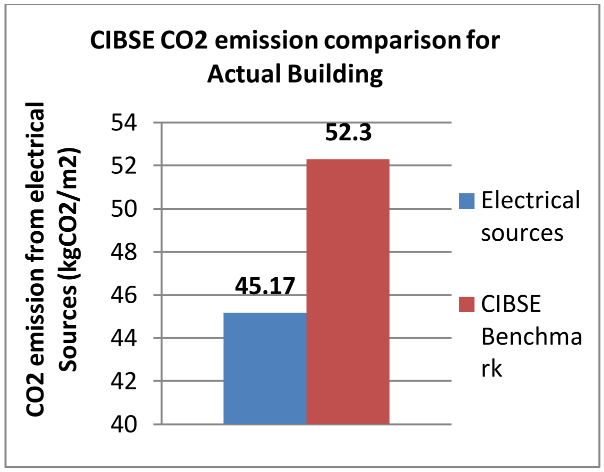


Figure 74- CO_2 emission comparison with CIBSE benchmark for 2012 (Actual Building)

Notional Building

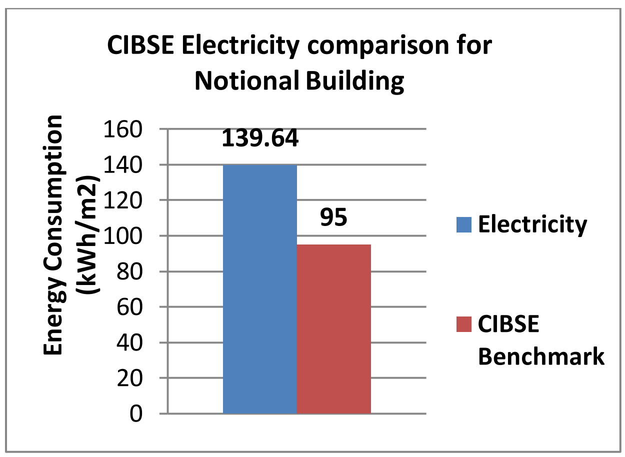


Figure 75- Electricity comparison with CIBSE benchmark for 2012 (Notional Building)

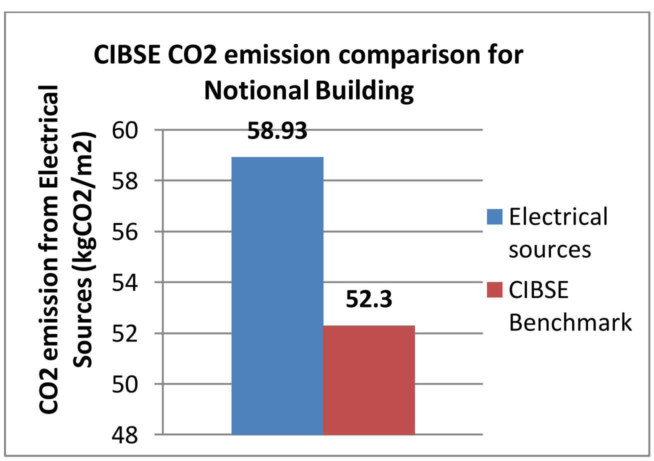


Figure 76- CO_2 emission comparison with CIBSE benchmark for 2012 (Notional Building)

Chapter 8- Analysis and discussion of results

Case study A: Loch Lomond and Trossachs National Park Authority HQ

For case study A heating is provided by means of a biomass boiler and a back up gas boiler. The biomass boiler uses locally sourced wood chip pellets as fuel and this biomass boiler was sized on a base load. When the boiler is switched on, the hot water is supplied to the buffer tanks and these buffer tanks provide heating to the building throughout the morning whenever heating is required. The boiler then turns on again whenever heating is required during the night. From the graphs shown in the results section it is clear that due to the working of the boiler according to the demand, a considerable amount of energy is saved and alongside this the running cost is also reduced. The purpose of back up boiler is to supply heating during times when the heating demand is at its peak and that the biomass boiler cannot meet the sudden increase in demand. It is clear from the results, that the gas boiler has supplied heating only during the months of December, January, February and March and that the consumption is well under the benchmark values. As the graph shows, the overall heating consumption for the year 2009 is well below the benchmark value of CIBSE and this is shown in figure 16.

Considering the electrical consumption for case study A, the major usage of electricity is to power the lighting systems, communication systems, computers and some kitchen equipment. When looking at the energy consumption data , during the summer months of April, May, June and July the electricity consumption value is 0kW and this data was obtained from the building's BMS. However there is a slight increase during the winter season and this may be due to a number of reasons such as reduced daylight, increased number of occupants. Moreover when comparing with the CIBSE benchmark, the value of electricity is 47.41kW against the benchmark value of 95kW for a gallery building and this emphasizes the fact that design procedures undertaken actually proved to be vital in reducing the building's energy consumption. The CO_2 analysis also showed the similar kind of results and as expected the equivalent amounts of CO_2 emitted from the electrical and heating sources are well below the CIBSE benchmark values and this justifies that the building is carbon efficient.

The modelling approach proved to be a vital factor in understanding the real time scenario existing inside the reception. Figure 12 shows that the maximum value of temperature is around 30°C during the month of July, but this maybe due to the model being simulated without the definition of a plant system as well as the choice of materials used for the walls. In a similar way when the results obtained for the winter month simulation showed that the maximum temperature is around 16°C (figure 14) but this value is quite below the designers proposals. It is understandable that if a ventilation system and boiler plant was incorporated within model the values obtained would have been at par with the designers proposals. However using the limited details available and due to the time scale of the project the results thus obtained from ESP-r stresses the fact that the building is low carbon built and that it performs as per the designers proposals and that the BREEAM rating of EXCELLENT awarded to this building is justified through this analysis.

However since the analysis has been performed using the data obtained for the year 2009, there could be a marginal increase or decrease in these values for the year 2012. Future POE/energy performance analysis could be done for the 2012 data and comparisons can be drawn against those values obtained from 2009.

Case Study B: The Scottish War Blinded Facility, Linburn Centre

For case study B, heating is provided by a Ground Source heat pump (GSHP). The ground source heat pump is powered by electricity to extract heat from the ground and this installation is a first step towards low energy solution. The GSHP utilises this electricity at a high level of efficiency and that the pumps efficiency throughout the year is almost 70%. The results for the year 2009 show that during the winter months of December, January, February and March the heating demand is quite high and this might be due to the climatic conditions prevailing in the area. However as the summer sets in the energy consumption drops to as low as 4000kWh which is almost 60% reduction from the maximum consumption during the year. When this annual consumption was compared with the CIBSE benchmark, figure 33 shows that the electricity consumption is higher than the benchmark by a value of 20kW and this might be due to the fact that the hot water heating is also provided from the GSHP system. In such cases, a stand-by system such as a back-up gas boiler could be used to provide hot water throughout and additionally the GSHP system should have been installed in such a way that it works according to the heating demand.

With regards to the CO_2 analysis, figure 34 shows that the emission from the building exceeded the benchmark limit by a value of $1kgCO_2/m^2$ which on the overall aspect is understandable that this is due to the increased of electricity to power the ground source heat pump. The 'B' rating awarded is therefore justified through this heating and CO_2 analysis.

The results from ESP-r showed that the temperature value during the summer months fluctuates between 15°C and 25°C throughout the year but in figure 29 it can be seen that during one particular day in July the temperature value reaches 30°C which essentially brings out the fact that there is overheating inside the room. As earlier mentioned since a ventilation system was not defined for the model, this result could have been possible, however most of the values are at par with the designers proposal of 23°C. In the same way the results obtained for the winter month simulation showed that the maximum temperature inside the art room would be around 24°C (figure 31) which is also at par with the design criteria. As per the design report the RH level during the summer is expected to be around 70% and figure 30 shows that the RH level stays below 70% for almost the entire the summer months and this proves that the ESP-r result is quite accurate despite certain assumptions which were made to simulate the model. In a similar way the relative humidity results for winter was also compared with the designers proposals and this seemed to be a bit contrasting. The designers predict that even during winter the RH level would be 70% but there is a slight variation in the ESP-r result. Figure 32 shows that the RH level reaches almost 90% during the start of January and this can be due to the occupancy level assumption or due to the high temperatures prevailing inside the art room. Though the same composition of materials were not used and that the definition of a ventilation strategy was neglected, similar results have still been able to be obtained. Future works could therefore include the complete modelling of this building along with the definition of a ventilation system and to analyse the results through an ESP-r simulation.

Case Study C: The Scottish National Portrait Gallery

Case study C being a refurbishment steps were taken to reduce the gas and electricity consumption through the installation of energy efficient measures. For case study C, the heating is provided by gas fired boiler which serves all areas of the building. From the results obtained it is clear that during the year 2008 the overall gas consumption is around 1203738kWh when compared to the overall consumption of 805474kWh for the year 2012. This reduction in gas consumption is due to the fact that the gas boiler has been designed to work according to the demand of the building. However this building being a place of public attraction, large number of people visit the place around the year and that especially during the winter season the heating demand is high and the gas consumption has been the same during the winter for both the years. During the summer there has been a drastic reduction in the gas consumption due to the less heating demand during this season. Over the 4 years the gas consumption has been reduced by a margin of 33% due to the refurbishment measures such as insulation of roofs and installation of a new boiler system which works according to the demand and so on. The gas consumption values were then compared with the CIBSE benchmark and this showed that for the year 2008 the actual energy consumption in the building was higher than the benchmark by a margin of 90kWh/m^2 (shown in figure 51), whereas for the year 2012 the gas consumption value was well below the benchmark value by a margin of 22kWh/m^2 (figure 53). In a similar way, the CO_2 emission comparison with the benchmark also showed the same kind of results. For the year 2008, figure 52 shows that the CO_2 emission from gas was higher than the benchmark value by a margin of 15kgCO_2/m^2, whereas for the year 2012 the value had reduced to 37kgCO_2/m^2 which is below the benchmark value of 38.5kgCO_2/m^2 (figure 57). This considerable reduction in the CO_2 emission values is due to the fact that the heating demand has been lowered due to the energy efficient measures undertaken by the M&E service engineers during the refurbishment process.

The electrical system for case study C included the fluorescent lighting system for the galleries, the roof lit lighting system and the equipments used inside the gallery. Similar to the heating analysis, the electrical analysis results also showed a drastic reduction over the 4 years. For the year 2008 the annual consumption stood at 728970kWh and for the year 2012 the annual consumption stood at 616220kWh. When looking at the electrical consumption for the year 2008, it is clear that the lack of daylighting systems more artificial lighting had been incorporated. Whereas, during the refurbishment stage, installation of daylighting techniques such as dimmers and configuring windows to be opened to allow more natural light into the building have been the major factors that have reduced the need for artificial lighting. The annual consumption value was then compared with the CIBSE benchmark value and the result obtained stated that for the year 2008 the annual consumption value exceeded the benchmark value by a margin of 100kWh/m^2 (figure 50) . For the year 2012 this value had reduced to 136kWh/m^2 which is still above the benchmark value of 70kWh/m^2. When looking on the overall perspective the electricity consumption has been reduced by a margin of 15% which is a positive factor. The electrical consumption was then converted to equivalent amounts of CO_2 emission and similar analysis was performed. The CO_2 analysis for the year 2008 showed that the actual value was exceeding the benchmark value by 30kgCO_2/m^2 (figure 52) and that for the year 2012, the value of CO_2 emission is exceeding only by a margin of 15kgCO_2/m^2 (figure 56). However it is possible that this value could still be reduced if the artificial lighting systems are improvised and additionally if daylighting principles are put into fuller use thereby reducing the electrical demand.

As per the design report it was predicted that during summer the maximum temperature inside the building would be around 23°C and that during winter the lowest temperature would be 18°C. When the model was simulated in ESP-r the results obtained were slightly different. Figure 48 shows that during summer it is expected that the maximum temperature would be 26°C and the lowest possible to be around 17°C . In a similar way figure 49 shows that during winter the maximum possible temperature values are expected to reach 28°C and the lowest value would be 17°C. This variation is due to the fact that the ventilation system was neglected and additionally it can be due to the occupancy judgement which was considered to simulate the model. However if more details related to the building construction and mechanical services are available detailed modelling can be performed and more accurate results at par with the designers proposals can be obtained. Last but not the least, the Scottish National Portrait Gallery was refurbished with a view to improve the building's energy consumption and improve the occupant's comfort and from the above analysis and simulation it is clear that the designers and the M&E service engineers have taken the best possible to achieve these excellent results.

Case Study D: Collegelands Office, High street

The main heating source for cases study C is through electric heaters and henceforth electricity is the only fuel source throughout the building. Since the building is located in Scotland the heating demand is expected to be higher during winter and as per the designers proposals for the months of December, January, February and March the heating demand was expected to be around 459781kWh. However when the VRV system was installed, the actual building performed otherwise. For the months starting from December to March the total monthly heating consumption was around 130,934kWh which is considerably lower than what was expected. This is due to the fact that the VRV system has very efficiency and performs accordingly to the demand.

With regards to the lighting consumption the notional building shows that there is 0kWh consumption from the lighting equipment during the month of January which is contradictory because this value was obtained by the designers and for the period of 12 months the total consumption from the lights is proposed to be around 26142kWh. Since collegelands is an open plan office building, equipments prove be a vital source for electricity consumption and in a similar way the total consumption from the equipments was predicted to be 520851kWh. Figure 61 shows the energy consumption data for the actual building and when looked at the energy consumption from lights and electricity sources there seems to be a variation in the actual performance. The total consumption from lights for the year 2012 is around 341000kWh and that from the equipments it is 449272kWh which is way beyond the designers proposals. This value proved to be critical when comparisons were drawn out with the CIBSE benchmark as there existed a possibility where the building's electricity consumption could be more than the benchmark.

When the overall consumption was mapped with the CIBSE benchmark, the results were noteworthy. Figure 65 shows that the total electricity from the notional building is higher than the benchmark value by a margin of 44 kWh/m^2 and the corresponding CO_2 emission also exceeds the benchmark value by 6 $kgCO_2/m^2$. Similarly figure 63 shows that the electricity consumption from the actual building is higher than the benchmark value which can due to the fact that electricity is being used for all purposes including hot water heating and along with that there are possibilities of human error when handling the BMS. On the other hand the corresponding CO_2 emission values has dropped below the benchmark value by $7kgCO_2/m^2$ which is what the building designers expected. This drop in CO_2 emission hence paved way for the building to be awarded an Energy performance rating of B which states that the building is carbon efficient.

For this building the design report did not include any details related to the internal temperature of the building or about the relative humidity levels. However the modelling was done to foresee how the building would perform when simulated in ESP-r and the results were noteworthy. Figure 65 shows that the maximum internal temperature inside the floor would be 30°C and that this value is obtained since the VRC refrigerant system was not imposed into the model. However for any building of this kind, the temperatures would not go beyond 25°C. However the relative humidity levels were around 50% for most part of the summer except for two occurrences in June where the RH level was around 70% which could possibly deter the comfort level of the occupants. For the winter simulation the maximum temperature inside the floor was noted as 17°C which is quite lower than what the designers would predict. It is at this point the VRV system provides cooling which thereby increases the temperature to around 23°C.

On the overall aspect with the analysis of the energy consumption data from the building's BMS it is worthwhile to say that the Energy performance rating of B which was awarded to the building is justifiable on the basis of the CO_2emissions from the building.

Chapter 9 - Conclusion

As a result of the literature review, the development of a methodology for energy performance analysis and the application of the methodology on 4 non-domestic buildings, various conclusions have been drawn with relation to sustainable/green building design, where Post occupancy evaluation fits into that process and what significance it has when evaluating the building's energy performance and also the necessity for awarding the buildings with an energy performance certificate or a BREEAM excellent rating.

Green Design

The term 'Green Design' covers a wide spectrum of environmental design principles/strategies such as building design, construction and use. The ultimate aim of any architect is to design a building which can heat or cool itself without the installation of a mechanical service. However from architects perspective, this view involves various factors such as designing the building appropriately in terms of orientation, sun paths and prevailing winds. All these above factors contribute to a building's energy-saving strategy. One such heating strategy is that the building's fabric should meet the current building standard U-values. The U-values determine how efficiently the walls, roofs, windows keep the heat inside the building without the necessity of a mechanical aid. By employing materials with better U-values, heat loss through the building envelope can be minimised and thereby an increase in energy efficiency can be foreseen. Moreover this heat loss through building envelope via air leakage through components can contribute to carbon emissions and in one way or the other good construction along with air tightness testing can reduce carbon emission.

The case studies illustrate that cooling from a mechanical source is necessary during the summer months owing to an increase in temperature. Since the buildings are located in Scotland cooling is a necessity only for a few months in summer and to reduce the need for cooling, the most efficient way is to shade the windows and other apertures. Shading protects the building from unwanted direct sunlight and in some cases shading also increases thermal insulation. Additionally openable windows should be installed so that fresh air can come into the building which thereby enhances the comfort of the occupants.

The case studies further illustrate that, in order to provide a healthier and pleasant living condition, proper ventilation with an abundance of daylight is necessary. Daylighting techniques which reduce the need for artificial light also offers substantial energy saving and reduces consequent environmental damage i.e. reduced artificial light usage reduces the electricity consumption and thereby carbon emission is reduced. Additionally the reduced use of a mechanical ventilation system also influences energy-saving measures, however certain issues with comfort level arises when building design more focussed towards maximising natural ventilation and daylight. When external air very warm, still opening windows and roof lights may not provide the required cooling to reduce the temperature. With Scotland having a cold climate it is accepted that overheating for a relatively shorter period of time can be tolerable. However to reduce the possibility of constant overheating the installation of high performance glass is advisable.

When looking at the broader perspective it may not be possible to address and eradicate all the issues discussed above, however user comfort compromise can be minimised through an environmentally sensitive design.

Generation of energy from Renewable Sources

Sustainable buildings being the frontrunner these days there are more benefits for renewable energy generation. CO_2 emission reduction being the first priority from these energy generation techniques, employing such measures conforms to the ethos of sustainability. There are various technologies which are currently in use which comes under the sustainability criteria and some of them are biomass, hydro, micro-CHP, geothermal, solar PV and wind. All these systems are becoming more easily available and frequently present in modern buildings. Before installing these systems it is vital to consider the feed-in tariffs for all these systems and among these biomass has the cheapest tariff of 2.9p/kWh for wood chips and 4.2p/kWh for wood pellets whereas the tariff for all other systems exceeds 5p/kWh and varies according to the scale of generation.

Wood-chip is considered as carbon neutral i.e. CO_2 released during combustion is absorbed by trees which thereby grows and is later used as fuel. As with case study A, biomass boilers are generally fired on wood products which produce hot water to circulate heat around the building and thereby the amount of carbon emission is henceforth reduced. Geothermal source such as a heat pump is a central heating system that uses earth as a heat source to provide heating and cooling and substantially they reduce the emissions and the electricity which is used to power them can be generated from renewable sources.

Many renewable technologies were at a relative stage of development during the last decade. There were problems during the installation and at the early stage of usage which needed to be nursed and all these problems were due to the low levels of experience using such systems. However as years have passed, most of these problems were addressed and constant exposure to such systems meant that these systems could be installed wherever possible and that they could also be monitored and taken care of. From the case studies it is seen that only two buildings have these systems installed i.e. Case study A - biomass boiler and Case study B - ground source heat pump, whereas the other two buildings use gas boilers and VRV system respectively. When looking at all the buildings it is seen that are certain issues with the biomass boiler system in case study A which is clearly apparent i.e. shutting down of the boiler when demand is high. With regards to the other buildings there are no issues which could be identified from the various systems installed and moreover from the energy performance analysis it is clear that all buildings are performing at par with the benchmarks but still certain improvements are necessary which can further enhance the performance of the building.

Final Word

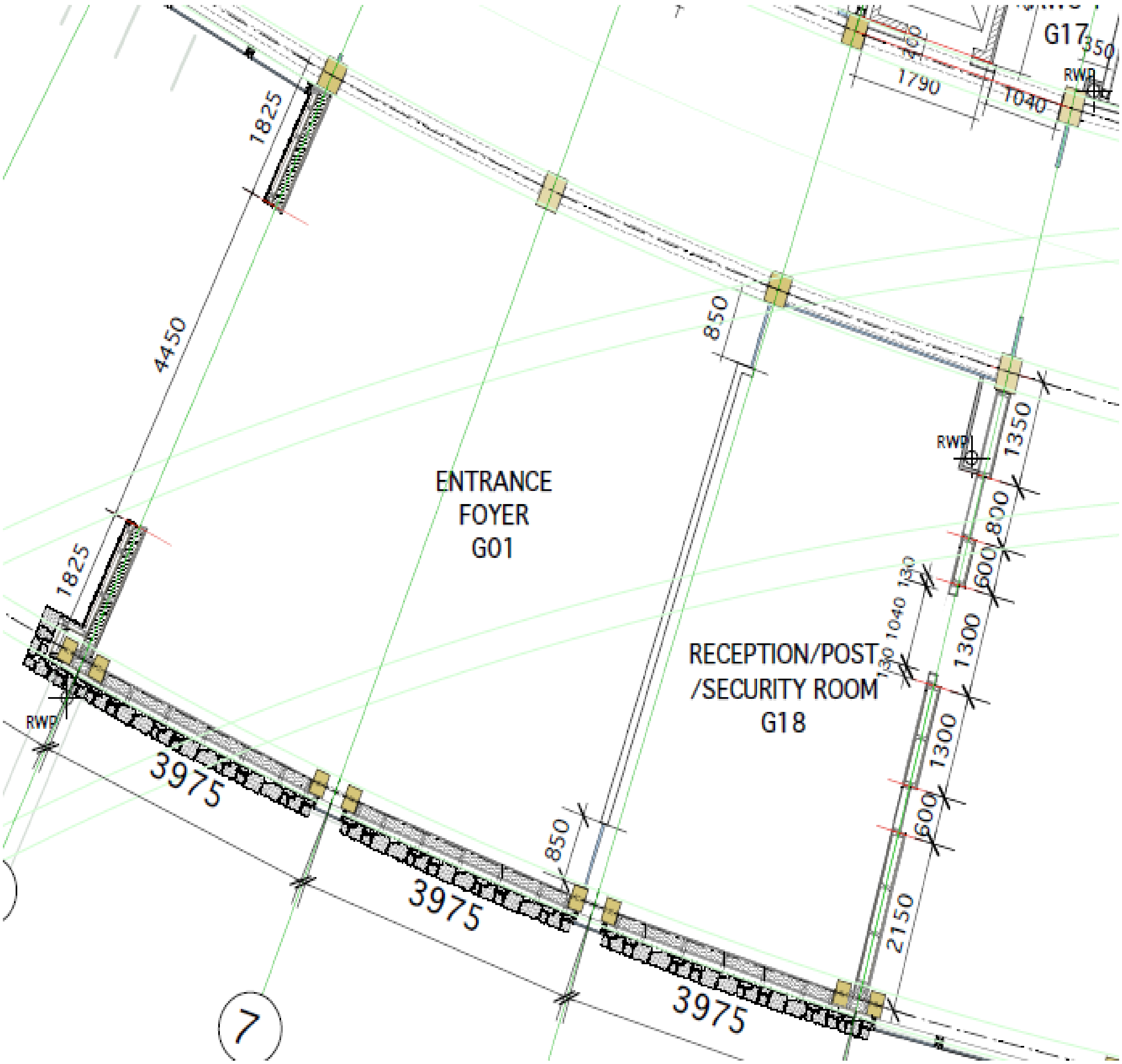
From a broader perspective it is ideally recommended that every new building should address some form of energy performance evaluation throughout the building lifecycle. Through extensive case study knowledge, framework could be built which can be shared across the design and construction disciplines which paves way for promoting best practice and furthermore lessons are learned in order to avoid the repetition of mistakes. This step is especially important for sustainable building design where innovative technologies and materials are used alongside the passive design. However buildings can underperform owing to a number of factors and targets are not always achieved. This can be due to problems with technology, human errors where users do not fully understand the working of a complex building management system.

The methodology used for this project is simple and effective. It takes into account the benchmarks set out by organisations and brings out a fair comparison of actual building performance against the industrial benchmarks. The results from this comparison are evident and prove that assessment methods such as BREEAM are helpful for engineers when undertaking a post-occupancy evaluation. However it is evident from previous projects that building occupants are often the best judges of buildings and they provide the valuable feedback for any sort of building evaluation. This project did not include this procedure due to the timescale available. Future works could include interviews with clients and occupants and the summary of these results along with the energy performance analysis can be used as a complete Post-occupancy evaluation technique since POE is an important element of sustainable building and it is only by this evaluation that the building's true sustainable credentials can be verified.

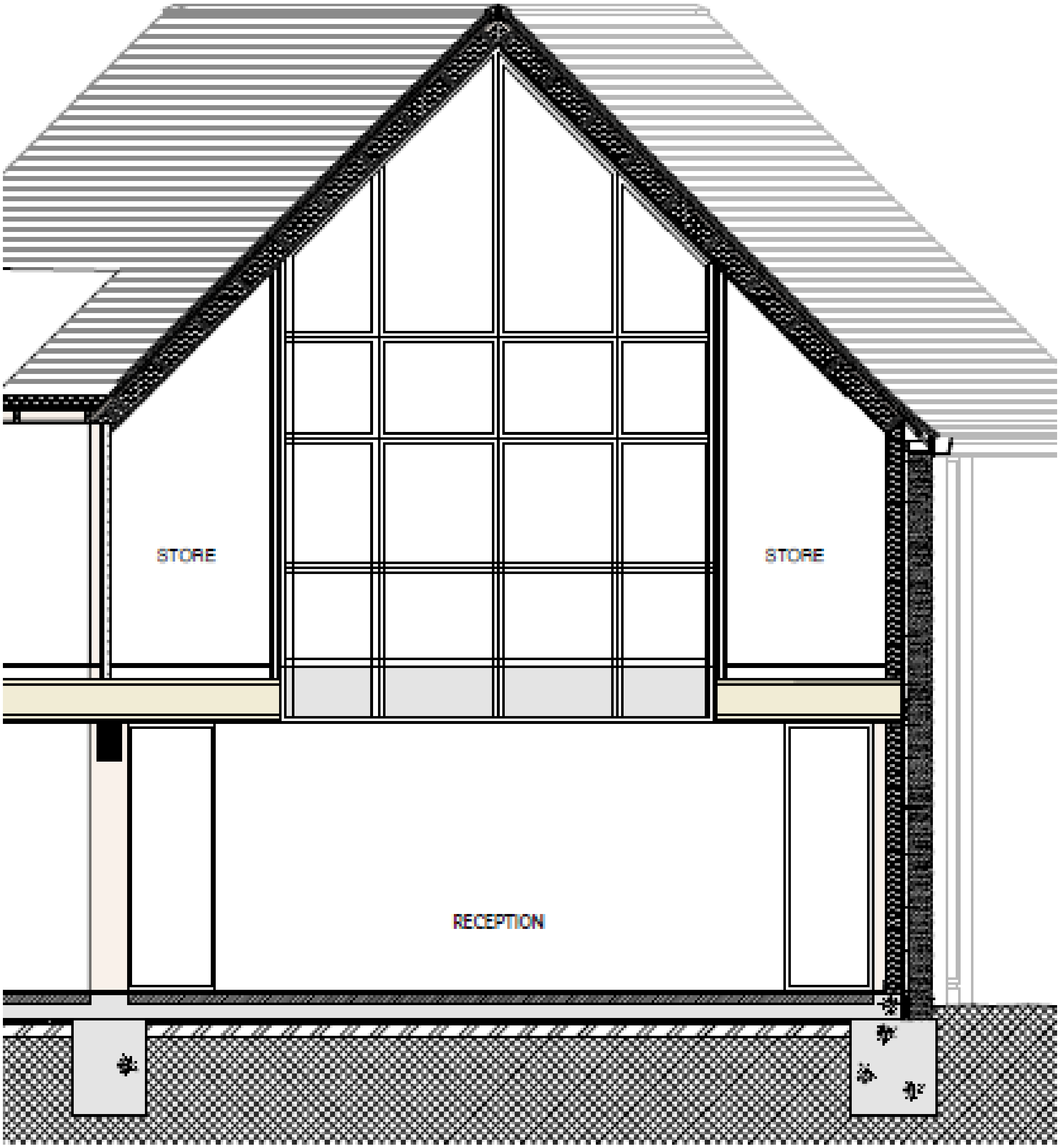
Appendix A - Building plans and section diagrams

A.1 Loch Lomond and Trossachs National Park Authority HQ

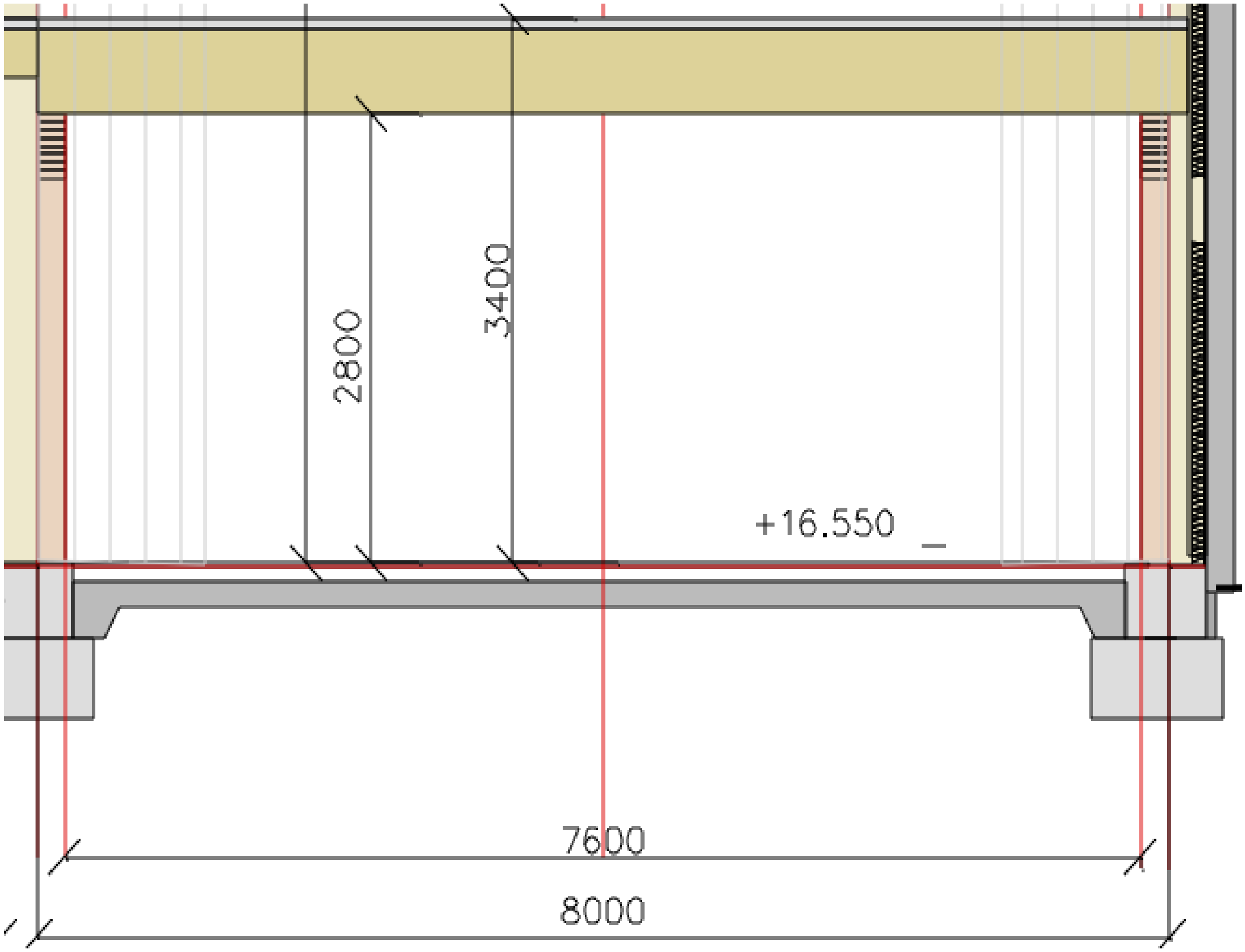
Reception Layout (Source: Page\Park)



Reception Front Elevation (Source: Page\Park)

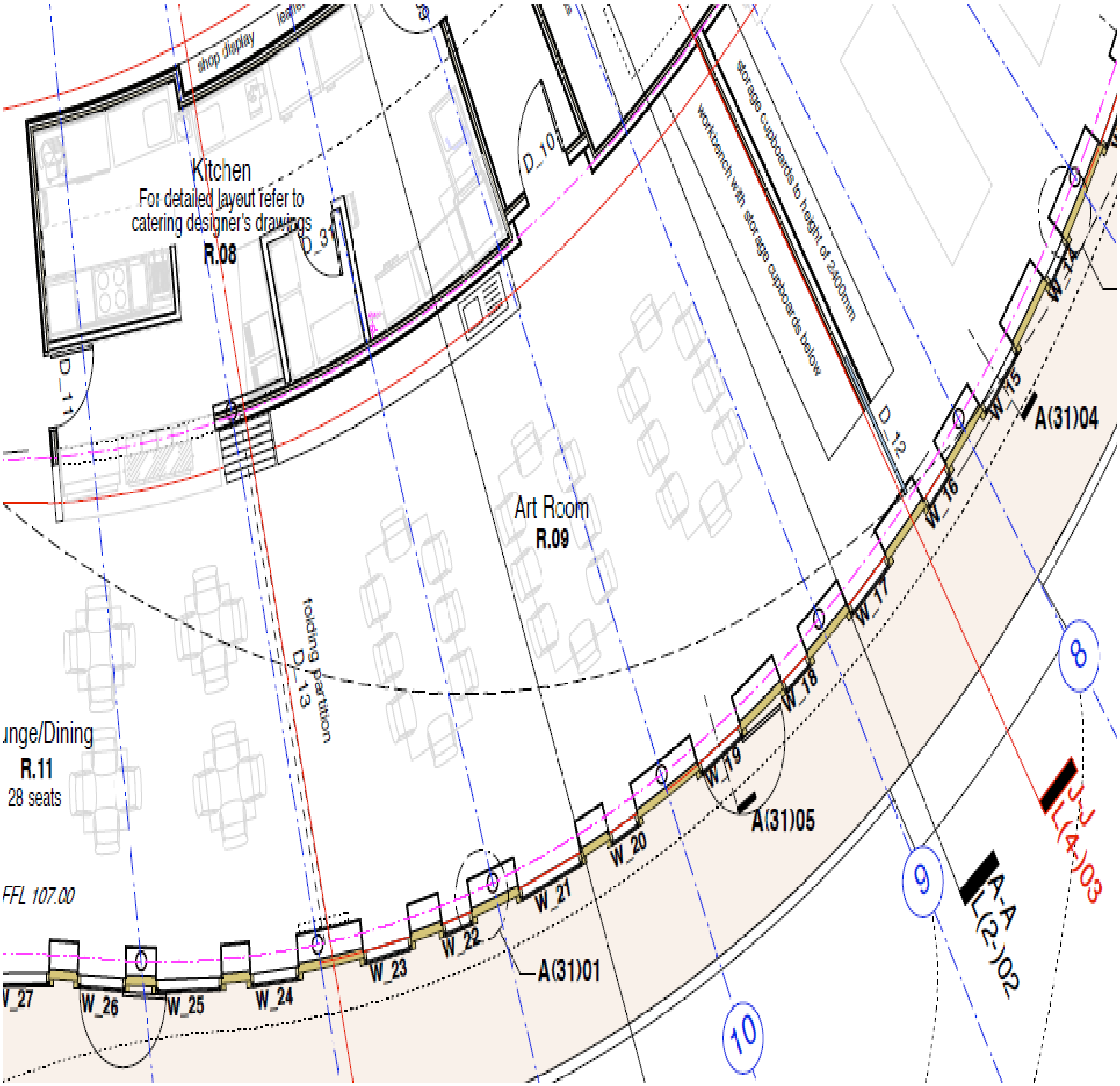


Reception dimensions (Source: Page\Park)

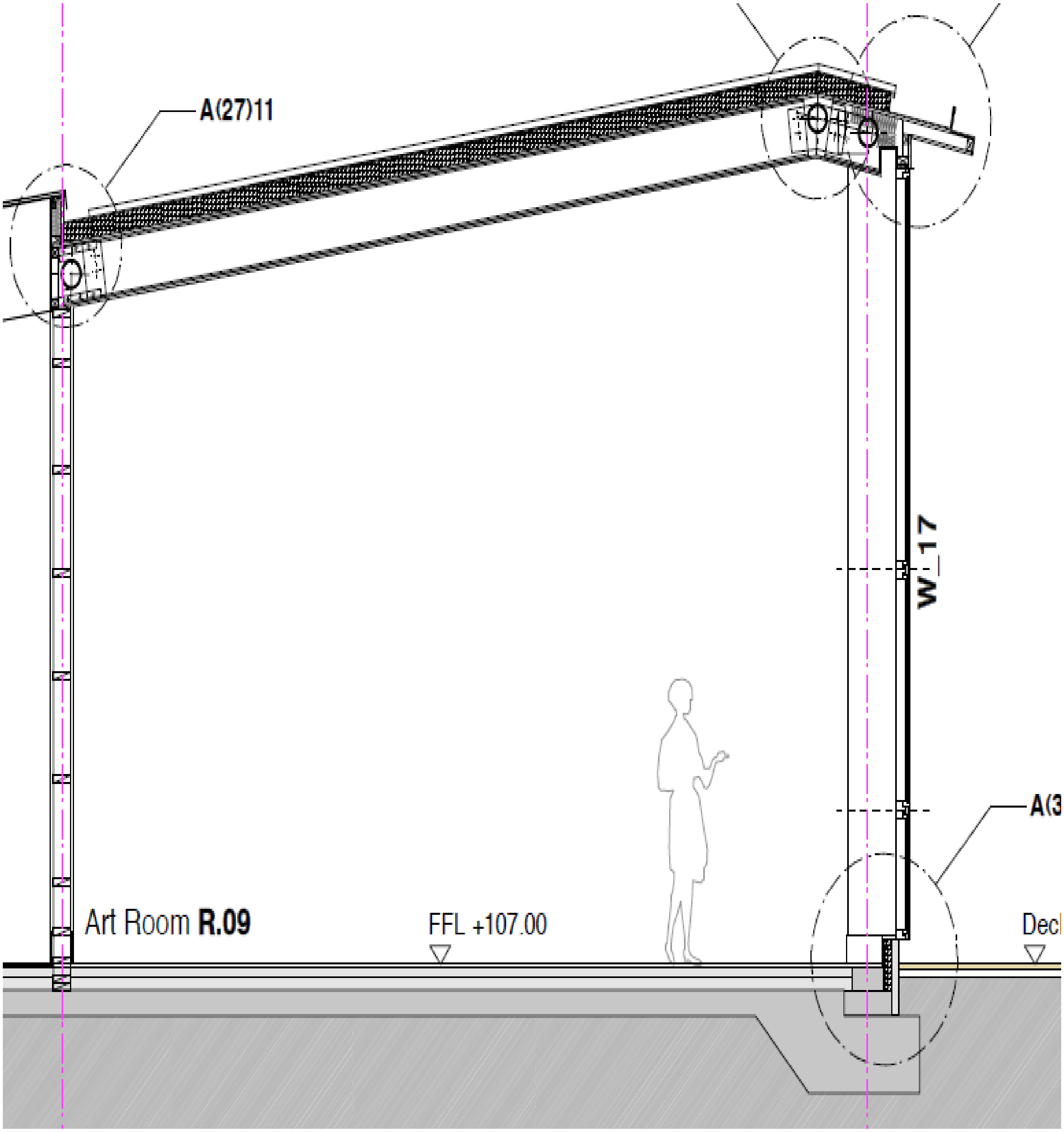


A.2 Scottish War Blinded

Art Room- Top View (Source: Page\Park)

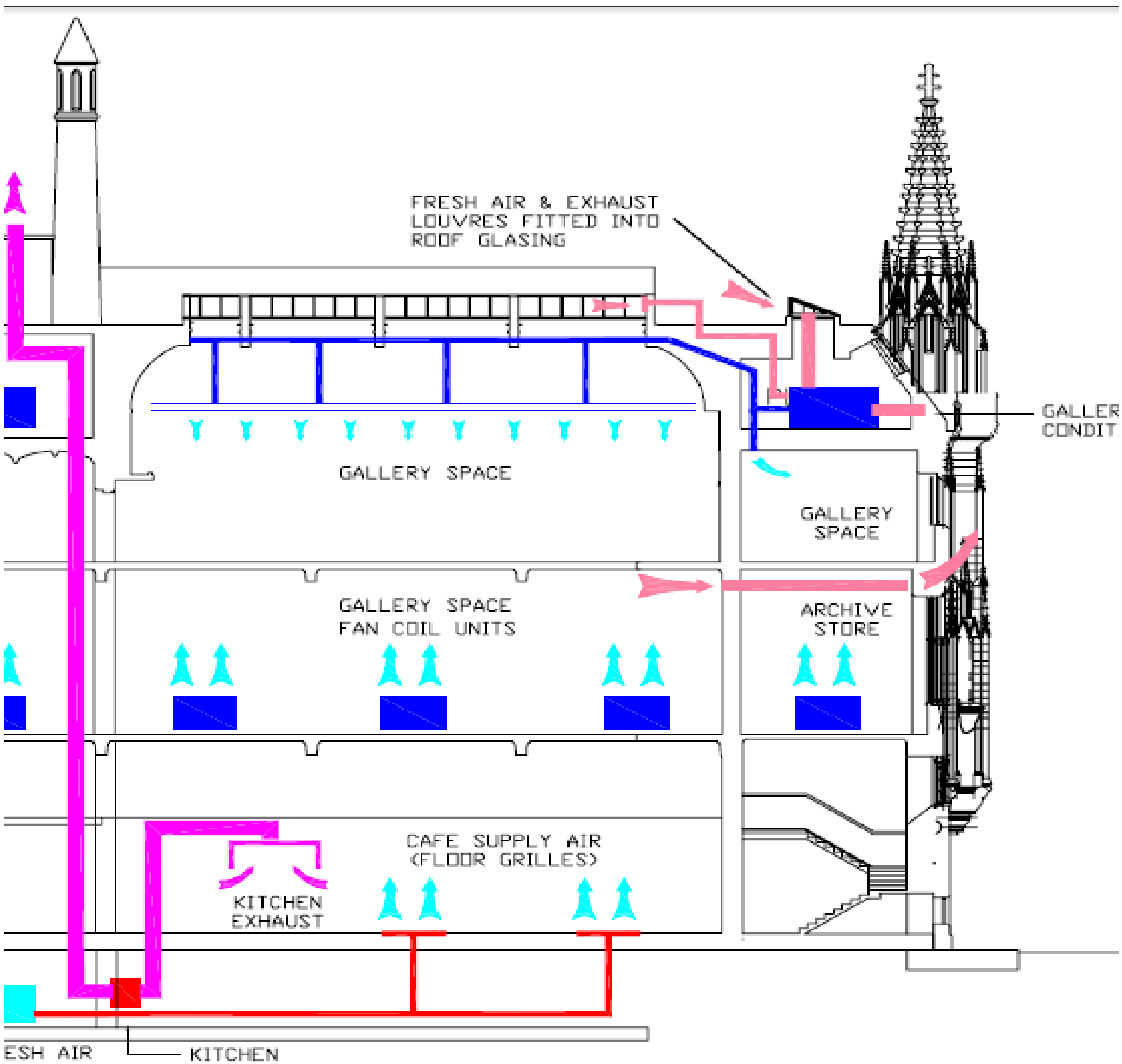


Art Room- Front Elevation (Source: Page\Park)

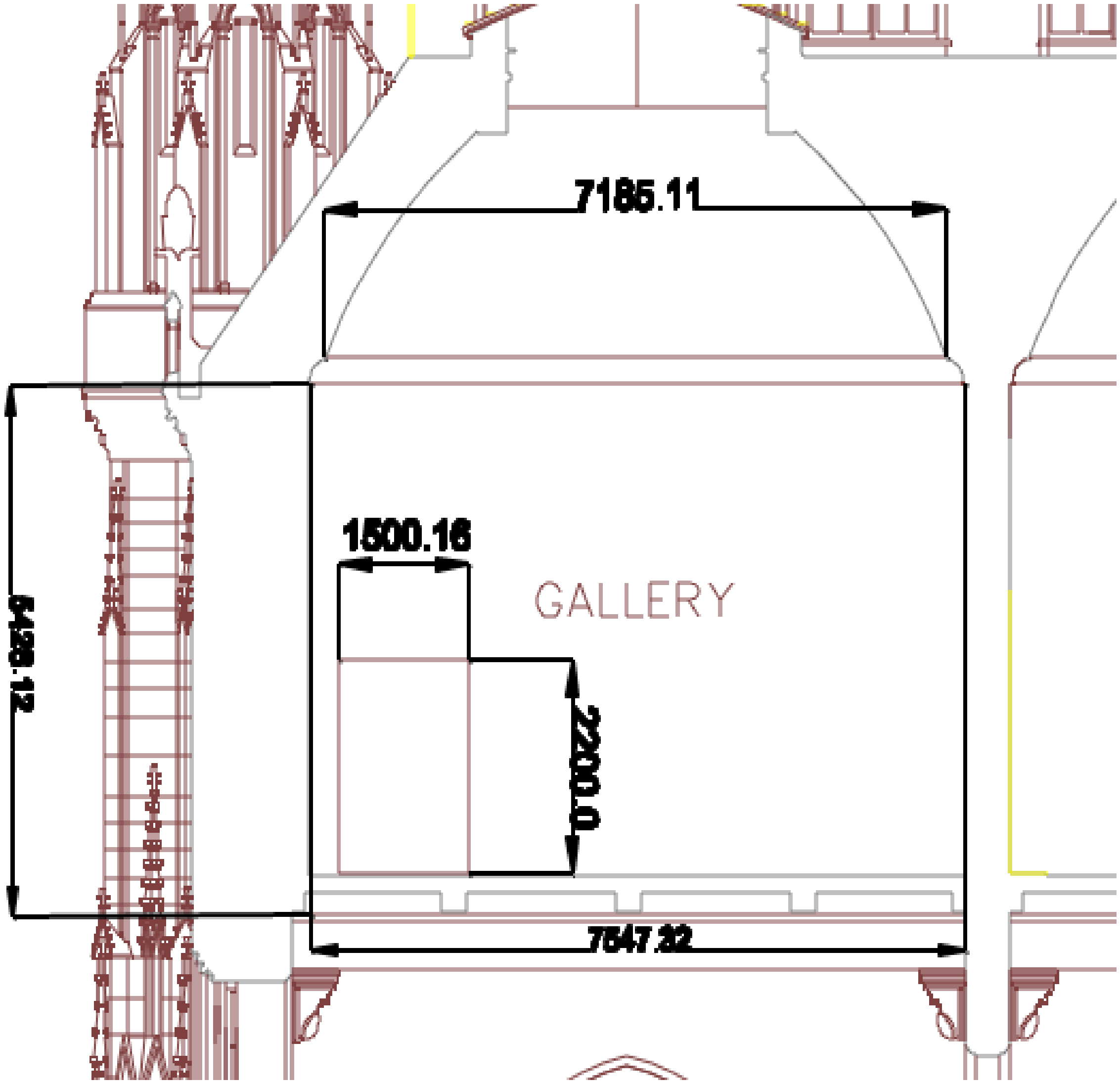


A.3 Scottish National Portrait Gallery

Gallery Front View (Source: Page\Park)



Gallery- Dimensions (Source: Page\Park)



Appendix B- Energy Performance Certificate

B.1 Loch Lomond and Trossachs National park

BREEAM

Environmental Assessment Award

This is to certify that

Loch Lomond & The Trossachs
National Park
Authority Headquarters
Carrochan Road
Balloch

has achieved the rating of

EXCELLENT

Under

BREEAM for Offices 2005

The assessment was carried out at the
Design Stage

The design achieved an Environmental Performance Index of

1	2	3	4	5	6	7	8	9	10

Signed on behalf of Building Research Establishment Ltd.

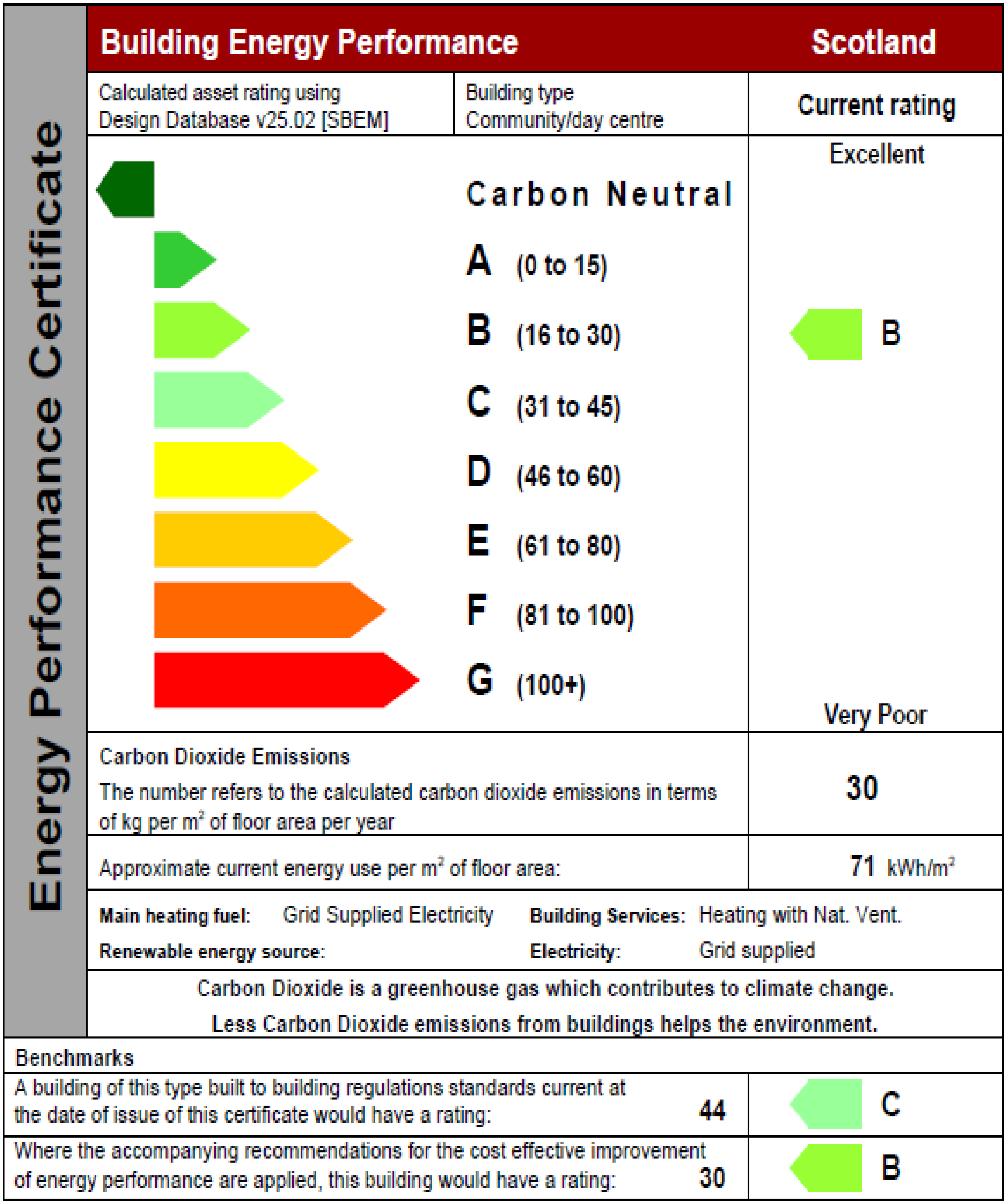
		Date:	12 December 2006
Licensed Assessor:	Jane Boyle	*On behalf of:*	HLM Architects
Developer/ Contractor:	CBC Ltd	*Architect:*	Page and Park Architects
M&E Consultant:	Buro Happold	*Client:*	Loch Lomond and The Trossachs National Park Authority

This environmental assessment has been carried out at the design stage. No assumptions should be made about performance of aspects not covered by the assessment report. BREEAM is a registered trademark of the Building Research Establishment Ltd.

BRE

B.2 Scottish War Blinded

Energy Performance Certificate for buildings other than dwellings



Energy Performance Certificate

Building Energy Performance — **Scotland**

Calculated asset rating using Design Database v25.02 [SBEM]	Building type Community/day centre	Current rating

Excellent

Carbon Neutral

A (0 to 15)

B (16 to 30) — Current rating: B

C (31 to 45)

D (46 to 60)

E (61 to 80)

F (81 to 100)

G (100+)

Very Poor

Carbon Dioxide Emissions The number refers to the calculated carbon dioxide emissions in terms of kg per m² of floor area per year	30
Approximate current energy use per m² of floor area:	71 kWh/m²

Main heating fuel: Grid Supplied Electricity **Building Services:** Heating with Nat. Vent.

Renewable energy source: **Electricity:** Grid supplied

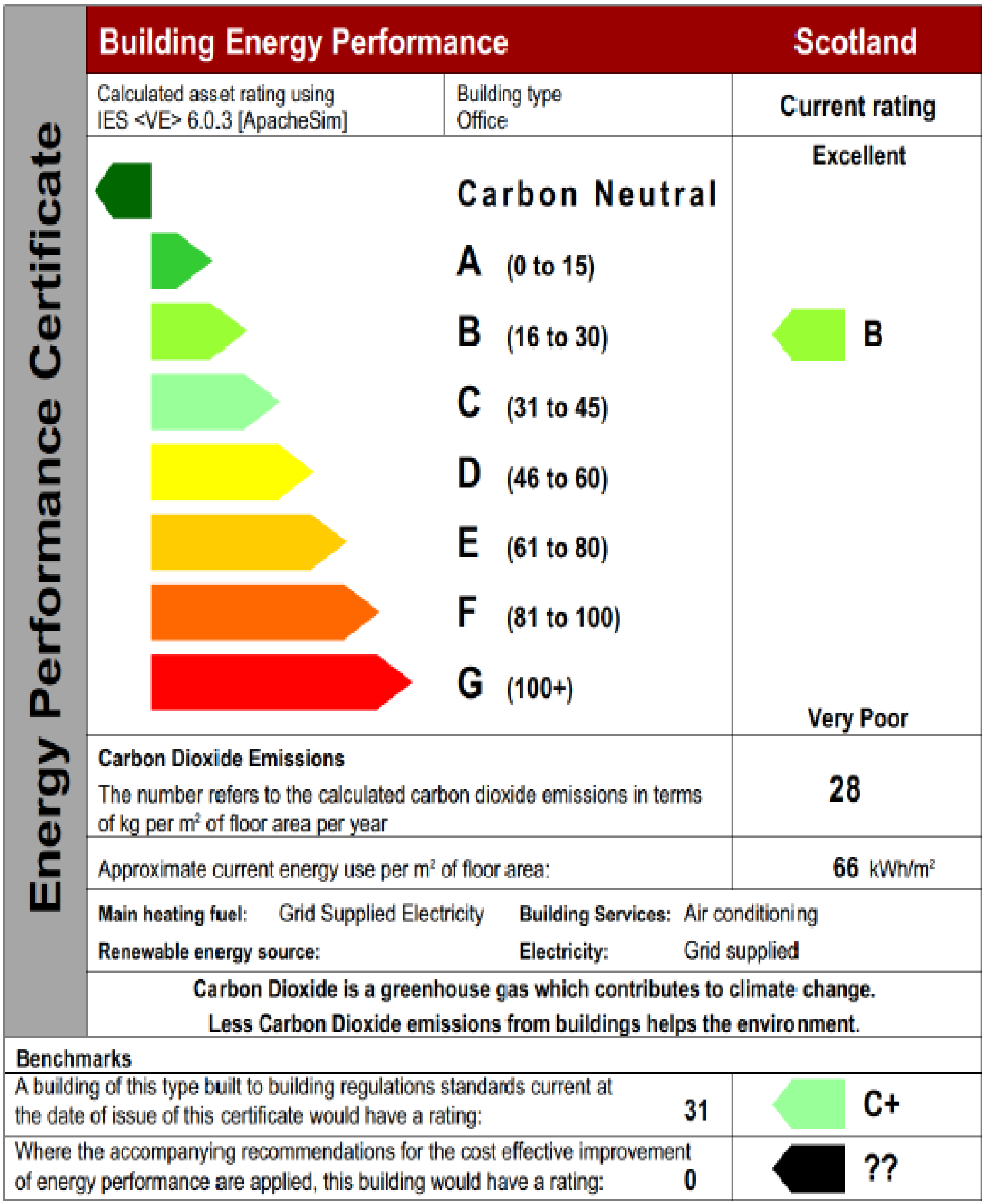
Carbon Dioxide is a greenhouse gas which contributes to climate change.
Less Carbon Dioxide emissions from buildings helps the environment.

Benchmarks

A building of this type built to building regulations standards current at the date of issue of this certificate would have a rating:	44	C
Where the accompanying recommendations for the cost effective improvement of energy performance are applied, this building would have a rating:	30	B

B.3 Collegelands, High Street

Energy Performance Certificate for buildings other than dwellings



Energy Performance Certificate

Building Energy Performance | **Scotland**

Calculated asset rating using IES <VE> 6.0.3 [ApacheSim]	Building type Office	Current rating
		Excellent

Carbon Neutral
A (0 to 15)
B (16 to 30) — B (current rating)
C (31 to 45)
D (46 to 60)
E (61 to 80)
F (81 to 100)
G (100+)

Very Poor

Carbon Dioxide Emissions The number refers to the calculated carbon dioxide emissions in terms of kg per m^2 of floor area per year	28
Approximate current energy use per m^2 of floor area:	66 kWh/m^2

Main heating fuel: Grid Supplied Electricity **Building Services:** Air conditioning
Renewable energy source: **Electricity:** Grid supplied

Carbon Dioxide is a greenhouse gas which contributes to climate change. Less Carbon Dioxide emissions from buildings helps the environment.

Benchmarks

A building of this type built to building regulations standards current at the date of issue of this certificate would have a rating:	31	C+
Where the accompanying recommendations for the cost effective improvement of energy performance are applied, this building would have a rating:	0	??

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